

RAINWATER HARVESTING AND THE ASSESSMENT OF GMELINA ARBOREA SAWDUST-CEMENT-BONDED TANK FOR STORAGE

BY



**AKINOLA, Olanike Olowoiya
(AGE/95/5776)**

AUGUST, 2006

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**A THESIS IN THE DEPARTMENT OF AGRICULTURAL
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ONDO STATE, NIGERIA**

AUGUST, 2006

CERTIFICATION

(a) (By the Student)

This work has not been presented elsewhere for the award of a degree or any other purpose.


Akinola Olanike

15/08/06
Date

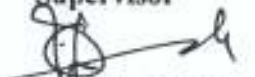
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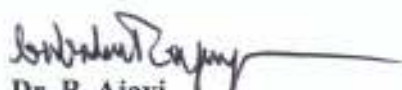


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This programme would have been abandoned but for the interest of my darling husband, Mr Babajide Anthony Aladenola, he said if I drop it he will continue, you are such a wonderful husband. The good Lord will uphold our home, thanks a lot.

DEDICATION

This work is dedicated to the crown of my glory, Mr Babajide Anthony ALADENOLA.



ABSTRACT

Safe water availability is a critical problem in the post – rainy season in Akure, humid Southwest Nigeria. The potential of rainwater as a sustainable option for solving the problem of seasonal water shortage was assessed. Also, the suitability of *Gmelina arborea* sawdust-cement-bonded tank was assessed.

Rainfall data for fourteen years (1980-1993) for Akure , Southwest Nigeria was collected from the International Institute for Tropical Agriculture (IITA), Ibadan and used to determine the number and length of wet and dry days; the critical dry periods and the quantum of harvestable rainwater. The analysis of the fourteen years data (1980-1993) presents an average annual rainfall of 1462.2mm, harvestable rainwater of 92m³ per annum and average wet and dry days of 109 and 256 respectively. The period of scarcity remains November to February as it is in other areas of Southwest Nigeria.

A *Gmelina arborea* sawdust-cement-bonded storage tank of model size 0.006m³ was designed using three different mix ratios of cement: *G. arborea* sawdust (3.0:1.0, 2.5:1.0, 2.0:1.0). The evaluation of these mix ratios gave a tensile strength of 110N/mm², 104N/mm², 95N/mm² and compressive strength of 5000KN, 3000KN and 2000KN respectively. The aging test conducted on the three mix ratios showed that the ratio 3.0:1.0 became stronger as the compressive strength increased to 5500KN confirm that the mix ratio 3.0:1.0 is the best ratio for constructing the tank.

Rainwater was collected and tested to establish its quality. Some of the collected rainwater samples were stored in the three tanks produced from the three mix ratios of cement and sawdust and their quality was monitored every two weeks for two months. The physico-chemical analysis results gives a pH of 6.85, Hardness – 220 Alkalinity determination – 0.7,

Acidity determination - 0.7, Total suspended solid – 350 and dissolved free CO₂ – 0.4 for the rainwater sample before storage. The physico-chemical analysis result of the rainwater after storing for two months did not show significant difference compared to the one before storage and they fall within the acceptable limits of the World Health Organisation standard.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL BACKGROUND

The rural communities in Ondo State just like many other communities in developing countries have very limited access to safe potable water. Their location often makes the provision of pipe borne water costly and difficult. Governmental effort at reducing the problem has been through the sinking of boreholes. However, this effort has not been very successful, because most of these boreholes have failed due to various reasons as observed in Communities in Ondo State. In a few cases where they are functional; it is not adequate to satisfy the water needs of the communities. Thus, these communities therefore depend on streams, which may be polluted, and of doubtful quality. (see Punch, Feb 27, 2006. "Ondo communities groan under water scarcity").

