Global Research Journal of Geography: ISSN-2360-8005, Vol. 2(1): pp 010-066, March, 2014.

Full Length Research Paper

Hydrological studies of the university of Cape Coast school of agriculture research station at Twifo Wamaso.

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Accepted 24th March 2014

The textural characteristics, hydraulic conductivity, and plasticity index of soils have been determined by grain size distribution test, infiltration rate analysis, and Atterberg Limits test respectively, on twenty sample locations spread over 150 acres at the University of Cape Coast (UCC) research station at Twifo Nwamaso in the central Region of Ghana. The soil tests were conducted at depths of 0.5 m and 1.0 m at each location. Meteorological data analysis and topographic survey were also used to respectively identify the rainfall pattern, run-off pattern, as well as the direction of flow. Unified Soil Classification System was adopted for the soil classification since grain size distribution had a significant effect on the engineering properties of the soil. The soil was classified as well or uniformly graded sand, sandy gravel, gravelly sand, silty sand, and sand with some clay. From the modified plasticity chart, 72% of the fine particles were observed to be silt with high and very high plasticity. Results show that, the soil is the histosols type with absence of iron-rich laterite, based on its values for Specific gravity and other engineering characteristics. The average bulk density values of 1.88 tonnes/m3 and 2.02 tonnes/m3 for the 0.5 m and 1.0 m depths respectively are considered to be relatively high, and that may hinder root penetration as permeability of the soil decreases. The well sorted soil exhibited high porosity with relatively low hydraulic conductivity with an average value of 0.234 cmhr-r. The infiltration rate test revealed that, for irrigation, the application rate of water of 0.026 cm/sec will be good enough for the soil to be saturated to support plant growth. The pH of the soil is moderately acidic with the subsurface soil being more acidic than the surface soil which is due to more clay identified at 1.0 m depth which suggested an illumination process at the site. The values obtained from the moisture content and the relative humidity test show that, even in the dry season, the soils contain water which is a result of the rainfall pattern of the area. The site is thus recommended for agricultural activities as confirmed by its engineering properties analyses.

Keywords: Textural characteristics, hydrologic conductivity, Plasticity index, soil, Twifo Wamaso, University of Cape Coast

INTRODUCTION

The School of Agriculture of the University of Cape Coast has acquired 400 acres of land at Twifo Wamaso in the Twifo Praso District in the Central Region of the Republic of Ghana for a research station, the first of its kind in the history of the University. The station is to serve as a research centre for students, researchers, and lecturers in agriculture and other related fields. Agricultural production shall be carried out to the fullest with the view to developing the parcel of land into a commercial venture. Currently, the topographic, geologic and hydrologic data covering the site is not detailed enough to permit prudent decision making. Since water is the driving force for life and plays a major role in all agricultural activities, it will be needed in this station for plant growth, irrigation, and other economic activities
This thesis will concentrate on providing detailed

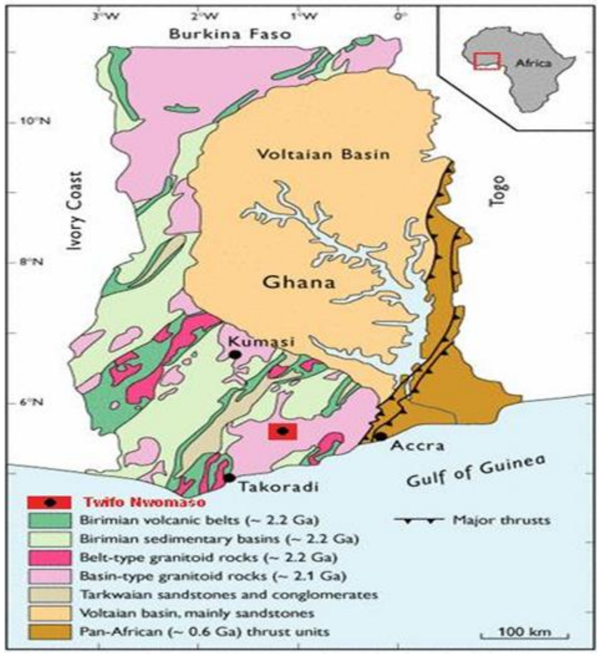

Figure 1. Map of Ghana showing the study area.

Source: Ghana Geological Survey Department.

topographic, hydrologic and index geotechnical analysis of data for a portion (150 acres) of the station so as to enable farm planners and managers to use the information obtained from the study to make decisions that will sustain activities to be conducted at the station.

The objectives of this research are to survey the land at a scale of 1:2500 and determine the detailed topography and hence the direction of ground water flow, determine the soil characteristics and infiltration rate of water through it so as to determine the type of crops that will do well when planted. study the run-off patterns, assess the anthropogenic impacts such as urban development that can degrade the hydro ecosystem,

It is expected that information obtained from this research will be used to provide topographic, hydrologic and index geotechnical information that would affect the present and future planning of the farm, it will be used to assess the risk of water related hazards that would threaten beneficial activities of the research station, it will be used to draw appropriate conclusions and recommendations to the University authorities based on the findings.

The methods employed for this study include: review of literature pertinent to the subject. Field work included the following; collection of soil samples from the field to assess its characteristics, conduct infiltrometer tests to determine the hydraulic conductivity of the site,

collection of meteorological data to study the precipitation patterns of the area and topographical survey to enable a detailed study of surface runoff and ground water flow direction in the area.

Laboratory Analyses will include; soil analyses: particle size, bulk density, moisture content, temperature, pH, humidity, Atterbergs Limits, specific gravity, and sedimentation.

Cartographic Work: plotting of spot height (contours) to a scale of 1:2500 and the analysis of results.

The facilities available which were employed include: library and computer facilities at the University of Mines and Technology (UMaT) and the University of Cape Coast (U.C.C), Geotechnical laboratory at UMaT, soil science laboratory at U.C.C, Information from Meteorological service department, and Community water and sanitation department all in Cape Coast and professional and technical supervision.

The project report is presented in six chapters. Chapter 1 is an introduction to the background, objectives, methodology, justification and facilities available for this research work. Chapter 2 presents relevant information about the study area where as Chapter 3 is a review of the relevant literature. Sampling and analytical methods is presented in chapter 4. Chapter 5 deals with field/laboratory results, data analysis and discussion. Chapter 6 presents the observations, conclusions and recommendations for the research.

Relevant information about the study area

Location, accessibility and size

As shown in the Figure 1, Twifo Wamaso is located in the south central portion of Ghana. It is within the Twifo

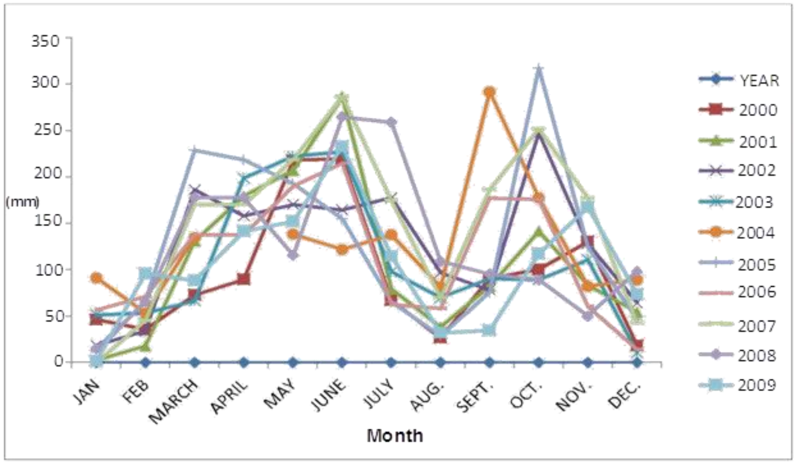

Figure. 2.2 Rainfall pattern for Twifo Praso.

Heman Lower Denkyira District Assembly (THLDDA) in the Central Region. Wamaso is about 15 km North-West off the Pra River from Twifo Praso, the District Capital, along the main Twifo Praso –Dunkwa -on- Offin road.
Twifo Hemang Lower Denkyira District (THLDD) is one of the Thirteen (13) Districts in the Central Region of Ghana. THLDD is bounded on the North by the Upper Denkyira District; to the South by the Abura-Asebu-Kwaman-Kese District, Cape Coast District and Komenda-Edina-Eguafo-Abirem District; on the West by the Wassa Mpohor District; and on the East by the Assin North and South Districts.
The District has a total land area of 1 199 km^2 and 1 510 community settlements, eight (8) Area Councils, and four (4) paramountcy, namely: Hemang, Denkyira, Twifo and Atti Morkwa.

Physiography

Twifo Wamaso lies within Latitude 05º 37'N and Longitude 01º 32'W on an average altitude of 60 m to 350 m above mean sea level. The area is generally hot with a temperature ranging between 26 º C and 32 º C with relatively high humidity ranging from 65-75%. The highest mean temperatures occur between March and April whereas the lowest is recorded in August.
Annual average rainfall is between 900 and 1 600 mm with the heaviest occurring in June. As indicated in Figure 2, there is however, a dry period from December to February when the North East Trade Winds set in, bringing harmattan conditions during which visibility reduces considerably. The major rainy season begins from May to July while the minor season begins in August through to November (see Figure 2). Wind direction is mainly south westerly with a speed of about 5 knots.

Vegetation

Twifo Wamaso which consists basically of secondary forest lies within the forest belt of the country with good soil fertility favorable for the cultivation of tropical plants like cocoa, oil palm, plantation, cassava, etc. Rapid growth of vegetation is due to high temperature and heavy rainfall, which in effect, gives the forest a luxuriant and evergreen look all year round. The canopy created by the thick trees in this zone does not permit enough sun rays to affect the proper growth of the undergrowth. However, due to rapid expansion of the cocoa, palm and timber industries and an increase in farming activities in general, some portions of the evergreen forest have been turned into a secondary forest. Low lying areas are swampy during the rainy season. There are, however, large areas of forest reserves including the Kakum National Park, Bimpong Forest Reserve, Pra Suhyen Forest reserve, Minta Forest Reserve and Bunsaben Forest Reserve. The forest reserves and the Kakum National Park together cover 288 km^2 or 24.0 per cent of the entire surface area of the District (Anon, 2000).

Topography and drainage

The topography of THLDDA (Figure 3) is in general, undulating with gentle slopes at elevations ranging between 950 m and 1 000 m above mean sea level. The highest point in the District is Bepotsin (212 meters), west of Mfuom. The Pra River and its tributaries including Obuo, Bimpong, Apakama and Ongua drain the area. They take their sources from the top of the series of ridges cutting across the strike of rocks: their courses attributed to faulting, jointing, and softening of

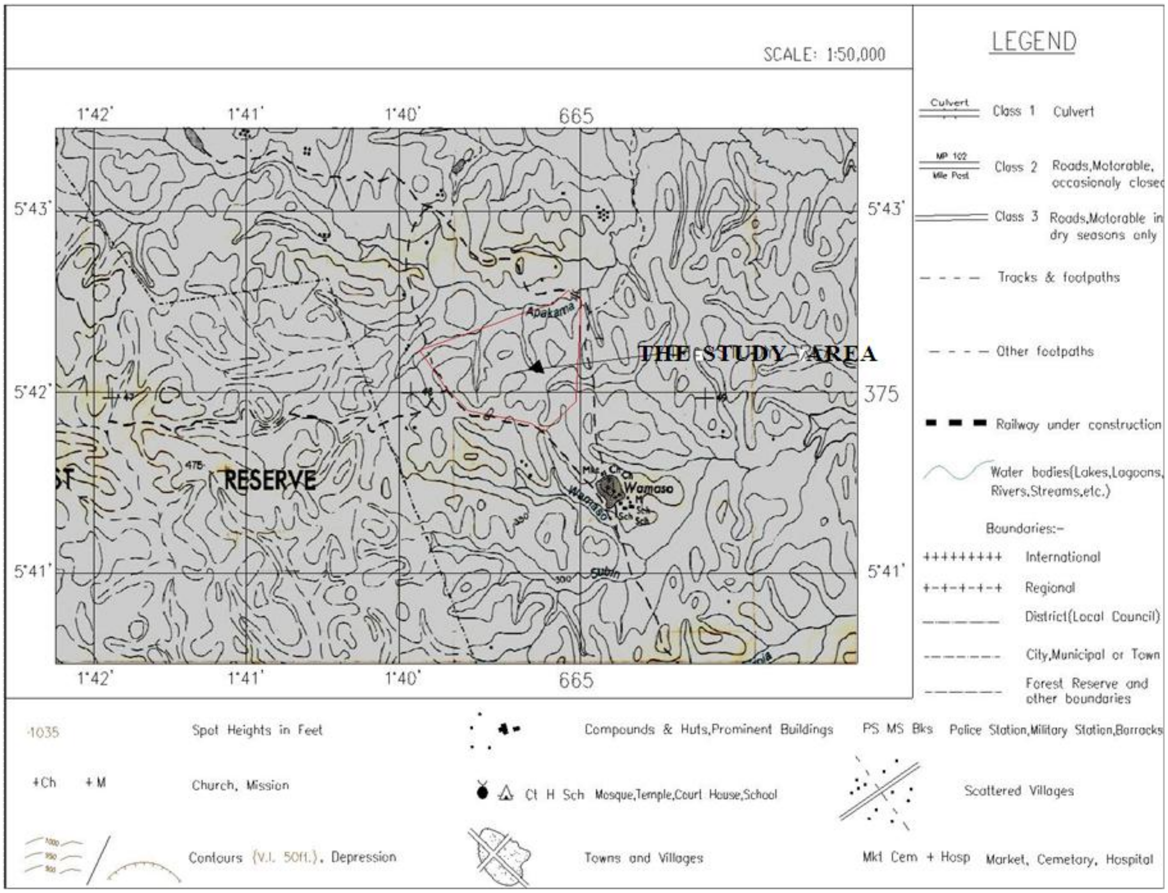

Figure 3. Topographic map of Ghana showing the study area

Source: Ghana Survey Department

rock by weathering. The District has generally, a rolling landscape (Anon, 2000

Geology, hydrogeology and mineral deposits of the area

From Figure 4 and 5, it is observed that the area is underlain by granitic rocks.

The study area is also rich in mineral deposits. The minerals found in the district include: gold at Mfuom, River Botro and Afiafiso, diamond at Afiafiso and manganese at Asamang and Mampong. Within the Pra River can be found Birimian and Tarkwaian rocks, which holds the potential for the exploitation of gold and manganese. The bed of River Pra also contains alluvial gold deposits. The rocks in the Pra River (eg.Wamaso albitized granodiorite) can also be used for quarrying. The Pra River could also be used for fishing. However, this activity is limited by the presence of large rock outcrops, which prevent the use of canoes on a large scale.

Wamaso Albitized Granodiorite

Wamaso albitized granodiorite is the upper-most unit of the Pra River complex. The lower surface of the main lense shaped body is in contact with the Agona albitized quartz diorite, the upper surface with the quartzo-feldspathic and pelitc schists of the Birimian. There are two types of the Wamaso albitized granodiorite. These are porphyritic albitized granodiorite and foliated sheared and crushed albitized granodiolite (Anon, 2008).

Basic granitic intrusives and granites underlie almost all the study area (Fig. 2.4). The granites are either of Bongo, Dixcove or Cape Coast type. Major rock types comprise well-foliated, medium grained, potash rich muscovite biotite granites, grano-diorites and pegmatites. The rocks are often associated with schists and gneisses and intrude the lower Birimian meta-sediments. Groundwater occurs mainly in fractured portions of the bedrock. However, some amount of water may be obtained from the overburden and at the interface between the overburden and the bedrock. Borehole yields are variable, varying between 0.2 - 15m^3/h depending upon the degree and intensity of fractures in the underlying bedrock. Borehole depths are medium, ranging between 20 m and 50 m. Aquifers have been intercepted at various depths ranging from 7 to 30 m with a mean value of 27 m. A mean static water level of 5.20 m has also been found from existing borehole

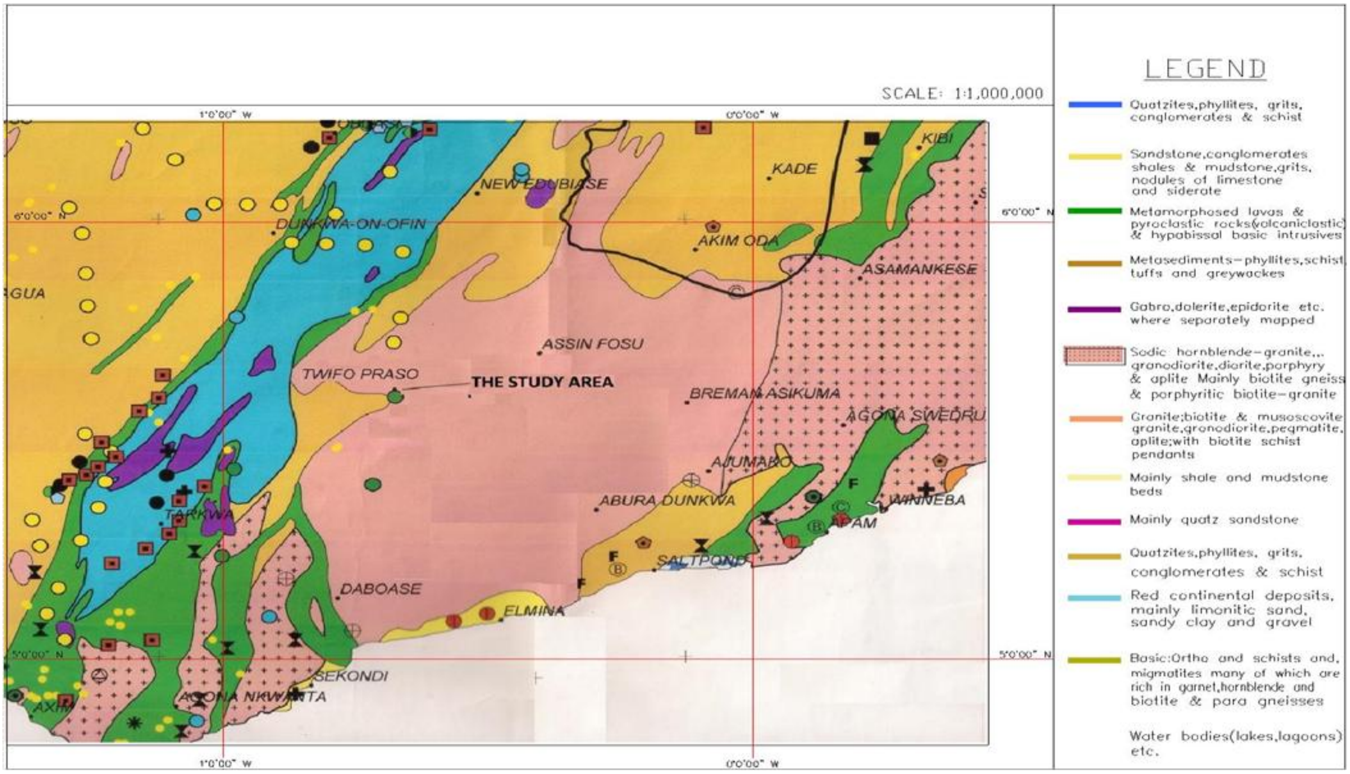

Figure 4. Geological map of Ghana on a larger scale.

Source: Ghana Geological Survey Department.

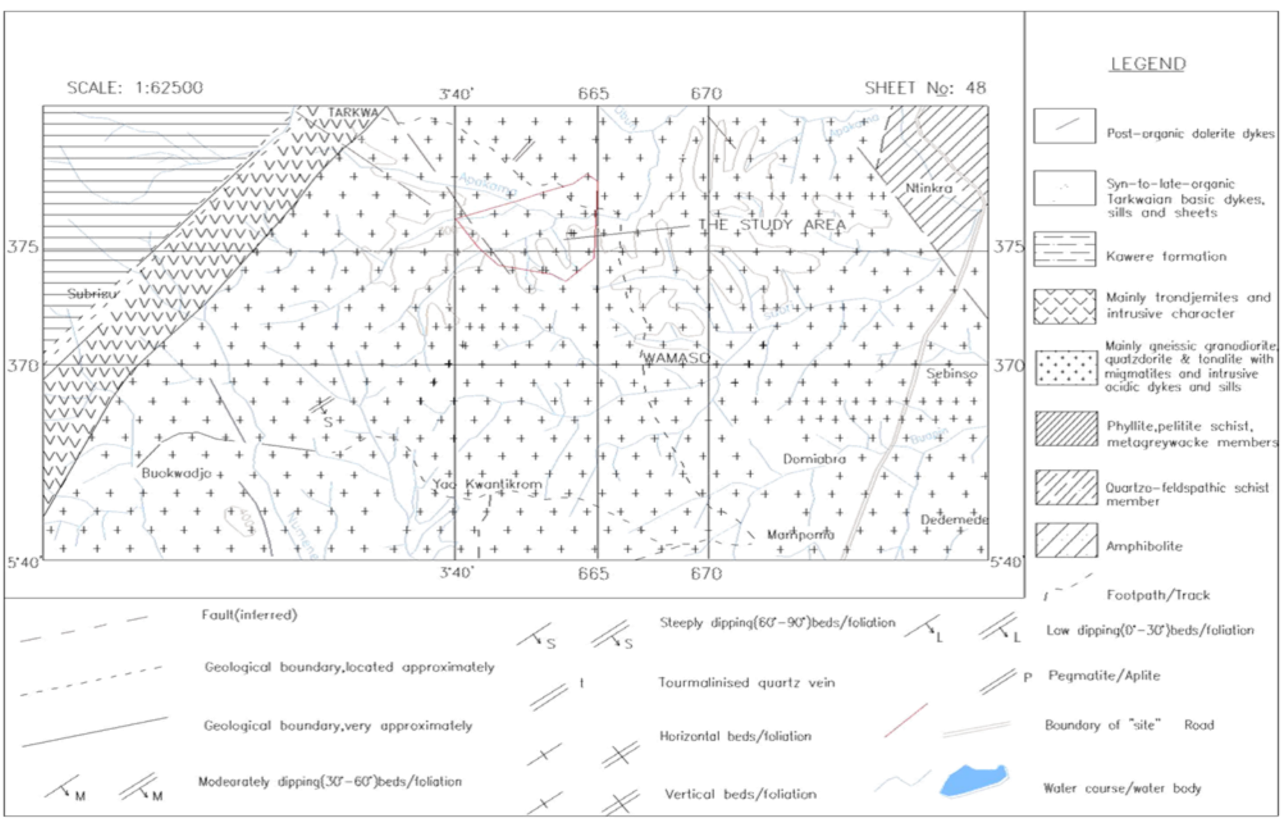

Figure 5. Geological Map of Ghana; Dunkwa S.E., Field Sheet Number 48.

Source: Ghana Geological Survey Department.

Table 1. Physical properties of the Cape Coast Granite

Hardness	6 to 7 on Moh's Scale
Density	2.6 to 2.8 Kg/cm^3
Compressive Strength	140 to 210 N/mm^2
Modulus of Rupture	15 to 25 N/mm^2
Water Absorption	0.1-0.6%
Average Wear	Less than 1%
Porosity	Quite low
Weather Impact	Resistant

Source: Anon, (2009a).

Table 2. Chemical composition of Cape Coast granite

Silica (SiO2)	70-75%
Al2O3	10-15%
CaO+MgO	Less then 0.5%
FeO + Fe2O3	2-4%
Alkalies	4-6%
TiO2	Less then 0.5%
Loss On Ignition (LOI)	Less then 0.5%

Source: Anon, (2009a).

records (Anon, 2008).

Granite

Anon, (2008) observed that, Granites found in the study area are post Tarkwaian and can be divided into three groups:

- Bongo Granites;
- Dixcove Granite Complex;
- Cape Coast Granite complex.

