DESIGN, CONSTRUCTION AND EVALUATION OF CLEAR WATER WASHBORE AT ROMI FADAMA, KADUNA STATE.

BY

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PGD/AGRIC/98/99/46

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF POST GRADUATE DIPLOMA (PGD) IN AGRICULTURAL ENGINEERING (SOIL AND WATER ENGINEERING OPTION)

FEDERAL UNIVERSITY OF TECHNOLOGY,

MINNA, NIGER STATE.

JULY, 2000

CERTIFICATION

This is to certify that this project (DESIGN, CONSTRUCTION AND EVALUATION OF CLEAR WATER WASHBORE AT ROMI FADAMA, KADUNA STATE) was conducted by ISTIFANUS A. MANDE, during 1998/99 academic year in partial fulfilment of the requirement for the award of Post-graduate Diploma (PGD) in Agricultural Engineering (Soil and Water Engineering Option), Federal University of Technology, Minna.

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ABSTRACT

The study was conceived to help the small scale irrigation farmer. Romi Fadama is an extensive flood plain (about 15 hectares) occasioned by alluvium deposition with a potential for small scale irrigation development on the bank of River Romi in Chikun LGA of Kaduna State. Source of irrigation water in this fadama has been the River Romi that flows quite a distance away thus, the need for an alternative source of irrigation water particularly for those farmers whose plots are not on the bank of the river. Alternative well designs and construction techniques for groundwater abstraction from fadama aquifers were investigated. Tests and analysis of results for soil particle size distribution, infiltration, yield (pumping and recovery) test(s) as well as recharge rate(s) were conducted. Results showed that effect of well diameter (750mm) on recharge (11.15cm/hr) was very minimal. Permeability measurements (9.74cm/hr) indicated that surface water contributes immensely in the recharge of the aquifer. Transmissivity (T = 1265.09 m^2/day) and storativity (S = 7.91 x 10^{-3}) results of the aquifer and the textural class of the soil (silty clay loam) show yield potentials of the washbore. However high variability in soil size fractions as revealed in the particle size distribution analysis is an indication of likely variation in permeability and consequently, well recharges within the fadama. The clear water washbore is feasible in Romi fadama. On the whole, the clear water washbore method will become cost in-effective when shallow groundwater exploration methods other than test-hole drilling are employed.

DEDICATION

This work is dedicated to the fadama small scale irrigation farmer out there for his effort at striving to ensure adequate food security to his fellow Nigerians.

ACKNOWLEDGMENT

I wish to acknowledge the support and understanding of my supervisor Engr (Dr) M. G. Yisa, HOD, Dept of Agricultural Engineering, who despite his tasking schedule, made out time to guide and supervise this project work. To the entire lecturers and staff of the department, I sincerely appreciate your untiring effort in seeing me through the programme.

I am also indebted to my dear wife Ruth and children, Mary, Edward and Israel for their patience and understanding while pursuing this course. To Mr & Mrs Ambi, Ngozi Okereke who did the typesetting work and others too numerous to mention, all your support and assistance in whatever manner is sincerely acknowledged. May you all be rewarded in a special way.

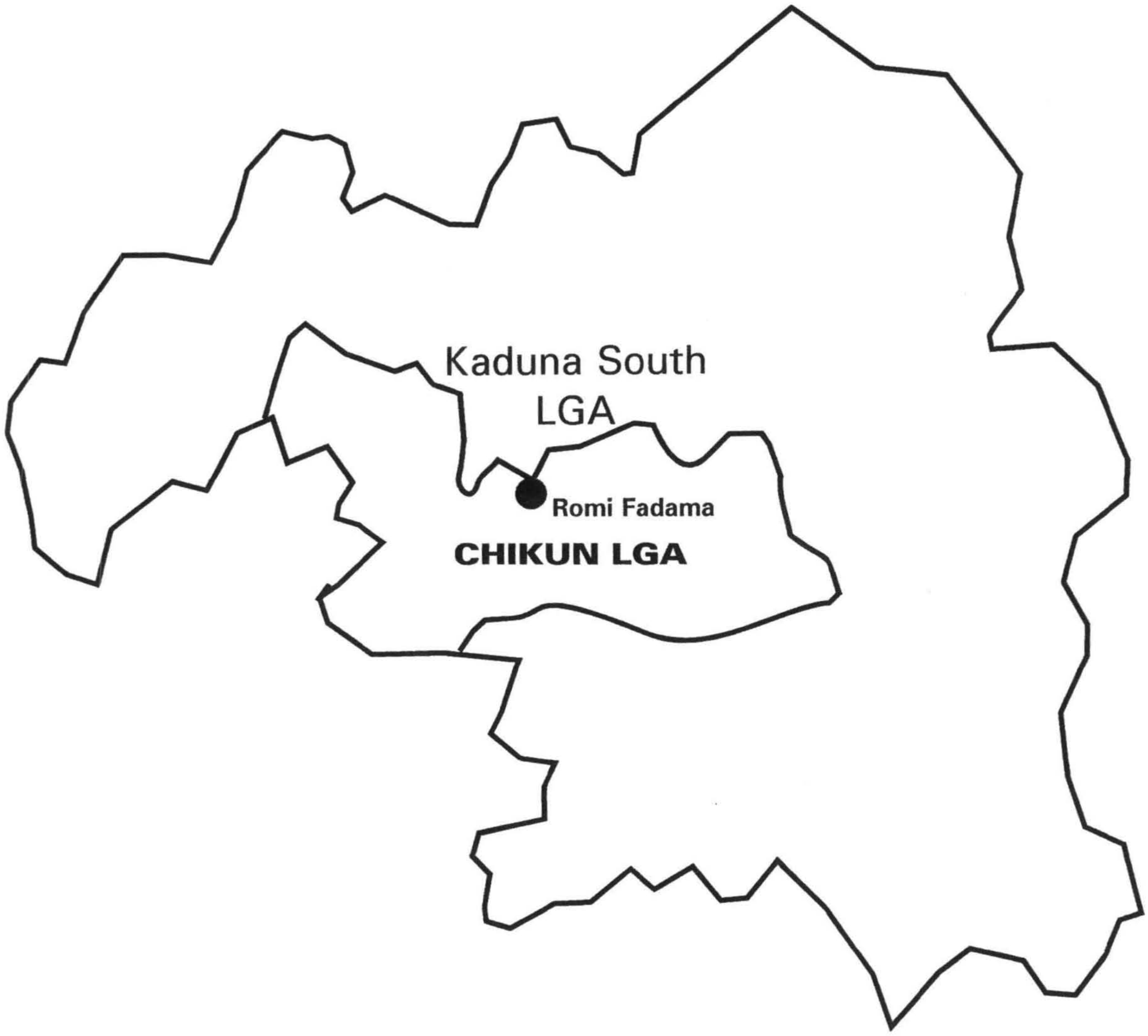

FIG 1.4: Location map of Romi Fadama

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CHAPTER 1

1.0 INTRODUCTION

Nigeria's population is increasing rather rapidly thereby necessitating the need for increase food production. To achieve this noble objective, substantial investment was made in the construction of dams and reservoirs for irrigation purposes. River Basin Development Authorities (RBDAs) and State Agricultural Development Projects (ADPs) were established in the mid 1970s as a complement to the small and medium scale irrigation schemes operated by various States Ministry of Agriculture and National Resources (MANR). All these efforts have not translated into increased food production largely due to our farmers inability to manage such sophisticated and complicated projects which has led to the near collapse of these projects particularly, the River Basin Development Authorities. This has prompted the Federal Government of Nigeria to shift focus from the medium and large irrigation subjects to development of the abundantly rich "fadama" that abound for small scale irrigation purposes. If properly harnessed the benefits from fadama small - scale irrigation together with yields from the hither to, predominantly rainfed agriculture should meet the country's food security needs. Thus alternative sources of irrigation water in the fadama other than direct pumping from rivers or hand dug wells need to be explored.

1.1 Definition of the Problem

There are unarguably rich vast expanse of fadama lands (i.e. flood plains) that abound particularly in the Northern part of Nigeria that could be harnessed for irrigation development. Source of irrigation water in the fadama has principally been direct pumping from rivers flowing by or hand dug wells. However, there are those "fadamas" that have no river flowing by that need to be developed for irrigation. Thus, there is need to explore alternative source of irrigation water which is the washbore for small scale irrigation development in the fadama.

1.2 Aims and Objective of the Project

The aims and objective of the project is based on the following:

(a) To explore the possibility and or feasibility of exploiting ground water for irrigation purpose(s) in "fadama" lands that have no river running through or by them using the clear water jetting method.

(b) To boost dry season farming particularly, "fadama" small - scale irrigation as a complement to the predominantly rain fed agriculture for increased food production.

1.3 Scope of the Project

The scope of the project entailed

(a) Feasibility study of the area to ascertain the occurrence of ground water.

(b) Collection of soil samples at different points from the proposed site of the well.

(c) Determination of soil infiltration rate.

(d) Collection and relating all available hydrological data, contour map with meteorological data from relevant agencies and existing reports to provide an acceptable design report of the washbore.

(e) Determination of recharge capability of the washbore.

(f) Design and Construction of the Washbore

(g) Evaluation of the cost and performance of the clear water washbore construction method.

1.4 Description of the project area.

Romi fadama is located between latitude 10^0 26' 70" and longitude 7^0 24' 31" and lies in the lower watershed of River Kaduna. At the eastern part of the land, the fadama is bordered by Romi river flowing in the East -West direction. The land area of Romi fadama stands at about 20ha. The water resources of the state are primarily as surface water flows in the rivers and as shallow ground water in the unconfined to semi - confined aquifers which are present in the alluvial sediments deposited along the fadama (river flood plains). The depth of alluvial cover is typically less than 15m above the basement complex and younger granite (Kaduna State Water Board, 1987).

1.4.1 Land forms

The topography of the lower watershed of River Kaduna of which River Romi is a tributary is comprised of many landform types. the dominant feature is the drainage divide between the Lake Chad Basin and Niger River Basin which tends roughly South East and Northwest.

Although drainage into the fadama is controlled primarily by elevation, the water Resources are primarily as surface water flow in the rivers and as shallow groundwater in the fadama.

1.4.2 Basement complex and younger granites

Basement Complex and Younger Granites underlie about 98% of the state. The bedrock underlying Kaduna State has very limited potential for the development of groundwater for small - scale irrigation especially in the Southern part of the state. Thousands of boreholes and and dug wells have been completed in this terrain for domestic water supply. The yields of boreholes are relatively low, often barely adequate to support withdrawal by a hand pump. Even where borehole yields are adequate, the depth to the water table is sometimes well beyond the suction lift of a centrifugal pump. More over, the boreholes are deep and heavy - duty drilling equipment is required for construction. The cost of constructing a washbore in these areas would be excessively high except in the fadama lands where the formation is of alluvium deposits occasioned over time.

1.4.3 Newer basalt

The newer basalt occur around Manchok and Kagoro in the Southern part of the State. The basalts are Plateau basalts which have been extruded from volcanoes in the tertiary period. The flows are reported to be composite in nature and comprised of ash deposits, zones of weathering and occasionally zones of alluvium between individual basalt flow layers. The possibility exists that sufficient water is available in the alluvium deposits layers, however, heavy - duty drilling equipment (rigs) is required to penetrate through the basalt and the cost of a washbore would be excessively high. The clear water washbore method is unlikely to be feasible in these areas.

1.4.4 Recent alluvial deposits

These deposits are sediments which have formed overtime and occur along the river, flood plains. The sediments are erosional material derived from the granitic rocks mostly in the eastern part of the state e.g Saminaka area.

Typically, the deposits are unconsolidated gravels, sands, silly and clays. The thickness of the deposits varies greatly from less than 1m to upwards of 10m along the major flood plains. A very good over view of the basic process of alluvium deposition is obtained from loggings of the well.

1.5 Hydro-meteorology

1.5.1 Precipitation

The climate of Kaduna State varies from tropical sub - arid in the north to sub - humid in the south. The mean annual rainfall ranges approximately 300mm in the north to 400mm in the south. The rainfall occurs from mid - May to October and is absent from November to April which marks the irrigation season. The rainy seasons are associated with the South - West trade winds across the state and the dry seasons are associated with the North-East trade winds, that occur between December and February are associated with dry and dusty harmattan winds (see Fig 1.5).