An alternative to the use of streams in providing for their domestic water need is the sinking of shallow wells, which unfortunately varies with the weather cycle, and are limited in supply. This makes the communities to experience hardship for domestic water supply particularly during the dry season when most of shallow wells would have dried up. The situation is worrisome particularly in Ondo State, when viewed against the background that the State is located in humid rainforest zone where there is abundant rainfall spreading over two third of the year with a short break in-between. The excess during the rainy period, if properly annexed can be used to augment supply during the three to four dry months in the

year, in spite of the proportion lost to deep percolation, evaporation and runoff. The process of water loss is shown in figure 1

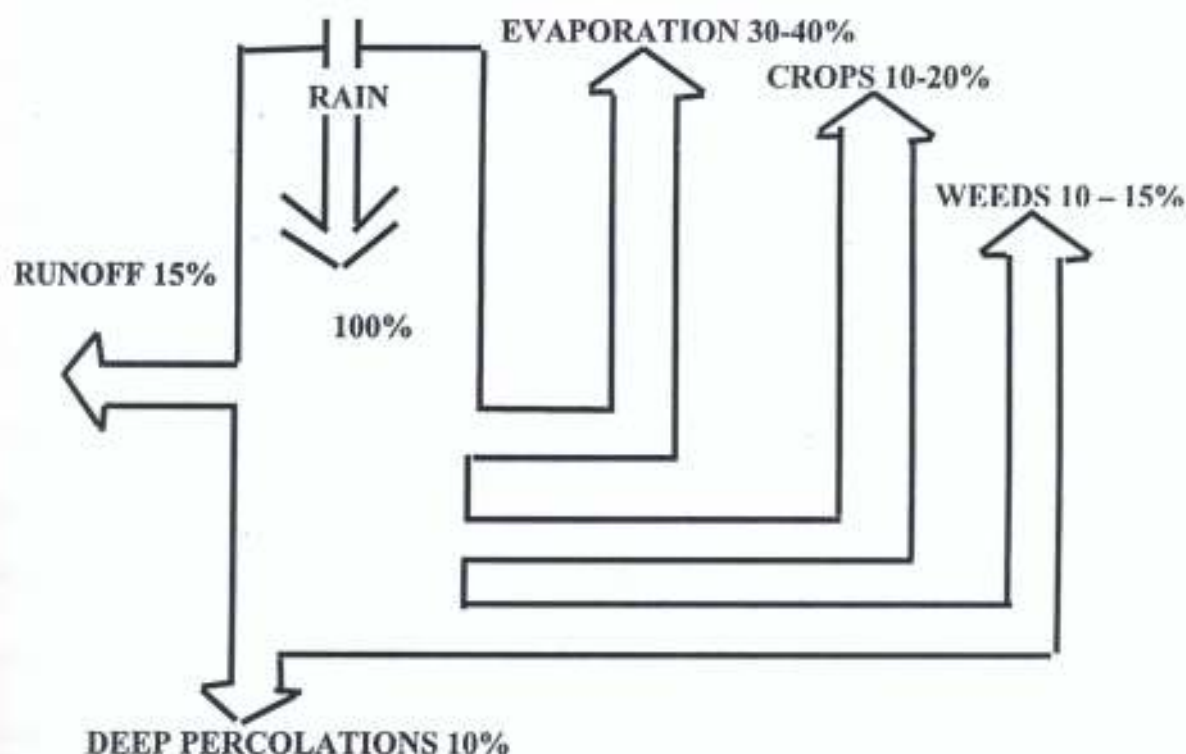


Fig 1: Schematic presentation of wastage of valuable rainwater in rainfed systems

Hatibu et al 2004

It is therefore imperative to apply innovative technologies and also improve on indigenous practice of rainwater harvesting in order to make safe water more available. The benefit of rainwater harvesting is enormous. It can be used to satisfy multiple objectives including reduction of poverty, access to safe water, conserving the environment, prevention of erosion and land degradation and provision of food security.

1.2 BASIS OF WATER HARVESTING

Water is essential to all life - human, animal and vegetation. It is used in many different ways for food production, drinking, domestic uses and industrial use. Water is one of the earth's most precious, indispensable but threatened resources. Water, unlike other resources such as oil, for which coal, wind, hydroelectric or nuclear power can be an alternative, has no substitute (Gorbachev and Peres, 2000).

Globally water is being wasted and abused thereby reducing water supply, whilst the demand for water is rising fast, because of expanding population coupled with industrialisation and urbanisation (Falkenmark 1999; Glieck 1998; Rosegrant 1997). "Green water" (rainwater) of all water resources is probably the most undervalued resource despite the fact that it is responsible for the largest part of the world's food and biomass production. The whole issue of global food security is closely linked to water availability (Falkenmark, 1997)

In Nigeria, water pollution occurs in both rural and urban areas. In rural areas, drinking water from natural sources such as rivers and streams is usually polluted by organic substances from upstream users who use water for agricultural activities. Many factories in Nigeria are located on river banks and use the rivers as open sewers for their effluents. Water quality is also threatened by oil spillages from petroleum exploratory activities and this endangers local sources of water supply and fresh water living resources.