The Cape Coast Granite complex consists of well foliated and medium grained muscovite-bioitite granite, granodiorites and pegmatites. It is often associated with schists and gneisses and intrudes the lower Birrimian meta-sediments (Anon, 2008). One characteristic of the granite is that, it is not inherently permeable, but secondary permeability and porosity have developed as a result of fracturing and weathering. The hydraulic potential depends on the degree of fracturing and on the potential recharge of the aquifer, which is directly related to the annual rainfall and water streaming. For this reason, the underlying granites have been categorized into two groups: those located in the southwestern savanna zone and those in the forest zone (Anon, 2008).

a) Southwestern Savanna Zone

The towns located in the southwestern savanna zone are underlain by Cape Coast and Dixcove granites. Annual rainfall (about 800 mm) that enhances the development of secondary permeability and porosity in granite is low in this zone.

The depth to bedrock is shallow, ranging between 0-5 m. Deep weathering has not occurred in these areas. Fractures that also accumulate groundwater are not well developed and that ground water potential is low in this zone. Average yield from boreholes in this zone is about 0.41 m^3/h with very low success ratio of about 20%. The groundwater in this zone is often saline probably because the rainfall that is to recharge the groundwater flows into the stream channels as runoff due to the impermeable nature of the topsoil and shallow bedrock (Anon, 2009a).

b) Forest Zone

In this zone annual rainfall is high (1 000-1 600 mm) and weathering processes penetrate deeply along fracture systems in the granite and gneiss and they commonly have been eroded down to low-lying areas. Boreholes could yield as high as 54 m^3/h, with an average of 9 m^3/h (Anon, 2009a) Table 1.

Chemical Properties

Chemically, granitic rocks are igneous/metamorphic; composed of quartz, feldspar and ferromagnesian minerals like kriolite, chlorite, garnet, etc. Typical granite will have the following chemical composition (Anon, 2009a) Table 2.

Soils, ecological zones and agricultural land use

Soil studies, conducted in parts of the study area, have been focused upon its agricultural suitability. Anon (1996) observed that the soils are dominated by oxysols and heavily leached, acidic and clayey. The study area is located in a tropical environment and generally exhibits a well-developed soil profile.

The District has five (5) main soil types, namely: The Nsaba-Swedru Compounds, Nta-Offin Associates, Asuansi-Kumasi Associates, Bekwai-Nzema-Oda compound, and Juaso-Manso-Kyekyewere-Kakum Compound.

The Nsaba-Swedru Compounds

These are soils developed over granite, and respond well to phosphorus fertilizer application. They are excellent for the cultivation of tree crops such as cocoa, oil palm, cola, citrus and coffee, and food crops such as plantain, cocoyam, banana and cassava. They can be found in the northern part of the District around Mampoma, Morkwa, Agona and Nkwankyemaso (Anon, 2000).

Nta-Offin Associates

These soils are developed over rocks, which are poorly weathered. They are generally suitable for the cultivation of tree crops such as citrus, cola and oil palm. In addition to the tree crops, these soils tend to support semi-perennial food crops, dry season vegetables, sugar cane and rice. They are found around Brofoyedur and Bukruso (Anon, 2000).

Asuansi-Kumasi Associates

These are soils developed over Tarkwaian rocks, which are moderately drained and are good for the cultivation of tree crops such as cocoa and forestry products. They also support food crops such as plantain, cocoyam, maize cassava and banana. They have low soil nutrient and require nitrogen and phosphorus fertilizer usage. Leaching needs to be avoided. These soils are found in the southern section of the District around Jukwa, Mampong, Ntafrewaso, Watreso and Krobo (Anon, 2000).

Bekwai-Nzema-Oda compound

These soils are suitable for the cultivation of perennial tree crops such as coconut and citrus and food crops such as maize cassava and cocoyam. They are found around Bepobeng, Moseaso, Nyinase and Tweapease (Anon, 2000).

Juaso-Manso-Kyekyewere-Kakum Compound

These soils support perennial tree crops such as cocoa, oil palm, coconut, coffee and food crops including maize, cassava and plantain. They can be found around Mafi, Bonsaho, Ashire, Mmbraim, Afiaso, Mampoma and Wawase areas (Anon, 2000).

Socio-economic set up, and population growth:

Demographic characteristics and population density

The THLDD had a population of 53 066 people in 1970, 95 988 people in 1984 and 107 787 in 2000 showing a steady increase in population. The current population growth rate in the District is 2.2 % which is higher than the corresponding regional growth rate of 1.8% but less than the national growth rate of 2.6%. The relatively high population growth rate is attributed to the fertile soil which supports crops like oil palm, cocoa, plantain, cassava and others, which has resulted in many settler/migrant farmers living in the District (Anon, 2000).

Age-sex distribution

The age-sex structure of the District depicts a situation where males outnumbered females until the trend was reversed during the 2000 population census. The high level of male emigration for jobs elsewhere explains this. The sex composition may be measured by sex ratio, which is the number of males per 100 females. The sex ratios for 1970, 1984 and 2000 population census counts were 109:100, 100:100 and 99:100 respectively. The declining proportion of males is a reflection of increasing male out-migration since 1 970 (Anon, 2000).

Dependency ratio

Age Dependency Ratio (ADR) is the ratio of the youth (10-20 years) and the elderly (age 65 and above) to the adult working population (21-64 years). In 1970, the ADR for the District was 109% and the corresponding figure for the Region was 108.8%. The ratio for 1984 was 98.6%. A sample survey study carried out by JEAVCO Associates Limited in October 2000 indicates that the District's ADR is 75%. This means that in reality fewer people were working and every worker has nearly two or more mouths to feed. In 1984, the Economic Dependency Ratio (EDR) for the district and the region were 14.0% and 20.8% respectively. The EDR is the ratio of economically inactive to active population. This underscores the high level of economic burden shouldered by the economically active working population. Increased job opportunities and improved productivity can reduce the economic burden. This economic dependency ratio is slightly on the higher side considering the fact that the average income in the district for 1994 was GH¢31 499 per month, which was below the poverty line of approximately GH¢40 000.00 per month for the country for 1993 (Anon, 2000).

Population by settlements

The THLDD is a typical Rural District. There are 1 510 settlements in the District. Only two of them namely, Twifo Praso and Hemang with population of 11 853 and 8 240 are currently statistically urban. The urban population constitutes only 14% of the District's population. These two urban settlements perform typically agricultural functions with very limited urban functions and formal employment avenues. Other larger communities are: Jukwa, Mampong, Wawase, Krobo, Nyenase, Ayaase, Mfuom, Apenkro, Wamaso, Ntafriwaso, and Nuamakrom. Most of the rest are farmsteads, usually with populations below 300 people. All the major settlements are located along the main

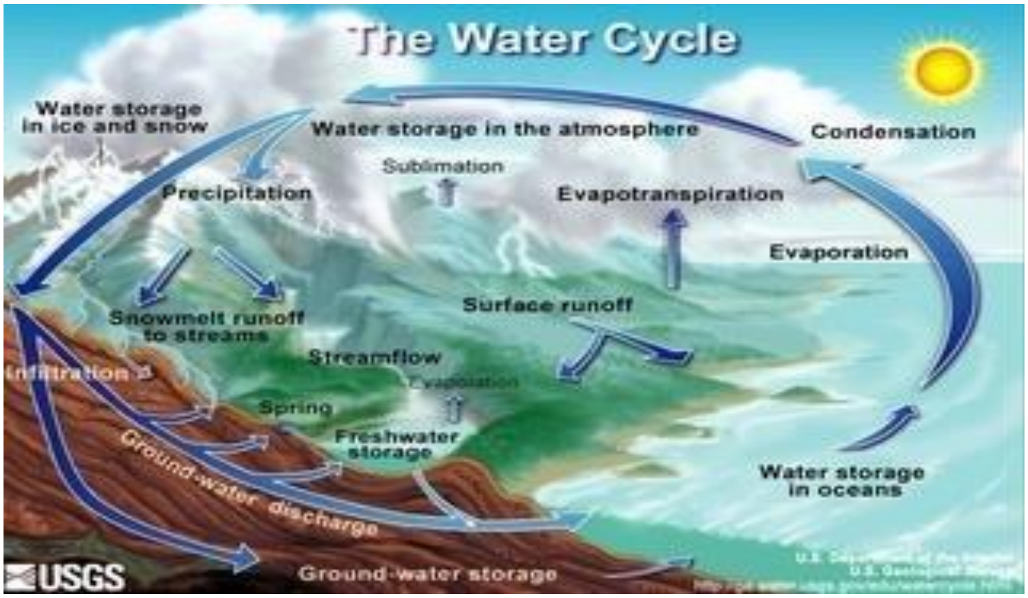

Figure 6. The water cycle

Source: Anon, 2009a

Cape Coast - Twifo Praso - Dunkwa trunk road (Anon, 2000).

Occupational distribution

A sample survey conducted in 1994 by Department of Planning, Kwame Nkrumah University of Science and Technology (KNUST) revealed that as much as 51 per cent of the labour force is engaged in agriculture indicating that the THLDD is an agricultural oriented one. This is followed by Ghana Government service, which employs 28 per cent of the working population. Commerce comes third with 16 per cent and, finally, industry with 5 per cent. A sample survey conducted in 2000 by JEAVCO Associates Limited confirms the result of the earlier study. For a sustained development of the District, there is the need to improve the industrial sector by establishing small-scale industries to process the numerous agricultural raw materials that abound in the District such as oil palm, ginger, cassava and timber (Anon, 2000).

Rural-urban split

The THLDD depicted a rural-urban split of 92.8 as against 63.1:36.9 for the nation in 1984. In 2000, the district's rural-urban ratio was 86:14. This situation poses a problem for the distribution of higher order services in the district. This is because services need some threshold populations before they can be provided; implying that many of the small communities may not qualify for higher order services. Many people have settled in Twifo Praso, Hemang, Jukwa and Wawase from the surrounding villages (Anon, 2000).

Environmental situation

The THLDD is a densely forested area. The extensive forest has given rise to a large-scale timber extraction and illegal chainsaw operations in the District. Apart from lumbering, the other major economic activities include crop/livestock farming and small-scale mining. The slash and burn method of farming has degraded the vegetation (Anon, 2000). Anon, (2000) observed that the combination of these activities, among others, has caused some form of environmental degradation. The extraction of timber has immensely depleted some economic trees, deteriorated some roads and caused some sort of destruction to cash and food crops. Farming practices have also affected the environment adversely by reducing the forest from primary to a secondary state.

Literature review

The hydrologic cycle

Hydrology is the study of the movement, distribution and quality of water throughout earth and thus addresses both hydrologic cycle and water resources (Anon, 2009a). The water cycle or the hydrological cycle describes the continuous movement of water on, above, or below the surface of the earth. Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states among liquid, vapor, and ice at various places in the water cycle. Although the balance of water on Earth remains fairly constant over time, individual water molecules can come and go. Figure 6 below describes the water cycle.

Water resources are sources of water that are useful or potentially useful to humans. Uses of water include agricultural, industrial, household, recreational, and environmental activities. Hydrological research is very useful as it allows us to better understand the world in which we live and also provide an insight for environmental engineering, policy and planning. Water covers 70% of the earth surface.

L'vovich (1974) observed that precipitation infiltrates around three-quarters of the world's land area; and almost all the water that plants use, and which recharges groundwater, infiltrates through the soil zone. The nature and activity of pedogenetic processes depend on climate, lithology and time, working closely together with topography, the biosphere and the hydrodynamics of the regolith (Lucas and Chauvel, 1992). Pedologically, a soil is considered to be both a biological and geologic medium at the earth's surface that has been sufficiently weathered by physical, chemical and biological processes to allow the growth of rooted plants (Freeze and Cherry, 1979).

Toth (1999) has examined groundwater as a geologic agent, identifying physical, chemical and kinetic processes as the main factors by which it interacts with the environment. These processes are manifested in a variety of natural phenomena, including soil formation. The physical and chemical characteristics of a soil play a vital role in the recharge and chemistry of groundwater because both soil texture and structure control the hydraulic properties, while soil composition affects water quality. These considerations pertain to both soil and rock and should be obtained during groundwater resource studies (Freeze and Cherry, 1979; Hem, 1992; Stone, 1999). It has also been suggested that the nature of soil and the drainage characteristics of an area should be closely considered during hydrogeochemical studies (e.g. Edmunds, 1981).

During these studies, the type of clay formed in an area can be inferred through physical tests (Head, 1997). In addition, it is important to estimate the rate of transpiration, when it falls below the potential rate, when determining the water balance of drainage basins and soil profiles. This is because the field capacity and permanent wilting point values of soil and soil depth control the available water capacity of the soil. These parameters directly depend on the soil texture, underlying the importance of soil mapping for hydrological studies (Holmes, 1961).

The aforementioned factors influence infiltration of water, which is the rate at which a given soil can absorb precipitation in a given condition. Part of the infiltrated water flows laterally as interflow at shallow depths, while another part percolates to the groundwater table. A third part remains above the water table in the zone of unsaturated flow (Davis and DeWiest, 1991)

Dingman (1994) noted that detailed infiltration studies in the field are rare; and where they have been conducted, few measurements are made in the major soil types only. Although these values show a high degree of spatial variability and are used as indices, they are nevertheless valuable (Dunne and Leopold, 1998).

Water cycle

From Figure 6, the sun which drives the water cycle, heats water in the big rivers. Water evaporates as vapor into the air. Ice and snow can sublimate directly into water vapor. Evapotranspiration is water transpired from plants and evaporated from the soil. Rising air currents take the vapour up into the atmosphere where cooler temperatures cause it to condense into clouds. Air currents move clouds around the globe; cloud particles collide, grow, and fall out of the sky as precipitation (Anon, 2009a).

Most precipitation falls back into the oceans or onto land, where the precipitation flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water towards the oceans. Runoff and groundwater are stored as freshwater in lakes. Not all runoff flows into rivers. Much of it soaks into the ground as infiltration.

Horton (2004) observed that some water infiltrates deep into the ground and replenishes aquifers, which store huge amounts of freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge. Some groundwaters find openings in the land surface and come out as freshwater springs. Over time, the water returns to the ocean, where our water cycle started.

Different processes

a) Precipitation

Condensed water vapour that falls to the earth's surface. Most precipitation occurs as rain, but also includes snow, hail, fog drip, graupel, and sleet. Approximately 505 000 km^3 of water fall as precipitation each year, 398 000 km^3 of it over the oceans (Walker, 1987).

b) Canopy interception

This is the precipitation that is intercepted by plant foliage and eventually evaporates back to the atmosphere rather than falling to the ground.

c) Runoff

Runoff is the variety of ways by which water moves across the land. This includes both surface runoff and channel runoff. As it flows, the water may infiltrate into the ground, evaporate into the air, become stored in lakes or reservoirs, or be extracted for agricultural or other human uses.

Table 3 Average Reservoir Residence Times

Reservoir	Average residence time
Oceans	3 200 years
Glaciers	20 to 100 years
Seasonal snow cover	2 to 6 months
Soil moisture	1 to 2 months
Groundwater: shallow	100 to 200 years
Groundwater: deep	10 000 years
Lakes (see lake retention time)	50 to 100 years
Rivers	2 to 6 months
Atmospere	9 days

Source: Anon, (2009a).

d) Infiltration

This is the flow of water from the ground surface into the ground. Once infiltrated, the water becomes soil moisture or groundwater.

e) Subsurface flow

The flow of water underground, in the vadose zone and aquifers is called Subsurface Flow. Subsurface water may return to the surface (e.g. as a spring or by being pumped) or eventually seep into the oceans. Water returns to the land surface at lower elevation than where it infiltrated, under the force of gravity or gravity induced pressures. Groundwater tends to move slowly, and is replenished slowly, so it can remain in aquifers for thousands of years (Walker 1987).

f) Evaporation

The transformation of water from liquid to gas phases as it moves from the ground or bodies of water into the overlying atmosphere is called evaporation. The source of energy for evaporation is primarily solar radiation. Evaporation, often implicitly includes transpiration from plants, though together they are specifically referred to as evapotranspiration. Total annual evapotranspiration amounts to approximately 505 000 km^3 of water, 434 000 km^3 of which evaporates from the oceans (Anon 2009).

g) Sublimation

The state change directly from solid water (snow or ice) to water vapour is called Sublimation.

h) Advection

This is the movement of water in solid, liquid, or vapour states through the atmosphere. Without advection, water that evaporated over the oceans could not precipitate over land.

i) Condensation

This is the transformation of water vapour to liquid water droplets in the air, producing clouds and fog.

ii) Transpiration

Transpiration is the release of water vapor from plants into the air. Water vapour is a gas that cannot be seen.

Residence times

The residence time of a reservoir within the hydrologic cycle is the average time a water molecule will spend in that reservoir (Table 3). It is a measure of the average age of the water in that reservoir (Anon 2009a). Groundwater can spend over 10 000 years beneath the earth's surface. Particularly old groundwater is called fossil water. Water stored in the soil remains there very briefly, because it is spread thinly across the earth, and is readily lost by evaporation, transpiration, stream flow, or groundwater recharge. After evaporating, the residence time in the atmosphere is about 9 days before condensing and falling to the Earth as precipitation (Table 3).

In hydrology, residence times can be estimated in two ways. The more common method relies on the principle of conservation of mass and assumes the amount of water in a given reservoir is roughly constant. With this method, residence times are estimated by dividing the volume of the reservoir by the rate by which water either enters or exits the reservoir. Conceptually, this is equivalent to timing how long it would take the reservoir to become filled from empty if no water were to leave or how long it would take the reservoir to empty from full if no water were to enter (Anon, 2009a).

An alternative method to estimate residence times, which is gaining popularity in dating groundwater, is the use of isotopic techniques. This is done in the subfield of isotope hydrology.

Changes over time

(Anon 2009a) explained that the water cycle describes the processes that drive the movement of water throughout the hydrosphere. However, much more water is "in storage" for long periods of time than is actually moving through the cycle. The storehouses for the vast majority of all water on earth are the oceans (Table 3). It is estimated that, out of the 1 386 000 000 km^3 of the world's water supply, about 1338 000 000 km^3 is stored in oceans, or about 95%. It is also estimated that the oceans supply about 90% of the evaporated water that goes into the water cycle.

During colder climatic periods more ice caps and glaciers form, and enough of the global water supply accumulates as ice to lessen the amounts in other parts of the water cycle. The reverse is true during warm periods. During the last ice age glaciers covered almost one-third of Earth's land mass, with the result being that the oceans were about 400 ft (122 m) lower than today. During the last global "warm spell," about 125 000 years ago, the seas were about 18 ft (5.5 m) higher than they are now. About three million years ago the oceans could have been up to 165 ft (50 m) higher (Anon, 2009a).

The scientific consensus expressed in the 2007 Intergovernmental Panel on Climate Change (IPCC) summary for Policymakers is for the water cycle to continue to intensify throughout the twenty first century, though this does not mean that precipitation will increase in all regions. In subtropical land areas places that are already relatively dry precipitation is projected to decrease during the twenty first century, increasing the probability of drought. The drying is projected to be strongest near the poleward margins of the subtropics (for example, the Mediterranean Basin, South Africa, southern Australia, and the Southwestern United States). Annual precipitation amounts are expected to increase in near-equatorial regions that tend to be wet in the present climate, and also at high latitudes. These large-scale patterns are present in nearly all of the climate model simulations conducted at several international research centers as part of the forth Assessment of the IPCC (Anon, 2009a).

Human activities that alter the water cycle include: agriculture, industry alteration of the chemical composition of the atmosphere, construction of dams, deforestation, afforestation, removal of groundwater from wells, water abstraction from rivers, and urbanization.

Effects on climate

The water cycle is powered from solar energy. 86% of the global evaporation occurs from the oceans, reducing their temperature by evaporative cooling. Without the cooling effect of evaporation the greenhouse effect would lead to a much higher surface temperature of 67 °C and a warmer planet.

Effects on biogeochemical cycling

While the water cycle is itself a biogeochemical cycle, flow of water over and beneath the earth is a key component of the cycling of other biogeochemical cycle. Runoff is responsible for almost all of the transport of eroded sediment and phosphorus from land to water bodies. The salinity of the oceans is derived from erosion and transport of dissolved salts from the land. Cultural eutrophication of lakes is primarily due to phosphorus, applied in excess to agricultural fields in fertilizers, and then transported overland and down rivers. Both runoff and groundwater flow play significant roles in transporting nitrogen from the land to water bodies. The dead zone at the outlet of the Mississippi River is a consequence of nitrates from fertilizer being carried off agricultural fields and funneled down the river system to the Gulf of Mexico. Runoff also plays a part in the carbon cycle, again through the transport of eroded rock and soil (Anon, 2009a).

Soil

Soil is one of the most common materials we take for granted. However the support of soil is very important for the survival of human race. Soil together with air, water and radiation from the sun ensures the continuity of mankind. Bell (1983) describes soil as an unconsolidated assemblage of solid particles between which voids are present. Soils may either contain water or air, or both.

Soil is derived from the weathering of rock materials which may have suffered some amount of transportation prior to deposition and it normally contains organic matter. Soil also partly consists of decayed organic matter that covers large parts of the land surface of the earth. As used in an agricultural context, soil supports crop growth and can be tilled.

Properties of soil that make it useful

i. It provides water, nutrients and anchorage for plants and trees in natural forests and grasslands, annual and perennial crops and planted grassland.
ii. Soil is the habitat for decomposer organisms which have an essential role in the cycling of carbon and mineral nutrients
iii. Soil acts as a buffer for temperature change and for the flow of water between the atmosphere and ground water.
iv. Because of its ion exchange properties it acts as a pH buffer, and retains nutrient and other elements against loss by leaching and volatilization (Wild, 1996).

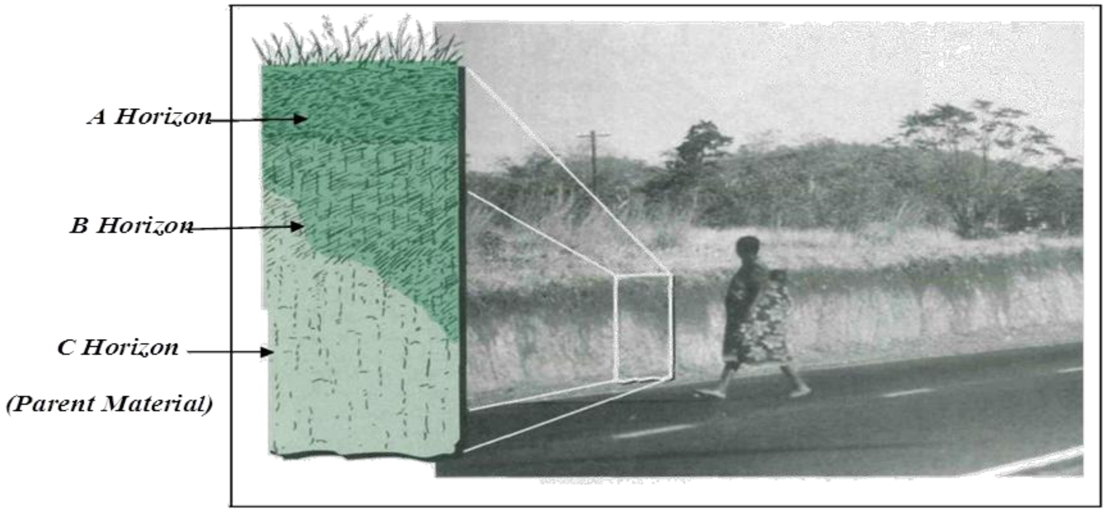

Figure 7. The Soil Profile
Source: Brady and Weil, 1993.