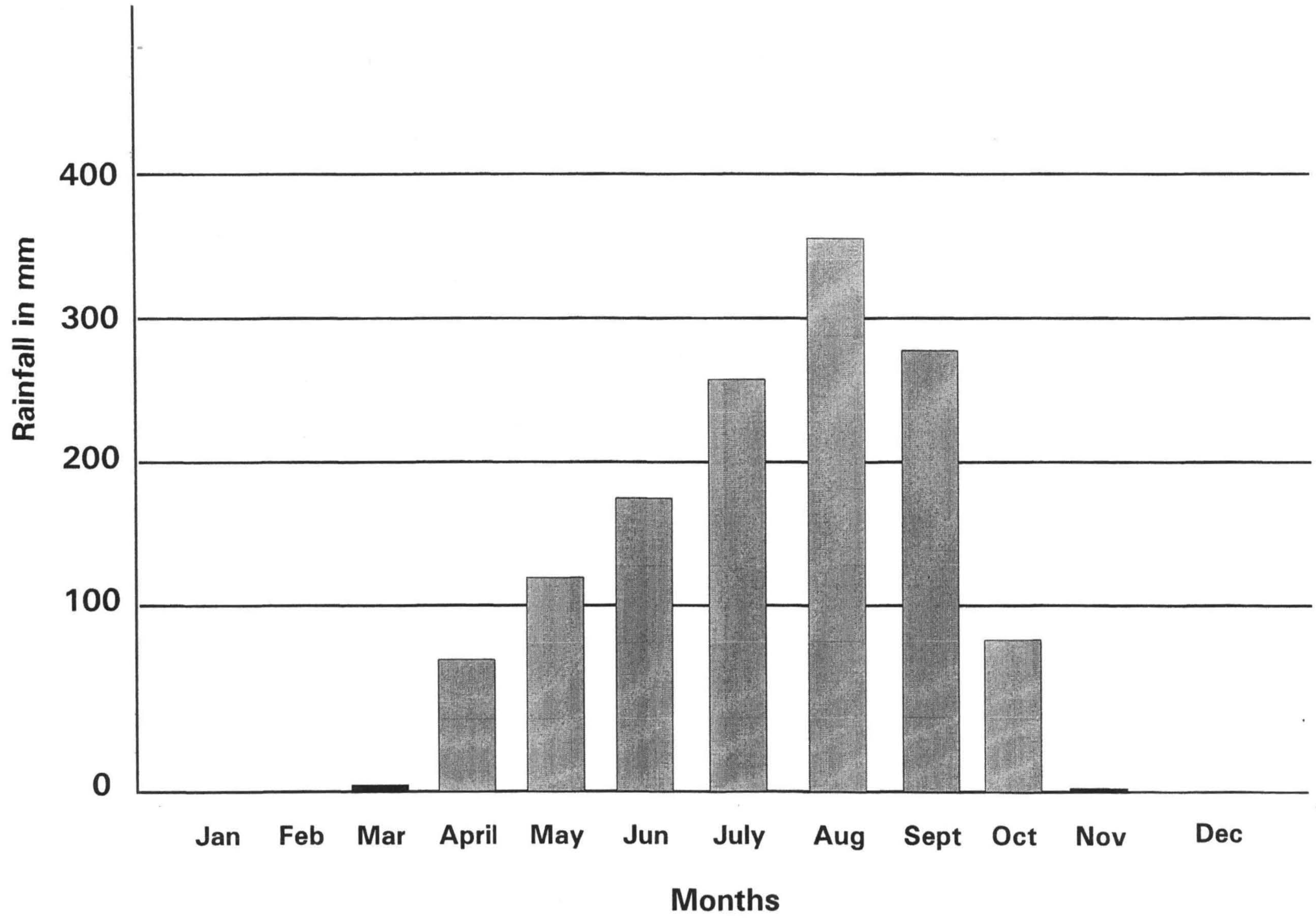


FIG 1.5: RAINFALL DISTRIBUTION AT KADUNA (1992 - 1999)

1.5.2 Discharge

The average discharge for Romi River along Kaduna - Abuja Road based on the discharge data for period of 10 years obtained from Kaduna State Water Board stood at about 6.104 cubic metre per second.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Definition of a Washbore

Washbore is a term for a shallow tubewell, the construction of which is achieved by the use of clear water jetting technology to bore the hole, the depth of which can go up to 10m (World Bank, 1990).

2.2 Background information

Wells have been an integral part of man's life and activity, supplying clean pure water where surface supplies were inadequate. (Hansen et al 1980). These supplies are either used for domestic, irrigation or industrial purposes. The initial exploitation of ground water has been generally from relatively easier and cheaper sources, and subsequently, more difficult and costlier sources are tapped. The rate of development is not only dependent on the ease of the ground water availability but also on other factors such as technical know-how, government planning, financial and technical facilities available to the farmer and socio - economic factors (Michael, 1978).

The main source of ground water utilization for irrigation development would continue to be open well, followed by shallow tubewell such as washbore. Efficient and economical utilization of ground water through wells depends on the design of wells to best suit the characteristics of the water bearing formation (Michael, 1978). Dug wells are usually shallow wells, generally less than 15m in depth and may be up to 1m in diameter. In the past they were usually excavated by hand and even today in many areas, this is the principal method of construction (Hansen, 1979).

Flow of ground water into wells is influenced by the physical characteristics of the water bearing formation, the number and extent of these formations, the elements of well design and the methods used for constructing and developing the wells (Michael, 1978).

The mode of occurrence and distribution of ground water is controlled by the geology of the area concerned. Groundwater abounds in both consolidated igneous and metamorphic rock materials and unconsolidated sands.

Aquifers are water-bearing formations which contain groundwater and yield water to any hole or well dug through (Gibson and Singer, 1971). Confined and an unconfined aquifer exists. The confined aquifer is one in which the water is confined under a pressure greater than atmospheric by an overlying impermeable layer while the unconfined is overlaid by an upper impermeable layer and water are virtually at atmospheric pressure. (Gibson and Singer, 1971).

Aquifers vary considerably in the capacity to store water due to differences in their porosity and permeability. According to Meizer (1923), "the percentage porosity by volume of well water stored in un-cemented sediments ranges from about 16 to 38% percent while that of clay is almost 45% percent". In theory, a saturated layer of sandstone of 10 percent porosity and 10m thick contains 10,000 cubic metre of water per hectare, and that such a comparatively coarse grained rock is not only porous but also permeable and most of the water it contains may be withdrawn by means of wells. In contrast a clay absorbs up to 47% of water but remains more or less non-water yielding and impermeable due to the small size of the pore space which holds water tightly through the capillary pores (Kowal and Knabe, 1979).

The majority of successful high yielding wells over the years have been drilled in sedimentary rock formations, because primarily most sedimentary basins usually have generous proportions of lithologies with good reservoir characteristics. For instance, most sands, sandstones, limestones and dolomite formations are very good aquifers at relatively shallow depths (Agagu, 1984).

2.3 Groundwater resource of Nigeria

The land area of Nigeria is directly underlain by crystalline and sedimentary rocks in almost equal proportions. In fact more than 50% of the land area is underlain by Basement Complex crystalline rocks.

Just as much is known about the surface hydro-geology of the Basement Complex of Nigeria, much also remain unknown in the Basement Complex rocks (Omorinbola, 1982).

Ideas about the geo-hydrology of the Basement Complex have been conflicting. Du Perez and Barber (1965) described the Basement Complex areas as poor groundwater regions with a recorded average yield of 4000 litres per hour at an average depth of 40.5m and over 30% failure in water borehole drilling. Recent experiences have shown that much better results can be obtained with adequate shallow aquifer geo-physical investigation and improved well construction techniques. Offodile (1983) reported that the deep weathering encountered in recent studies of some Basement areas have given rise to regolith aquifers with higher yields of between 6800 litres per hour to 18200 litres per hour with reasonable draw-downs.

The Nigerian crystalline areas have been depicted problematic hydrologically by Offodile (1983). Perched aquifers or pockets of groundwater occur in these crystalline areas in various extent. Problematic the perched aquifers are, they appear to present good groundwater potentials and are increasingly providing reliable aquifers for small scale village, in industrial and other supply schemes (Offodile, 1983).

Like in most other groundwater bearing formations, the water table in the regolith fluctuates in sympathy with the seasonal pattern of rainfall distribution. The fluctuation is of such a fashion that enables saturated zone thickness to be predicted in a given area at a point in time (Omorinbola, 1982). The important practical implication is that wells should ideally be sunk during the dry season when the water table in the fadama is at its lowest level. Such wells would not only be deeper but more reliable and relatively more high yielding than those constructed in the wet season when water-table fluctuates closer to the soil surface.

Areas underlain by thick sedimentary deposits are capable of holding large quality of groundwater (Offidile, 1983). Of the six major sedimentary deposits of Nigeria, the Chad formation has the largest artesian occurrence. A flow of about 16,000 litres per hour has been recorded from a 500m borehole. Du Perez (1961) made an estimate of 9,100 million litres of water per annum from 146 artesian wells within Dikwa emirate in Borno State.

In contrast with the deep groundwater aquifer of the Basement Complex areas, shallow groundwater abound in the flood plains (fadama) of the major rivers. The Jama'are river in Gombe State is noted for its large expanse of fadama. Its deposits are coarse sand to five gravels underlying an area of 2km or more wide. Most of the tubewell innovations in Gombe State Government's fadama development effort are within the river flood plain. The water table varies from the surface to 35cm below the surface depending on local topography, Wardrops (1983) estimated approximately 200 litres per minute at Tsumba along the Jama'are river flood plain.

There is lack of documentation in boreholes and wells (washbores inclusive) in fadama areas and the information available from water resources agencies on boreholes may not be very useful in shallow well (such as washbore) development for fadama small scale irrigation. For instance, there is no literature pointing out that the surface horizon may be relatively more productive per unit depth on account of their generally higher hydraulic conductivity.

2.4 Location of Washbores

The right location of a well that produces a good steady water supply all the year round could be done by any average individual interested in the location of shallow wells by using his common sense, intelligence and good judgement for successes of wells in various terrains.

Clues that can be very helpful in selecting washbore sites and to a larger extent shallow wells generally, summarized by FAO (1976) are the location and depth to water of existing wells, existence of springs and/or streams, relative location of infiltration areas and rock out cropping which might constitute an impervious layer and existence of known water loving plants (phreatophytes). As reported by Blackwadt (1976), most flood plains farms are of fragmented size(s) which makes it most in-economical to carry out detailed geophysical investigation of the shallow aquifer for pragmatic selection of well/washbore site. A more veritable tool of investigation is to carry out a reconnaissance survey of the fadama for vegetation such as banana trees, date palms, bulrush, sugarcane etc. Occurrence of these phreatophytes in the fadama indicate the presence of shallow ground water to a depth of about 5m especially, in areas where groundwater is the only permanent water source.

Rowles (1995) emphasized that the advice of local drillers whose knowledge of the countryside and experience may be excellent even though their well construction techniques are obsolete should not be despised.

Successful wash-boring depends on the knowledge of the storage capacity and permeability available from geological information and other sources, otherwise, success would be a matter of chance. Rowles (1995) suggested that a veritable and practically dependable field source of information for locating wells generally (whether washbore or borehole) is to drill test-holes from which lithological recordings (logging) are made. Generally, location of a well comprises lithological (geological) information, local information and /or topography.

2.5 Well designs

Researches into shallow well construction, has been limited to the fadama plains of Northern parts of Nigeria. Pangotra (1982) tested the Indian technology of well designs in the Sokoto fadama areas. This included the borehole drilling, bail down (popularly referred to in Sokoto as bailer) and washbore methods. The adoption of the tubewell technology has been very gradual.

Carter (1984) reported four techniques for drilling shallow tubewells by Bauchi State Agricultural Development Project (BSADP) and Kano State Agricultural and Rural Development Authority (KNARDA) in their fadama areas. Three of these methods are variation of the washbore techniques (Washbore with bentonite drilling mud; washbore by single jetting and clear water and washbore by double jetting) while the fourth uses a small hydraulic rotary, trailer- mounted drilling rig.

FAO (1977) described the construction method for small diameter wells practiced in India, Egypt and other developing countries. Here are brief descriptions of the well designs:

(a) **Jetted Washbores:** A high velocity of water forced out from the bottom of a vertical. 2" or 3" diameter PVC/Steel (GI) pipe washes away materials ahead of it as it is being drilled into the soil formation.