Green water (rainwater) accounts for about 60% of the world staple food production through rainfed agriculture. The concept of green-water was first introduced by

Falkenmark (1995) to distinguish water from rainfall from water that occurs in rivers, lakes and aquifers normally referred to as “**blue water**”. The storage medium for greenwater is unsaturated soil. The process through which greenwater is consumed is transpiration. Hence the total amount of greenwater resources available over a given period of time equals the accumulated amount of transpiration over that period. In this definition, irrigation is not taken into account.

Generally there is a distinction between rainfed agriculture in temperate zones, the wet tropics and the semiarid tropics. Rainfed agriculture in temperate zones has been highly mechanized and production is highly efficient. In the wet tropics and semi arid tropics, rainfed agriculture is mostly done on the subsistence level and can only be made efficient by reducing the risk emanating from the occurrence of dry spells through supplementary irrigation or rainwater harvesting.

In sub-Saharan Africa, about 90% of the food production is rainfed; the relative importance of irrigation is minor except along major rivers such as Nile, Niger, Zambezi Euphrates etc. Despite the cheaper cost of rainfed agriculture compared to irrigated agriculture, much attention is yet to be given to rainfed agriculture which does not require costly and extensive engineering works (Rockstrom 1997; Brooks 2002).

The practice of rainwater harvesting dates backs to centuries (Evenari et al., 1971) and therefore is often referred to as traditional technology (Underhill 1984). It is highly developed in arid and semiarid regions of the world, examples include Negev desert

(Evernari et al, 1971) the desert areas of Arizona and Northwest Mexico (Zaunderer and Hutchinson, 1988) and Southern Tunisia (Pacey and Cullis, 1986). The importance of traditional, small scale systems of rainwater harvesting in sub-Saharan Africa has recently been recognized (Critchley and Reij, 1989). Simple stone lines are used in Burkina Faso and Mali for example, earthbundling systems are used in eastern Sudan, Kenya and the Central rangelands of Somali (Critchley, 1987)

The practice of rainwater harvesting has increased not only because of shortfall in rainfall but also due to critical inter and intra seasonal variability of rainfall (FAO, 1994, Barron et al, 2003), particularly in semi arid and arid areas. In addition valuable rainwater is lost in rainfed systems (see fig 1). Sources of losses include deep percolation beyond the reach of plant roots, evaporation and runoff that is as high as 42% of the annual rainfall in the humid rainforest zone of southwestern Nigeria (Aina, 2000). Runoff rate is related to soil surface characteristics, which limit infiltration.

Therefore for efficient food production and sustainable agriculture in rainfed areas particularly in wet tropics and semiarid tropics, there is the need for effective rainwater management, crop planning and judicious allocation of stored rainwater. Conserved rainwater can be optimally used for supplemental irrigation (SI) to crops especially during the critical growth stages.

This need is further recognized by the New Partnership for Africa Development (NEPAD) that one of the four, fundamental mutually reinforcing pillars on which to base the immediate improvement of Africa's agriculture, food security and trade balance, is

extending the area under sustainable land management and reliable water control systems (NEPAD 2003). This thesis will therefore focus on the design of formal rainwater storage structure (tank) which account for a large fraction of the cost of any rainwater harvesting system so as to make it cheap and affordable.

1.3 STATEMENT OF PROBLEM

The availability of safe water for domestic use is a critical problem in suburban and rural area of Akure in Humid South Nigeria especially in the dry period. This is due to the fact that existing water supply facility cannot meet the increased demand as a result of rising population and unsustainable human activities such as dumping of waste in drainages which result in contamination and pollution of groundwater sources. Also food production in this area as in other Southwestern Nigeria is mainly on a subsistence scale and is predominantly rainfed. The subsistence scale is not sufficient and so cannot satisfy the food requirement of the people. In the dry season there is little or no food production. The implication of these are; food shortage, unavailability of some fresh foods. In addition, prolonged dry spell during rainy season can lead to crop failure.

1.4 SPECIFIC OBJECTIVE

The specific objective of this research project is to design and construct a rainwater storage structure (model) that can store rain water collected from the roof top of farm shed for vegetable production and rooftop of rural household for domestic use during the dry season.