Soil formation

Mostly, soil is the end product of weathering of rocks, which involves a number of chemical, physical and biological processes. It may be formed either directly from the bedrocks or from further breakdown of transported sediments. Montgomery (1995) observed that the different kinds of weathering processes are largely affected by climate, topography, the composition of the material from which the soil is formed, and governs a soils final composition. The durability of the rock mass concerned also affects the rate of weathering and thus not only upon the vigor of the weathering agent. The durability of a rock mass is governed by its mineralogical composition, texture and the incidence of discontinuities within the rock.

Bell (1983) observed that based on its method of formation, soils are normally sedimentary, residual or fill. Sedimentary soils are those in which the individual particles were created at one location, transported and deposited finally at another location. Transportation affects sediments by abrasion and solution.

Generally silt-, sand-, and gravel-sized particles are formed by the physical weathering of rocks while chemical weathering forms clay-sized particles. A residual soil is formed when a rock is weathered at one location and there is little or no movement of the individual soil particles to another location. If the rate of deposition exceeds the rate of removal of the product decomposition, accumulation of residual soil profile may be divided into three zones.

These zones are grouped into the upper, intermediate, and partially weathered zones. The upper zone is where there is a high degree of weathering and removal of material where as the intermediate zone is where there is some amount of weathering at the top part of the zone, but also some deposition toward the bottom part of the zone. Finally the 25 partially weathered zone is where there is the transition from the weathered material to the unweathered parent rock.

Lambe and Whitman (1969) indicated that residual soils tend to be more abundant in humid, warm regions that are favorable to chemical weathering of rocks and have sufficient vegetation to keep the weathering product from being easily transported as sediments.

Soil profile and soil horizons (layers)

Soil is made up of layers which may be of different physical and chemical properties. These layers are called horizons. Soil horizons are identified on the basis of colour, texture and structure**.** Taken together, these horizons comprise the profile of this soil, as shown in the enlarged diagram. The vertical section exposing a set of horizons in the wall of a pit is termed as a soil profile. The upper horizons are designated A horizons. They are usually higher in organic matter and darker in color than the lower horizons. Some constituents, such as iron oxides and clays, have been moved downward from the A horizons by percolating rainwater. The lower horizon, called a B horizon, is sometimes a zone in which clays and iron oxides have accumulated, and in which distinctive structure has formed. The presence and characteristics of the horizons in this profile distinguish this soil from the thousands of other soils in the world.

Soil profile is easily seen on road cuts and other ready-made excavations which normally serve as windows to the soil.

Pedologic horizons are distinguished by the proportion of organic material to which the material has been removed (eluviated) or deposited (illuviated) by chemical or physical processes. Soils horizons are designated by letters as shown in Figure 7.

Horizons within a soil may vary in thickness and have somewhat irregular boundaries, but generally they parallel the land surface (Figure 7). This horizontal alignment is expected since the differentiation of the regolith into distinct horizons is largely the result of influences, such as air, water, solar radiation, and plant material, originating at the soil-atmosphere interface. Since the weathering of the regolith occurs first at the surface and works its way down, the uppermost layers have been changed the most, while the deepest layers are most similar to the original regolith, which is referred to as the soil's parent material. The boundaries are however gradual in most case and sharp on a few occasions.

The organic-matter-enriched horizons nearest the soil surface are called the A horizons which are also known as zone of leaching. The A-horizon consists of the most intensively weathered rock material, being the zone most exposed to surface processes. Unless the local water table is exceptionally high, precipitation infiltrates down through this horizon. In doing so the water may dissolve soluble mineral and carry them away with it (Montgomery, 1995). Brady and Weil (1993) observed that the layers underlying the A horizon contain comparatively less organic matter than the horizons nearer the surface. Varying amounts of silicate clays, iron and aluminum oxides, gypsum, or calcium carbonate may accumulate in the underlying horizons. The accumulated materials may have been washed down from the horizons above, or they may have been formed in place through the weathering process. These underlying layers are referred to as B horizons (Fig 3.2).

The C horizons are the least weathered part of soil profile. Plant roots and micro-organisms often extend below the B horizon, especially in humid regions, causing chemical changes in the soil water, some biochemical weathering of the regolith, and the formation of C horizons.

In some instances, one horizon may be divided into several recognizable sub-horizons. For example, the top of the A-horizon might consist of a layer of topsoil particularly rich in organic matter. This layer may be so organic-matter-rich that a distinct "O-horizon" can be designated. Sub-horizons also may exist that are gradations between A and B or B and C. It is also possible for one or more horizons locally to be absent from the soil profile. All variations in the soil profile arise from the different mix of soil-forming processes and starting materials formed from place to place (Montgomery, 1995). The total thickness of soil is partly a function of the rate of soil erosion. The latter reflects the work of wind and water the topography, and often the extent and kinds of human activities (Montgomery, 1995).

Soil structure

Soil structure is the way particles are arranged together. It is just as important as soil texture (the relative amounts of different sizes of particles) in governing how water and air move in soils. The building blocks from which soil is constructed are sand, silt, and clay particles, and the manner in which these building blocks are arranged together is called soil structure. Both structure and texture fundamentally influence the suitability of soils for the growth of plant roots (Wild, 1996).

The particles may remain relatively independent of each other, but more commonly they are associated together in aggregates of different-size particles. These aggregates may take the form of roundish granules, cube-like blocks, flat plates, or other shapes.

Soil water: a dynamic solution

Brady and Weil (1993) established the fact that, water is of vital importance in the ecological functioning of soils. The survival and the growth of plants and other soil organisms essentially depend on the presence of water in soils. The soil moisture regime, often reflective of climatic factors, is a major determinant of the productivity of terrestrial ecosystems, including agricultural systems. Movement of water, and substances dissolved in it, through the soil profile is of great consequence to the quality and quantity of local and regional water resources.

Water moving through the regolith is also a major driving force in soil formation. When the soil moisture content is optimum for plant growth (Fig. 3.3), the water in the large and intermediate-sized pores can move in the soil and can be used by plants. As some of the moisture is removed by the growing plants, however, that which remains is in the tiny pores and in thin films around soil particles. The soil solids strongly attract this soil water and consequently compete with plant roots for it. Thus, not all soil water is available to plants. Depending on the soil, one-fourth to two-thirds of the moisture remains in the soil after the plants have wilted or died for lack of water (Brady and Weil, 1993).

Soil: the interface of air, minerals, water, and life

Figure 8 shows the approximate proportions (by volume) of the components found in a loam surface soil in good condition for plant growth. Although a handful of soil may at first seem to be a solid thing, it should be noted that only about half the soil volume con-sists of solid material (mineral and organic); the other half consists of pore spaces filled with air or water. Of the solid material, typically most is mineral matter derived from the rocks of the earth's crust. Only about 5% of the volume in this ideal soil consists of organic matter.

However, the influence of the organic component on soil properties is often far greater than its small proportion would suggest. Since it is far less dense than mineral matter, the organic matter accounts for only about 2% of

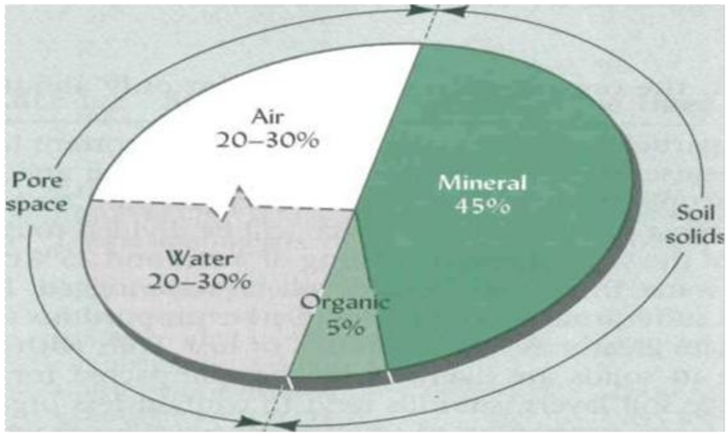

Figure 8. Volume composition of loam surface soil when good for plant growth.
Source: Brady and Weil (1993).

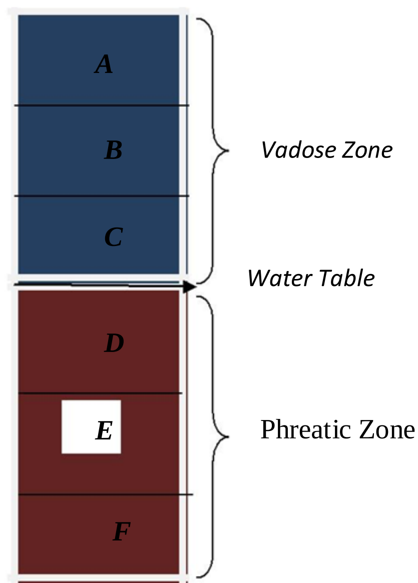

Figure 9. Classification of surface water

the weight of this soil (Brady and Weil, 1993).

The spaces between the particles of solid material are just as important to the nature of a soil as are the solids themselves. It is in these pore spaces that air and water circulate, roots grow, and microscopic creatures live. Plant roots need both air and water. In an optimum condition for most plants, the pore space will be divided roughly equally among the two, with 25% of the soil volume consisting of water and 25% consisting of air. If there is much more water than this, the soil will be waterlogged. If much less water is present, plants will suffer from drought (Brady and Weil, 1993).

The relative proportions of water and air in a soil typically fluctuate greatly as water is added or lost. Soils with much more than 50% of their volume in solids are likely to be too compacted for good plant growth. Compared to surface soil layers, sub soils tend to contain less organic matter, less total pore space, and a larger proportion of small pores (micro pores) which tend to be filled with water rather than with air (Brady and Weil 1993).

Hydrologic horizon

Dingman (1994) indicated that, to describe the movement of water in soils, it is very important to define another set of horizons based on the normal range of water contact and the soil pressure. In a given situation, the depths and thickness of these hydrologic horizons may vary with respect to time and space. In the subsurface, all gradations exist between freely flowing water and water firmly fixed in the crystal structure of minerals. However there are no sharp boundaries, between the horizons.

The hydrologic horizon comes in two major divisions (Figure 9) namely, the phreatic zone and the vadose zone. The vadose zone forms the upper part that is also subdivided into three sections; soil water A, intermediate vadose water B, and finally, capillary water C (water table). The phreatic zone involves; ground water D (phreatic water), water in unconsolidated pores E and water which is only in chemical combination with rocks F.

a) Soil water zone

This zone occupies the topmost part of the vadose zone and it consists of a layer from which plant roots can extract water during transpiration. It forms an upper boundary with the soil surface, while its lower boundary is infinite and irregular but effectively constant in time. Soil water zone accept water by the infiltration process due to the force of gravity. Conversely water is lost from this zone by the process of transpiration (or evaporation) and gravity drainage.

b) The intermediate zone

Davis and DeWiest (1991) made an indication that the intermediate zone commonly separates the saturated zone from the soil water. In arid regions, the intermediate zones which may occupy much of the soil profile extend over many tens of meters. Water enters and leaves this zone by percolation from above and gravity drainage respectively. In other situations (for example, in wetlands) it may be absent at least seasonally.

c) Capillary fringe (tension-saturation zone)

The term vadose zone is mainly used to describe the entire zone of negative water pressures above the water table (Dingman, 1994). The intermediate zone which is irregular in detail and forms boundary with ground water is rather abrupt in coarse-grained sediments, but is very gradual in silts and clays. The moisture content between the intermediate zone and the capillary fringe may be very minimal. The capillary fringe position constantly varies with changes in water level and amount of recharge. The upper part of the capillary fringe contains numerous pockets of air that shows the movement of water (Davis and DeWiest, 1991). The lowest portion of this zone is a region that is saturated or nearly saturated as a result of capillary rise.

d) Water table

The water table serves as a barrier between the zone of ground water or phreatic water and the capillary fringe (Fig. 3.4). It is also the level at which the groundwater pressure is equal to atmospheric pressure and may be conveniently visualized as the 'surface' of the groundwater in a given vicinity. It usually coincides approximately with the 'phreatic surface', but can be many feet above it.
Dingman (1994) also noted that, generally, water rises and falls with respect to seasonal climatic variation and to changes from individual storm events**.** Thus in arid regions it may be at depths of many tens of metres, while elsewhere, for example where the soil is developed in a few-metre layer of glacial till overlying dense crystalline bedrock, there is no water table in the soil at all or most of the time. As water infiltrates through pore spaces in the soil, it first passes through the zone of aeration, where the soil is unsaturated. At increasing depths water fills in more spaces, until the zone of saturation is reached. The relatively horizontal plane atop this zone constitutes the water table. A sustainable amount of water within a unit of sediment or rock, below the water table, in the phreatic zone is called an aquifer. The ability of the aquifer to store groundwater is dependent on the primary and secondary porosity and permeability of the rock or soil.

e) Zone of phreatic water

Ground water is mostly defined as the water below the water table, and the zone below the water is called the zone of saturation. Water that enters freely into wells is called Phreatic water. Water in the capillary fringe will not drain into a well unless it is a discharging well which is terminated below the water table (Davis and DeWiest, 1991). The zone of phreatic water merges at depth into a zone of dense rock with some water in pores, although the pores are not interconnected so that water will not migrate. The depth to dense rock varies with the geologic environment (Davis and DeWiest, 1991).

Relation between pedological and hydrologic horizons

Because of the variability in development of pedologic and hydrologic horizons, only a few generalisations can be made about the relatives between them. In non-wetland soils, the root zone usually occupies the zone of eluviation and may extend through the solun. Ordinarily the zone of eluviation and illuviation develop only in the unsaturated zone above the capillary fringe, but in some soils the seasonal high water table may move into the solun.
Soil hydrologic properties may change relatively abruptly in successive pedologic horizons. In some cases an impermeable or nearly impermeable layer called a hard pan or fragipan develops at or below the B-layer and percolating water may accumulate above this layer forming a perched water table above the general regional water table. However, other soils may show a more or less gradual decrease in hydraulic conductivity and porosity with depth (Dingman, 1994).

Infiltration

When it rains, water reaching the ground behaves in different ways, some percolate into the soil by gravitational pull, some flow as runoff into the stream by capillary action while small quantity evaporate back into the atmosphere (Figure 10). The process by which water on the ground surface enters the soil is termed as infiltration**.**
Infiltration rate in soil science is a measure of the rate at

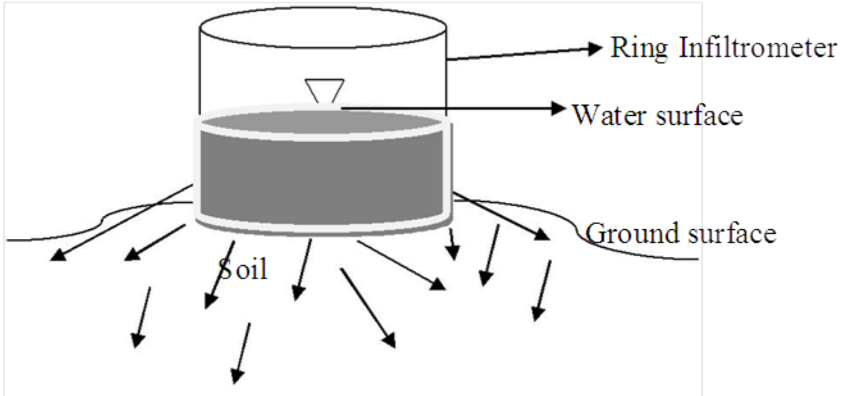

Figure 10. Pattern of wetting-front movement into an unsaturated soil from an infiltrometer

Table 4. Basic Infiltration rates for various soil types

Soil type	Basic infiltration rate (mm/hour)
Sand	< 30
Sandy loam	20 – 30
Loam	10 – 20
Clay loam	5–10
Clay	1–5

Source: Anon, (2009b

which soil is able to absorb rainfall or irrigation. It is measured in millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. Infiltration is related to the saturated hydraulic conductivity of the near-surface soil. Horton (2004) observed that, infiltration rate can be measured using a ring infiltrometer as shown in Figure 10.

Once water has infiltrated the soil, it remains in the soil, percolates down to the ground water table, or becomes part of the subsurface runoff process. The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, soil texture, structure, and transmission rate through the soil. Other factors include; vegetation types and covers, water content of the soil, soil temperature, and rainfall intensity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both p rotecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any kind of vegetative types.

The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain, without this the soil can become far less permeable. In chaparral vegetated areas, the hydrophobic oil in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soil. Other conditions that can lower infiltration rates or block them include dry plant litter that resists re-wetting, or frost**.** The table is a representation of threshold values for basic infiltration rate for various types of soils.

The process of infiltration can continue only if there is room available for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil and the rate at which previously infiltrated water can move away from the surface through the soil (Horton, 1933). Table 4 presents threshold infiltration rate values for different type of soils.

The maximum rate that water can enter a soil in a given condition is the infiltration capacity. If the arrival of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, ponding begins and is followed by runoff over the ground surface, once depression storage is filled (Horton 1933). This runoff is called Horton overland flow. The entire hydrologic system of a watershed is sometimes analyzed using hydrology transport models, mathematical models that consider infiltration, runoff and channel flow to predict river flow rates and stream water quality.

Horton (1933) suggested again that infiltration capacity rapidly declines during the early part of a storm and then tends towards an approximately constant value after a couple of hours for the remainder of the event. Previously infiltrated water fills the available storage spaces and reduces the capillary forces drawing water into the pores. Clay particles in the soil may swell as they become wet and thereby reduce the size of the

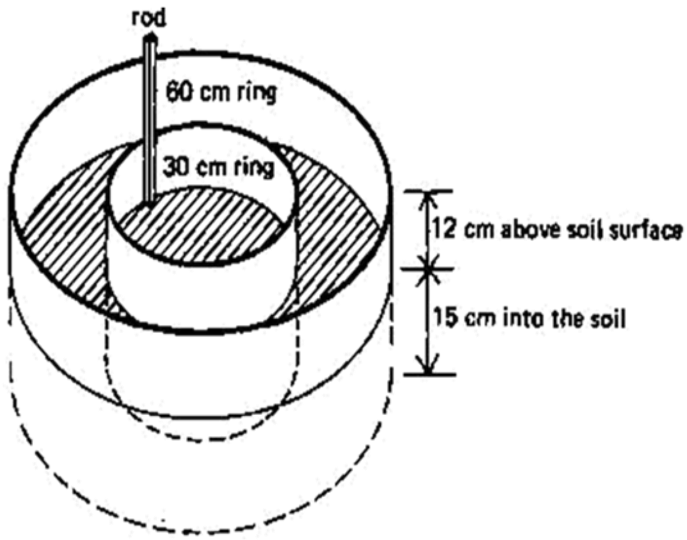

Figure 11. A set up of double ring infiltrometer

Source: Anon, 2009b.

pores. In areas where the ground is not protected by a layer of forest litter, raindrops can detach soil particles from the surface and wash fine particles into surface pores where they can impede the infiltration process.

Measurements of infiltration rates

Ring infiltrometers

A ring infiltrometer is a device used to measure the rate of water infiltration into soil or other porous media. Commonly used infiltrometers are single ring or double ring infiltrometer. This is a simple, inexpensive method for determining permeability of soils. The Double Ring Infiltrometer is the only EPA approved instrument of its kind available commercially. With the Double Ring Infiltrometer, it is easy to test several areas of a large tract to find the infiltration rate. It also provides comparative information that is useful for determining erosion rates, leaching and drainage efficiencies, irrigation patterns, and rainfall runoff. The instrument consists of two concentric rings driving plates, for inner and outer rings (Figure 11). The outer ring is 60 cm in diameter and the inner ring is 30cm in diameter. The two rings are driven to a depth of 15 cm into the ground and partially filled with water. The double ring design helps prevent divergent flow in layered soils. The outer ring acts as a barrier to encourage only vertical flow from the inner ring (Anon, 2009b).

During the first few minutes of infiltration, the total driving force is high, but it decreases as the water moves further into the soil. Eventually, the driving force due to capillarity dissipates and its value approaches zero. This leaves only the gravitational driving force which is always constant. Thus when the total driving force becomes constant, the infiltration rate becomes constant and is called the equilibrium infiltration rate (Anon, 2009b).

Because water infiltration into an unsaturated soil is influenced by both capillary and gravity forces, the water applied within an infiltrometer ring moves laterally as well as vertically as shown in Figure 11. The measured infiltration rate thus exceeds the rate that would be obtained if the entire surface were ponded. One way of reducing this effect is to use concentric rings (a double-ring infiltrometer) in which areas within both rings are ponded; the area between the two rings act as a "buffer zone" and measurements on the inner ring only are used to calculate the infiltration rate (Anon, 2009b).

The infiltration rate values for a given soil is the average of several measurements since its capacity tends to have considerable spatial variability, Dingman, (1994) found that the average of six single ring infiltrometer measurements of infiltration capacity was within 30% of the true value for a soil with uniform characteristics.

b) Sprinkler-plot studies

Another way of determining Infiltration rates is by recording the rate of runoff from well-defined plots on which a known constant rate of artificial rainfall, w, is applied at a rate high enough to produce saturation from above. In this case, the infiltration rate f(t) is computed from a formula as shown in Equation 1.

$$f(t) = w - q(t) \quad (1)$$

Where; q (t) is the rate of surface runoff from the plot (Dingman, 1994).

c) Observation of Soil-Water Changes

Dingman (1994) again discussed a third method of determining infiltration rate. This is to record changes in tension in tensiometers that have been installed at several depths during a natural or artificial water-input event. A plot of moisture characteristic curve is made to relate tension to water content. The increase in soil-water content at various depths during the event is used in determining the infiltration rate.

Factors affecting infiltration rate

The ultimate objective during a water-input event, is to estimate the infiltration rate, f (t), as a function of time, t. The value of (t) is determined by the effect of gravity and pressure forces on water arriving at the surface, which are in turn determined by the following:

a) Rate at which the water arrives from above as rainfall, or irrigation; or the depth of ponding on the surface. If the soil supports natural vegetation, particularly forest, the ground surface will usually consist largely of leaf litter, humus, and other organic matter that has a large number of large openings, and hence a high hydraulic conductivity, regardless of the texture of the mineral soil. During the rainy season or during a single rain storm, clay minerals swell reducing the effective surface porosity and permeability and limit infiltration (Dingman, 1994).

b) Saturated hydraulic conductivity at the surface and the degree to which surface soil pores are filled with water when the process begins. Saturation from below occurs when local recharge and/or ground water flow from up-slope causes the local water table to rise to the surface. It also occurs in the absence of a local water table at the beginning of an event where there is a more or less gradual decrease of porosity and hydraulic conductivity with depth or where there is a layer with significantly reduced conductivity at depth. Either situation may reduce or prevent percolation at depth, which in turn causes an accumulation of water arriving from above and ultimately the creation of a saturated zone and further prevent infiltration regardless of the hydraulic conductivity, the rate of input, or any other factor. Even when surface saturation does not occur, the antecedent water content affect the infiltration rate; high water content increases hydraulic conductivity which tends to increase infiltration rate (Anon, 2009b).

The net effect of antecedent water content on infiltration thus depends on the specific conditions of water-input rate and duration, the distribution of soil hydraulic conductivity with depth, the depth of the local water table, and the initial water content itself (Dingman, 1994).

c) Inclination and roughness of the soil surface. As long as ponding does not occur during a water-input event, the infiltration rate is governed by the water-input rate, and the hydraulic characteristics of the soil surface have no effect on infiltration. However, once ponding begins, the ponding depth will increase until it is sufficient to overcome the hydraulic resistance of the surface, at which time down slope runoff or overland flow begins. The rate of overland flow increases with increasing slope and decreases with increasing roughness. Thus, steeper slopes and smoother surfaces promote more rapid overland flow and, hence, less accumulation of ponded water on the surface and, other things being equal, lower infiltration rates (Dingman, 1994).

d) Chemical characteristics of the soil surface. Waxy organic substances produced by vegetation and micro-organisms tend to have negative contact angle with water surface, hence tends to "bead-up" instead of being drown into the pores by surface tension forces. Soils with such surfaces are called hydrophobic, and the effect of such compounds is minor under undisturbed vegetation.