(b) **Auger Washbores**: Cutting tips of a rotating anger at materials loose from bottom of the hole until the aquifer is stroke.

(c) **Driven Washbores:** A point on the lower end of a string of pipe allows the pipe to penetrate as it is driven on the upper end by heavy substances.

(d) **Hydraulic (Percussion) Washbores:** This hole is first augured and filled with water. Then, further drilling is by alternate raising and dropping of a string of pipe equipped with a cutting bit at the bottom to allow penetration.

(e) **Cable Tool (Percussion) Washbores:** A heavy cylindrical weight equipped with a cutting edge at bottom and with a cable attached to the upper end. The alternate raising and dropping, impact and compresses pulverized material at the bottom of the hole.

(f) **Bail-down Washbores:** A long cylindrical bucket with a check value at the bottom and a rope or cable attached to the top is alternatively raised and dropped in a hole partially filled with water. Penetration is accomplished by a combination of mechanical and hydraulic action.

Of these wells listed, only the Jetted Well method is being practiced in most Agricultural Development Projects (ADPs) implementing the National Fadama Development Project (NFDP). These 2" or 3" small diameter shallow wells have yield capacities of 100 - 300 litres per minute are suitable for irrigating up to 5 hectares (World Bank, 1990)

Development work on simple jetting technique by Methianu (1982) was carried out for water supply boreholes in Silsoe College, U.K. The method is very simple but very effective. Recent trials at Silsoe have successfully reached 20m depth in alluvial clays, silts, sands and gravels (Carter, 1984). Re-circulation of water has been used successfully and the simple technique is that of jetting with clear water without casing, then the well lining is introduced inside the jetting pipe prior to its removal. The advantage is that the removal of a jetting pipe is easier than withdrawal of temporary casing since jetting can continue if necessary during removal. The washbore is largely designed for irrigation in the fadama, where a washbore is capable of irrigating 2ha and to some extent drainage purpose(s) (World Bank, 1990).

2.6 Groundwater Recharge

Groundwater recharge is that amount of surface water which reaches the permanent water table either by direct contact in riparian zone or by down-ward percolation through the overlying zone of aeration (Rushton and Ward, 1979). It is the quantity which may be in the long-term available for abstraction and which is therefore of prime importance in the assessment of groundwater resource.

Recharges cannot be measured directly but through conceptual models which produce and acceptable estimate of recharge for input to the aquifer model. It is viewed as a function of effective rainfall (precipitation minus evaporation).

High infiltration capacity is usually indicative of substantial rates of groundwater recharges. Azeez (1972) observed the occurrence of high rate of groundwater recharge with an average annual recharge rate of more than 3m in certain areas of South Western Nigeria because of high infiltration capacity and rainfall and low runoff in the Basement Complex areas. He stressed on the great potentials of the groundwater yield of the Basement Complex which have not yet been utilized or fully utilized due to ignorance of its existence or lack of adequate technical know-how for its extraction.

2.6.1 Artificial groundwater recharge

Optimum development and sound management practices are vital to the sustainable use of ground water.

For water bearing formations readily recharged from the surface average, pumping rates may equal average recharges but should not exceed it.

2.6.2 Methods of artificial recharge

Groundwater recharge may be increased by soil conservation measures and artificial recharge procedures. The amount of rainfall or surface water that infiltrates into the soil varies with the soil surface and moisture content of the soil at the time of rainfall. Other dependable variables that influence artificial ground water recharge are infiltration opportunity time which depends largely on topography of the land, field structures (e.g contour bunds, terraces etc) that tend to hold the run-off water over long periods on the land surface. In addition, a potion of the river flow which cannot be utilized for irrigation can be harnessed to recharge ground water reservoirs. Artificial recharge methods are similar to surface irrigation methods.

2.6.2.1 Basin method

In this method, water is diverted to the uppermost of a series of basins separated from one another by low height levees which generally run on contours. The levees are constructed with materials such as stone or boulder which will withstand the overlapping of water. Where boulders are not available, suitable structures like bunds are constructed on the levees to allow water to drop from the higher basin to the lover. This method is best suited for ground surface(s) that are irregular and infested with a number of shallow gullies and ridges.

2.6.2.2 Furrow method.

In the furrow method of recharge, water is diverted from a main canal running along a contour into a series of parallel furrows that differ from irrigation furrows. These recharge furrows are flat bottomed and shallow enough to allow maximum possible surface area to come into contact with water.

2.6.2.3 Ground water recharge through pits and wells.

Where the water bearing stratum is overlain by an impermeable layer, surface methods of recharges (Basin and Furrow methods) may not be feasible or suitable. Water may penetrate the top soil but as soon as it strikes the impermeable layer, it may move away as inter-flow and may not join the water table. Depending on the depth of the impermeable layer, groung water recharge can be achieved through pits or wells. Most often, water is recharged into the soil through tubewells. Recharge through tubewells/washbores is also embarked upon where the land surface is unavailable for surface methods as a result of cultivation requirement.

2.7 Well discharge and recharge

A washbore albeit, well is said to be discharging when water is being pumped out of it. While the well is recharging as water flows through well intake (screen) from the surrounding aquifer storage in the direction of decreasing hydraulic gradient.

When a well is continuously pumped at a steady rate, an equilibrium is reached at which there is no withdrawal of water from storage of the aquifer between the steadily pumped well and a given distance into the aquifer (Michael, 1978). At equilibrium, a steady state is reached and the well discharge rate equals the pumping rate. Thus, the steady pumping rate equals steady recharge rate.

2.8 Groundwater drainage by pumped wells

Extensive drainage can be achieved by pumping from suitably located wells. It can be used to drain waterlogged fields particularly, where many wells are located at different points from which water could be drained.

The main physical defect of gravity drainage system is failure to lower the watertable to an adequate depth. Many (gravity) drains are too shallow and pumping groundwater in areas where a suitable permeable aquifer exists is a more effective means of lowering the watertable (Hansen et al, 1980).

Largê areas of irrigated lands have been drained by deep tubewells in the USSR, Pakistan, Australia and other countries (FAO, 1971).

2.9 Basics of Groundwater Formation

Three main groups of geological formations may be recognised in Nigeria, namely:

- Crystalline rocks
- Sedimentary rocks
- Alluvial deposits

2.9.1 Crystalline rocks

The crystalline rocks are very old and according to studies by various researchers/consultants, are said to occupy about 50% of Nigeria. Groundwater yields from boreholes drilled into these rocky formations indicate that even where they are close to the surface, they cannot meet the purpose of irrigation as the yields are usually minimal. (Wardrop Inc., 1993).

2.9.2 Sedimentary rocks

Sedimentary rocks are also quite old and include sandstones, shales and limestones. Of these, only sandstones are high yielding formation but where they occur, the water from such a formation can not be extracted by centrifugal pumps due to the suction head limitations of the pumps. Thus, sedimentary formations are not considered to be very suitable formations for wash boring except where the water table is very high.

2.9.3 Alluvial deposits

Alluvial deposits underlie the fadama plains of the main river systems of Nigeria. They are made up of sands, fine gravels, silts and clay deposits. Often, the sands and fine gravel are water bearing and are within the reach (less than 9m from the surface) of centrifugal pumps. Therefore, alluvial deposits make up the formation being exploited for small scale irrigation in the fadama through groundwater development. Flood plains are formed through several years of alluvial deposition. They occur along major rivers particularly in Northern Nigeria. Thus, the term fadama refers to flood plains formed through alluvial deposition of material (Wardrop 1993).

2.10 Types of Water Bearing Formations

The size of the pores and the total pore space of an aquifer vary with the type of formation material. Individual pores in a fine-grained material like clay are extremely small but the total pore space is usually large. While a clay formation has a large water holding capacity, water cannot move readily through the tiny pores and hence is not an aquifer even though it may be water saturated. Conversely, a coarse material such as sand contains large pore spaces through which water can move fairly easily and thus a good aquifer. Water enters the ground water reservoir from a natural or artificial recharge and flows out under action of gravity or extracted by wells.

2.10.1 Unconfined aquifer

It is a permeable bed only fairly filled with water and overlaying a relatively impervious layer. Its boundary is formed by a free, water table or phreatic level. It is also known as a free, phreatic, water-table or non-artesian aquifer. The water in a well penetrating, an unconfined aquifer does not, in general, rise above the water table.

2.10.2 Confined aquifer

An aquifer found between an impermeable layer above and below it, is said to be confined. It is also called an artesian aquifer. As a result of the confining layer, the water of the aquifer is not open to atmospheric pressure. Thus, it occurs within the pores of the aquifer at pressures greater than one (1) atmosphere and the water in the well stands above the top of the aquifer. The water level represents the artesian pressure in the aquifer.

2.10.3 Semi-confined aquifer

A semi-confined aquifer or leaky aquifer is a completely saturated aquifer that is bounded above by a semi-impervious layer and below by a layer that is either impervious or semi-pervious. The level or elevation to which the water level rises in a well that taps a semi-confined aquifer is referred to as the piezometric or static water level.

2.10.4 Perched water table aquifer

It is a special case of an unconfined aquifer. A local zone of saturation may occur/ exist at some level above the main water level. This may occur where an impervious stratum within the zone of aeration interrupts percolation and causes ground water to accumulate in a limited area above the stratum. The upper surface of the ground water in such a case is called a Perched Water table.

2.11 Water requirement

Evaluation of the yield of a washbore is based upon the hydrological conditions of the area such as rain fall, run off and recharge. when the yield potential of an area is not a limiting factor, a properly designed, shallow washbore should provide the required quantity of water to irrigate the entire area being cultivated by the fadama farmer. A washbore is designed on the basis of a life span of at least 10 - 15 years life (Michael, 1978). Minimum yield requirement for a washbore acceptable for irrigation in the fadama is 2.5litres per second (World Bank, 1990).

2.12 Classification of washbore

Washbores are classified on the basis of construction method as:

- driven
- jetted
- drilled.

2.12.1 Driven washbore

A driven tube well consists of a pipe and well point which are forced into the water bearing formation by driving with a drop hammer or suitable means. Driven tube wells usually have a well diameter of 3 - 7.5cm and depth range of 7 - 15m. They have small yields and their construction is limited to shallow depths in unconstipated formations free from boulders and other obstructions and commonly used for domestic water supply.

2.12.2 Jetted washbore

Is a typical washbore constructed with hand operated equipment or heavy duty equipment (rigs) depending on the formation. A hole in the ground is made by the cutting action of a stream of water pumped into the well through a small diameter pipe and forced against the bottom of the hole (where a jetting bit is used as the case is when using a rig, the water is forced against the bottom through the nozzles of the jetting bit). Jetted washbores are below 15m and are ideal for irrigation in the fadama.

2.12.3 Drilled washbore

Construction is by standard drilling procedure utilizing the type of equipment best suited to the formation encountered and involves four district operations.

- drilling operation
- casing installation
- well screen installation
- well development.

The depth of a drilled tube well/washbore is dependent on the formation being drilled and the capacity of the drilling equipment/rig.

2.13 Shallow aquifer investigation/exploration.

2.13.1 From topographic and aerial maps

The following are approaches used in the determination of groundwater occurrence.

1. Study of topographic maps for features indicating the presence of alluvial deposits such as meandering stream, oxbow lakes and ponds in the fadama, former stream channel on the flood plain and relatively long distance between contour lines.
2. Study of aerial photographs for features typical of alluvial deposits. Satellite imagery has also been considered for use in delineating fadama; particularly for large fadama. However, it is an extremely costly method of shallow aquifer investigation.

2.13.2 Survey methods.

2.13.2.1 Reconnaissance survey

Reconnaissance survey of the proposed fadama for vegetation such as banana trees, sugar cane, date palm, bulrush etc indicates presence of groundwater (0 - 5m). Other features such as marked boundaries and prominent features are noted.

2.13.2.2 Electrical resistivity method

- Electric logging
- Gamma - ray logging
- Electrical resistivity surveying.

2.13.2.3 Seismic refraction surveying.

The principle is based on the fact that shock waves travel through different earth materials at different velocities.

Electrical resistivity, seismic refraction and other modern methods such as radar are used only when exploring large fadama as the surveys are time consuming, analysis of results require high level of expertise and the results often inconclusive. Thus, geophysical surveys are not practical tools for investigating/evaluating groundwater on fadama. A state wide shallow aquifers study had earlier been conducted by Messrs Wardrop Eng'g Inc (1994).