1.5 OBJECTIVES OF THE STUDY

The objectives of this study are to: -

- a. estimate water requirement for domestic and agricultural use;

- b. evaluate the performance of mixes of *Gmelina arborea* sawdust and cement.
- c. design appropriate storage structures using local materials e.g. clav. sawdust.
- d. evaluate the quality of rainwater stored in these structures over time.

1.6 JUSTIFICATION OF STUDY

In the year 2000, 86% of the 1.2 billion people that lacked access to improved water sources were rural dwellers (WHO, 2004). It is also reported that only 61% of people in developing countries have access to adequate water supply while 36% had access to sanitation facilities (WHO, 1998). This is a grim situation for people in developing countries as the quality of life and life itself depends on adequate supply of freshwater (Frederick, 1991).

In Nigeria, about 59% of the households in rural areas depend on streams and 30.4% on private wells (Odin, 2005). In addition, 2% draw their water from boreholes. The streams and private wells particularly stand the danger of contamination especially during the raining season and this exposes a large proportion of the rural population to disease (among other dangers) which quite often reduce their productivity and life expectancy (The Federal Office of Statistics, 1987). In Nigeria, the increased accessibility to potable water contributed to decreasing the incidence of water borne diseases such as cholera, diarrhoea and guinea worm in many rural communities of the Federation (Idika, 2003 and Njoku, 2002).

This study will therefore advance knowledge in the science of rainwater harvesting in Nigeria and will significantly contribute to achieving the objectives of NEEDS and facilitate the attainment of the Millennium Development Goal (MDG) of access to potable water.

CHAPTER TWO



LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

The traditional system of rainwater harvesting dates back to many centuries. Various literatures and archeological evidences reveal this. The practice is popular in many parts of the World.

Rainwater harvesting include;

- Collection of surface runoff from a prepared catchment as practiced in Srilanka and South India.
- Collection of water from trees in Tropical Asia and occasionally practiced in some part of Africa.
- direct collection of falling rain are practice in deserts of India and Pakistan and
- roof water harvesting which is fast becoming popular around the world as an household water source.

Rainwater harvesting is highly developed in arid and semi- arid area (almost 30% of the earth's surface).Runoff irrigation in Negev desert of Israel is known worldwide dating back to 4000 years or even more (Evenari et al. 1971). Floodwater diversion technique were already applied several thousand years ago in Yemen, North west Mexico, Pakistan, Tunisia, Kenya and China (Reij et al 1988). The floodwater diversion technique applied in Yemen was traced back to 1000 BC (Brunner and Haefner 1986, Adato 1987 and Eger 1988). In Egypt; the NorthWest coast and Northern Sinai areas have a long tradition in

water harvesting. It has some wadi terracing structures that have been in use over the century.

In America notably the desert areas of Arizona and NorthWest New Mexico, floodwater farming has being practiced for at least the last 1000 years (Zaunderer and Hutchinson 1988). In India "tank" (khadin) system is traditionally the backbone of agricultural production. In West Rajasthan (India), large bunds called "tanks" (khadin) were constructed as early as the 15th century to accumulate runoff (Kolark et al. 1983). These "khadin" create a reservoir, which can be emptied at the end of the monsoon season to cultivate wheat and chickpeas. A similar system called "Ahar" was developed in state of Bihar, India (UNEP 1983, Pacey and Cullis 1986).

Also from India a research project called "Dying Wisdom" lists many rich traditional experiences in rainwater harvesting from the different fifteen environmental zones of the Country. However to keep pace with the population growth, urbanization and the green revolution, big dams were seen as the ultimate solution to the water situation of a country faced by perennial drought or flood or sometimes both. The constructions of big dams signify an end for the traditional harvesting systems. In Baluchistan (Pakistan), Oosterbaan (1983) described the old water harvesting technique called "Khushkaba" and "Sailaba" already in use. A flood diversion technique called "Warping" which harvest water as well as sediment is found in the loess Plateau of China (Ganzu province).

Water harvesting techniques were practiced in Northern Africa since Roman times. Archeological research review that the wealth of the food house of the Roman empire was largely based on runoff irrigation (Gilbertson, 1985). Traditional water harvesting in Subsaharan Africa notably Burkina faso, Sudan and Somali gained recognition in the early eighties (Critchley and Reij 1989, Bandre and Batta, 2002).