During bush fires the organic surface layer are burned off, and wetability and infiltrability of the surface is significantly reduced (Dingman, 1994).

e) Physical and chemical properties of water. The surface tension, density and viscosity of water affect the movement of liquid in the unsaturated zone, all properties that depend on temperature. Viscosity is especially sensitive. It's value at 30°C is less than half its value at 0°C, thus the hydraulic conductivity at 30°C is about twice as large it is at 0°C, other things being equal. Klock (1972), who measured infiltration rate twice as with 25°C water as with 0°C water in laboratory experiments, observed this effect (Dingman, 1994).

Water Content (Soil Moisture)

In the general progression of the hydrological cycle beginning with atmospheric water vapour and ensuing precipitation, the top layers of materials near the land surface provide the first of the sub-surface water storages. Water on the Earth's surface either in solid or liquid form occurs in a fairly homogeneous body and can be seen and measured with varying degrees of accuracy.

In the ground however, water is contained as a mixture among a heterogeneous collection of solids; quantities are much more difficult to assess. The study of soil moisture is of vital interest to the agriculturalist, especially in those countries where irrigation can improve the yield of food crops. More recently, the role played by soil moisture content in the management of water yields and flood control is being more fully appreciated (Dingman, 2004).

Water content or moisture content is the quantity of water contained in a material, such as soil, rock, ceramics, or wood on a volumetric or gravimetric basis. The property is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation (Lambe and Whitman, 1969).

Table 5. Four standard routinely measured water contents.

Name	Notation	Suction pressure (J/kg or kPa)	Typical water content (vol/vol)	Description
Saturated water content	Θs	0	0.2–0.5	Fully saturated water, equivalent to effective porosity
Field capacity	θfc	−33	0.1–0.35	Soil moisture after 2–3 days after a rain or irrigation
Permanent wilting point	θpwp or θwp	−1500	0.01–0.25	Minimum soil moisture at which a plant wilts
Residual water content	θr	−∞	0.001–0.1	Remaining water at high tension
Available water content	θa	θfc – θpwp	0.1-0.3	

Source (Dingman, 2002).

Measurement of Moisture Content

a) Laboratory methods

Volumetric water content can be directly measured using a known volume of the material, and a drying oven (Dingman, 2004). This is called the Direct Method. Other methods that determine water content of a sample include chemical titrations (for example the Karl Fischer titration), determining mass loss on heating (perhaps in the presence of an inert gas), or after freeze drying. In the food industry the Dean-Stark method is also commonly used.

b) Geophysical methods

There are several geophysical methods available that can approximate in-situ soil water content. These methods include: Time-Domain Reflectometry (TDR), neutron probe, frequency domain sensor, capacitance probe, electrical resistivity tomography, Ground Penetrating Radar (GPR), and others that are sensitive to the physical properties of water. Geophysical sensors are often used to monitor soil moisture continuously in agricultural and scientific applications (Dingman, 2004).

c) Satellite Remote Sensing Method

Satellite microwave remote sensing is used to estimate soil moisture based on the large contrast between the dielectric properties of wet and dry soil. The data from microwave remote sensing satellite such as: WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT are used to estimate surface soil moisture (Dingman, 2004).

Earth and agricultural sciences

In soil science, hydrology and agricultural sciences, water content has an important role for groundwater recharge, agriculture, and soil chemistry. Many recent scientific research efforts have been aimed towards a predictive-understanding of water content over space and time. Observations have revealed generally that spatial variance in water content tends to increase as overall wetness increases in semi-arid regions, to decrease as overall wetness increases in humid regions, and to peak under intermediate wetness conditions in temperature regions. There are five standard water contents that are routinely measured and used. These have been described in the Table 5.

a) Agriculture

When a soil gets too dry, plant transpiration drops because the water is becoming increasingly bound to the soil particles by suction. Below the wilting point plants are no longer able to extract water. At this point plants wilt and cease transpiring altogether. Conditions where soil is too dry to maintain reliable plant growth is referred to as agricultural drought, and is a particular focus of irrigation management. Such conditions are common in arid and semi-arid environments. Some agriculture professionals are beginning to use environmental measurements such as soil moisture to schedule irrigation. This method is referred to as "Smart Irrigation" (Brady and Weil, 1993).

b) Groundwater

In saturated groundwater aquifers, all available pore spaces are filled with water (volumetric water content = porosity). Above a capillary fringe, pore spaces have air in them too.

Most soils have water content less than porosity, which is the definition of unsaturated conditions, and they make up the subject of vadose zone hydrogeology. One of the main complications which arises in studying the vadose zone, is the fact that the unsaturated hydraulic conductivity is a function of the water content of the material. As a material dries out, the connected wet pathways through the media become smaller, the hydraulic conductivity decreasing with lower water content in a very non-linear fashion (Brady and Weil, 1993).

Influence of soil moisture content on soil solution composition

Despite the importance of the soil solution to plant growth, few studies have considered the influence of

moisture content on the composition of the soil solution. Indeed, soil solution has seldom been extracted from soils below field capacity, despite the relevance of such conditions to plants grown in the field. Soil solution was extracted from a variable-charge soil (Oxisol) and from several permanent-charge soils (Vertisols) at various moisture contents (potentials ranging from –5 to –230 kPa) using polyacrylonitrile hollow-fiber filter elements and pressure chamber apparatus (Brady and Weil, 1993).
For the Vertisols, a decrease in moisture content resulted in a proportionate increase in the soil solution ionic strength, a behavior similar to that expected from a solution without any solid-phase interaction. In contrast, for the Oxisol, the ionic strength remained constant as the soil moisture content decreased due to "salt adsorption."

Porosity and permeability

Bell (1983) explained porosity and permeability as the two most important factors governing the accumulation, migration and distribution of ground water. However, both may change within a soil mass in the course of its geological evolution. Furthermore it is not uncommon to find variations in both porosity and permeability per metre of depth beneath the ground surface.

Porosity

The porosity of a soil can be defined as the percentage pore space within a given volume of the soil. Total or absolute porosity is a measure of the total void volume and is the excess of bulk volume over grain volume per unit of bulk volume. It is usually determined as the excess of grain density (the specific gravity) over dry density, per unit of grain density.
The porosity of unconsolidated material depends on the packing of the grains, their shape, arrangement and size distribution. Porosity plays a role in the capability of a medium to transmit water. The relationship between porosity and hydraulic conductivity, however, is not a simple one and other factors besides porosity affect the value of hydraulic conductivity. Thus pore size of the same order, is far more important than porosity for the water transmitting capability of a medium (Bell, 1983).

Permeability (Hydraulic conductivity)

Coefficient of permeability

The capacity of a soil to allow water to pass through it is termed its permeability (or hydraulic conductivity). The coefficient of permeability (k) may be defined as the flow velocity produced by a hydraulic gradient of unity. The value of k is used as a measure of the resistance of flow offered by the soil, and it is affected by several factors:

- the porosity of the soil
- the particle size distribution
- the shape and orientation of soil particles
- the degree of saturation/presence of air
- the type of cation and thickness of adsorbed layers associated with clay minerals (if present)
- the viscosity of the soil water, which varies with temperature.

The range of values for k is extremely large, extending from l00 m/s in the case of very coarse-grained gravels to almost zero in the case of clay. In
granular material, k varies approximately inversely with the specific surface value, but in cohesive soils the 44 relationships are more complex. In clay soils, such factors as water content and temperature are significant, as also is the presence of fissures when considering the permeability of large masses (Whitlow, 1998).
Attempts have been made to relate permeability to grain size. Practically, such a relationship appears more possible for sand and silts than for clays, because of the particle size, shape, and overall soil structure. One of the more widely known relationship is $K=100D10^2$ (Whitlow, 1998).
Where k is given in centimetres per second and D10 is the 10 percent particle size, expressed in centimetres, from the grain-size distribution curves. This relationship was developed from the work of Hazen on sands. This expression applies only to uniform sands in a relatively loose condition. More recent studies to evaluate the permeability and filter properties of sands have determined a relationship between the D15 size and the k value for dense or compacted sands. A close approximation for coefficient of permeability based on the D15 size is $k = 0.35\ (D15)^2$ when d15 is expressed in millimetres and the k value is in centimetres per second. The permeability for loose sands will be greater than indicated by the equation (McCarthy, 1993).

Mass measurement of soils

Soil Particle density

Soil particle density Df is defined as the mass per unit volume of soil solids (in contrast to the volume of the soil, which would also include spaces between particles). Thus, if 1 cubic meter (m^3) of soil solids weighs 2.6 megagrams (Mg), the particle density is 2.6 Mg/m^3 (which can also be expressed as 2.6 grams per cubic

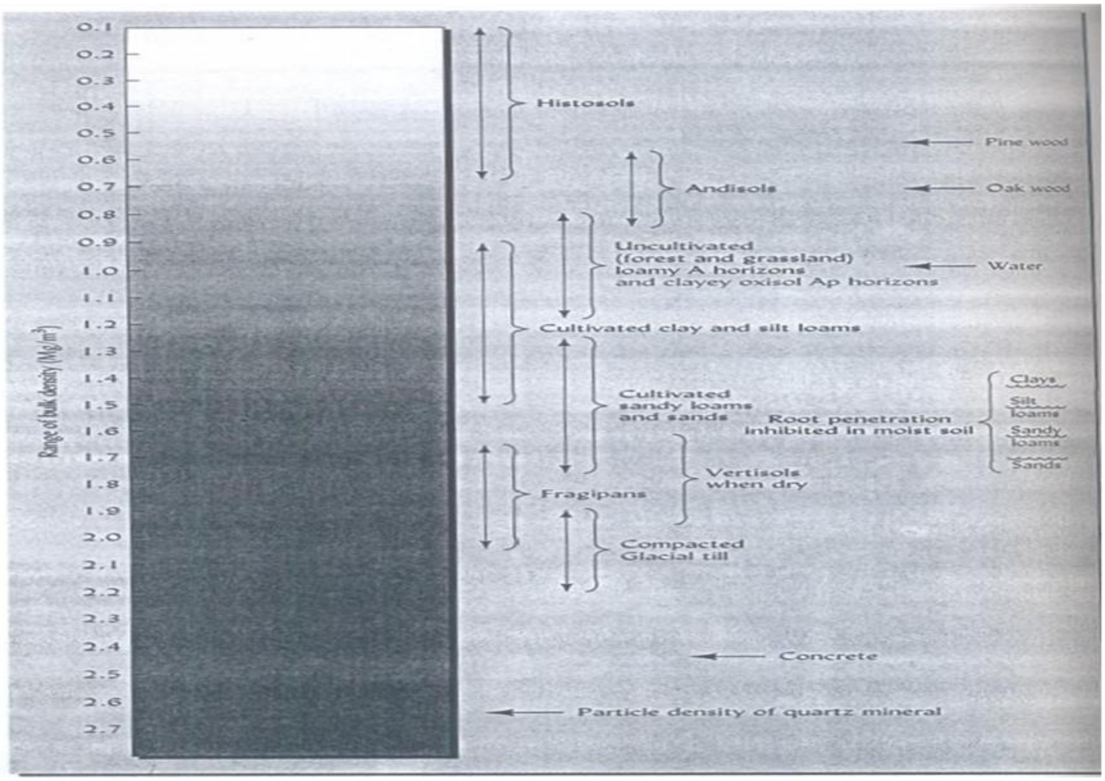

Figure 12. Bulk densities typical of variety of soils and soil materials.

Source: Brady and Weil, (1993).

centimeter). Particle density is essentially the same as the specific gravity of a solid substance. The chemical composition and crystal structure of a mineral determines its particle density. Particle density is not affected by pore space, and therefore is not related to particle size or to the arrangement of particles (soil structure).

Particle densities for most mineral soils vary between the narrow limits of 2.60 to 2.75 Mg/m^3 because quartz, feldspar, micas, and the colloidal silicates that usually make up the major portion of mineral soils all have densities within this range. For general cal-culations concerning arable mineral surface soils (1 to 5% organic matter), a particle den-sity of about 2.65 Mg/m^3 may be assumed if the actual particle density is not known.

This estimated particle density of 2.65 Mg/m^3 should be adjusted for certain soils. For instance, when large amounts of high-density minerals (such as magnetite, garnet, epidote, zircon, tourmaline, and hornblende) are present, the particle density of the soil may exceed 3.0 Mg/m^3. Organic matter, having a particle density of 0.9 to 1.3 Mg/m^3, is much less dense than soil minerals. Consequently, mineral surface soils with very high organic matter (15 to 20%) may have particle densities lower than 2.4 Mg/m^3. Typically, organic soils (Histosols) have particle densities between 1.1 and 2.0 Mg/m^3 (Brady and Weil, 1993).

Bulk density

A second important mass measurement of soils is bulk density Dh, which is defined as the mass of a unit volume of dry soil. This volume includes both solids and pores. A careful study of Fig. 3.4 should make clear the distinction between particle and bulk density. Both expressions of density use only the mass of the solids in a soil; therefore, any water present is excluded from consideration.

There are several methods of determining soil bulk density by obtaining a known volume of soil, drying it to remove the water, and weighing the dry mass. A special coring instrument can obtain a sample of known volume without disturbing the natural soil structure. For surface soils, perhaps the simplest method is to dig a small hole, collect all the excavated soil, and then line the hole with plastic film and fill it completely with a measured volume of water. Still another method involves coating a clod of soil with a waterproof film. The volume of the odd-shaped clod is determined by its buoyancy when suspended in water (Brady and Weil, 1993).

Factors affecting bulk density

Soils with a high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. Consequently, any factor that influences soil pore space will affect bulk density. Typical ranges of bulk density for various soil materials and conditions are illustrated in Figure 12

Figure 13. Pit profile showing the soil horizons up to 1.0 m depth.

Figure 14. Digging of profile pit CL1S4

SAMPLING AND ANALYTICAL METHODS

Soil Sampling

Forty (40) soil samples were taken from twenty (20) sample locations at the depth of 0.5 m and 1.0 m. This was done in the month of February, 2010. The horizons observed in the soil (Figure 13) represent a 'dynamic equilibrium' between soil composition, soil fabric and the physico-chemical conditions at each depth in the profile (Lucas and Chauvel, 1992).

Initially the number of samples needed to be taken at the field was determined based on the amount of variability within the field. The following factors were carefully considered: the size of the field, slopes, soil type and texture, cropping history, manure history, drainage and erosion. Once the sample points were defined, they were marked and then labeled with unique numbers such as CL1S1, BL1S4, and BL2S2 etc. Forty (40) representative samples were collected in all plus additional ten (10) for quality control analysis in the laboratory.

Equipment used

The following were used: site plan, safety equipment (helmet, gloves, and wellington boots), prismatic compass, surveyor's tape measure, flagging tapes, digital camera, plastic bags, log book, sample jar labels, field data sheet, spade and shovels, cutlasses, auger, and geologic hammer.

Procedure

A base line was constructed that stretched along the farm north. A number of cross lines were then established perpendicular to the base line at a constant interval of 200 m. Appropriate sample sites were located and pegged along the base and cross lines. Twenty (20) profile pits with 1.0 m by 1.0 m were excavated to a depth of 1.0 mm at the sample sites (Figure 13). However, in some few cases as in CL1S4 the depth of 1.0 m was not achieved because ground water was intercepted at about 0.6 m (Figure 14).

Figure 15. Soil samples being bagged at the site.

Figure 16. Stratus GPS being used to coordinate sample points

Figure 17. Infiltration rate measurement at the field.

Soil samples were obtained under two conditions, ”disturbed” and “undisturbed” conditions” A disturbed sample is one in which the structure of the soil has been sufficiently changed in such a way that its structural properties no longer represents an in-situ condition. However, an undisturbed soil sample is the one whose conditions are relatively close to the soil *in-situ*. In this case, it allows a test of the structural properties of the soil to be used to approximate the properties of the soil in-situ. The undisturbed samples were obtained by driving U100 tubes into the soil with the aid of a hammer after the top soil was cleared to a depth of 0.5 m and 1.0 m.

Two sets of representative soil samples were then taken from each profile pit at different levels. The first set was taken at the depth of 0.5 m while the second set was obtained at the depth of 1.0 m. The samples were then placed in plastic sample bags, sealed (Figure 15) and transported to the laboratory for analysis.

Geographic Positioning System (GPS) was used to co-ordinate all sample points (Figure 16) for plotting purposes.

Determination of infiltration rate

A double ring infiltrometer was used to assess the infiltration rate at the study site. Figure 17 represents a

Table 6. Methodology for infiltration rate measurement.

Step	Methodology
1	The 30 cm diameter ring was pushed into the ground as gently as possible up to at least 15 cm into the soil. The side of the ring was kept vertical while the measuring rod was driven into the soil so that approximately 12 cm is left above the ground.
2	The 60 cm ring was also pushed into the soil around the 30 cm ring to the same height and the jute cloth was placed inside the infiltrometer to protect the soil surface when pouring in the water.
3	The test was started by pouring water into the ring until the depth was approximately 70-100 mm. Water was added quickly at the same time, to the space between the two rings to the same depth. The water within the two rings is to prevent a lateral spread of water from the infiltrometer. Filter paper was placed on the soil to prevent splashing when water was been poured in.
4	The clock time was carefully recorded at the beginning of the test and the water level on the measuring rod was also noted. At time 'zero,' water was quickly added to fill the cylinder to its brim and kept the water level at the brim. The rate at which the level of water in the 30 cm ring was lowered was recorded using the measuring rod at 60sec interval of time.
5	After 1-2 minutes, recordings were made to the drop in water level in the inner ring on the measuring rod and water was added to bring the level back 5 to approximately the original level at the start of the test. Water level outside the ring was maintained similar to the one inside.
6	The test continued until the drop in water level was the same over the rest of the period of the test. Readings were frequently taken (e.g. every 1-2 6 minutes). When the last wetting front position was read, quickly, the water was poured from the top by tilting the cylinder. Linear graph was plotted with the position of the wetting front on the ordinate and time on-the abscissa. The linear portion of the curve indicated a constant infiltration rate (Figure 17). .

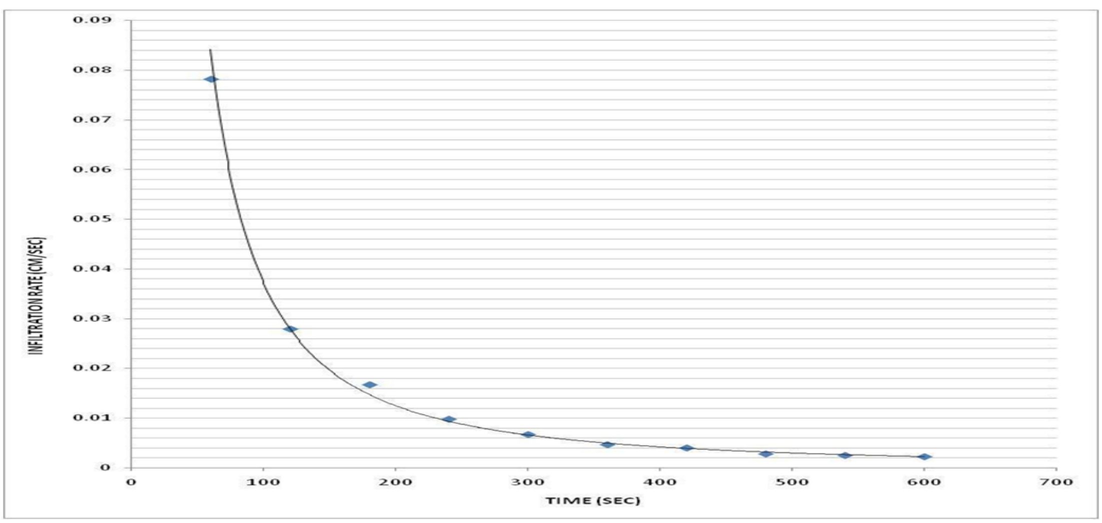

Figure 17. Infiltration rate graph.

field set up of a simple double ring infiltrometer. The infiltration rate is the speed at which water entered into the soil and this was measured by taking note of the decrease of ponded water in the inner infiltrometer with time (cm/sec). The rate depended on the soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles).

Equipment used include shovel/hoe, hammer (2 kg), watch, 5 litre bucket, timber (75 x 75 x 400), hessian (300 x 300) or jute cloth, at least 100 litres of water, ring infiltrometer of 30 cm diameter and 60 cm diameter, and measuring rod graduated in mm (e.g. 300 mm ruler).

Procedure

The step by step procedures have been summarized in Table 6.

After 1-2 minutes, recordings were made to the drop in

water level in the inner ring on the measuring rod and water was added to bring the level back 5 to approximately the original level at the start of the test. Water level outside the ring was maintained similar to the one inside.
The test continued until the drop in water level was the same over the rest of the period of the test. Readings were frequently taken (e.g. every 1-2 minutes). When the last wetting front position was read, quickly, the water was poured from the top by tilting the cylinder. Linear graph was plotted with the position of the wetting front on the ordinate and time on-the abscissa. The linear portion of the curve indicated a constant infiltration rate (Figure 16).
At least two infiltration tests were carried out at every sample location to make sure that the correct results were obtained. In all twenty tests were carried out at the research station.

Contouring

This was carried out in order to ascertain the topography and hence the direction of flow of ground water. Grids (a base line and cross lines) were constructed on the ground at an interval of 50 m. Wooden pegs were used to mark out all points that were considered. Global positioning system (GPS) was used to pick the X, Y; Z coordinates of all the points. However in some areas where there is a change in ground topography, random pickings were made. SURFER software was used to plot the data obtained at a scale of 1:2500.

Natural moisture content and specific gravity

This was determined from the undisturbed samples as they were brought from the field to the laboratory through measurement of wet and oven-dried weights of the test specimens, using a 0.01 sensitivity electronic balance.

Bulk density

a) Apparatus used

This include; waxing pot, thread, electronic balance, paraffin wax, knife, a beaker and an oven.

b) *Procedure*

Soil specimens were slashed into regular shapes and pieces weighing between 80 g to 150 g. At least for each sample, three labeled specimens were prepared for the density test while three were also prepared for moisture content test. The masses of the empty containers used were measured to the nearest gram. The specimens were also measured to the nearest gram. The specimens were then coated with paraffin wax and again weighed. A piece of thread was tied around the specimens and gently lowered into beaker containing the water until it was fully submerged. Care was taken such that the specimens do not touch any part of the beaker. The volume of water displaced in centimeter cube was recorded.

Atterberg limits

The empirical boundaries between each of the principal physical states of cohesive soil viz the liquid, plastic, semi-solid, and solid states are called Atterberg limits. The water content is the variable factor and hence used as an indicator for the consistency limits.

a) Liquid Limit (Cassagrande Method)

i) Apparatus

Liquid Limit device, grooving tool, palette knife, distil water, moisture content containers, balance, glass plate, and, an oven capable of maintaining temperatures up to 110°C

Procedure

The step by step procedures has been summarized in Table 7.

b) Plastic Limit Procedure

The plastic limit procedure is summarized in Table 8

Particle Size Distribution (Dry Sieving)

Particle size distribution test was done to determine the relative proportions of various sizes within the mass of the soil. An important application of particle size distribution is in connection with groundwater flow problems where it provides an indication of in-situ permeability and also in geotechnical processes such as grouting and chemical injection.

a) Apparatus

Set of sieves (depending on the maximum particle size), Balances Sieve, brush, Moisture content tins, Drying oven, Scoop.