2.13.2.4 Exploratory drilling.

Test-hole Drilling

Test-hole/test-well drilling is carried out by hand using augers or bailer as it is the most practical tool for determining shallow aquifer occurrence in fadama. In some cases, standard drilling equipment (rig) or boring the hole by jetting (wash boring) with clear water are used. Well log describing the substrata as drilling continues are kept for every change in the sub - strata as drilling progresses.

CHAPTER 3

3.0 METHODOLOGY

3.1 Reconnaissance Survey

Reconnaissance is the preliminary survey under taken by going round the project area to assess and note such physical features as boundaries', ponds, buildings, rivers etc. This exercise allows for proper planning of the best approach for topographic survey of the area and test drilling.

3.2 Soil Sample Collection

A profile (hole) was dug on project area in specified locations with a shovel. Two locations were chosen for the profiling. Samples were collected at different horizon depths, placed in polythene bags, labeled and taken to the laboratory for analysis. The size of each pit was 2m x 1m x 1m.

Also, samples were collected from the water bearing sands during the test-hole drilling and wash bore installation and analyzed in the laboratory.

The soil samples were spread in the laboratory under shade for drying. After drying, mortar and pestle were used to break-down the aggregate material and sieved.

3.3 Determination of Soil Particle Size Distribution

3.3.1 Apparatus

- Conical Flask
- Weighing balance
- Measuring Cylinder
- Thermometer
- Stirring Rod
- Hydrometer
- Mechanical Stirrer.

3.3.2 Reagents

Sodium hexameta phosphate Na $(PO_3)_6$

3.3.3 Procedure

50g was weighed of soil up to 2mm sieved soil into a conical flask. 100ml of Na $(PO_3)_6$ solutions were added and left for 30 minutes for the reaction to complete. This was then poured into a cup and then stirred using a mechanical stirrer for 3 -5 minutes. After which, it was then poured into a mercury cylinder and was added to a 1 litre mark. The particles were brought into suspension using a stirring rod. At 40 seconds, after removing the stirring rod, the hydrometer reading was taken and the temperature was also taken. The cylinder was left on a stable surface undisturbed and after 2 hours, the hydrometer and temperature reading were taken. A blank solution was prepared with distilled water and calgon (minus the soil sample).

Readings were also taken at 40 seconds, 2 hours with the hydrometer and thermometer. The determination of the texture was done by plotting the percentages of the particles on the soil texture triangle chart (Fig 4.3b).
The soil erodibility is the sand plus % silt divided by % clay. Therefore, average % sand silt and clay are 30, 40 and 30 respectively from the soil textural triangle.

3.4 Soil Infiltration Test

The objective of this test is to determine the rate at which surface water resulting from irrigation application and run-off occasioned by rain storms contribute to aquifer from the surface.

3.4.1 Apparatus

- cylinder infiltrometer, 30cm diameter
- cylinder infiltrometer, 60cm diameter
- tape (ruler)
- wrist watch

- mallets
- strong iron plate

3.4.2 Procedure

The field measurement was conducted by driving the two rings into the ground using the mallet, in such a manner that only 15cm was left exposed which was filled with water, the exact time the ring was filled being noted. Also the time it took the water in the cylinder to drain was taken. Initially, the experiment was started by considering 5 minutes for taking of readings.

After each reading, water is added into the infiltrometers to the 11.5cm mark. Later, the time for taking readings was changed to 10 minutes, 115 minutes, 20 minutes, 30 minutes were recorded. In all, three different sites were used for the conduct of the test (labeled site 1, site 2 and site 3).

3.4.3 Results of Infiltration Rate Test

SITE 1: Cylinder No.1

	Distance of water from Reference Point. cm		Infiltration During the period		
Elapsed Time (Min)	Before filling cm	After filling cm	Depth cm	Average Rate of infiltration cm/hr	Cumulative Infiltration cm
-	-	11.5	-	-	-
5	9	11.5	2.5	30	2.5
10	9.8	11.5	1.7	20.4	4.2
15	10.4	11.5	1.1	13.2	5.3
20	10.6	11.5	0.9	10.8	6.2
25	10.7	11.5	0.8	9.6	7.0
35	10.7	11.5	0.8	4.8	7.0
45	10.8	11.5	0.7	4.2	8.5
60	10.5	11.5	1.0	4.0	9.5
80	10.5	11.5	1.0	3.0	10.5
100	10.3	11.5	1.2	3.6	11.7
120	10.3	11.5	1.2	3.6	12.9
130	10.5	11.5	1.0	6.0	13.9

SITE 2:

	Distance of water from Reference Point. cm		Infiltration During the period		
Elapsed Time (Min)	Before filling cm	After filling cm	Depth cm	Average Rate of infiltration cm/hr	Cumulative Infiltration cm
-	-	11.5	-	-	-
5	9.2	11.5	2.3	27.6	2.3
10	9.9	11.5	1.6	19.2	2.9
15	10.3	11.5	1.2	14.4	5.1
20	10.5	11.5	1.0	12.0	6.1
25	10.6	11.5	0.9	10.8	7.0
35	10.7	11.5	0.8	4.8	7.8
45	10.6	11.5	0.9	5.4	8.7
60	10.8	11.5	0.7	2.8	9.4
80	10.9	11.5	0.6	1.8	10.0
100	10.9	11.5	0.6	1.8	10.6
120	10.9	11.5	0.6	1.8	11.2
130	10.9	11.5	0.6	3.6	11.8

SITE 3:

	Distance of water from Reference Point. cm		Infiltration During the period		
Elapsed Time (Min)	Before filling cm	After filling cm	Depth cm	Average Rate of infiltration cm/hr	Cumulative Infiltration cm
-	-	11.5	-	-	-
5	8.8	11.5	2.7	32.4	2.7
10	9.7	11.5	1.8	21.6	4.5
15	10.2	11.5	1.3	15.6	5.8
20	10.4	11.5	1.1	13.2	6.9
25	10.6	11.5	0.9	10.8	7.8
35	10.7	11.5	0.8	4.8	8.6
45	10.7	11.5	0.8	4.8	9.4
60	10.9	11.5	0.6	2.4	10.0
80	10.9	11.5	0.6	1.8	10.6
100	10.9	11.5	0.6	1.8	11.2
120	11.0	11.5	0.5	1.5	11.7
130	11.11	11.5	0.4	2.4	12.1

3.5 Yield (pumping and recovery) Test

Pumping and recovery tests were conducted for the wash bore using an observation well-located 10m away. The observation well was jetted to the same depth as the wash bore (7.5m).

For the pumping test, the wash bore was pumped using a 2" centrifugal (Robin) pump at a constant rate for 5 hours. The discharge for the pumping test was determined as 3.2 litres per second during development of the wash bore as the maximum sustainable flow without causing wash bore to run dry.

Water level draw-downs were measured in the pumping well and the observation well. The duration of pumping test was determined by the time required for stabilization to occur in the water level in the observation well or when draw dawn was linear with time and minimal compared to the saturated thickness of the aquifer immediately after the pumping test was stopped, water level recovery measurements were made in the observation well to determine recovery characteristics.

3.6 Recharge Rate Determination

One of the important methods of assessing the performance of a well is by determining its recharge rate. The recharge rate is easily discerned by means of a pumping test.

On the commencement of the pumping test, the static water level in the monitoring (observation) well and the wash bore were measured. The measurement was done by dipping a stick into the hole and noting the distance (depth) between the soil surface and the static water level. Static water level was measured using a sounding tape. The pump was started with the pump suction hose protected by strainer dipped into the well. Continuous pumping out of water from a well was done and changes from the pumping water level and static water level noted. The speed of the pump was reduced and allowed to run a steady state - a state at which the pumping water level was maintained.

As pumping continued at steady state, water levels in the observation well became lowered due to differential pressure gradients. The lowering of the water table in the observation well was measured 5, 10, 20, 30, 50, 60, 90, 120, 180 and 300 minutes (totaling 5 hours). The difference between the pumping water level and static water level gives the draw down. Equilibrium is said to have been reached when the cone of depression around the discharging well has reached stability. At equilibrium the discharge from the pumping well (pumping rates) equaled the recharge rate at the draw-down.

At equilibrium, the pump was put off, the time for the pumping water level to rise 10.cm inside the well was determined by a stop watch.

Recharge rate is calculated from theoretical equation.

$$\text{Recharge Rate} = \frac{A\,(hp - hn)}{t}$$

Where

	A	=	Cross-sectional area of well cm^2
	hp	=	Pumping water level cm
	hn	=	New height of water (hp-10) cm
	t	=	Time of rise from hp to hn. in min or hrs

The recharge rate was measured twice for the wash bore and the average rate

= 11.15cm per hr

3.7 Design of Washbore

3.7.1 Elements of washbore design

The design elements in a washbore (and wells) are:

- Well diameter
- Well depth
- Well screen
- Gravel packaging

3.7.1.1 Well Diameter

Choice of well diameter is largely dependent on the outer diameter of drilling bit when using a rotary rig) or drill/jetting pipe when jetting with a centrifugal pump.

The diameter of wash bore is usually the same from top to bottom and is given by the relationship.

WD = OD + A (Umar, 1988)

Where WD = Well (wash bore) diameter in inches/cm^2

OD = Outer diameter of drill pipe in inches/cm^2

A = Allowance provided for gravel packing and ranges from 0.5 - 1.0 depending on diameter of gravel packing material and drill bit (dimension-less).

For rotary rigs, as a thumb rule, the bit OD should not exceed two and a half times the drill-pipe OD (drill-pipe OD x 2.5) and SHOULDN'T be less than 20% bigger than your biggest tool diameter (tool OD x 1.2) i.e drill-collar OD or OD of an externally upset tool joint on the drill-pipe (Rowles, 1995)

For the wash bore constructed at Romi fadama,

Pump used = 2" (5cm) Robin Pump

Well diameter

WD = OD(drill-pipe) + 1

= 2" + 1

= <u>3"</u>

≃ 7.5cm (750mm)

3.7.1.2 Well Depth

The depth of a well is often determined from the electrical log geo-physical survey or log of a test-hole or from logs of other nearby wells in the same aquifer or during the drilling of the wash bore. It is desirable to complete the well to the bottom of the aquifer since more of the aquifer thickness can be utilized as the in-take portion of the well, resulting in higher specific capacity, more draw-down thereby permitting greater well yield.

Static water level (SWL) = 5.8m

The depth of well to bottom of aquifer for wash bore at Romi Fadama

$d = 7.5m$

(i) Thickness of aquifer

Depth of wash bore d = 7.5m

Static water level (SWL) = 5.8m

$$\text{Thickness of aquifer} = d - SWL = 7.5 - 5.8m = \underline{1.70m}$$

3.7.1.3 Well Screen

A well screen is a strainer that separates the groundwater from the granular material in whose pores it is contained.

Often referred to as the in-take section, well screen design is a critical element in well construction. The screen permits water to flow into the well and keeps sand and gravel out. The quality of water that can be tapped from a well depends on:

- length of the screen
- diameter of screen
- screen slots
- total slotted area

choice of a screen for a formation is determined by the sizes of grain material from aquifer bearing stratum.

(i) **Screen Length**

Selection of a screen length is usually matter of engineering judgement and experience. The flowing equation (Walton, 1962) was used in selecting the screen length.

$$h = \frac{Q_o}{A_o V_o}$$

where h = screen length

Q_o = max expected discharge capacity of well, litre/sec.

A_o = effective open area per metre length of the well screen, m^2
It is determined as provided by the manufacturer.

V_o = enhance velocity at the screen, m/sec
ranging from 3 - 7.5m/sec)

i.e $h = \frac{3.2}{0.25 \times 7.5}$

$= 1.71m$

$\simeq$ **1.70m**

(ii) **Screen Diameter**

In wash bore construction, the diameter of screen is usually the same as the diameter of casing pipe since the diameter of the hole is same from top to bottom of the aquifer.

Thus, screen used was (750m) diameter screen.

(iii) **Screen slot opening**

Size of screen slot opening (perforating) is based on the grain-size distribution. For homogenous formation, screen slot opening should retain 40 - 50% of the aquifer material. However, 40% is a common design parameter. Size of slots commonly used is 1.5 to 5mm beyond which no substantial reduction in clogging is obtained. Width of slots varies from the range 0.2 to 0.5mm and 2 to 5mm depending on grain size distribution of aquifer and screen construction. Slot openings can be achieved by using hack-saw.