2.2 CONCEPT, DEFINITION AND GOALS OF WATER HARVESTING

2.2.1 Concept

Water harvesting can be referred to as the collection of runoff for productive purposes instead of runoff being left to cause erosion; it is harvested and utilized (Finkel, 1987).

Water harvesting can be considered as a rudimentary form of irrigation. The difference is that with water harvesting the farmer has no control over timing. Runoff can only be harvested when it rains.

2.2.2 Definition

There is no generally accepted definition of water harvesting. According to FAO (1991), water harvesting in its broadest sense is defined as the collection of runoff for its productive use. Productive use include irrigation, provision of domestic and livestock water, concentration of runoff for fodder and tree production and less frequently water supply for fish ponds (Critchely and Siegert, 1991).

Water harvesting is also defined as the process of collecting and concentrating runoff water from a runoff area into a run-on area, where the collected water is either directly applied to the cropping area and stored in the soil profile for immediate use by the crop i.e. runoff

farming or stored in an on-farm water reservoir for future productive uses, i.e. domestic use, livestock watering, aquaculture irrigation. The collected water can also be used for groundwater recharge and storage into the aquifer i.e. recharge enhancement (FAO, 2003). Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral water courses.

2.2.3 Goals of Rainwater Harvesting

The goals of water harvesting according to Oweiz and Prinz, 1994) are:

- i. increasing yields and prolonging cropping season in rain fed farming
- ii. restoring the productivity of land which suffers from inadequate rainfall
- iii. supplying drinking water for animals
- iv. minimizing the risk in drought prone areas
- v. combating desertification by tree cultivation
- vi. fighting soil erosion
- vii. recharging ground water.

2.3 CLASSIFICATIONS

Classification of water harvesting varies among different authors (Reij et al, 1988). The six forms that are generally recognized are

- (a) roof top water harvesting
- (b) water harvesting for animal consumption
- (c) interrow water harvesting
- (d) microcatchments water harvesting
- (e) medium sized catchment water harvesting.
- (f) large sized macrocatchment water harvesting

Therefore the classification of this form depends on;

- i. Source of runoff (external) or within field catchments
- ii. Methods of managing water (maximizing infiltration in soil, storing water in reservoirs and inundating cropland with floods) and
- iii. Use of water (domestic, livestock, crop production, gully rehabilitation etc)

The basic categories of water harvesting systems for plant production according to FAO (1990) are:

- (a) Micro catchments (rainwater harvesting)
- (b) External catchments systems (rainwater harvesting)
- (c) Flood water farming (floodwater harvesting)

2.3.1 Microcatchments (rain water harvesting)

It is sometimes referred to as **“within- field catchments system”**. It is a method of collecting surface run off from a small catchments area and storing it in the root zone of an adjacent infiltration area. It is also sometimes described as soil and water conservation techniques or in-situ water harvesting techniques. Its main characteristics are:

- ❖ overland flow harvested from short catchments length
- ❖ catchment length usually between 1 and 30 meters
- ❖ runoff stored in profile
- ❖ ratio of catchment : cultivated area usually 1:1 to 3:1
- ❖ normally no provision for overflow
- ❖ plant growth is even

Typical examples used in West Africa include terraces, earth or rock bunds, tied ridges, rock dikes, stone lines, planting pits or basins.

2.3.2 External Catchment System (rainwater harvesting).

It is referred to as **“long slope catchment technique”**. Its main characteristics are

- ❖ overland flow or rill flow harvested
- ❖ runoff stored in soil profile
- ❖ catchment usually 30-200 metres in length
- ❖ ratio catchment : cultivated area usually 2:1 to 10:1
- ❖ provision for overflow of excess water
- ❖ uneven plant growth unless land leveled

Typical examples include Trapezoidal bunds (for crops) and contour stone bunds (for crops)

2.3.3 Flood water farming (floodwater harvesting)

It is often referred to as **“water spreading”** and sometimes **“spate irrigation”**. Its main characteristics are

- ❖ turbulent channel flow harvested either (by diversion or by spreading within channel bed/ valley floor)
- ❖ runoff stored in soil profile
- ❖ catchment long (may be several kilometers)
- ❖ ratio catchment : cultivated area above 10:1
- ❖ provision for overflow of excess water

Typical examples include permeable rock dams (for crops) and water spreading bunds (for crops).