Table 7. Procedure for cassagrande liquid limit test.

Step	Methodology
1	Liquid limit apparatus was first examined to make sure it was clean and then with no side play at the hinge. The next thing was to check the height through which the cup falls, it should be 100 mm.
2	Not less than 200 g of the air-dried soil was made to pass through a 425 um sieve to remove the coarser particles.
3	Soil that has been spread was on the glass plate was thoroughly mixed with distil water using palette knife until it became a thick paste.
4	The soil was remixed using the palette knife; Ensuring the cup is resting on the base. The sample was press down to exclude any trapped air. It was then leveled off using the palette knife paralleled to the base with a minimum depth of 10 mm.
5	The counter was set to read zero
6	By using chamfered edge of the grooving tool, the samples were divided by drawing the grooving tool along the diameter of the cup that passesthrough the centre of the hinge.
7	The handle of the machine was turned anticlockwise at a speed of 2 turns per second. The number of blows needed to close the groove formed in (6) above for distances of 13 mm was recorded. This was made between 40 to 50 blows for the first test, when more than 50 blows were needed; more water was added and the process, repeated.
8	Portions of material, which had just flowed, were placed together into a previously weighed and numbered moisture content container. The container with its contents was weighed, oven dried and re-weighed to determine the moisturecontent.
9	The material remaining in the cup was returned to the glass-plate; remixed with the rest of the sample together with a little more water to obtain a uniform softer consistency. Procedures 4-8 were repeated to obtain a lower count of blows.
10	The experiment was conducted for at least 4 different moisture contents so that the number of blows was fairly evenly distributed between about 50 and 10 and with two each side of 25. The moisture content of each tin from each blow-count wasCalculated
11	A plot of the average moisture contents against the average number of blows on the semi-log graph paper was made. Then the best straight line of fit was drawn through the points. The water content corresponding to 25 blows to the nearest 0.1% was then read. This result was quoted to the nearest whole number as the liquid limit.

b) Procedure

A representative sample was dried in an oven. A reasonable quantity depending on the size of the
particles was taken for the test. By cone and quartering method, the samples were evenly reduced in size. The whole specimen was weighed and corrected to the nearest 1 g after it had been dried in an oven and had allowed to cool. With the receiver at the base, each sieve was weighed to the nearest 0.1 gm and putting them together in descending order of aperture size. The dried samples were placed in the top sieve, covered with the l i d and hand-shaken for 10-15 minutes.

After that time, the material retained on each sieve was examined to see that it consisted of only individual particles. Any agglomeration of particles not naturally cemented together was broken down and sieved further. 100 ml of water was added to a soil placed in a flask. The flask was shook thoroughly having added 25 ml of sodium hexametaphosphate solution. It was again vigorously shaken for 30 minutes. The material retained on each sieve was weighed. Where the amount retained exceeded the given in the table provided, the material was subdivided into smaller portions and received. Percentage passing each sieve size was plotted as ordinate against the particle size, which was drawn to a log scale on the particle size sheet.

Sedimentation (Pipette Method)

Sedimentation method was done to determine the particle size distribution of fine grain soils. The sedimentation test for fine particle analysis makes use of suspension of particles in water of a known concentration. The principle is that the falling velocity of a sphere in a fluid is a function of the diameter of the sphere. This is governed by Stoke's Law, the larger particles settle at the bottom more quickly than the smaller particles. The density of the suspension is measured at specific time intervals.

a) Apparatus

Sampling pipette, two 500ml glass sedimentation tubes, glass weighing bottles, 63um sieve and other sieves, balance, drying oven, stop clock, constant temperature bath, conical beaker, filtration equipment, 100ml measuring cylinder, 5ml pipette, glass rod fitted with rubber policeman, reagents, hydrogen peroxide. HCL, sodium hexametaphosphate, and distilled water.

b) Procedure

A sufficiently, small, representative sub sample of the air-dried soil was obtained by quartering or riffling (approx. 30 g of sandy soil and 12 g for clayey soil). A small portion of the original soil was tested with few drops of HCL. Effervescence was observed followed by acid treatment by washing. Soil samples were placed in a conical beaker, and 50 ml of distilled water was added to it. The suspension was gently boiled until the volume was reduced to 40 ml. Suspension was allowed to cool, and 75 ml of H2O2 was added and the mixture was left overnight. 100 ml of water was added to a soil placed in a flask. The flask was shaking thoroughly having added 25 ml of sodium hexametaphosphate solution. It was again vigorously shaken for 30 minutes.
The suspension was then washed through a 63 µm sieve using not more than 150 ml water, the suspension passing through/transferred to a 500 ml sedimentation tube. Distilled water was then added to make up to the 500 ml. The material retained on 63 µm sieve was dried and sieved separately.
The sedimentation tube containing the soil suspension was transferred to a constan t temperature bath, with inserted rubber bung and was allowed to stand in water up to the 500 ml mark until it had reached the constant temperature. Similarly, a sedimentation tube containing 25 ml sodium hexametaphosphate diluted with distilled water to exactly 500 ml was left standing in the constant temperature bath until it had reached the temperature of the bath, after an hour. On reaching this temperature, both tubes were removed and thoroughly shaken by inverting the tubes several times. They were replaced in the bath. Stop-clock was started as the tube containing the soil suspension was returned to the bath. The rubber bungs from both tubes were then removed.

Soil pH Determination

The soil reaction or pH was determined by weighing 10 g of air-dry soil sample into a centrifuge bottle. 25 ml of distilled water was then added and shaken horizontally for 15 minutes. The resulting suspension was measured using a potentiometric electric pH meter. The meter was first calibrated using a buffer of 4 and 7.

Hydraulic conductivity

Materials used include calipers, cylindrical pipes, measuring cylinder, pipette, stop watch, retort clamp and stand, distilled water, cotton material and a twine, rubber bang. The procedure followed is presented in Table 7:

Calculation

Q = KA (H/I)…………………………………………..…..(2)

Where Q = Volume rate of flow across a plane normal to the direction of flow.
K = Hydraulic conductivity, which is the volume rate of flow through a sample of unit cross – sectional area.

A = cross – sectioned area of the cylinders.

H = hydraulic head, which is the brim of the tube. L = Length of soil sample in the cylinders.

FIELD/LABORATORY TEST RESULTS, DATA ANALYSYS AND DISCUSSIONS

Source of Water at the Study Area

The major source of water at the study area is rainfall. There are however few streams (Figure 18) such as Obun, Subri and Apakama that run into River Pra, the largest river in THLDDA. Fig. 2.2 was plotted from rainfall data obtained from the meteorological station at Twifo Praso. The figure shows the rainfall pattern over a period of ten years: between 2000 and 2009 and reveals consistency which can make planning for water for agricultural purposes quite straight forward.
It is also observed that, there is a dry period from December to February when the North East Trade Winds set in bringing harmattan conditions during which visibility reduces considerably. The major rainy season sets in from May to July, while the Minor season begins in August through to November.
The wind direction is mainly calm (00) with an average beau fort force of zero (0) throughout the year. This supposes that, economic plant and other farming activities will not be disturbed by the wind.

Topology of the site

Figure 18 shows results of the topographic survey of the study area at a scale of 1:2500. It is observed that the elevation of the survey area is between 260 m and 400 m above mean sea level. The topography is relatively undulating. In view of this, the direction of runoff flow is expected to be distributed over the entire study area.
Since the gradient of the ground surface of the study area is undulating, and runoff is expected to flow over most of the land, it will enhance infiltration of precipitation into the subsurface and that will enhance plant growth.
Low relief areas are associated with ground 62 discharge points. However with better sorting coefficient and *Ks* value, precipitation recharge will be better in those areas and are expected to act as low-yielding regolith aquifers compared to the high relief areas.

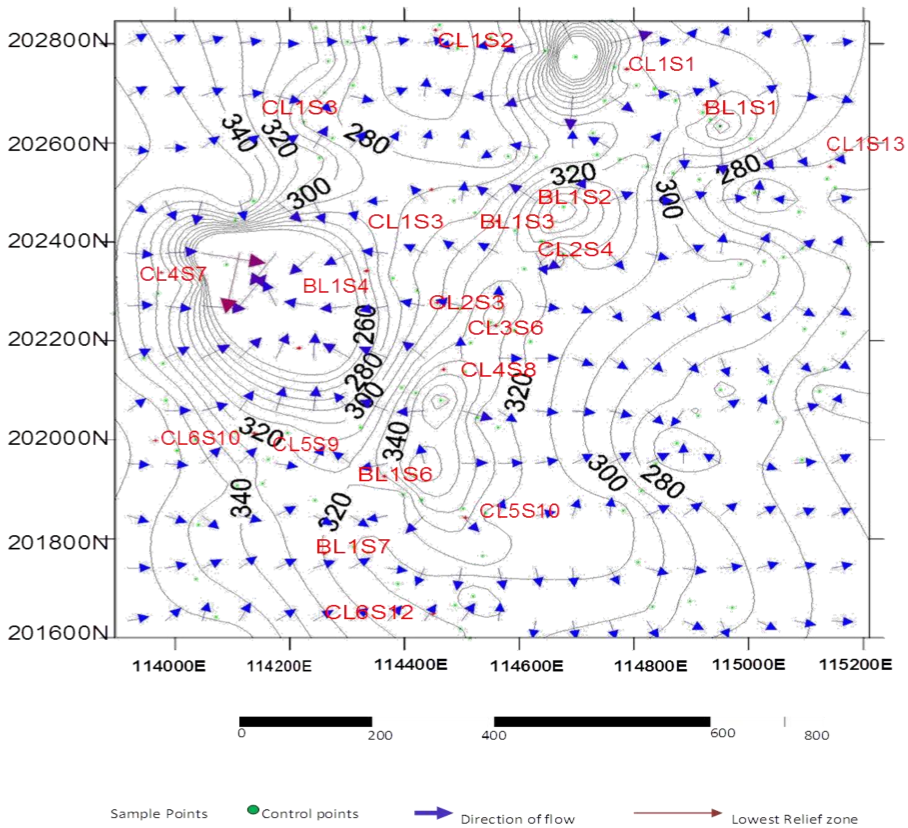

Figure 19. A detailed contour map of the study area showing the direction of flow.

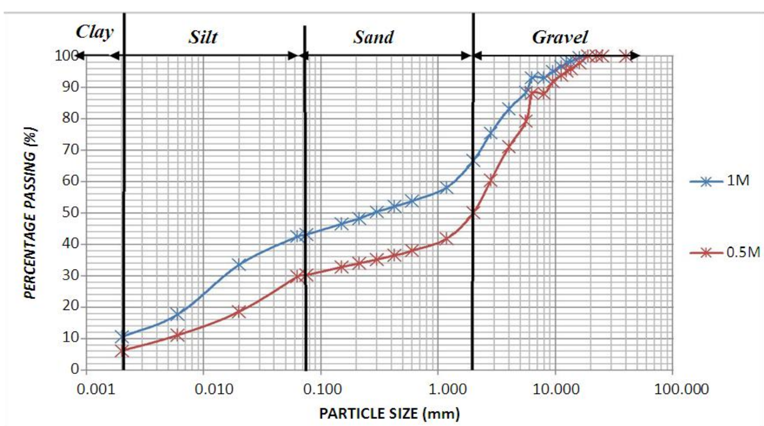

Figure 19. Grain size distribution curve for sampe BL1S1.

Isolated swamps observed may be 'outcrops' of shallow water tables in areas underlain by Sandstones. Kuma and Younger, (2002) noted that some of the possible reasons, in addition to outcropping water tables, which may account for these swamps are:

i) Weathering of the rocks, in part, to clay soils resulting in low infiltration capacities.

ii) Annual rainfall of over 1750 mm exceeding the holding capacity and/or transmissive properties of the regolith aquifers, and

iii) Unweathered bed rocks being closed to the surface and its storage, and transmissive properties being too low to accommodate large volumes of recharge during short periods of time.

Soil classification

Using the Grain Size scale for sediments (shown in Appendix 1), the soil was classified based on both its grain size distribution and plasticity. Figure 19 shows the grain size distribution curves for sample BL1 S1 at 0.5 m and 1.0 m depth from the surface. It is observed from Figure 19 that less than 50% of the samples passed through the 0.075 mm sieve for both depths, indicating: coarse grained soil with about 30-40% fines. The size fraction indicates that both the plasticity and grain size distribution have a significant effect on the engineering properties of the soil. The graphs also show well grading of the soil at both levels.

Similar graphs were plotted for the remaining samples (Appendix 2). From the results of the various graphs, the soils have been classified based on their particle sizes and summarized in Table 10a. It is observed that, the soils are distinctly well graded or uniformly graded. Table 8 presents the summary of soils Cu and Cc.

The grading of the soil was determined by direct observation of the particle size distribution curve. That is: if the shape of the curve is not too steep but more or less constant over the full range of the soil's particle sizes, and the particle size distribution extends evenly over the range of the particle sizes within the soil with no deficiency or are expansive clays that make poor road excess of any particular particle size, then the soil is said to be well graded. Any other form of distribution curve than the former is said to be poorly graded. However, for some guidance, the Uniformity Coefficient (Cu) and Coefficient of Curvature (Cc) of the soils were also calculated in order to aid in the classification based on the soil uniformity and gradation. These were calculated from the effective size (D10), D30, and D60 of the soil. The formulae are stated below;

$CU = D_{60}/D_{10}$………………………………………………....(3)

$CC = (D_{30})^2/D_{10} \times D_{60}$……………………………………(4)

The porosities were estimated from the soils' specific gravities and bulk densities by the formula:

$$\boldsymbol{Porosity = 1 - \frac{Bulk\ density}{Particle\ density} \times 100} \quad \ldots\ldots\ldots\ldots(5)$$

Results of atterberg limits

The Atterberg limits test was used basically to measure the nature of fine-grained fractions in the samples. This test was also conducted in order to know the proportion of silt and clay in the fine particles.

To further classify the soils based on its fines, the graphs below (figure 20) were plotted in order to determine the plastic and liquid limits as well as the plasticity index of the soil at twenty locations at the depths of 0.5 m and 1.0 m. The results have been presented in Table 9

Table 9 is the summary of Atterberg Limits result for the thirty six soil samples. Those soils with high plasticity index of more beds or foundations (Brady and Weil, 1993).

The data in Table 9 were then plotted on the modified plasticity chart as shown in figure 21. It is observed from the chart that, majority of the samples plotted below the A- line, and clustered between intermediate and very high plasticity with some few of them having low and extremely high plasticities. It is also observed that most of the soil fines are silt with a few classifying as clay. The plots marked red and blue on the plasticity chart are for 0.5 m and 1.0 m depth respectively.

From the graph, a total of 72% of the soils plot in the zone of high and very high plasticity. It therefore suggests that the water holding capacity of the soils is moderately higher and the clays within are the types. In case of building in this type of soil, the ground should be compressed end increase its density to avoid differential settlement with time. However, crops will do well even in the dry season; because, the soils are able to keep water for considerably long time. 22.2% of the soils are classified in the range of low and extremely high plasticity with only 5.6% having intermediate plasticity.

The textural classification adopted is as follows:

(i) If the main size group is more than 60% and none of the remaining size fraction attains 20%, then the name of the main size group alone is used.

(ii) If, on the other hand, any of the remaining groups is present with 20% or more, it is added to qualify the main constituent. A loam is a soil containing sand, silt and clay in roughly equal proportions (Kuma and Younger, 2002)

For plants and crops cultivation purposes, the Textural Triangle (appendix 9) was used to classify the soil. The results are presented in table 10b.

Specific gravity

The specific gravity usually means the relative density of a substance with respect to water. Table 11 shows the average specific gravity of the various samples of the study area.

It is observed from Table 11 that, the soil is typically organic (Histosols) since the specific gravity values falls within 2.6 to 2.8. The few sample points such as CL1S1 1.0 m, CL1S3 1.0 m, etc show an indication of the presence of less organic substances. This might be due to the degree of weathering and deposition as compared to the topography of the ground surface. There is also an absence of tropical iron-rich laterite which is generally indicated by a specific gravity of 3.0 or more. The sand particles are composed of quartz since the specific gravity is around 2.65.

Bulk and dry densities

The bulk density of a soil is the mass of the soil particles divided by the total volume they occupy. Table 12 shows the results of bulk and dry densities determined for the 40 samples.

The bulk density of a soil plays an important role in

Table 8. Cu and Cc of the soil.

Sample no	D_{10}	D_{30}	D_{60}	Cu	Cc	Sample no	D_{10}	D_{30}	D_{60}	Cu	Cc
BL1 S1 0.5 m	0.006	0.060	2.90	483.3	0.21	BL1 S5 0.5 m	0.005	0.600	5.00	925.9	13.33
BL1 S1 0.9 m		0.017	1.40			BL1 S5 1.0 m		0.016	0.75		
CL1 S1 0.5 m		0.009	0.21			CL4 S70.5 m		0.013	0.30		
CL1 S1 1.0 m		0.014	2.50			CL4 S7 1.0 m	0.150	1.800	3.50	23.3	6.17
CL1 S2 0.5 m		0.061	2.00			CL4 S8 0. 0.5 m		0.007	0.13		
CL1 S2 1.0 m		0.042	0.40			CL4 S81.0 m		0.018	0.59		
BL2 S2 0.5 m		0.013	2.30			BL1 S6 0.5 m	0.008	0.600	6.00	750.0	7.50
BL2 S2 1.0 m		0.005	0.06			BL1 S61.0 m		0.013	0.21		
CL1 S3 0.5 m	0.003	0.400	2.00	666.7	26.67	CL5 S9 0.5 m		0.050	1.80		
CL1 S3 1.0 m		0.015	2.20			CL5 S9 1.0 m		0.021	0.21		
BL2 S3 0.5 m	0.009	0.150	6.00	666.7	0.42	CL5 S10 0.5 m	0.090	0.300	2.90	32.2	0.34
BL2 S31.0 m		0.060	1.50			CL5 S10 1.0 m		0.021	2.00		
CL1 S4 0.4 m	0.075	0.240	0.55	7.3	1.40	BL1 S7 0.5 m	0.008	0.055	0.33	41.3	1.15
CL1 S4 0.6M	0.075	0.190	0.47	6.3	1.02	BL1 S7 1.0 m		0.017	0.29		
BL1 S1 0.5 m	0.003	0.085	0.78	300.0	3.56	CL6 S11 0.5 m		0.002	0.20		
BL1S4 1.0 m	0.003	0.040	0.69	230.0	0.77	CL6 S11 1.0 m	0.004	0.097	0.65	154.8	3.45
CL3 S5 0.5 m	0.005	0.240	1.60	320.0	7.20	CL6 S12 0.5 m	0.002	0.010	0.25	138.9	0.22
CL3 S5 1.0 m		0.014	1.25			CL6 S12 1.0 m		0.006	0.15		
CL3 S6 0.5 m	0.090	0.230	0.49	5.4	1.20	CL1 S13 0.5 m		0.017	3.00		
CL3 S6 1.0 m	0.180	0.390	0.90	5.0	0.94	CL1 S131.0 m	0.004	0.220	0.90	225.0	13.44

If Cu < 4.0 then the soil is uniformly graded.
If Cu > 4.0 then the soil is well graded.

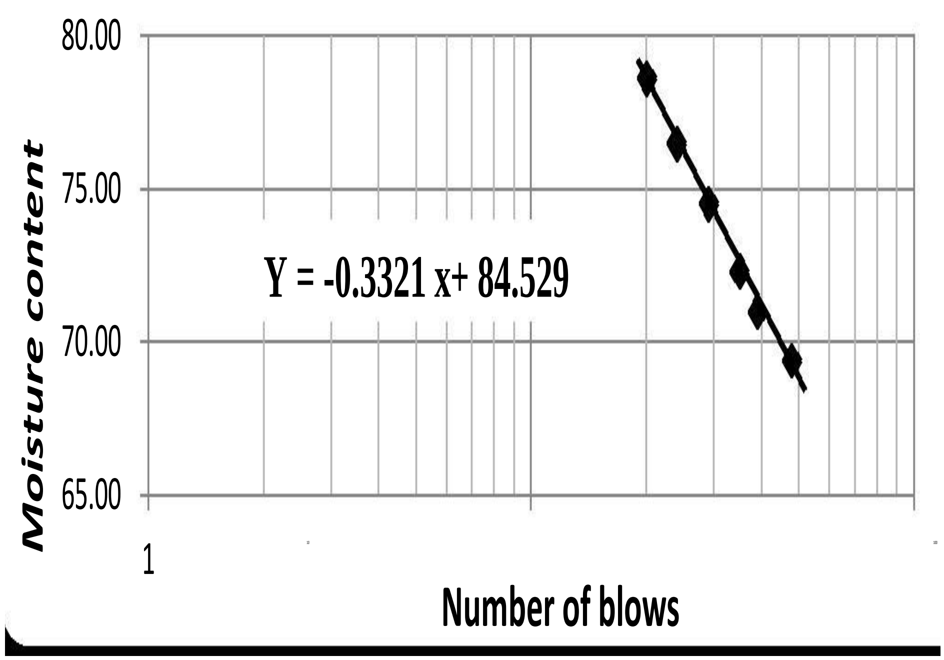

Figure 21. Graph for determination of Atterberg limits for the BL1S1 soil samples.

Table 9. Atterberg limits for the 36 soil samples.