3.8 Construction and Installation of Washbore

3.8.1 Materials and equipment

- 2" petrol engine water pump, fuel, oil, suction hose, delivery hose, with same specification as suction hose (2"), strainer, hose couplings and clips.
- Medium duty 2" GI pipe 6m, 3m and 1.5m lengths for jetting 3" GI cutting

edge, 3" x 2" GI reduce r sockets, 2" GI sockets, Bends, Nipples, 24" pipe wrenches (2No.).

- Tangit gum, PVC screens, PVC casing fits (63mm or 50mm diameter). PVC fittings.
- Optional coarse sand, water tank or bowser.

3.8.2 Procedure(s)

Step 1.

Drill pilot hole hand anger or digger removing the top clay and silt preferably down to about 0.5m.

Step II

After having established the site, decide whether to reuse the drilling water or not, if the water is to be reused dig a pit 1m x 1m x 0.7m approximately some 3 - 4m from the pilot hole.

Step III

Assemble the drilling pipe 3 - 4m with GI bend and drilling bit.

Step IV

Assemble the pump with suction hose strainer and delivery hose connected to GI bend.

Step V

Hold the GI pipe vertically with the help of 2 labourers at the top of the test-hole or about 0.5m inside the hole.

Step VI.

Start the pump. The drilling operation is performed by jetting stream of water under pressure and washing the cuttings. Ensure that all cuttings are removed before lowering the GI drilling pipe further.

If the penetration is difficult, apply a downward reciprocating thirst by lifting and dropping the pipe continuously. By this method, it could be possible penetrate through the bases of clays when encountered. When the 3m penetration is achieved, remove the 3m drilling pipe and change it to 6m and continue drilling, then change to 9m and continue drilling. The change in pipe lengths should be achieved with minimal loss of time. When penetrating the aquifer, the pipe will have the tendency to go down on its own. Examine the cuttings closely for the best available formation of coarse sand and gravel. When full depth of the drilling pipe has been penetrated it could be possible to establish the depth at which the best aquifer exists. The drilling pipe is then moved up and down while the pumping is continued so as to bring out all the fine cuttings to the surface leaving the coarse sand and gravel where the screen is subsequently to be located. The pump is slowed down.

Step VII.

Assemble the PVC casing and screen to match the location of the aquifer.

Step VIII.

The jetting pipe is withdrawn and the assembled tubewell installed instantaneously into the hole.

Step IX.

If the hole has collapsed and the screen could not be lowered to the required level, remove the drilling bit and insert the jetting pipe close to the casing and screen and start the pump again. With the help of further jetting lower the screen to the required position.

Step X.

Cutting off any length which about 25cm above the surface from the casing pipe and correct the PVC reducer or PVC nipple with 2" GI bend.

Depth attained was 7.5m.

3.8.3 Well development

Connect the washbore with the pump, and pump clear water slowly till all the fine sand close to the screen is removed. Insert coarse sand (i.e. gravel pack the sides of the hole) and gravel around the washbore with pump still running slowly, so that the coarse sand is packed up to 1m above the top of the screen.

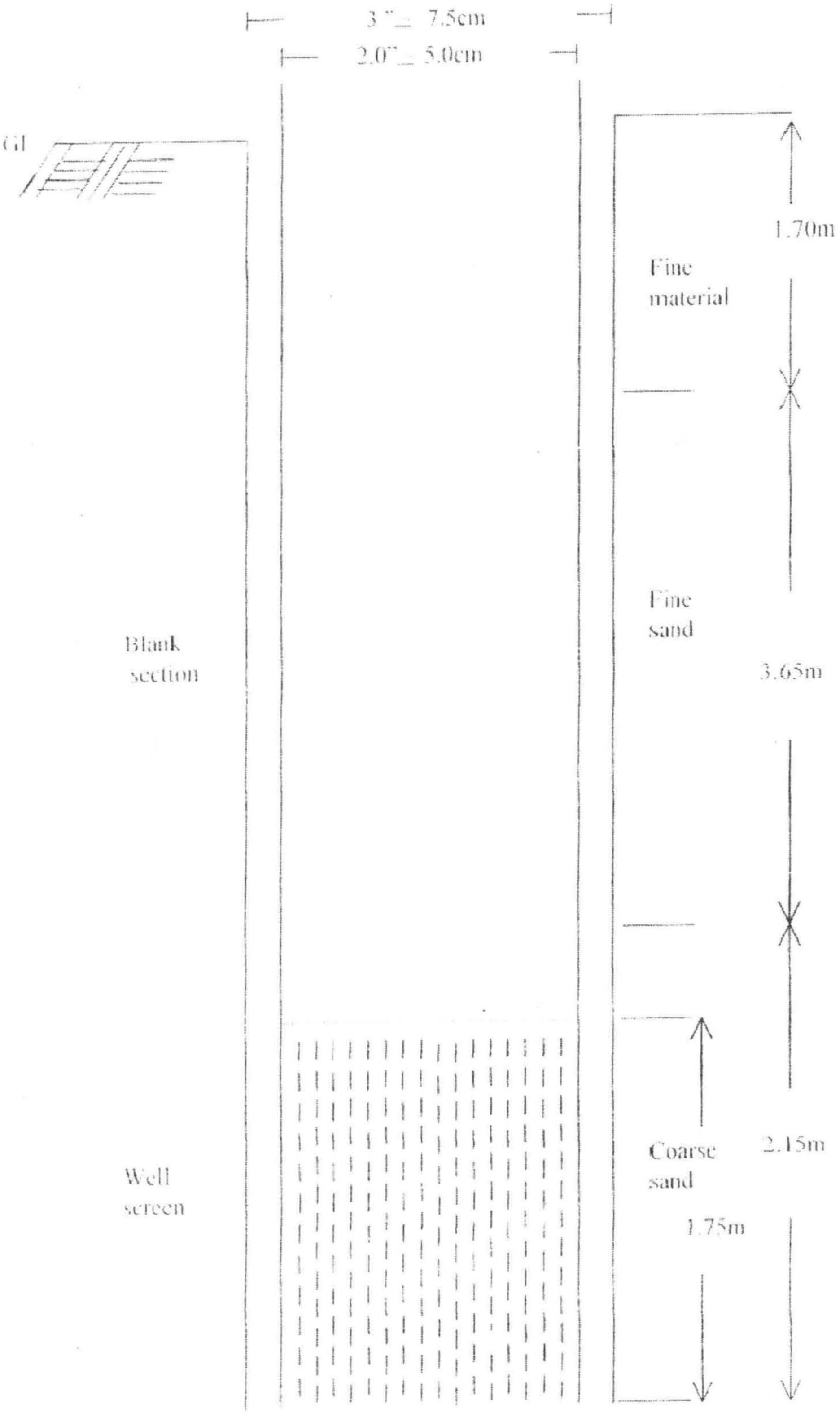


FIG 3.8 A cross-section of the washbore

3.9 Evaluation of Water Abstraction Techniques

The objective of evaluating the various alternative methods of washbore construction is to allow for the selection of the most cost effective construction method for fadama shall scale irrigation which can easily be adapted. The appropriate method to be used depends to a large extent on the geological conditions of the sub-structure. Where there is a thick layer of land clay overlaying the aquifer a small rotary rig is used. Where the overlaying clays and silts are relatively thin, and there is not a problem with heaving sand, the percussion/bailer method is preferred. Where the upper clay and silt layer is thin but the water-bearing sands, are loose and washbore or rig are best. In this case, based on the material obtained from the water-bearing aquifer in which the aquifer is being overlay by a thin layer of clay, the clear water jetting method was considered most appropriate.

Moreso, that the method is most economical compared to others.

3.9.1 Criteria for comparison of techniques

In comparing the different methods of well construction, a number of criteria need to be considered. In selecting the suitable criteria it must be decided whether or not there is sufficient information that is either available or can be obtained at a reasonable cost. Criteria overlap and as such it is not necessary to take every factor into account. The following criteria informed the choice of the water wash bore jetting method

- cost of installation
- flexibility of equipment
- capability to achieve high efficiency wash bore
- availability of inputs.
- ease of mobilization to site
- rate of wash bore completion (Production rate)
- level of technical expertise
- ease of operation.

3.10 Cost of Washbore Installation

The cost of completing a functional washbore differs in the method of construction. The cost of rotary rigs alone makes cost analysis of washbore installation for methods other than the clear water washbore fitting method difficult. Costing include among others equipment purchase, operation and maintenance, material manpower and technical knowledge required, for handling equipment. Due to extreme uncertainty in economic indicators such as foreign exchange rate and trend (rate) of inflation within the country, the sensitivity of the cost calculation for each method has not been tested since most of the equipments are imported.

Logistic support, although not addressed as a separate consideration, is a critically limiting factor in determining the construction efficiency of all drilling techniques. In theory, several tubewell completions per day (production rate) are possible with full vehicle support or easy accessibility to site.
In overall, the clear water wash bore jetting method is the cheapest of all drilling techniques.

Table 3.10: Estimated Costs for a Washbore by the clear water jetting method.

Item	Cost	
	N	K
2" Water pump with hoses (Robin)	35,000	00
3 No 3" GI drill Pipe @ ₦850/pipe length of 3m long	3,450	00
3 No 2" PVC pipe casing @ ₦700/3m length	2,100	00
24" pipe wrench	4,300	00
18" pipe wrench	4,100	00

1 No 2" PVC screen (2m long)	750	00
2 No couples	500	00
4 No clips	300	00
Fuel @ ₦20/1 with lubricant	130	00
3"-2" Reducer	300	00
3" G.I bend	450	00
Miscellaneous	10,000	00
	₦60,400	**00**

3.11 Production Rate

A critical factor in comparing the various washbore construction techniques is the rate at which a washbore will be completed. Basically, this factor is dependent upon the formation in which the drilling is being undertaken. For instance, the time it will take to drill a washbore in an alluvial deposit of an old river course or on the river bed itself will be very much more faster and cheaper than drilling in a formation underlaid by very thick clay or basement complex. Another factor that determines the rate at which a washbore is completed is the accessibility to the drilling site as well as experience of the plumber that is expected to couple the drill pipe lengths completed as well as PVC casings at completion of drilling exercise.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Percentage Soil Sample

The percentage soil samples include % sand, % silt and % clay.

The total percentage sand = 178%

The total number of sand sample = 6

Average = $\frac{\text{Total \% Sand}}{\text{Total no of sand sample}}$

= $\frac{178}{6}$

= 30%

The total percentage silt = 238%

Total No. of silt sample = 6

Average = $\frac{238}{6}$

= 40%

The total percentage clay = 178%

Total no of clay sample = 6

Average = $\frac{\text{Total\% Clay}}{\text{Total no of clay sample}}$

= $\frac{178}{6}$

= 30%

Textural Class

From the above results, the textural class of Romi fadama from where soil samples were taken is **Silty Clay Loam.**

4.2 Infiltration Test

4.2.1 Results and calculation(s)

The mean data derived from the field infiltration rate was from Romi Fadama, collated and analysed during 130 minutes test(s) The result of infiltration rate of soil is 9.74 cm/hr.