2.4 DEVELOPMENTS IN WATER HARVESTING

Developments in water harvesting techniques had increased over the years and once traditional technology began to experience modifications and the improvements due to rising pressure on land and the prevailing drought across the regions of the world.

In India group of villagers began to revive the once dying traditional water systems on realising that this system offers a better and cheaper alternative to big or small dams. The contemporary practices now being adopted by farmers to harvest rain include, check dams, contour trenches, bunds, contour stone walls, jaldhar model, polymer bunds and a host of others (Dying wisdom, 1997).

Frasier (1994) stated that in the United State of America, research emphasis was on runoff catchments and the reduction of seepage losses. Burdass (1975) and Laing (1981) described "roaded" catchments used in Australia as consisting of parallel ridges ("roads") of steep, bare and compacted clay surveyed at gradient that allows runoff to occur without causing erosion of the intervening channels. The surfaces are compacted with tractor and rubber roller and the surface is chemically treated with sodium salts. The roaded catchments are 100m or less long and spaced 15 – 18metres apart. The areas between drainages are shaped much like high-crowned roads to serve as catchments. Side slopes of the catchment roads and longitudinal slopes of the drainage is not more than 2% to prevent

erosion. The catchments are cleared of vegetation, smoothened and are treated to reduce infiltration.

Water harvesting structure called "Bolsas" which are earthen walled basins that "catch" water diverted from seasonal creeks ("arroyos") are used in Mexico (Barrow 1987). Ben Asher (1988) in harvesting study reviewed the micro-catchment technique of water harvesting in Israel. He studied soil surface characteristics especially crust which is used for studying and modeling runoff behaviour and analyzing the economy of the water harvesting technique.

In Jordan, earth dams have been in use since 1964 (Shatanawi, 1994). In 1987 rainwater harvest was established for tree crop research in Syria (Ibrahim, 1994). The International Centre for Agricultural Research in the Dry Areas (ICARDA) carried out a research work on the improvement of various water harvesting technique and harvesting area suitable for various West Asian and Northern African (WANA) environments (Oweis and Prinz 1994). Their findings showed that the appropriate choice of technique depend on the amount of rainfall and its distribution, land topography, soil type and soil depth and local socio-economic factors and that the systems should be site specific.

The water harvesting methods applied strongly depend on local conditions and include such widely differing practices as bunding, pitting, micocatchments water harvesting, floodwater and groundwater harvesting (Prinz, 1996)

2.5 DEVELOPMENTS IN WATER HARVESTING IN AFRICA

The technique of water harvesting also recorded some progress in Africa. A runoff based farming known as "Contourri" is practiced in different parts of Libya (AlGhariani 1994). The three traditional water harvesting techniques common in Tunisia are the "Meskat", "Jessour" and the "Mgoud" (Tobbi 1993). The "meskat", microcatchment system consist of an impluvium Catchment Basin (CB) which is 125m in size and a "manka" or cropping area of about 250m. Thus the ratio of the cropping area to the catchment is 2:1 i.e. Cropping Catchment Ratio (CCR) is 2:1. Both are surrounded by a 20cm high bund, equipped with spillways to let runoff flow into cropped area. The "Jessour" system is a terraced wadi system with earth dry stone walls ("Sirra"). The sediments accumulating behind the dikes are used for cropping. Most "Jessour" have a lateral or central spillway. "Mgouds" in central Tunisia are channel systems used to divert runoff from wadi into fields (Tobbi, 1994). Runoff ponds were also established by Tunisian government to complement the existing water harvesting techniques (Achouri 1994). Many locally well adapted traditional water harvesting techniques was recognized in the anti atlas region of Morocco. (Kutsch, 1982). One of this is the "matfia" which is an old technique for storing water for human and animal consumption (Tayaa 1994).

In SubSaharan Africa various traditional techniques have been reported (Reij et al 1988, Critchley et al 1992 a; 1992b). In Somali the "Caag" and "Gawan" systems were described by Abdi 1986 and Reij et al (1988). The Caag system is a technique used to impound runoff from small roadside drains. Sometimes ditches are dug to direct the runoff. The runoff is directed by the use of earth bunds. The entire plot may be a hectare or more in size. The alignment of the bunds is achieved by eye and by experience. In this system

runoff is impounded to a maximum depth of 30cm. If water stands for more than five days or so, the bund may be deliberately breached to prevent water logging (Reij et al. 1988). The Gawan system is used where the land is almost flat and where there is less runoff. Small bunds are made which divide plots into "grids" of basins. In both of these systems sorghum is the usual crop grown. In Ethiopia, Sudan and Botswana, checkdams are built to reduce overland flow (Barrow 1987).