Sample No	Liquid Limit	Plastic Limit	Plasticity Index	Sample No	Liquid Limit	Plastic Limit	Plasticity Index
BL1 S1 0.5 m	60.39	31.69	28.70	CL4 S7 0.5 m	51.99	28.13	23.86
BL1 S1 1.0 m	64.74	39.71	25.03	CL4 S7 1.0 m	78.80	33.45	45.35
CL S1 0.5	56.54	34.45	22.09	CL4 S8 0.5 m	54.55	31.20	23.35
CL S1 1.0 m	68.34	37.87	30.47	CL4 S8 1.0 m	81.16	35.67	45.49
CL1 S2 0.5	48.22	34.63	13.59	BL1 S6 0.5 m	57.82	31.61	26.21
CL1 S2 1.0 m	83.33	45.74	37.59	BL1 S6 1.0 m	76.22	41.32	34.90
BL2 S2 0.5 m	75.50	35.98	39.52	CL5 S9 0.5 m	67.36	32.63	34.73
BL2 S2 1.0 m	76.21	37.06	39.15	CL5 S9 1.0 m	91.63	43.15	48.48
CL1 S3 0.5 m	68.05	38.79	29.26	CL5 S10 0.5 m	69.19	35.31	33.88
CL1 S3 1.0 m	82.14	44.90	37.24	CL5 S10 1.0 m	91.70	46.58	45.12
BL3 S3 0.5 m	41.47	25.77	15.70	BL1 S7 0.5 m	37.17	21.69	15.48
BL3 S3 1.0 m	72.24	40.94	31.30	BL1 S7 1.0 m	53.82	26.15	27.67
BL1 S4 0.5 m	25.84	18.27	7.57	CL6 S11 0.5 m	60.02	33.55	26.47
BL1 S4 1.0 m	38.39	20.56	17.83	CL6 S11 1.0 m	80.24	38.73	41.51
CL3 S5 0.5 m	31.68	23.96	7.72	CL6 S12 0.5 m	76.75	40.66	36.09
CL3 S5 1.0 m	65.71	34.68	31.03	CL6 S12 1.0 m	74.59	41.91	32.68
BL1 S5 0.5 m	74.93	41.93	33.00	CL1 S13 0.5 m	15.69	14.83	0.86
BL1 S5 1.0 m	75.78	38.63	37.15	CL1 S13 1.0 m	34.20	21.64	12.56

Classification adopted is:
PI < 35 is low plasticity
35 ≤ PI ≤ 50 is intermediate plasticity
50 ≤ PI ≤ 70 is high plasticity
70 ≤ PI ≤ 90 is very high plasticity
> 90 is extremely high plasticity

Table 10a Classification of the soil at each sample location

Sample Sample No	Location	Percentage Grain Fractions Gravel	Sand	Silt	Clay	Classification
CL1 S1	0.5 m	8.63	68.30	11.57	11.50	Well graded Sand
	1.0 m	41.38	37.41	14.71	6.50	Well graded Sandy gravel with silt
CL1 S2	0.5 m	39.40	43.34	13.56	3.70	Well graded Gravelly sand with silt
	1.0 m	24.87	40.54	15.09	19.50	Well graded Gravelly sand with clay
BL2 S2	0.5 m	41.88	33.25	16.56	8.30	Well graded Sandy gravel with silt
	1.0 m	11.51	55.62	22.77	10.10	Well graded Silty sand
CL1 S3	0.5 m	49.24	34.47	5.39	10.90	Well graded Sandy gravel
	1.0 m	18.24	49.94	22.02	9.80	Well graded Silty Sand
BL3 S3	0.5 m	49.28	44.87	2.92	2.93	Well graded Sandy gravel
	1.0 m	41.88	36.53	14.94	6.64	Well graded Sandy gravel with silt
CL1 S4	0.5 m	4.72	92.54	1.74	1.00	Uniformly graded Sand
	1.0 m	4.25	93.17	1.07	1.50	Uniformly graded Sand
BL1 S4	0.5 m	17.68	66.35	7.97	8.00	Well graded Sand
	1.0 m	17.48	62.98	5.64	13.90	Well graded Sand
CL3 S5	0.5 m	30.58	58.71	7.90	2.81	Well graded Gravelly sand
	1.0 m	22.81	54.61	22.58	0.00	Well graded Gravelly sand with silt
CL3 S6	0.5 m	5.49	93.32	0.00	1.20	Uniformly graded Sand
	1.0 m	11.06	88.25	0.09	0.60	Uniformly graded Sand
BL1 S5	0.5 m	63.27	25.76	2.97	8.00	Well graded Sandy gravel
	1.0 m	31.78	45.88	14.30	8.04	Well graded Sandy gravel with silt

Table 10a. Classification of the soil at each sample location **(Cont.).**

Sample		**Percentage Grain Fractions**				
Sample No	Location	Gravel	Sand	Silt	Clay	Classification
CL4 S8	0.5 m	8.70	70.07	16.70	4.53	Well graded Sand with some silt
	1.0 m	6.67	49.29	39.44	4.60	Well graded Silty sand
BL1 S6	0.5 m	63.27	28.76	3.97	4.00	Well graded Sandy gravel
	1.0 m	12.10	65.20	8.30	14.41	Well graded Sand with clay
CL5 S9	0.5 m	35.71	40.02	19.17	5.10	Well graded Gravelly sand with silt
	1.0 m	11.19	65.18	15.03	8.60	Well graded Sand with silt
CL5 S10	0.5 m	52.38	40.80	3.94	2.88	Well graded Sandy gravel
	1.0 m	39.32	43.04	11.24	6.40	Well graded Gravelly sand
BL1 S7	0.5 m	5.17	87.09	3.90	3.84	Well graded Sand
	1.0 m	3.39	74.68	17.23	4.70	Well graded Sand with silt
CL6 S11	0.5 m	7.30	55.92	29.00	7.78	Well graded Silty sand
	1.0 m	12.82	74.32	4.30	8.56	Well graded Sand
CL6 S12	0.5 m	18.31	55.34	13.20	13.15	Well graded Sand with gravel
	1.0 m	13.29	59.18	9.20	18.33	Well graded Sand with clay
CL1 S13	0.5 m	49.24	28.97	14.99	6.80	Well graded Sandy gravel with silt
	1.0 m	13.50	74.71	7.30	4.50	Well graded Sand
CL4 S7	0.5 m	7.26	65.18	21.10	6.46	Well graded Silty sand
	1.0 m	63.98	31.94	1.47	2.60	Well graded Sandy gravel
BL1 S1	0.5 m	49.94	38.93	6.18	4.95	Well graded Sandy gravel
	1.0 m	33.34	48.99	10.60	7.07	Well graded Gravelly sand

Table 10b. Classification of the soil using the Textural Triangle

Sample		**Percentage Grain Fractions**				
Sample No	Location	Gravel	Sand	Silt	Clay	Classification
CL1 S1	0.5 m	8.63	68.30	11.57	11.50	Sandy Loam
	1.0 m	41.38	37.41	14.71	6.50	Loamy Sand
CL1 S2	0.5 m	39.40	43.34	13.56	3.70	Loamy Sand
	1.0 m	24.87	40.54	15.09	19.50	Sandy Loam
BL2 S2	0.5 m	41.88	33.25	16.56	8.30	Sandy Loam
	1.0 m	11.51	55.62	22.77	10.10	Sandy Loam
CL1 S3	0.5 m	49.24	34.47	5.39	10.90	Loamy Sand
	1.0 m	18.24	49.94	22.02	9.80	Sandy Loam
BL3 S3	0.5 m	49.28	44.87	2.92	2.93	Sand
	1.0 m	41.88	36.53	14.94	6.64	Loamy Sand
CL1 S4	0.5 m	4.72	92.54	1.74	1.00	Sand
	1.0 m	4.25	93.17	1.07	1.50	Sand
BL1 S4	0.5 m	17.68	66.35	7.97	8.00	Loamy Sand
	1.0 m	17.48	62.98	5.64	13.90	Sandy Loam
CL3 S5	0.5 m	30.58	58.71	7.90	2.81	Sand
	1.0 m	22.81	54.61	22.58	0.00	Loamy Sand
CL3 S6	0.5 m	5.49	93.32	0.00	1.20	Sand
	1.0 m	11.06	88.25	0.09	0.60	Sand
BL1 S5	0.5 m	63.27	25.76	2.97	8.00	Sand
	1.0 m	31.78	45.88	14.30	8.04	Loamy Sand

Table 10b. Classification of the soil using the Textural Triangle.

Sample		Percentage Grain Fractions				
Sample No	Location	Gravel	Sand	Silt	Clay	Classification
CL4 S8	0.5 m	8.70	70.07	16.70	4.53	Loamy Sand
	1.0 m	6.67	49.29	39.44	4.60	Sandy Loam
BL1 S6	0.5 m	63.27	28.76	3.97	4.00	Sand
	1.0 m	12.10	65.20	8.30	14.41	Sandy Loam
CL5 S9	0.5 m	35.71	40.02	19.17	5.10	Sandy Loam
	1.0 m	11.19	65.18	15.03	8.60	Sandy Loam
CL5 S10	0.5 m	52.38	40.80	3.94	2.88	Sand
	1.0 m	39.32	43.04	11.24	6.40	Loamy Sand
BL1 S7	0.5 m	5.17	87.09	3.90	3.84	Sand
	1.0 m	3.39	74.68	17.23	4.70	Sandy Loam
CL6 S11	0.5 m	7.30	55.92	29.00	7.78	Sandy Loam
	1.0 m	12.82	74.32	4.30	8.56	Sand
CL6 S12	0.5 m	18.31	55.34	13.20	13.15	Sandy Loam
	1.0 m	13.29	59.18	9.20	18.33	Sandy Loam
CL1 S13	0.5 m	49.24	28.97	14.99	6.80	Loamy Sand
	1.0 m	13.50	74.71	7.30	4.50	Sand
CL4 S7	0.5 m	7.26	65.18	21.10	6.46	Sandy Loam
	1.0 m	63.98	31.94	1.47	2.60	Sand
BL1 S1	0.5 m	49.94	38.93	6.18	4.95	sand
	1.0 m	33.34	48.99	10.60	7.07	Loamy sand

Table 11. Specific gravity result for 40 soil samples

SAMPLE NUMBER	AVERAGE Gs	SAMPLE NUMBER	AVERAGE Gs
BL1 S1 0.5 m	2.6	BL1 S5 0,5 m	2.7
BL1 S1 0.9 m	2.7	BL1 S5 1.0 m	2.6
CL1 S1 0.5 m	2.6	CL4 S7 0.5 m	2.5
CL1 S1 1.0 m	2.5	CL4 S7 1.0 m	2.6
CL1 S2 0.5 m	2.6	CL4 S8 0.5 m	2.7
CL1 S2 1.0 m	2.6	CL4 S8 1.0 m	2.5
BL1 S2 0.5 m	2.6	BL1 S6 0.5 m	2.6
BL1 S2 1.0 m	2.6	BL1 S6 1.0 m	2.6
CL1 S3 0.5 m	2.6	CL5 S9 0.5 m	2.6
CL1 S3 1.0 m	2.5	CL5 S9 1.0 m	2.6
BL3 S3 0.5 m	2.6	CL5 S10 0.5 m	2.5
BL3 S3 1.0 m	2.6	CL5 S10 1.0 m	2.6
CL1 S4 0.4 m	2.5	BL1 S7 0.5 m	2.6
CL1 S4 0.6 m	2.6	BL1 S7 1.0 m	2.6
BL1 S1 0.5 m	2.6	CL6 S11 0.5 m	2.6
BL1S4 1.0 m	2.7	CL6 S11 1.0m	2.6
CL3 S5 0.5m	2.6	CL6 S12 0.5 m	2.6
CL3 S5 1.0 m	2.7	CL6 S12 1.0 m	2.6
CL3 S6 0.5 m	2.6	CL1 S13 0.5m	2.6
CL3 S6 1.0 m	2.7	CL1 S13 1.0 m	2.6

determining if the soil has the physical characteristics necessary for plant growth, building foundations and other uses. One significant inference of bulk density of soil is the amount of surface area a soil has. Large surface area of the soil implies greater ability to retain water and nutrients. Lower bulk density implies greater surface area. The bulk density of soils greatly depends on the mineral makeup and the degree of compaction. Bulk densities are always equal to half the soil particle density and inversely related to its porosity. Typical organic soils are those with densities between 1.1 tonnes/m^3 and 2.0 tonnes/m^3.

From Table 12, the average bulk densities for the soils are 1.88 tonnes/m^3 and 2.02 tonnes/m^3 at the depths of 0.5 m and 1.0 m respectively. It is observed that, in most of 75 the sample points, the bulk density values increases with depth. This is due to the effect of cultivation and the decrease of organic matter content with depth. The bulk density values for the soils are relatively high and may cause hindrance to root penetration if the ground is not prepared well for cultivation. This increase in density will cause a decrease in permeability, thereby making field crops more susceptible to the adverse effects of water logging. The portions with higher bulk densities are good grounds for building and road construction. Transport and maintenance section can also be sited at those portions.

Porosity of the Soil

Porosity is a fraction between zero and one, typically ranging from less than 0.01 for solid granite and to more than 0.5 for peat and clay. However, it can also be represented as percentage (%). In this research, the porosities were expressed as percentages as shown in the Table 13. The porosities were estimated from the soils' specific gravities and bulk densities by the

Table 12. Bulk and dry densities for the soil.

Sample number/Location	Average Bulk density	Average dry density(tonnes/m^3)	Sample number/Location	Average Bulk density	Average dry density(tonnes/m^3)
BL1 S1 0.5 m	1.89	1.58	BL1 S5 0.5 m	1.76	1.41
BL1 S1 0.9 m	2.00	1.79	BL1 S5 1.0 m	2.07	1.81
CL1 S1 0.5 m	1.77	1.49	CL4 S7 0.5 m	1.87	1.60
CL1 S1 1.0 m	1.87	1.59	CL4 S7 1.0 m	1.88	1.64
CL1 S2 0.5 m	1.78	1.45	CL4 S8 0.5 m	1.83	1.55
CL1 S2 1.0 m	1.89	1.65	CL4 S8 1.0 m	1.91	1.67
BL2 S2 0.5 m	1.84	1.48	BL1 S6 0.5 m	1.85	1.57
BL2 S2 1.0 m	1.79	1.44	BL1 S6 1.0 m	1.82	1.52
CL1 S3 0.5 m	1.80	1.45	CL5 S9 0.5 m	1.86	1.54
CL1 S3 1.0 m	1.71	1.45	CL5 S9 1.0 m	1.85	1.57
BL3 S3 0.5 m	1.94	1.70	CL5 S10 0.5 m	1.90	1.63
BL3 S3 1.0 m	1.95	1.64	CL5 S10 1.0 m	1.95	1.72
CL1 S4 0.4 m	2.12	1.84	BL1 S7 0.5 m	1.92	1.64
CL1 S4 0.6 m	2.09	1.77	BL1 S7 1.0 m	1.97	1.70
BL1 S4 0.5 m	1.89	1.70	CL6 S11 0.52 m	1.77	1.39
BL1 S4 1.0 m	1.94	1.77	CL6 S11 1.0 m	1.82	1.51
CL3 S5 0.5 m	2.09	1.87	CL6 S12 0.5 m	1.77	1.40
CL3 S5 1.0 m	2.01	1.83	CL6 S12 1.0 m	1.81	1.43
CL3 S6 0.5 m	1.89	1.68	CL1 S13 0.5 m	2.08	1.87
CL3 S6 1.0 m	1.98	1.71	CL1 S13 1.0 m	2.09	1.90

It was observed that, the highest porosity is obtained when the grains are uniformly graded. The addition of most other grain sizes tends to lower porosity proportionately, although the addition of clay increases it (Pettijohn, 1975).

From the Table 13, it is noted that the soils exhibit moderate porosities. Locations where the porosity of subsurface soil is lower than the surface soil is a result of compaction by gravity. However the decrease in porosity of surface soil shows that, the soils are not well sorted and the clays among them will have higher hydraulic conductivity due to the way clay minerals have been structured. Similarly, sandy aquifers within the study area will have lower hydraulic conductivity. In general, the total porosity of soils falls within the range of 30 to 70%. In sand, porosities below 40% are liable to restrict root growth due to excessive strength. Landon, (1991) noted that, anaerobism occurred in soils with up to 30% air-filled porosity (AFP), but depends on the local conditions around the roots and the presence or absence of intact water films; normally, however, the soils were anaerobic at AFP value below 10 to 15%.

Hydraulic Conductivity

Table 14 presents the average hydraulic conductivity values for soil of the study area. The average hydraulic conductivity in cmhr^{-1} is 0.234 for the 1.0 m depth of the site. This result is indicative of the soil texture of the site. The hydraulic conductivity value of 0.234 cmhr^{-1} is regarded as very slow in comparison to the conductivity classification of FAO (1963), which gave conductivity classes and their respective values as very slow; < 0.8, slow; 0.8 – 2.0, moderately rapid; 6.0 – 8.0, rapid, 8.0 – 12.5 and very rapid; 12.5, all in cmhr^{-1}. Again, the average hydraulic conductivity value of 0.234 cmhr^{-1} recorded at the site also implies that the soil is generally; clay, silty clay, clay loam, and sandy clay loam which is the most predominant. This value also implies that when drainage is necessary, close drainage spacing is required and where necessary, sub soiling is advocated to facilitate drainage at the site.

From Table 14, it was observed that the average hydraulic conductivity of the sub-layer, which is 1m below the soil surface, was 0.245 cmh^{-1}. This value

Table 13. Porosities of the soil.

Sample No	Location	Porosity (%)	Sample No	Location	Porosity (%)
CL4 S8	0.5 m	28.55	CL1 S1	0.5 m	35.36
	1.0 m	31.2		1.0 m	27.58
BL1 S6	0.5 m	31.67	CL1 S2	0.5 m	32.08
	1.0 m	29.23		1.0 m	25.68
CL5 S9	0.5 m	51.68	BL2 S2	0.5 m	28.27
	1.0 m	28.94		1.0 m	26.22
CL5 S10	0.5 m	27.66	CL1 S3	0.5 m	34.05
	1.0 m	51.68		1.0 m	23.52
BL1 S7	0.5 m	26.88	BL3 S3	0.5 m	26.86
	1.0 m	30.96		1.0 m	29.23
CL6 S11	0.5 m	38.78	CL1 S4	0.5 m	22.37
	1.0 m	19.02		1.0 m	28.07
CL6 S12	0.5 m	31.36	BL1 S4	0.5 m	25.21
	1.0 m	20.8		1.0 m	23.52
CL1 S13	0.5 m	21.85	CL3 S5	0.5 m	31.34
	1.0 m	20.71		1.0 m	21.18
CL4 S7	0.5 m	30.85	CL3 S6	0.5 m	35.23
	1.0 m	27.93		1.0 m	21.42
BL1 S1	0.5 m	27.23	BL1 S5	0.5m	36.69
	1.0 m	17.82		1.0 m	27.03

Table 14 Hydraulic conductivities for the soil.

Sample location	Depth (m)	Hydramlic Conductivity / (cmhr^{-r})
CL1S1	0.5	0.183 ± 0.090
	1.0	0.163 ± 0.112
CL1S2	0.5	0.189 ± 0.093
	1.0	0.183 ± 0.112
CL1S3	0.5	0.178 ± 0.090
	1.0	0.129 ± 0.112
CL1S3	0.5	0.124 ± 0.093
	1.0	0.220 ± 0.112
CL3S5	0.5	0.250 ± 0.090
	1.0	0.252 ± 0.112
CL4S7	0.5	0.264 ± 0.090
	1.0	0.360 ± 0.112
CL4S8	0.5	0.380 ± 0.090
	1.0	0.385 ± 0.112
CL5S9	0.5	0.372 ± 0.090
	1.0	0.369 ± 0.112
CL5S10	0.5	0.395 ± 0.093
	1.0	0.252 ± 0.112
CL6S11	0.5	0.265 ± 0.093
	1.0	0.272 ± 0.112
CL6S12	0.5	0.248 ± 0.090
	1.0	0.244 ± 0.112
BL1S1	0.5	0.241 ± 0.090
	1.0	0.517 ± 0.112
BL1S4	0.5	0.131 ± 0.090
	1.0	0.145 ± 0.112
BL1S5	0.5	0.132 ± 0.090
	1.0	0.146 ± 0.112
BL1S6	0.5	0.160 ± 0.090
	1.0	0.184 ± 0.112
BL1S7	0.5	0.192 ± 0.090
	1.0	0.178 ± 0.112
BL2S2	0.5	0.144 ± 0.003
	1.0	0.146 ± 0.112
BL3S3	0.5	0.351 ± 0.090
	1.0	0.365 ± 0.112

	For 0.5 m depth	For 1.0 m depth
Average	0.234 cmhr^{-r}	0.245 cmhr^{-r}
Maximum	0.395 cmhr^{-r}	0.518 cmhr^{-r}
Minimum	0.124 cmhr^{-r}	0.119 cmhr^{-r}
Range	0.271 cmhr^{-r}	0.398 cmhr^{-r}
95% confidence interval.		
Standard error	0.021291	0.026521

according to the FAO.
(1963) is classified to be very slow and this also correlates with the soil textural class identified at the site. These revelations imply that when such a site is subjected to irrigation, it would not require frequent or copious amounts of water. On the other hand, such a field when inundated with flood water may require some drainage gutters in order to facilitate drainage. The predominantly sandy clay, sandy clay loam through to

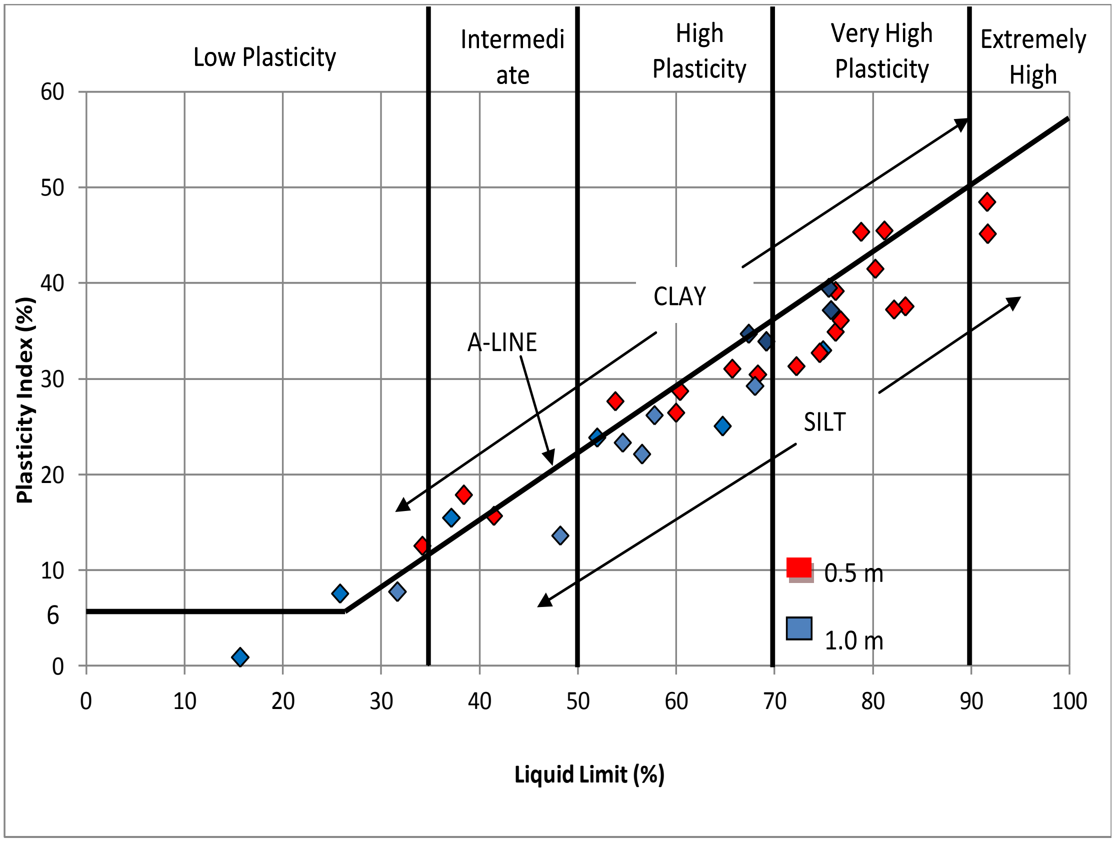

Figure 22. Modified plasticity chart with plots of the samples containing fine particles

clay soil types identified also confirms the topography of the site (figure 22).

The soil pH

All plants have different pH preferences. The pH level of the soil directly affects soil life and the availability of essential soil nutrients for plant growth. Soil bacteria, a microscopic soil occupant responsible for the decomposition of organic material into simpler nutrient forms that become food for plants, thrives at about 6.3 – 6.8 pH. When soil is acidic, minerals such as zinc, aluminum, manganese, copper and cobalt are soluble and available for plant uptake. However, they can also be excessive in presence and therefore, toxic to plants. Alkaline soil on the other hand, may contain a higher quantity of bicarbonate ions, and this can affect optimum growth in plants by interfering with the normal uptake of other ions. The most common range of soil pH is 4 to 8 pH, and the range for optimal availability of plant nutrients for most crops is 6.5 to 7.0 pH (Anon, 2010). Results of pH determinations of the site are depicted in Table 15. The average pH value of the 0.5 m and 1.0 m depth of soil sample is 4.8 and 4.6 with standard deviations of 0.9 and 1.2 units respectively. The values fall within the most common range of soil pH. The pH value recorded for the subsurface soil is 0.2 units lower than the pH value for the 0.5 m depth. This value is attributed to some amounts of clays identified in the 1.0 m soil depth. The study area is strongly acidic with small portion being medium to slightly acidic.
The pH classification adopted is as follows:

- 5.0 pH is strongly acid.
- 6.0 pH is medium acid to slightly acid.
- 7.0 pH is very slightly acid to slightly alkaline.
- 8.0 pH is slightly alkaline to medium alkaline.
- 9.0 pH is strongly alkaline

(Anon, 2010).