4.2.2 Computation of Average Infiltration rate cm/hr for site 1, 2, 3 in Article 3.5.

SITE 1

1. $\frac{60}{5} \times 2.5 = 30$ cm/hr
2. $\frac{60}{5} \times 1.7 = 20.4$ cm/hr
3. $\frac{60}{5} \times 1.1 = 13.2$ cm/hr
4. $\frac{60}{5} \times 0.8 = 9.6$ cm/hr
5. $\frac{60}{10} \times 0.8 = 4.8$ cm/hr
6. $\frac{60}{10} \times 0.7 = 4.2$ cm/hr
7. $\frac{60}{15} \times 1.0 = 4.0$ cm/hr
8. $\frac{60}{20} \times 1.0 = 3.0$ cm/hr
9. $\frac{60}{20} \times 1.2 = 3.6$ cm/hr
10. $\frac{60}{20} \times 1.2 = 3.6$ cm/hr
11. $\frac{60}{10} \times 1.0 = 6$ cm/hr

SITE 2

1. $\frac{60 \times 2.3}{5} = 27.6$ cm/hr

2. $\frac{60 \times 0.7}{5} = 19.2$ cm/hr

3. $\frac{60 \times 1.2}{5} = 14.4$ cm/hr

4. $\frac{60 \times 1.0}{5} = 12.0$ cm/hr

5. $\frac{60 \times 0.9}{5} = 10.8$ cm/hr

6. $\frac{60 \times 0.8}{10} = 4.8$ cm/hr

7. $\frac{60 \times 0.9}{10} = 5.4$ cm/hr

8. $\frac{60 \times 0.7}{15} = 2.8$ cm/hr

9. $\frac{60 \times 0.6}{20} = 1.8$ cm/hr

10. $\frac{60 \times 0.6}{20} = 1.8$ cm/hr

11. $\frac{60 \times 0.6}{20} = 1.8$ cm/hr

12. $\frac{60 \times 0.6}{10} = 3.6$ cm/hr

1. $\frac{60}{5} \times 2.7 = 32.4$ cm/hr

2. $\frac{60}{5} \times 1.8 = 21.6$ cm/hr

3. $\frac{60}{5} \times 1.3 = 15.6$ cm/hr

4. $\frac{60}{5} \times 1.1 = 13.2$ cm/hr

5. $\frac{60}{5} \times 0.9 = 10.8$ cm/hr

6. $\frac{60}{10} \times 0.8 = 4.8$ cm/hr

7. $\frac{60}{10} \times 0.8 = 4.8$ cm/hr

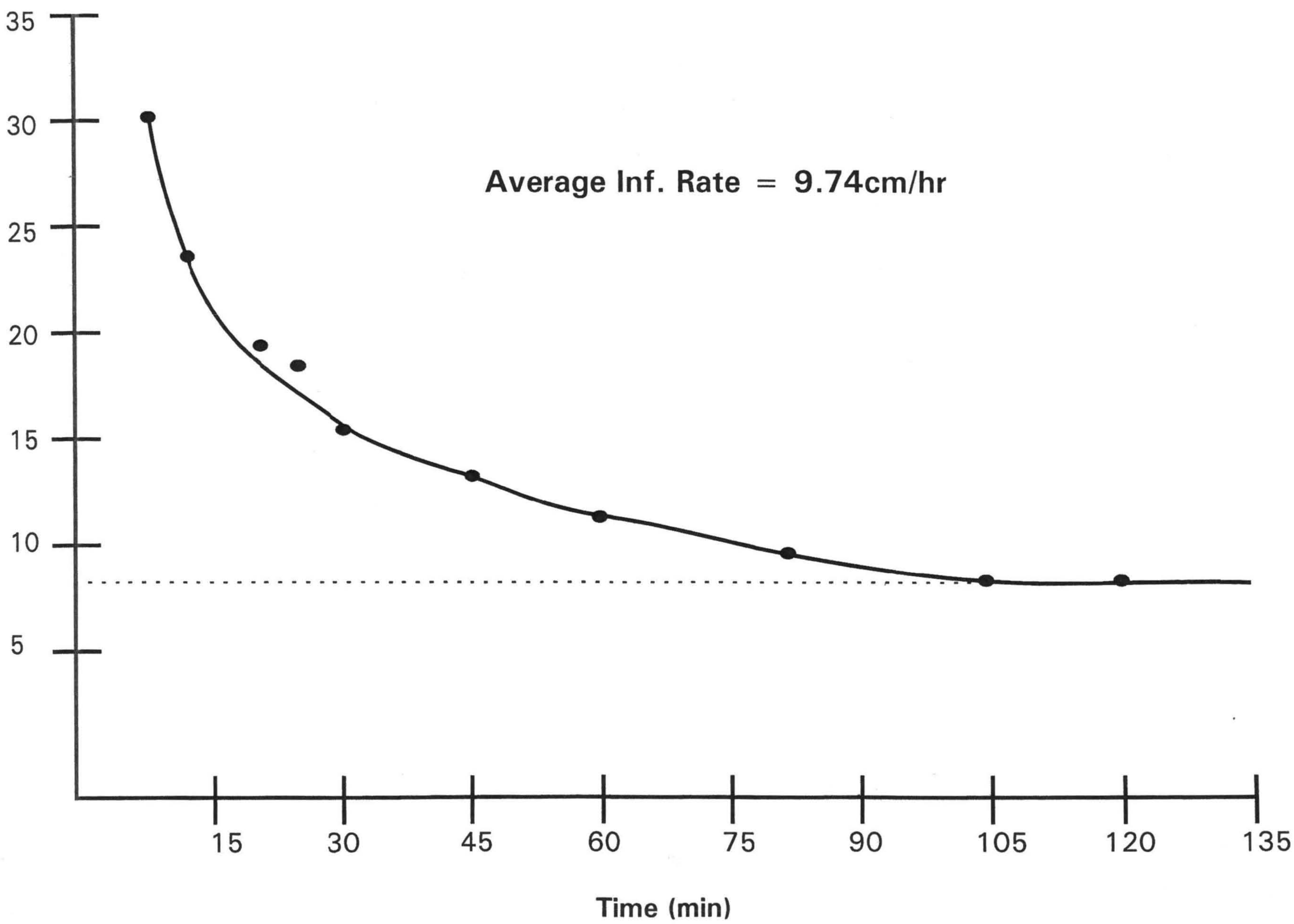
8. $\frac{60}{15} \times 0.6 = 2.4$ cm/hr

9. $\frac{60}{20} \times 0.6 = 1.8$ cm/hr

10. $\frac{60}{20} \times 0.6 = 1.8$ cm/hr

11. $\frac{60}{20} \times 0.5 = 1.5$ cm/hr

12. $\frac{60}{10} \times 0.4 = 2.4$ cm/hr



g 4.2: Average Infiltration Rate for Romi Fadama

4.3 Soil Particle Size Distribution

The soil textures within a profile were variable probably as a result of alluvium deposition in the fadama. The soil materials were coarse to intermediate in particle size distribution. The soils were sands ranging from coarse loamy sands to sandy clay loams (Table 4.3a). Low silt fraction, medium clay content and high sand fractions were characteristics of the soils. Generally, the clay content decreased with depth (Table 4.3a). The mean clay content of the 0 - 15, 15 -30, 30 - 45, 45 - 60, 60 - 75, 75 - 90, and 90 - 105cm depths well 16.9, 8.0, 11.6, 12.7, 15.7, 17.4,and 19.9% respectively. A deviation from the trend occurred in the 0-30cm layer which may be due to the cumulative effect of the population size. The silt fraction ranged 18.4% in the surface 0 - 15cm layer but decreased gradually to 5.9% in the 90-105cm depth. The sand fraction exhibited no particular tread between depth intervals. All the horizons were dominantly sands. The percentage sand content varied between 64.0 to 84 .4% with the highest value in the 15-30 cm layer.

The co-efficient of variation ranged from 9.0 to 28% for sand, 24.4 to 41.7% for silt and 5.4 to 5.4% for clay.

Generally, the analysis revealed high variability in size fractions.

Recharge rates of wells constructed in this fadama are likely yo exhibit some variability in their recharge capabilities.

Table 4.3b: Sample Sieve Analysis Summary

Sieve Number	Sieve Opening (mm)	(inches)	Cumulative Wt Retained (g)	Com. % Retained
10	2.00	0.079	47	11.63
14	1.41	0.056	59	14.60
20	0.84	0.033	125	30.94
25	0.71	0.028	160	39.60
40	0.42	0.017	302	74.75
60	0.25	0.010	364	90.10

Pan wt 404 100

Original wt 407

Table 4.3c: Soil -Particle fractions proposed by United States Department of Agriculture and International Soil Science Society.

Fraction	Particle USDA	Diameter ISSS
Gravel	>2mm	>2mm
Very Coarse Sand	1 to 2mm	-
Coarse Sand	0.5 to 1mm	0.2 to 2mm
Medium Sand	0.25 to 0.5mm	-
Fine Sand	0.1 to 0.25mm	0.02 to 0.2mm
Very Fine Sand	0.05 to 0.1mm	-
Silt	0.002 to 0.05mm	0.002 to 0.02mm
Clay	<0.002mm	<0.002mm

Source: Michael, A. M. (1978) "Irrigation: Theory and Practice"

Table 4.3a: Particle size distribution and texture of the soil at different soil depths *

Parameter	Depth (cm)	Gravel (g/100g)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	Texture
X	0-15	0.9	33.8	30.9	18.4	16.9	Loam
CV		89.8	31.5	34.5	41.7	54.0	
X	15-30	1.9	53.0	31.1	7.9	8.0	Coarse Loamy sand
CV		40.5	22.7	28.2	38.0	17.2	
X	30-45	3.5	53.9	25.9	8.9	11.6	Coarse Loamy sand
CV		65.0	22.4	11.7	24.4	36.4	
X	45-60	3.7	55.5	24.8	6.4	12.7	Coarse Loamy sand
CV		52.7	22.4	18.8	33.0	36.5	
X	60-75	3.1	41.6	25.2	6.9	15.7	Coarse sandy loam
CV		41.1	12.5	18.0	33.0	24.0	
X	75-90	2.4	50.4	25.0	5.3	19.4	Coarse sandy clay
CV		117.4	5.8	15.3	39.6	8.0	loam
X	90-100	3.0	49.9	24.3	5.9	19.9	
		50.5	3.0	15.0	35.3	5.4	Sandy clay loam

X Mean of Population

CV Coefficient of variation (%)

* International Society of Soil Science Classification.