The water stored in Sudan using water pans "Haffirs" is used for domestic and animal consumption as well as for pasture improvement and paddy cultivation (UNEP 1983). The use of this water pans also cut across North Eastern province of Kenya and parts of Somalia (Critchley, 1987). In eastern part of Sudan, a traditional system of harvesting rainwater in "terraces" is widely practiced (Critchley 1987). It consists of earthen bunds with wing walls, which impound water to depths of at least 50cm on which sorghum is planted. Within the main bunds there may be smaller similar bunds which impound less runoff on which planting can be done earlier. In Northern Ethiopia and Eritrea, storm floods from the hilly terrain are captured and diverted into leveled basins in the arid low lands/cropland. Water spreading (Spate irrigation) is well developed with main diversion canals, secondary / branch, tertiary and farm ditches which distribute floodwater into cultivation basins with contour bunds to enhance uniform water application. A series of main canals for different group of farmers are normally constructed together to reduce destruction by floods (Fentaw et al., 2002). Extensive flood irrigation of paddy rice in cultivation basins (Commonly referred to as "majaluba") created from 25 – 100cm high earth bunds is practiced in semi and central parts of Tanzania (Mwakalia and Hatibu 1992,

Hatibu et al, 2000, Lameck 2002). It is estimated that 32% of Tanzania rice production originate from cropland where Rainwater harvesting is practiced. Similar techniques have been used for maize and sorghum in Tanzania.

Road or foot path run off harvesting is practiced in parts of Kenya (Machakos and Laikipia areas) in which flood water from road/foot path drainage is diverted either into storage for supplemental irrigation or into croplands (wildflooding, contour bunds, deep trenches with checkdams to improve crop yields. Similar systems are practiced in Southwestern Uganda where runoff from gullies, grazing land or road drainage is diverted into banana plantations (Kiggundu, 2002).

The wide variety of water harvesting techniques practiced in the last thirty years in West Africa is aimed at combating the effect of the drought that prevailed in this region especially between 1979 and 1987. This water conservation technique is used for rehabilitation of degraded land in certain areas (Critchley and Reij 1989, FAO 2001). In Countries such as Burkina faso, Mali, Niger, Senegal and Northern parts of Ghana and Nigeria, crop production is limited by insufficient rainfall and or poor temporal and spatial distribution of rain. The rainwater harvesting systems in this region are varied with many modifications. The types include rock/bunds, terraces, stonelines, tied ridges and planting basins.

One of the indigenous techniques that conserve water for food security in Burkina faso and Mali (Wright 1985) is the "Zay system". It consists of basin of about 20-30cm in diameter

and 10–15cm in depth (Bandre and Batta 2002). The holes store rainwater for plant growth. The pits are spaced out leaving 50-100cm between them. Manure and grasses are mixed with some of the soil and put into the zay to increase nutrient status and water holding capacity. The pits fill up when it rains, and the water infiltrates into the soil where it is stored. Zays are often applied in combination with bunds to conserve runoff.

Zougmore et al (2000) through a study in Kirsi village, Burkina faso was able to establish that 31% of rainfall was lost through runoff in plots that was not lined with stone rows. The study showed that under water limiting conditions, the stone row technique was efficient in improving soil water content through runoff control because runoff reduction increased from 12% with 33m space between stone lines to 23% with 25m stone line spacing. Individual micro reservoirs were initiated by Dugue (1986) in Burkina Faso. From his intervention, Dugue (1990) found that the farmer's micro reservoir requires 25man-days for construction. Irrigation water is applied through two PVC tubes placed under the dike and fitted with wide funnels (40cm in diameter) Water is provided manually by two people with buckets, downstream a third person directs the water flow into the earthen canals. It was used for sowing maize in a fish-bone pattern. "Zai" planting technique was reported to have a better water use efficiency than flat planting at three sites in Niamey, Niger (Fatondji , 2002). In a further study, the soil in farmable areas was amended with manures. It was observed that the quality of amendment (manures) combined with the Zai technique played a significant role in increasing the yield. This modification is called "Tassa".