Infiltration Rate

The infiltration rate test was conducted on the soil in

Table 15. Soil pH values in distilled water.

Sample location	Depth (m)	pH (H_2O) 1:25
	0.5	4.2 ± 0.9
CL1S3	1.0	3.6 ± 1.2
	0.5	6.0 ± 0.9
CL1S2	1.0	4.1 ± 1.2
	0.5	5.8 ± 0.9
CL1S13	1.0	7.4 ±1.2
	0.5	4.1 ± 0.9
CL1S1	1.0	5.0 ± 1.2
	0.5	5.4 ± 0.9
CL3S3	1.0	4.1 ± 1.2
	0.5	4.1 ± 0.9
CL4S8	1.0	3.8 ±1.2
	0.5	4.0 ± 0.9
CL4S7	1.0	4.0 ± 1.2
	0.5	4.2 ± 0.9
BL1S7	1.0	3.6 ± 1.2
	0.5	6.3 ± 0.9
BL1S4	1.0	3.8 ±1.2
	0.5	3.6 ± 0.9
BL1S5	1.0	7.1 ± 1.2
	0.5	5.8 ± 0.9
BL1S1	1.0	5.7 ± 1.2
	0.5	6.4 ± 0.9
BL1S4	1.0	6.0 ± 1.2
BL1S6	0.5	4.1 ± 0.9
	1.0	3.9 ± 1.2
BL2S2	0.5	4.4 ± 0.9
	1.0	4.3 ± 1.2
	0.5	5.1 ± 0.9
BL3S3	1.0	3.7 ± 1.2
	0.5	4.0 ± 0.9
BL3S3	1.0	4.1 ± 1.2
	0.5	4.1 ± 0.9
CL5S9	1.0	4.4 ± 1.2

For .05m depth For 1.0m depth
Average 4.8 4.6
Maximum 6.4 7.4
Minimum 3.6 3.6
Range 2.8 3.8
Standard error: 0.2204 0.2922

order to determine its field capacity for irrigation purpose. The field observation was conducted in the dry season, because at that time, all the macro pores open to the surface and are available to conduct water into the soil. In the soil with expanding type of clays, the initial infiltration was particularly higher as water poured into the network of the shrinkage cracks. Consequently, the sudden decrease in infiltration rate was due the closed up of the shrinkage cracks because many macro pores had filled with water.

A graph of infiltration rate/sec was plotted against time in seconds (figure 23) to determine the infiltration rate of the soil. The result of similar graphs plotted for the twenty (20) locations with their temperature and relative humidity has been summarized in Table 16. The temperature and the relative humidity of the soils were determined by using a digital thermo-hydrograph.

From Table 16, the average infiltration rate for the site is 0.026 (cm/sec) that means the site is predominantly made of sandy-loam. It also means that, in the dry season, the application rate of water to the soil that will be saturated enough for plant support should be 0.026 cm/sec. The range falls within 0.013 cm/sec to 0.041 cm/sec. and that corresponds to soil types from clay-loam to sandy-loam (Anon, 2009b). However the lower values; 8×10^{-3} cm/s and 9×10^{-3} cm/s indicate that a relatively high amount of clay is present at such locations. Conversely, the high value of 9.9×10^{-1} cm/s is an indication of coarser grain sand.

Soil temperature has significant effect on pest control, chemical reactions as well as biological interactions. Some plants do well in low temperature whereas others

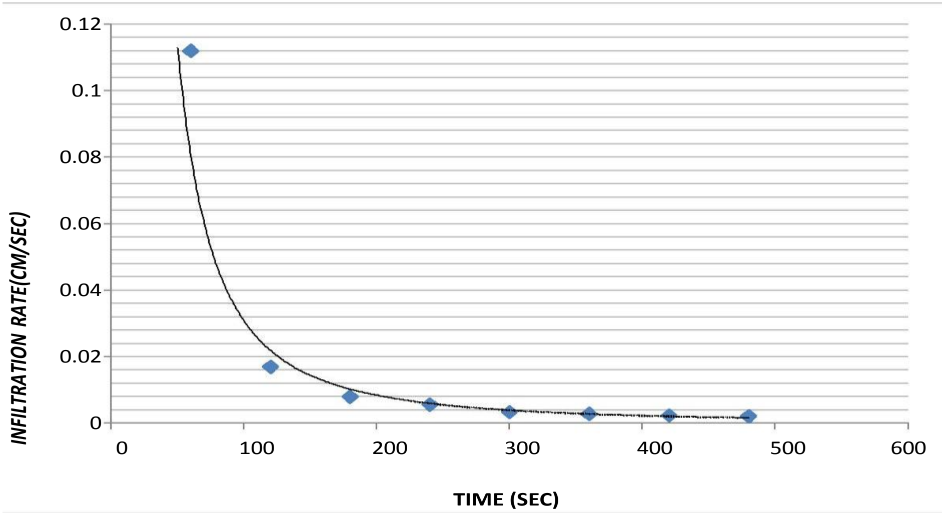

Figure 23. Graph for the determination of infiltration rate of the soil at pit 4.

Table 16. Average infiltration rate for the study area.

Sample number	Infiltration rate(cm/sec)	Temperature (°C)	Relative humidity
BL1 S1	0.041	31	72
CL1 S1	0.018	33	65
CL1 S2	0.019	33	75
BL2 S2	0.026	32	73
CL1 S3	0.015	31	70
BL3 S3	0.02	31	69
CL1 S4	0.009	31	71
BL1 S4	0.041	32	73
CL3 S5	0.008	31	74
CL3 S6	0.099	31	74
BL1 S5	0.024	33	75
CL4 S7	0.024	33	75
CL4 S8	0.023	32	70
CL5 S9	0.018	33	73
CL5 S10	0.016	31	73
BL1 S7	0.013	31	74
CL6 S11	0.016	32	72
CL6 S12	0.021	30	70
BL1 S7	0.019	31	70
BL1 S6	0.053	32	73

do well in high temperature. The temperatures of the study site (Table 16) fall within the range of 31°C to 33°C which is moderately good for economic plant and trees (Anon, 2009c). The relative humidity of the study site which falls within the range of 65 to 75 also give an indication that, even in the dry season, there is a considerably good amount of moisture content that will support plant growth and other economic activities.

OBSERVATION, CONCLUSIONS AND RECOMMENDATION

Observations

- The soil is predominantly well graded with high to very high plasticity.

- The rainfall pattern is very consistent and would allow good farm planning.

- The topography of the survey area is relatively undulating with elevation between 260 and 400 metres above mean sea level. In view of this, the direction of runoff flow is expected to be distributed over the entire land. Since the gradient of the land is gentle and runoff is expected to flow over most of the land, it will enhance infiltration of precipitation into the subsurface and that will enhance plant growth. Soil located in the low relief areas are the discharge points.
- The average infiltration rate for the site is 0.026 (cm/sec). The value suggests that in the dry season,
- when 0.026 cm amount of water is applied onto the soil at each point, it will be saturated enough for plant support.
- The soils are moderately acidic with average pH values of 4.8 and 4.6 for the 0.5 m and 1.0 m depths respectively.
- Anthropogenic effect is not likely since the Station is not close to the Community.
- Considerable portion of the land provide good grounds for buildings and roads construction as indicated by their grading, plasticity, and the topography of the land.
- Few portions are good for irrigation as indicated by their texture, grain size, and plasticity index.
- Taking into consideration the dry period in which the survey was conducted and the moisture content results, it is obvious that the soil retains quite significant amount of water even in the dry season. This is as a result of the rainfall pattern of the area which shows that, even in the dry season, rain does fall.
- Most of the fine grain soils are silt; since they were found to appear below the A-line when plotted on the modified plasticity chart.

Conclusions

- The soil is typically organic (Histosols)
- Based on the Unified Soil Classification System, the soil is classified as sand, sandy gravel, gravel sand, silty sand with intermediate to very high Plasticity.
- From the Textural Triangle the soil is predominantly Sandy Loam, Loamy Sand and Sand.
- The soil contains the needed reasonable porosity, permeability, and organic content that can support plant growth.
- Flooding is seldom to occur at the site due to the silty nature of the fines particles.

Recommendations

- The University can go ahead and use the land for its intended purpose.
- Developers and planners of the station must ensure a well prepared scheme or lay-out before the commencement of the project.
- It will be advisable for the University authorities to acquire more land at Twifo Nwamaso up to not less than 500 acres based on the observations and the conclusions above.

DEDICATION

This Thesis is proudly dedicated to King Jehoshaphat Yaw Ankomah Gyamera (my son),

AKNOWLEDGEMENT

''I will praise the Lord with my whole heart; I will shew forth all the marvelous works'' (Psalm 9:1). All praises and honor belongs to the Lord most-high, for He has done everything possible for this work to be a success.
My in-depth gratitude goes to Professor Jerry S. Kuma, the distinguished Supervisor of this research. He actually went beyond his role as a Supervisor, and became my mentor, friend, and above all, a counselor. I also extend my appreciations to all Lecturers and staff of the Geological Engineering Department in UMaT, Soil Science Department, UCC, Meteorological Service Department, Community Water and Sanitation Company all in Cape Coast and last but not the least, the Chief and people of Twifo Nwamaso for their numerous help they offered me.
I cannot forget you, Mr Liberty Ammamoo Kwashie (Principal Inspector of Lands/Municipal Lands Officer, Tarkwa and beyond), Professor B. A Osei (Head, Soil Science Department, UCC), Dr. Okae Anti, UCC, and Mr. George Koomson (MSc Colleague) for the encouragement, advice, technical and emotional contribution you offered me. To all Gyam Eng. Staff I say a big thank to you especially, Abeka, Amed, Nii, Kum, Erick and Cynthia Quaidoo.
This work would not have been successful without making constant reference to other people's study. I therefore give complement to all authors, researchers, and senior members in the Profession. Finally, let me express my sincere appreciation to the members of my humble family, Mrs Adjoa Gyamera, Mary Ann, and Abena Tetteh for their constant prayers, affection and the emotional support they offered.
To all colleagues at the School of Agric. (UCC), I say thank you.

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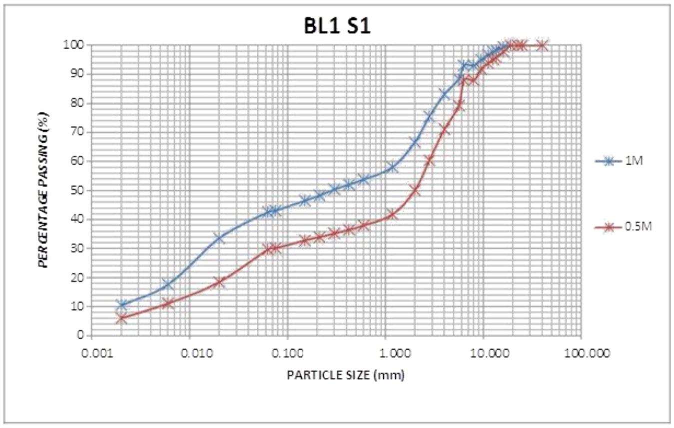
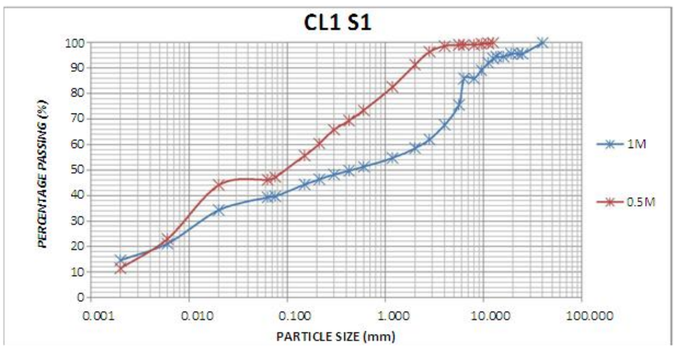
APPENDICES

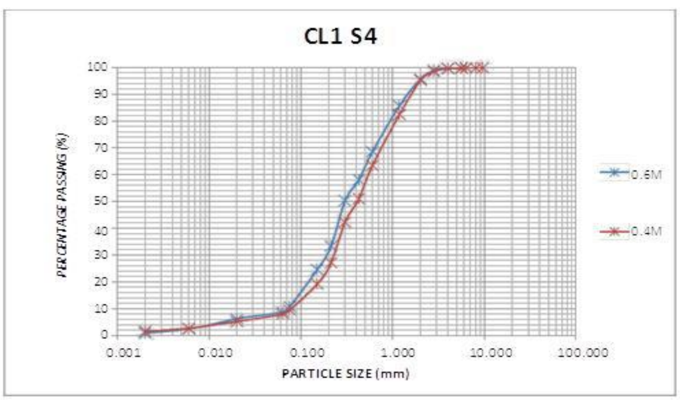
Appendix 1. Grain size scale for sediments.

	U.S. Standard sieve mesh	Millimeters		Phi (φ) units	Wentworth size class
GRAVEL		4096		-12	
		1024		-10	Boulder
		256	256	-8	
		64	64	-6	Cobble
		16		-4	Pebble
	5	4	4	-2	
	6	3.36		-1.75	
	7	2.83		-1.5	Granule
	8	2.38		-1.25	
	10	2.00	2	-1.0	
SAND	12	1.68		-0.75	
	14	1.41		-0.5	Very coarse sand
	16	1.19		-0.25	
	18	1.00	1	0.0	
	20	0.84		0.25	
	25	0.71		0.5	Coarse sand
	30	0.59		0.75	
	35	0.50	½	1.0	
	40	0.42		1.25	
	45	0.35		1.5	Medium sand
	50	0.30		1.75	
	60	0.25	¼	2.0	
	70	0.210		2.25	
	80	0.177		2.5	Fine sand
	100	0.149		2.75	
	120	0.125	⅛	3.0	
	140	0.105		3.25	
	170	0.088		3.5	Very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
MUD – SILT	270	0.053		4.25	
	325	0.044		4.5	Coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	Medium silt
		0.0078	1/128	7.0	Fine silt
		0.0039	1/256	8.0	Very fine silt
MUD – CLAY		0.0020		9.0	
		0.00098		10.0	Clay
		0.00049		11.0	
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

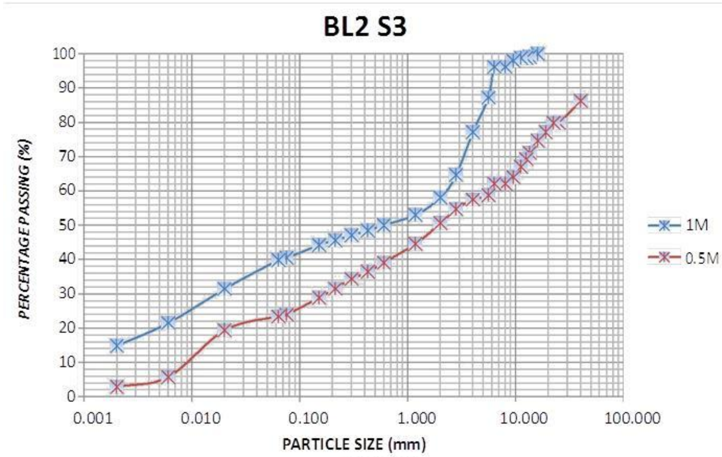
Appendix 2 Grain size distribution curve for the soil samples

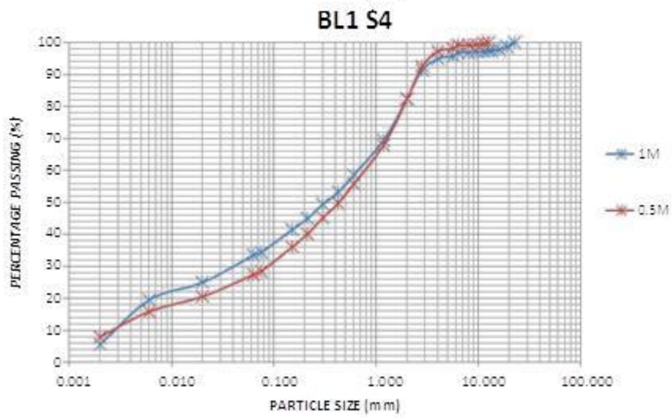


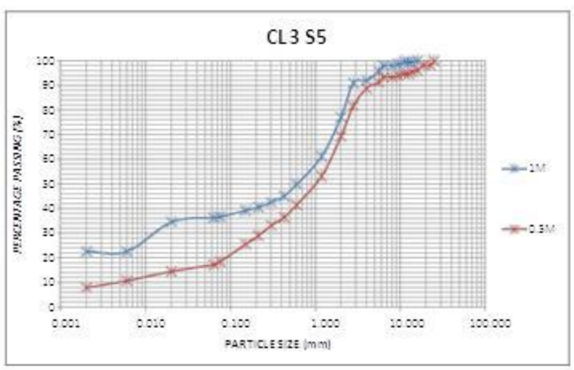


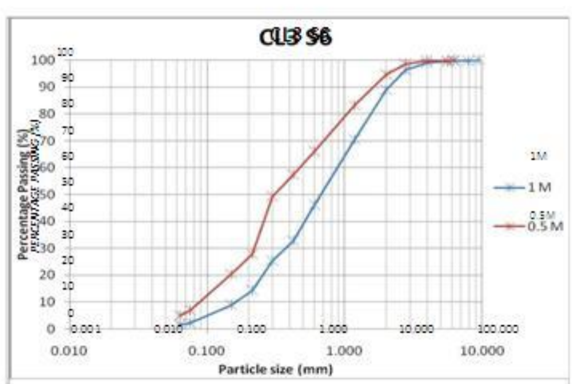


Appendix 2. Grain size distribution curve for the soil samples (cont'd)

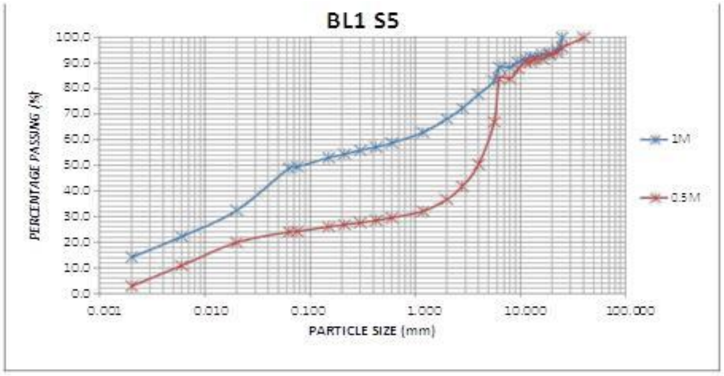


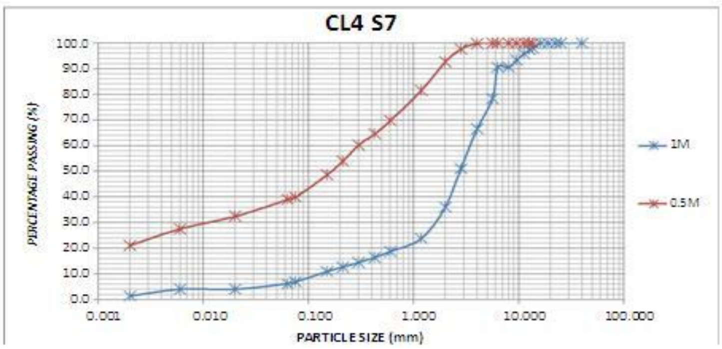


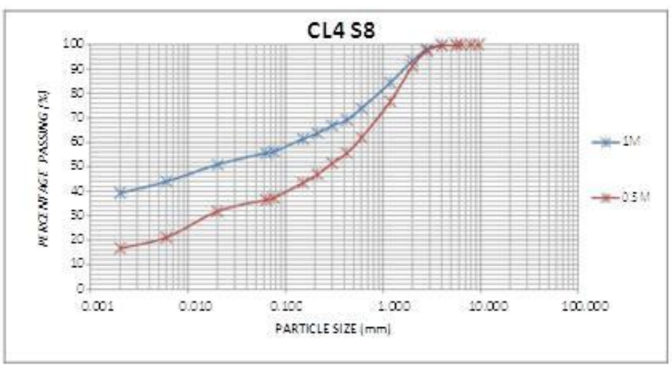


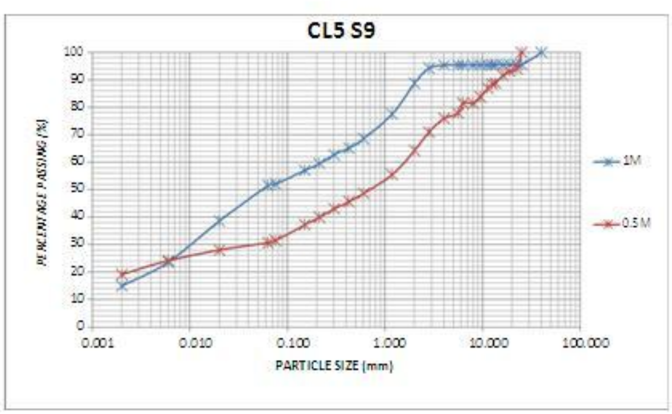


Appendix 2 Grain size distribution curve for the soil samples (cont'd)

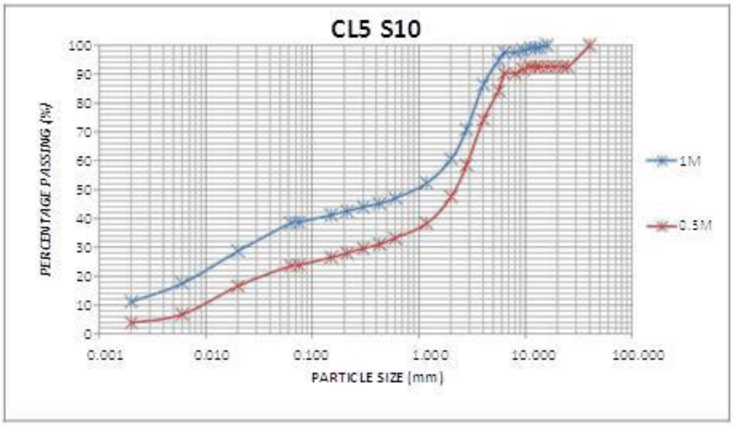


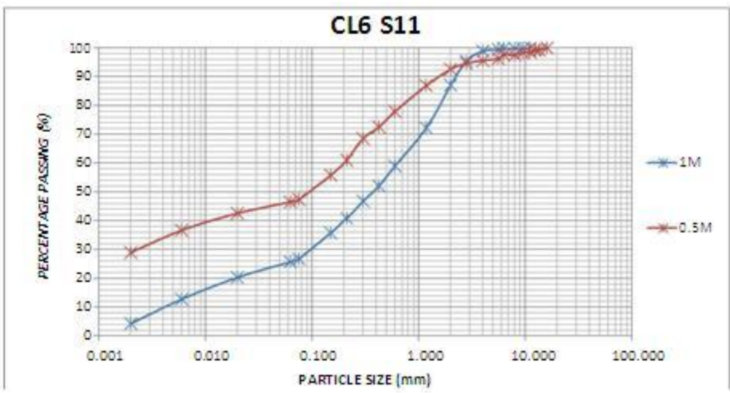


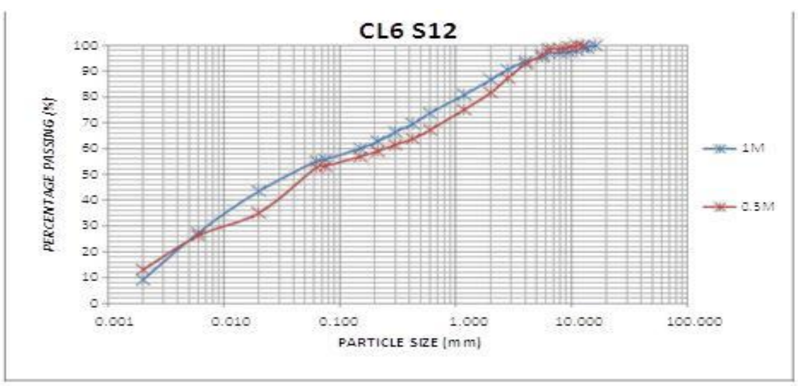


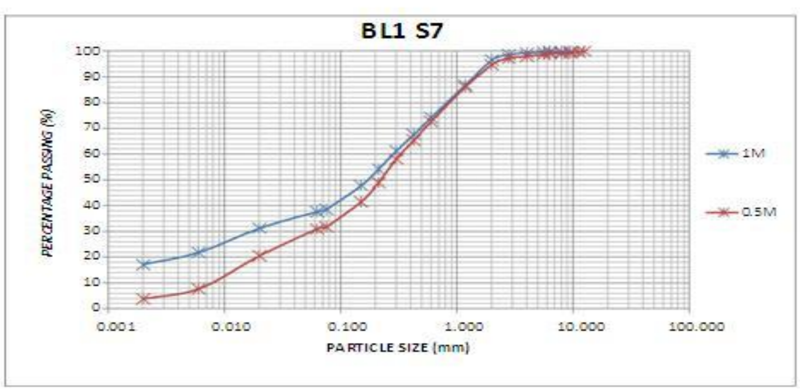


Appendix 2 Grain size distribution curve for the soil samples (cont'd)