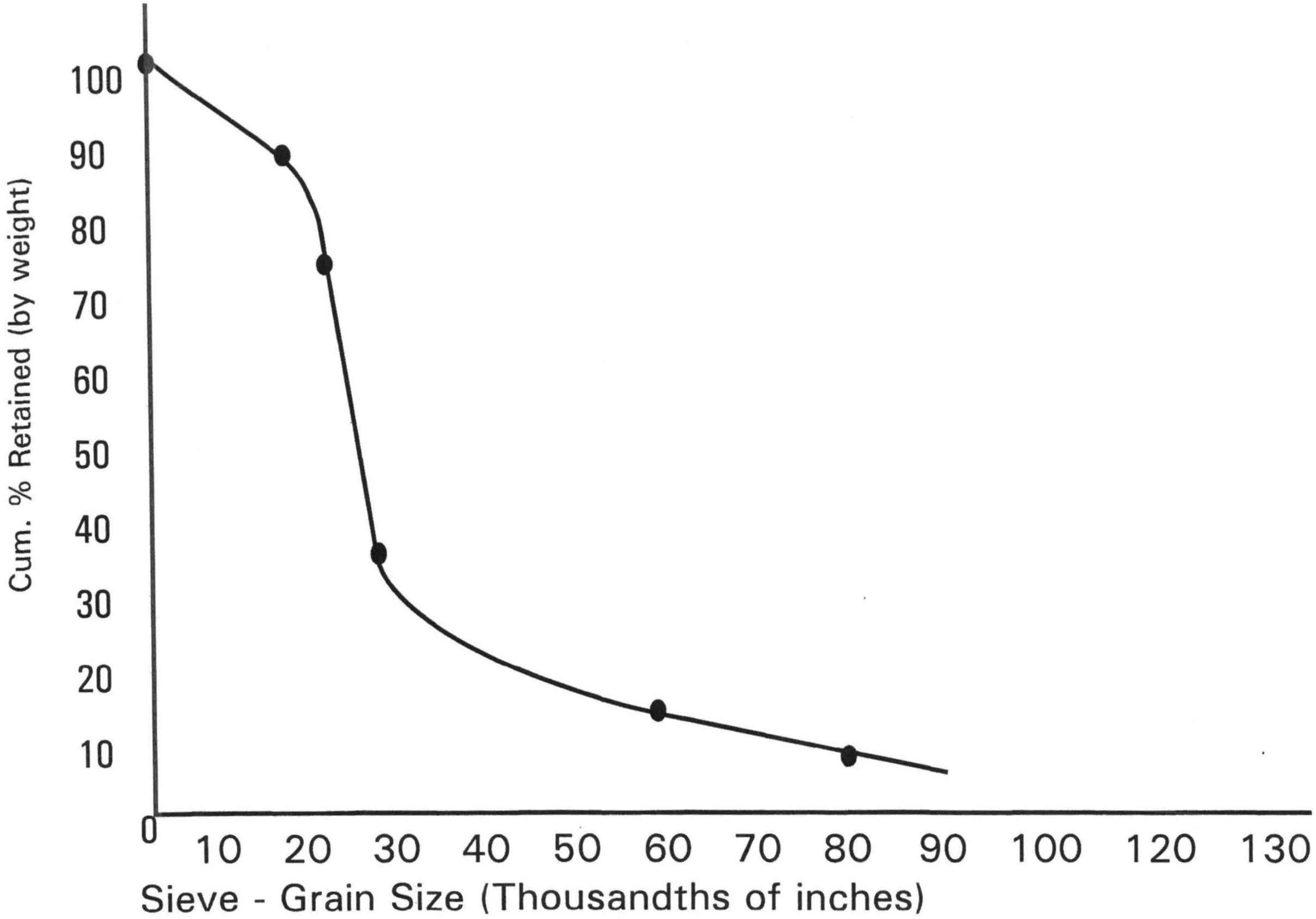


Fig 4.3a: Aquifer grain size distribution

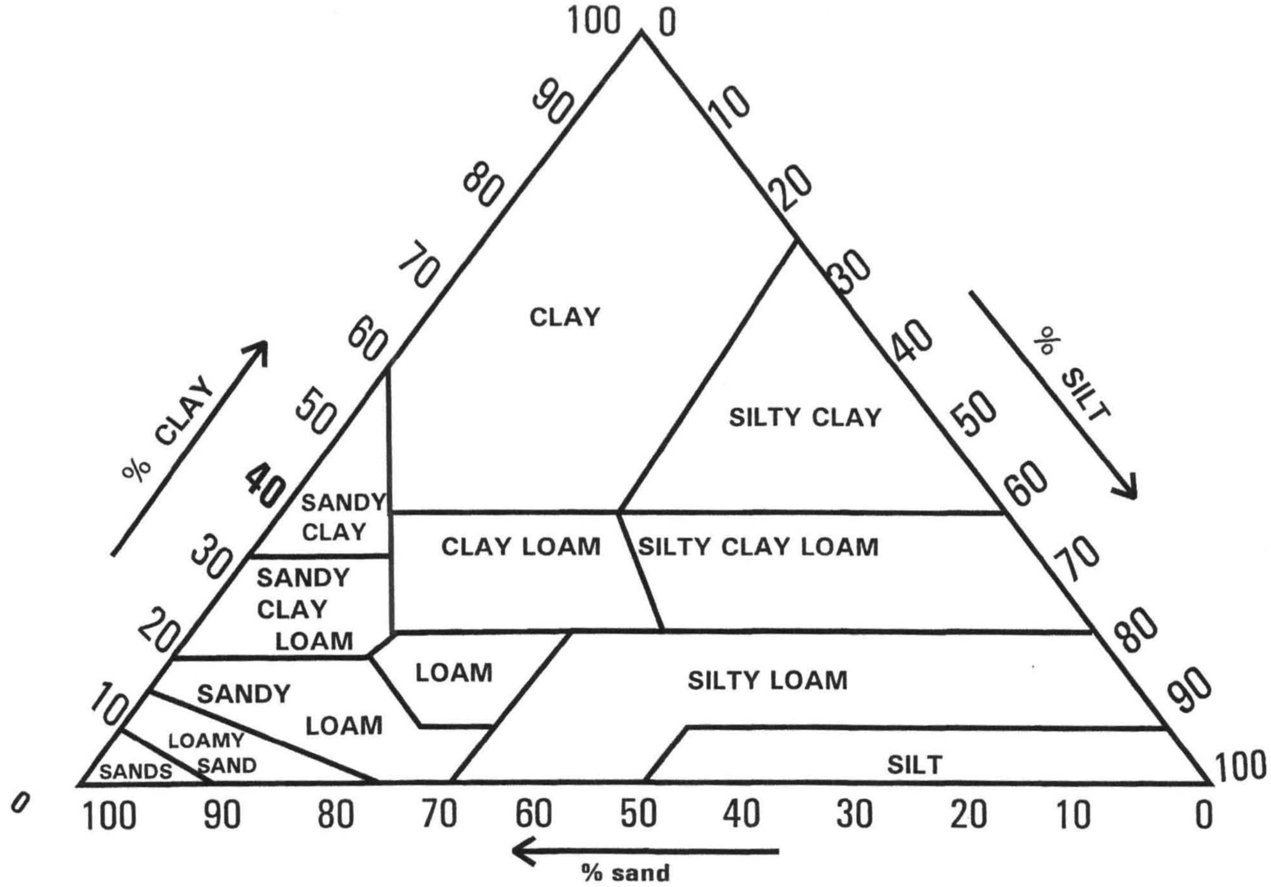


Fig 4.3b: International Soil Texture Triangle
Source: Michael A. M. (1978)
"Irrigation Theory and Practice"

4.4 Analysis of Pumping Test Data

Analysis of pumping test data provides the information required to determine the appropriate abstraction rate from the wash bore, and the sustainable yield from the aquifer. Analysis was done manually and with the calculator using Cooper - Jacob semi-log methods. From these plots (Fig 4.4), the aquifer transmissivity and storativity (storage coefficient) were calculated. The formula used in at calculation were as follows:

$$T = \frac{2.3\,Q}{4\pi \ \Delta S}$$

Where T = transmissivity in m^2/day

Q = discharge (m^3/day)

ΔS = change in draw-down over one log cycle (m)

and

$$S = \frac{2.25\,Tt_o}{r^2}$$

Where T = Transmissivity

t_o = elapsed time (min).

r = radius of pumping well & observation well (m)

Transmissivity, **T** and storativity, **S** were determined to be **1265.09 m^2/day** and **7.91 x 10^{-3}** respectively.

Elapsed Time t (min)	Draw down Δs	Log t (min)
0	0	∞
5	2.4	0.7
10	2.7	1.0
20	3.0	1.3
30	3.6	1.5
50	4.1	1.7
60	4.3	1.8
90	4.8	2.0
120	5.4	2.2
180	6.1	2.3
300	7.6	2.5

Table 4.4: Pumping Test data for Romi Fadama

Constant discharge

$Q = 3.2$ l/s

$\simeq 276.48\ m^3/day$

$r = 10m$

$\Delta s = 0.04m$

Appendix 2b:

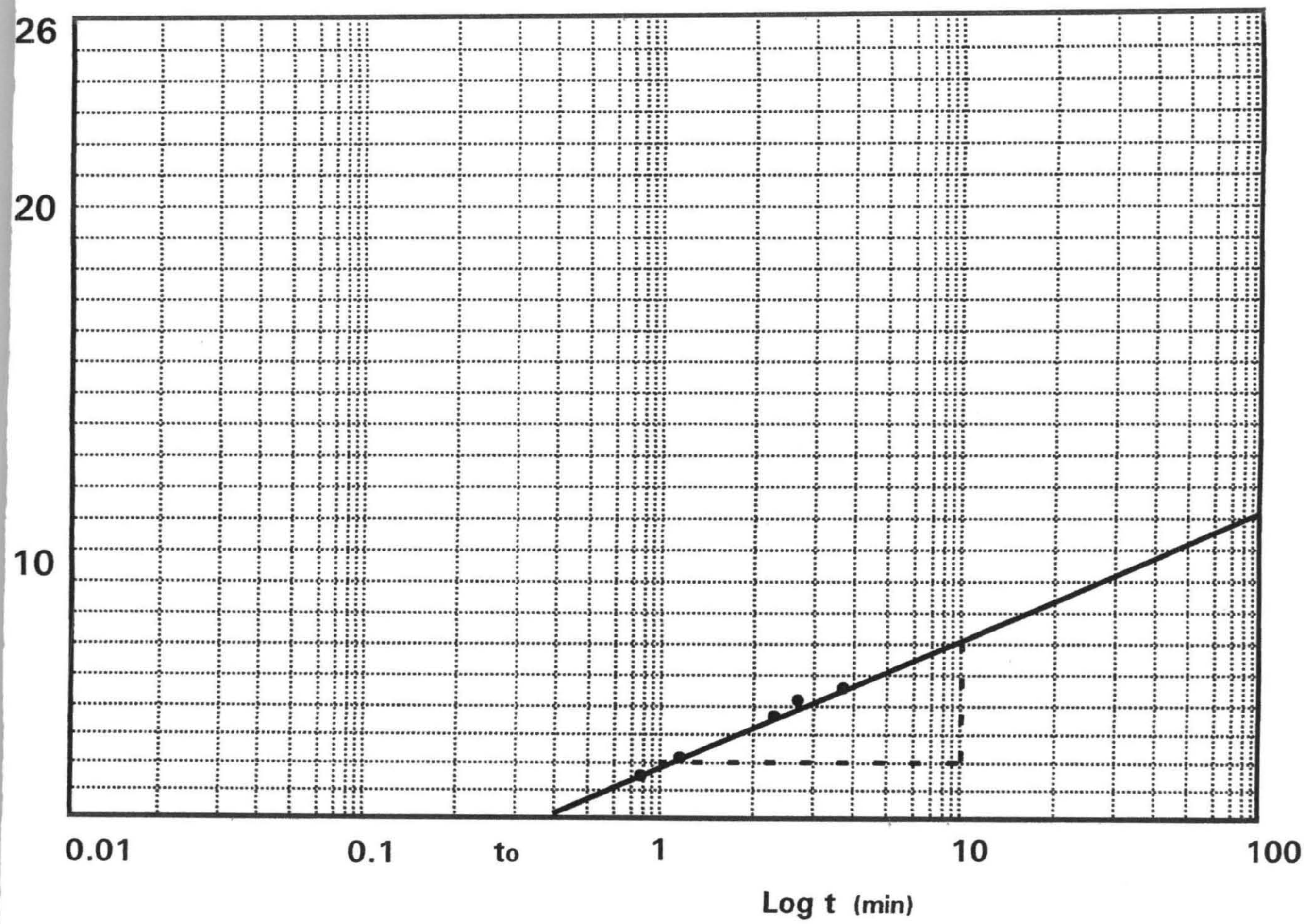


Fig. 4.4: Jacobs semi-log graph for determination of T & S values

$t_o = 0.4 \text{ min} = \frac{0.4}{60 \times 24} = 2.78\ 10^{-4}$days.

$\Delta s = 7 - 3 \text{ cm} = 4\text{cm} = 0.04\text{m}$

$Q = 3.2 \text{l/s} = \frac{3.2}{1000} \text{m}^3/\text{s} = \frac{3.2}{1000} \times 60 \times 24 \text{m}^3/\text{day} = 276.48 \text{m}^3/\text{day}$

Transmissivity

$$T = \frac{2.3Q}{4\pi\ \Delta s} = \frac{2.3 \times 276.48}{4\pi \times 0.04} = 1265.09 \text{m}^3/\text{day}$$

Storativity

$$S = \frac{2.25Tt_o}{r^2} = \frac{2.25 \times 1265.09 \times 2.78 \times 10^{-4}}{10^2} = 7.91 \times 10^{-3}$$

4.5 Effect of groundwater abstraction on water table levels.

Water-table is the natural level of free groundwater. Natural groundwater flows through an aquifer under a natural hydraulic gradient but an artificially induced flow can be initiated by imposing an increased hydraulic gradient around a well and the artificial induction is by means of a pump. When water is being retrieved from a well, the well is said to be discharging. The water level in the vicinity of a discharging well falls as the rate of pumping increases or as time increases at a fixed steady rate of abstraction and the degree of fall of water level decreases with increasing distance from discharging well. The moisture condition at time of measurement may affect soil conductivity and hence, draw-down. However, when no pumping is taking place, the water pressure within the well is less than that of the formation outside the well. During abstraction the pressure within the well is lowered and pressure gradient is created by the well and greater pressure outside the well. The greater pressure in the well surround would force water into the well and flow occurs. The lowering of pressure within the well could be accompanied by lowering of the water table in the well vicinity. Water then flows radially into the well from all directions by a converging flow.

Perhaps, pumping groundwater in areas where suitable permeable aquifers exist would be a more effective way of lowering the water table and in drainage by controlling excess water in water logged soils. This could diversify crops and cropping systems.

4.6 Recharge Process

Under natural conditions, the aquifers are replenished through infiltration of surface waters during the rainy season and by hydraulic connection with perennial streams running through/or across fadama. At the end of the dry season, the water level in an aquifer is at its lowest point, generally very near the elevation of the water level in the river which is also at its lowest point. When the rains begin and stream channels, fill, the hydraulic head in the river becomes higher than in the aquifer which causes water to flow into the aquifer. The process continues until an equilibrium is reached between the water levels in the river and in the aquifer.

Most often, there is not a direct lateral connection between the river and the aquifer.