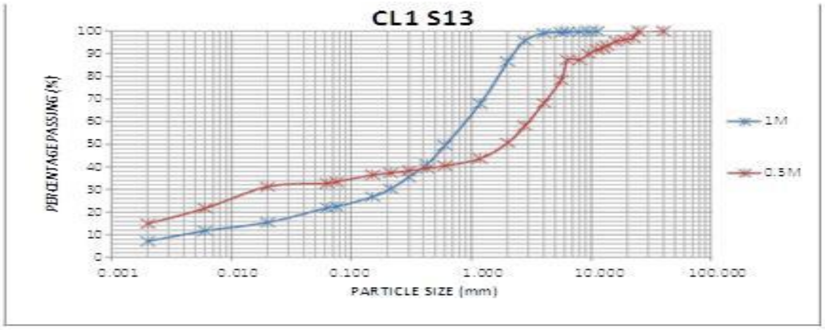


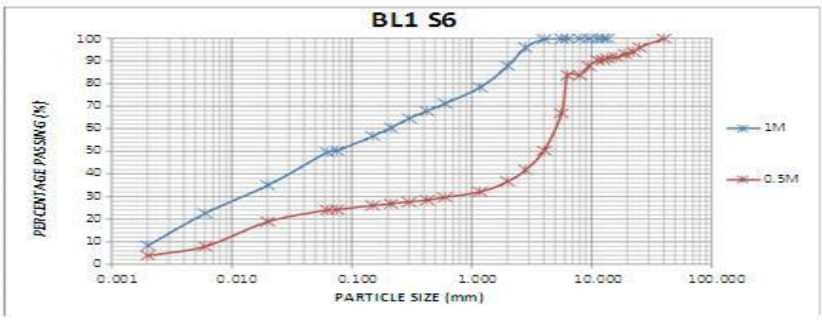




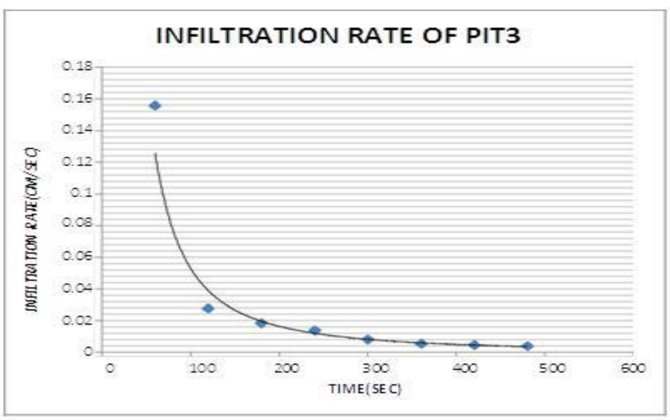


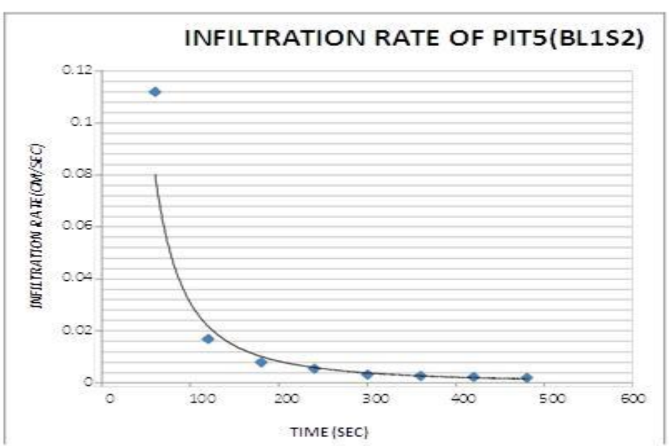
Appendix 2 Grain size distribution curve for the soil samples (cont'd)



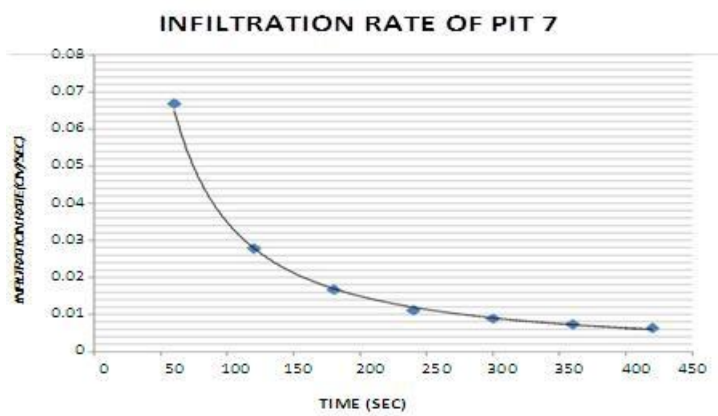


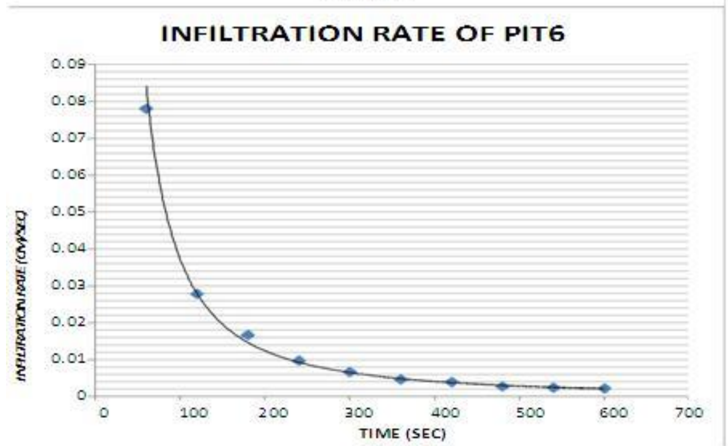
Appendices 3 Graph for the determination of infiltration rate of the soil

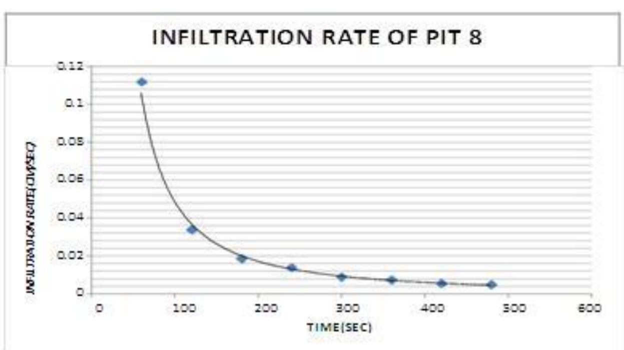


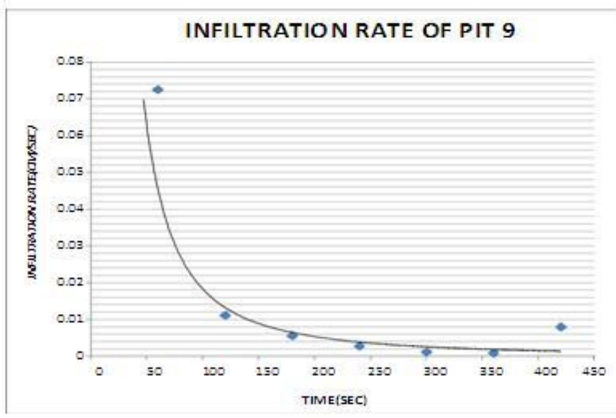


Appendices 3 Graph for the determination of infiltration rate of the soil (cont)

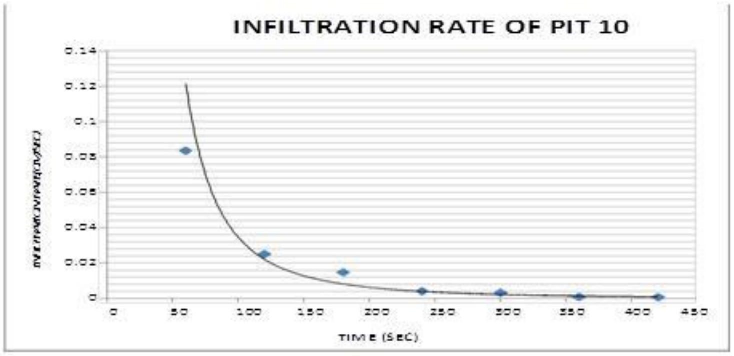


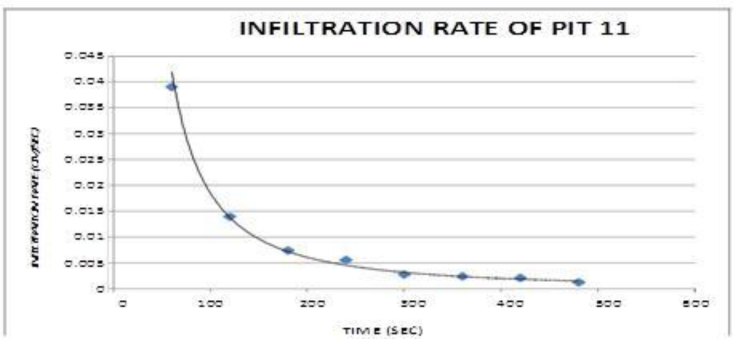






Appendices 3. Graph for the determination of infiltration rate of the soil (cont'd)





Appendix 4. Topographic data of the study site

71	RC1	202837.9	114461	261.61	rd o
					sp on cl near daha
73	CL1A	202790	114492.2	263.61	stream
74	RC2	202812.2	114550.1	277.608	rd o
75	RC3	202785.5	114645.2	293.606	rd o
76	RC4	202772.7	114698.2	519.604	rd o kwamena fynn jn
77	RC5	202845.9	114761	317.599	
78	RC6	202751.9	114766.3	312.603	
79		202684.9	114748.5	323.606	
80	CL1B	202715.1	114804.4	320.603	sp
81	GS1	202709.2	114835.4	308.603	
82	GS2	202685.3	114872.5	313.602	
83	GS3	202660.5	114919.6	300.602	
84	CL1C	202646.5	114932.7	316.602	sp
85	GS4	202633.6	114949.7	342.602	

Appendix 4. Topographic data of the study site (cont.)

86	GS5	202607.8	115002.8	306.601	
87	CL1D	202527.2	115136.1	266.6	
	STAP1	202509.3	115150.1	259.6	
	RC7	202618.8	114727.8	300.61	
90	BL1A	202575.8	114735.9	304.611	sp
91	GS6	202548.7	114688	312.614	
92	GS7	202570.5	114628.9	296.615	
93	GS8	202572.3	114580.9	270.616	
94	GS9	202566	114774.9	319.61	
95	GS10	202552.1	114822	325.609	
96	GS	202538.3	114868	285.608	
97	GS	202525.5	114913.1	283.608	
98	GS	202498.8	115009.2	244.605	
99	GS	202460.1	115087.3	261.605	
100	GS	202401.3	115154.5	265.605	
101	GS	202394.5	115210.5	259.603	
102	GS	202347.1	115172.7	271.609	
104	GS	202387.1	115093.5	270.607	
105	GS	202369	115059.6	285.609	
106	GS	202359.9	115026.6	297.611	
107	GS	202354.9	114985.7	303.612	
108	GS	202307.7	114971.8	297.614	
109	GS	202295.9	115042.9	289.613	
110	GS	202224.1	115097.1	272.614	
111	GS	202215.3	115164.1	263.612	
114	GS	202143.2	115131.4	263.616	
115	GS	202098.2	115122.5	243.618	
116	GS	202117.9	115038.5	273.62	
117	GS	202036	115048.8	273.623	
118	GS	201960.1	115092	264.625	
119	GS	202100.6	114950.5	266.623	
120	GS	202048.5	114911.7	282.627	
121	GS	201993.4	114874.9	258.63	
122	GS	201951.2	114837.1	271.633	
123	GS	201897.1	114812.3	290.636	
124	GS	201857	114781.4	315.639	

126	GS	201753.1	114806.8	308.642
127	GS	201663.2	114832.1	300.645
128	GS	201674.4	114897	285.642
130	GS	201661.7	114971.1	284.641
131	GS	201584.5	114909.3	279.646
132	GS	201515.4	114867.6	274.65
133	GS	201436.2	114834.9	268.654
134	GS	201335.2	114810.2	262.659
135	GS	201249.2	114823.5	259.662
136	GS	201190.2	114818.7	260.665
139	GS	201224.6	114929.6	280.66
140		201098.2	114829	274.668
141		201007.1	114788.3	296.673
142		200928.2	114827.6	277.675
143	GS	200894.8	114696.7	323.681
144	RC	200823.7	114669	334.684
145	RC	200739.9	114726.3	285.686
146	RC	200848.7	114104.9	338.702
147	RC	200927.2	114540.6	310.684
148		200997	114474.4	350.684
149	RC	201054.6	114353.2	349.685
150	RC	201189.2	114230.7	406.684
151		201285.8	114125.4	392.683
153		201476.7	114095.7	335.676
154		201558.7	114101.5	374.673
155		201642.6	114072.2	358.67
156		201719.5	114036.9	351.669
157		201828.5	114041.5	346.664
159		201978.3	114004	361.659
161		202079.3	113984.7	356.656
163	RC	202255	113895.1	351.647
172	BL1	202295.2	113970.9	328.644
174	BL2	202323.5	114044.8	310.651
181	BL3	202353.6	114090.7	9.641
183	BL4	202443.7	114105.4	338.637
184	BL5	202481.8	114137.3	348.634

185	BL6	202507.1	114217.2	310.631	
186	BL7	202569.2	114252	315.627	
187	BL8	202609.2	114274.8	284.625	
188	BL9	202642.1	114224.7	285.625	
189	BL10	202701.2	114260.5	290.622	
190	BL11	202715.4	114310.5	277.619	
191	BL12	202764.2	114267.3	309.619	
192	BL13	202798.2	114272.2	299.617	
193	BL14	202804.3	114301.1	284.616	
194	BL15	202832.1	114245.1	309.617	
195	BL16	202832.4	114329	270.614	
196		202470.6	114677.3	372.617	
197		202428.6	114654.4	358.62	
198		202400.5	114638.5	344.621	sp
199		202422.4	114592.5	326.622	
200		202458.1	114523.3	296.623	
201		202483	114486.2	297.623	sp
202		202373.6	114676.6	297.621	
203		202371.7	114694.6	325.621	sp
204		202345.4	114608.7	326.625	
205		202265.3	114567	344.629	
206		202237.2	114550.1	345.372	sp
207		202221.4	114591.1	324.63	sp
208		202198.5	114619.2	317.63	
209		202266	114495	316.632	
210		202301.8	114421.9	298.632	
211		202326.6	114379.8	295.634	sp
212		202196.1	114515.2	331.633	
213		202137.1	114505.4	346.636	
214		202079.9	114463.6	381.64	sp
215		202045.2	114527.8	323.639	
216		202025.3	114562.8	323.639	sp
218		202094.8	114419.6	345.641	
219		202105.7	114394.6	322.641	sp
220		202069.5	114327.7	299.645	steam
221		202025.4	114323.8	306.647	

Appendix 5. Rainfall data from 1999 to 2008

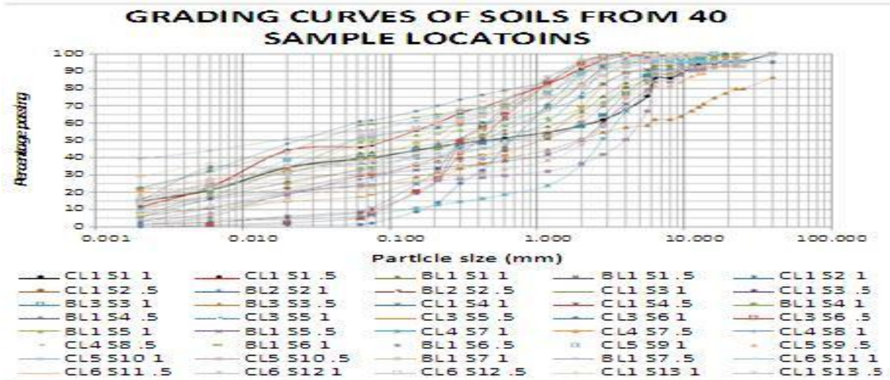
GHANA METEOROLOGICAL AGENCY

MONTHLY RAINFALL (IN MM) FOR TWIFO PRASO

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
YEAR	RR	RR	RR	RR	RR	RR	RR	RR	RR	RR	RR	RR
2000	46.3	35.7	73.0	89.6	218.0	220.1	67.0	26.8	90.3	100.6	130.3	18.5
2001	2.2	17.9	130.9	179.4	207.2	286.3	79.0	38.3	82.3	141.6	83.6	54.3
2002	18.3	34.1	186.4	158.2	170.4	164.7	177.7	97.0	78.3	247.6	128.3	64.5
2003	51.4	53.2	66.4	198.7	222.5	227.6	97.7	70.0	90.3	89.7	110.9	10.8
2004	91.4	53.2	135.0	-	138.5	122.0	137.9	81.4	292.1	177.7	82.2	89.3
2005	11.1	67.0	228.8	218.4	192.9	154.7	65.0	28.5	75.8	317.5	125.0	46.6
2006	56.8	71.0	137.8	137.8	190.0	214.8	62.4	58.2	177.3	175.6	60.2	14.1
2007	0	45.1	170.2	170.2	218.4	287.0	174.9	70.1	186.7	251.9	177.4	42.5
2008	15.1	65.4	178.0	178.0	115.7	265.1	259.3	109.1	95.5	89.4	50.0	98.3
2009	1.6	96.2	88.3	141.5	152.3	232.9	114.6	32.1	34.7	117.3	167.6	73.5

REGIONAL METEOLOGICAL OFFICER
REGIONAL METEOROLOGICAL OFFICE
CIPE COAST

Appendix 6



SAMPLE NUMBER		BL1 S1 0.9M			BL1 S1 0.5M	
BOTTLE NUMBER	7	21	8	7	10	11
mass of bottle+soil+water, (m_3)g	82.3	86.8	80.6	82.0	81.0	80.3
mass of bottle+soil, (m_2)g	35.4	41.9	34.5	35.2	34.7	33.6
mass of bottlel full of water only, (m_4)g	75.5	80.3	74.2	75.4	73.9	74.2
mass of bottlel, (m_1)g	24.9	31.5	24.1	24.8	23.2	23.3
mass of water used(m3-m2)g	46.9	44.9	46.1	46.8	46.3	46.7
mass of soil used(m2-m1)g	10.5	10.4	10.4	10.4	11.5	10.3
volume of soil(m4-m1)-(m3-m2)ml	3.7	3.9	4.0	3.8	4.4	4.2
Gs OF SOIL PARTICLES	2.8	2.7	2.6	2.7	2.6	2.5
AVERAGE Gs		2.7			2.6	

SAMPLE NUMBER		CL1 S1 1M			CL1 S1 0.5M	
BOTTLE NUMBER	8	6	7	10	3	21
mass of bottle+soil+water, (m_3)g	80.7	81.3	81.7	80.4	82.9	86.6
mass of bottle+soil, (m_2)g	34.7	35.4	35.2	33.7	36.0	41.8
mass of bottlel full of water only, (m_4)g	74.2	74.8	75.5	74.0	76.1	80.3
mass of bottlel, (m_1)g	24.1	24.9	24.9	23.3	25.7	31.5
mass of water used(m3-m2)g	46.0	45.9	46.5	46.7	46.9	44.8
mass of soil used(m2-m1)g	10.6	10.5	10.3	10.4	10.3	10.3
volume of soil(m4-m1)-(m3-m2)ml	4.1	4.0	4.1	4.0	3.5	4.0
Gs OF SOIL PARTICLES	2.6	2.6	2.5	2.6	2.9	2.6
AVERAGE Gs		2.5			2.6	

Appendix 7 Specific gravity determination of the soil (cont'd)

SAMPLE NUMBER		CL1 S2 1M			CL1 S2 0.5M	
BOTTLE NUMBER	3	21	7	5	3	11
mass of bottle+soil+water, (m_3)g	82.7	86.6	81.9	81.4	83.1	80.6
mass of bottle+soil, (m_2)g	36.1	41.9	35.4	36.0	36.2	34.0
mass of bottlel full of water only, (m_4)g	76.2	80.3	75.5	75.1	76.1	74.2
mass of bottlel, (m_1)g	25.7	31.5	24.9	25.7	25.7	23.6
mass of water used(m3-m2)g	46.6	44.7	46.5	45.4	46.9	46.6
mass of soil used(m2-m1)g	10.4	10.4	10.5	10.3	10.5	10.4
volume of soil(m4-m1)-(m3-						

Appendix 8 Infiltration rate analysis for PLT 1 (BL1S4)

TIME (SEC)	INTAKE (ML)	INTAKE (CM3)	INTAKE (CM)	INFILTRATION RATE	INFILTRATION CUMM
60	3750	3750	12.525	0.020875	
120	3450	3450	11.523	0.096025	
180	3000	3000	10.02	0.05567	
240	2000	2000	6.68	0.0278	
300	1920	1920	6.4128	0.021376	
360	1500	1500	5.01	0.01392	
420	1000	1000	3.34	0.00795	
480	800	800	2.672	0.00557	
540	800	800	2.672	0.004948	
600	800	800	2.672	0.004453	
660	800	800	2.672	0.004048	
					0.041

Appendix 8 cont'd infiltration rate analysis for PIT 2 (CL1S13)

TIME (SEC)	INTAKE (ML)	INTAKE (CM3)	INTAKE (CM)	INFILT. RATE	INFILT. CUMM
60	1000	1000	3.3484	0.0558	
120	1800	1800	6.02712	0.050226	
180	2450	2450	8.20358	0.04558	
240	400	400	1.33936	0.00558	
300	300	300	1.00452	0.0033484	
360	100	100	0.33484	0.000930	
420	100	100	0.33484	0.0007972	
480	100	100	0.33484	0.0006976	
540	100	100	0.33484	0.000620	
600	100	100	0.33484	0.000558	
					0.018

Appendix 9. Textural Triangle