The alluvial aquifers underlying the fadama are typically former channels of the river and thus are relatively long and narrow. The points at which these old channels intercept the present channels are where recharge occurs most effectively. The surface materials over most of the fadama are clays and silts which have low inter-granular hydraulic conductivity. However, desiccation cracks are quite common in clays. These openings provide pathways for flood water to infiltrate downward to recharge the aquifers.

From the infiltration test and re-charge rate determination, recharge would naturally be fast. However the pathways along which the recharge water moves into the aquifer are long and the hydraulic gradients are relatively low and therefore this recharge process is typically slow. As a result, full replenishment of the aquifer should be late in the rainy season when the rains would have fully established. Recharge rates for the 2hr period was determined to be 11.15cm.

4.7 Discharge Process

During dry season, the water level in the river drops, the hydraulic head in the aquifer becomes higher than that of the river. As a result, water moves from the aquifer to the river channel, thereby sustaining flows in the river long after the rainy season has ended. Where there are extensive alluvial aquifers beneath the flood plain, the discharge to the river may sustain flow throughout the dry season when irrigation activities are at their peak.

Vertical withdrawal of water from aquifer by evapo-transpiration is also an important and significant factor. Where the water level is close to the surface, water is abstracted through plants, by phreatic consumption.

To determine the full extend of recharge for the aquifer at Romi Fadama, long-term monitoring of the well is required. Monitoring of this washbore at Romi fadama that has become a test well in case of future development of the land for irrigation purpose, on regular basis becomes imperative to obtain a full season cycle of readings.

In any case, the discharge data that was obtained for River Romi along Kaduna-Abuja road and the average infiltration rate (1.3cm/hr) of the soil provides an insight into the good recharge potentials of the alluvial in this fadama.

4.8 Irrigation Return Flows

A significant portion of the water applied on the ground to support crop growth infiltrates downward and returns to the aquifer. Michael (1978) considered a return flow of about 30% of irrigation water to the aquifer as a common phenomenon.

4.9 Effect of the Soil on Tyre Pressure during Traction

Heavy soils such as clay exhibit poor infiltration properties which causes slippage during traction thereby resulting in power wastage.

Power wastage can very much be assumed to be minimal as a larger proportion of the soil within the study area is of coarse material (sands).

Since the first layer comprising of silty and clayey material in a rather thin layer, one may assume that there might be slippage of some sort (minimal though). In a situation of this nature, if traction is found inadequate the pressure in the tyre may be reduced to provide for a better grip. Machineries with good tyre threading may not have the pressure in the tyres reduced since the threads would ensure good grip on the soil.

SUMMARY AND CONCLUSION

In exploring the feasibility of the clear water washbore jetting method for Romi fadama various construction methods were considered. The performance of the design however depends on the recharge rates and yield of the well. If an engineering design aims mainly at performance, relative cost and useful life of a design, then the washbore by clear water jetting method would be most economical and profitable to the fadama small-scale irrigation farmer than the other washbore construction methods because of their disadvantages in accessibility to site and drilling costs. The clear water jetting method inspite of its relative cheapness and the ease with which drilling is completed, has the disadvantage of difficulty in penetrating very thick clays and for formation underlaid by granitic basements thus, it is best for old river courses or alluvium deposited formations. It however, has an advantage in case of adoption of the technology by an un-skilled farmer which should be the ultimate goal of any irrigation planner.

The high permeability values obtained during the infiltration rate(s) test from the fadama connote that construction of shallow wells should be adequate for the area rather than the highly expensive deeper tubewell that may be abortive. Hence, the feasibility of the washbore by clear water jetting method at Romi fadama.

It is thus recommended that possibilities of fitting jetting pipe with a drill bit even if it is improvised, to enable easy penetration into consolidated formations need to be explored.

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DAILY MEAN DISCHARGES IN CUSECS (1992 - 1999)

DATE	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
1	27.50	297.0	241.0	165.0	2173.0	2291.0	3275.6	266.6	109.0	48.6	33.0	30.0
2	27.0	357.5	229.8	254.0	3301.5	4036.4	3043.0	258.2	105.0	48.6	32.4	28.1
3	27.0	329.6	234.0	213.0	3218.5	5066.6	2701.0	243.6	101.2	48.0	31.8	27.5
4	26.6	295.5	234.0	231.2	2954.0	5808.4	2222.6	236.8	97.8	48.0	31.2	27.0
5	23.5	242.3	215.4	295.5	2654.0	7745.4	1872.6	225.6	95.3	47.4	30.6	26.2
6	21.5	192.6	183.0	413.4	2635.4	7926.3	1587.5	218.6	91.9	47.4	30.0	25.8
7	20.6	288.0	217.8	537.0	2366.6	7086.0	1505.0	213.0	88.6	46.8	247.5	25.8
8	19.8	289.5	282.0	645.4	2229.8	6141.3	1493.0	207.0	86.0	46.8	254.0	25.4
9	19.3	289.5	289.5	645.4	2219.0	5541.6	1356.4	204.6	84.4	45.6	231.2	25.4
10	18.4	366.0	244.9	705.4	2183.5	5166.3	1210.2	192.6	81.8	45.0	96.2	25.4
11	18.0	317.5	248.8	723.0	2716.2	5282.2	1117.4	184.2	80.2	44.4	67.2	25.1
12	17.4	239.6	301.8	603.0	3107.8	5098.4	1015.8	178.2	77.6	43.8	57.6	25.1
13	17.0	191.4	347.0	625.0	2927.8	5276.8	962.0	169.8	75.9	43.2	51.0	25.1
14	16.7	195.0	350.0	567.0	3653.8	5658.2	923.0	163.8	71.5	42.0	39.6	24.7
15	15.8	269.4	246.2	432.1	3918.0	5928.0	852.1	160.2	68.0	41.4	45.6	24.7
16	15.4	627.0	191.4	541.0	2631.6	6176.4	746.3	157.8	65.6	40.8	39.0	24.3
17	15.1	599.0	205.8	737.7	1963.3	8054.4	703.2	151.0	63.2	40.8	37.8	24.3
18	14.4	344.0	171.0	806.1	1678.4	8887.8	595.0	148.0	61.6	40.2	38.4	23.9
19	14.0	386.2	142.0	905.6	1313.7	9101.6	477.2	145.0	59.4	39.6	33.6	23.5
20	13.7	411.7	118.0	1041.8	1091.2	9391.6	454.8	140.0	58.2	39.0	47.4	22.8
21	20.6	428.7	146.0	1421.0	1021.0	9123.3	477.6	137.0	56.4	38.4	46.2	22.4
22	23.5	275.0	142.0	1946.4	1083.4	8760.0	433.8	133.0	55.8	37.8	43.8	22.0
23	21.5	252.7	214.4	1768.4	1091.2	8909.1	420.2	129.7	55.2	37.2	33.0	21.5
24	21.1	272.2	183.0	1606.2	1052.2	8682.0	401.5	126.4	54.6	36.6	32.4	21.5
25	45.6	329.6	165.0	1855.8	1128.2	8034.0	382.8	125.3	53.4	36.0	31.2	21.1
26	62.4	289.5	202.0	2083.0	1112.0	6990.0	364.1	123.1	52.8	35.4	31.2	21.1
27	54.6	272.2	147.0	1999.8	1678.2	6240.6	334.4	120.0	51.6	35.4	30.6	20.6
28	204.6	216.6	156.6	2237.0	1163.3	5171.6	319.0	119.0	49.8	34.8	30.6	20.6
29	142.0	205.8	134.0	3111.9	1644.3	4274.4	309.8	115.0	49.8	34.8	30.0	20.2
30	277.8	208.8	157.8	3326.2	1612.6	3587.6	292.5	112.0	49.2	33.6	-	19.8
31	-	213.0	-	3441.4	1778.0	-	289.5	-	49.2	33.0	-	19.3
MAX	277.8	627.0	350.0	3441.4	3918.0	9391.6	3275.6	266.6	109.0	48.6	254.0	30.0
MIN	13.7	191.4	118.0	165.0	1021.0	2291.0	289.5	112.0	49.2	33.0	30.0	19.3
MEAN	42.1	305.1	211.3	1157.6	2854.5	6514.6	1035.8	170.2	71.0	41.3	61.5	23.9

* SOURCE: Kaduna State Water Board
Hydro-Meteorological Year Book.

PENDIX 2:

RIVER ROMI AT KM 1, KADUNA - ABUJA ROAD
DAILY MEAN GAUGE HEIGHTS (1992 - 1999)

ATE	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
	2.93	5.60	5.20	4.60	12.92	13.25	15.78	5.39	4.07	3.31	3.05	3.00
	2.92	5.99	5.12	5.30	15.85	17.52	15.22	5.33	4.03	3.31	3.04	2.95
	2.92	5.81	5.15	5.00	15.65	19.62	14.35	5.22	3.99	3.30	3.03	2.93
	2.91	5.59	5.15	5.13	15.00	20.99	13.06	5.17	3.95	3.30	3.02	2.92
	2.83	5.21	5.02	5.59	14.18	24.12	12.04	5.09	3.92	3.29	3.01	2.90
	2.78	4.83	4.75	6.32	13.46	24.39	11.15	5.04	3.88	3.29	3.00	2.89
	2.76	5.54	5.04	7.00	13.08	23.10	10.88	5.00	3.84	3.28	3.25	2.89
	2.74	5.55	5.50	7.54	13.05	21.57	10.84	4.95	3.81	3.28	5.30	2.88
	2.73	5.55	5.55	7.54	12.95	20.51	10.38	4.93	3.79	3.26	5.13	2.88
	2.71	5.85	5.23	7.82	14.36	19.81	9.86	4.83	3.76	3.25	3.93	2.88
	2.70	5.73	5.26	7.90	15.38	20.03	9.52	4.76	3.74	3.24	3.59	2.87
	2,68	5.19	5.63	7.32	14.94	19.68	9.13	4.71	3.71	3.23	3.43	2.87
	2.67	4.82	5.92	7.42	16.67	20.02	8.92	4.64	3.69	3.22	3.35	2.87
	2.66	4.85	5.94	7.15	17.26	20,72	8.76	4.59	3.64	3.20	3.16	2.86
	2.63	5.41	5.24	6.43	14.17	21.20	8.47	4.56	3.60	3.19	3.26	2.86
	2.62	7.45	4.82	7.02	12.31	21.63	8.01	4.54	3.57	3.18	3.15	2.85
	2.61	7.31	4.94	7.97	11.44	24.58	7.81	4.48	3.54	3.18	3.13	2.85
	2.59	5.90	4.65	8.27	10.23	25.78	7.29	4.45	3.52	3.17	3.14	2.84
	2.58	6.16	4.39	8.69	9.42	26.08	6.68	4.42	3.49	3.16	3.06	2.83
	2.57	6.31	4.16	9.23	9.15	26.48	6.56	4.37	3.47	3.15	3.29	2.81
	2.76	6.41	4.43	10.60	9.39	26.11	6.52	4.34	3.44	3.14	3.27	2.80
	2.83	5.45	4.39	12.26	9.42	25.60	6.44	4.30	3.43	3.13	3.23	2.79
	2.78	5.29	5.01	11.72	9.27	25.81	6.36	4.27	3.42	3.12	3.05	2.78
	2.77	5.43	4.75	11.21	9.56	25.49	6.25	4.24	3.41	3.11	3.04	2.78
	3.26	5.81	4.60	11.99	9.50	24.55	6.14	4.23	3.39	3.10	3.02	2.77
	3.53	5.55	4.90	12.66	9.37	22.95	6.03	4.21	3.38	3.09	3.02	2.77
	3.41	5.43	4.44	12.42	9.69	21.74	5.84	4.18	3.36	3.09	3.01	2.76
	4.93	5.03	4.53	13.10	11.33	19.82	5.74	4.18	3.33	3.08	3.01	2.76
	4.39	4.94	4.31	15.39	11.33	18.03	5.68	4.13	3.33	3.08	3.00	2.75
	5.47	4.96	4.54	15.91	11.23	16.52	5.57	4.10	3.32	3.06	-	2.74
	-	5.00	-	16.18	11.75	-	5.55	-	3.32	3.05	-	2.73
[AX	5.47	7.45	5.94	16.18	17.26	26.48	15.78	5.39	4.07	3.31	5.30	3.00
[IN	2.57	4.82	4.16	4.60	9.15	13.25	5.55	4.10	3.32	3.05	5.00	2.73

* SOURCE: Kaduna State Water Board
Hydro-Meteorological Year Book.