Halfmoon is a crescent shape micro-catchments spaced 4m diameter and 40cm depth used in Tahoua (Niger) with annual rainfall of 400mm. Millet, sorghum, beans and local herbs were planted. The increased interest of the local people in this technique resulted in the creation of over 15000 similar micro catchments (Bruins et al, 1986). In 1988, special ploughs developed by Italian scientists were used in Niger for the implementation of (vallerani type) micro catchments on a large scale. Results from these plots showed excellent rates of tree establishment (Antinouri and Vallerani, 1994). The construction of earthdyke around the cropfield in Mali conserved moisture and increased the yield of sorghum (klemm 1990, Critchley et al 1992b).

In the upper west region of Ghana, bunds have been developed into a terrace system on the slopes to trap water for crops during the rainy season. Millet is the crop of choice under this system. Also in the same region in Ghana, stones are removed to create pits for collecting water in areas with high clay content in the subsoil (kranjac- Berisavljevic et al., 2002).

2.6 RAINWATER HARVESTING EXPERIENCE IN NIGERIA

In Nigeria, other than traditional methods of rainwater harvesting (RWH) for domestic use across the country, there is little or no evidence of rainwater harvesting for agricultural use in southwestern Nigeria. However in Northern part there are large river flood irrigation schemes during the dry season basically for cultivation of vegetables.

There are few documented examples of indigenous RWH techniques in Nigeria. Reij et al, (1996), in the compilation of indigenous soil and water conservation practices across Africa presented 28 case studies, which included only 3 from Nigeria and one of these was actually the study of fadama irrigation (Phillips Howard, 1996). This situation is in contrast

with extensive literature on RWH techniques elsewhere in West Africa (Niger, Burkina faso, Mali).

However, Kolawole and Adewumi (2001) presented a study of RWH practices in Borno, Kano and Katsina States. They concluded that RWH is a profitable agricultural technique in the semi-arid area of Nigeria especially in vegetable production. They noted that the techniques have been largely neglected by development agencies and are still largely indigenous with little or no attempt having been made to improve their technical efficiency. The most recent research on RWH is the one carried out in four agricultural communities; Erin Ijesa and Erin Oke in Oriade Local Government and Obamoro and Mafikuyomi in OlaOluwa Local Government areas of Osun State. The economic evaluation of adoption of RWH for crop production in this area is shown to be profitable in the long run as farmers will be able to pay for investment and operational cost and yet attain profit (Gowin J, 2006). The RWH reviewed above is for agricultural production and there is no documentation on formal rainwater harvest for domestic uses.

2.7 ROOF WATER HARVESTING (RWH)

Roof water or rainwater harvesting is an option, which has been adopted in many areas of the world where convectional water supply systems have failed to meet the needs of the people. The rural communities of Ondo State and other states in Nigeria fall into this category. Their water needs have not been met; therefore they can equally adopt formal RWH. It is a technique, which has been used since antiquity. Examples of Rainwater Harvesting (RWH) system can be found in the entire great civilisation throughout history. The technology can be as simple or as complex as required. In Nigeria, the practice is as

simple as placing a small container under the eaves of the roof to collect falling water during a storm. However, this informal Rainwater collection can only last for a few days. Therefore there is the need for formal rainwater harvesting although Domestic Rainwater Harvesting (RWH) is just an option and not a definite answer to household water problems. The report of the work carried out in the University of Warwick (Report A1, part1) showed that there is a complex set of inter-related circumstances which have to be considered when choosing the appropriate water source. Cost, climate, technology, hydrology, social and political elements, all play a role in the eventual choice of water supply scheme which is adopted for a given situation. RWH is only one possible choice, but one which is often overlooked by planners, engineers and builders. The reason that RWH is rarely considered is often due to lack of information - both technical and otherwise. It is a technology which is flexible and adoptable to a very wide variety of conditions, being used in the richest and the poorest societies on our planet, and in the wettest and driest regions of the world. It can be used to supplement and complement the capital intensive and technically complex traditional water supply systems, which are widely promoted, by governments and agencies throughout the world.

2.7.1 Styles of Roof Water Harvesting

Rainwater Harvesting is done in many different ways and a number of variables determine these patterns. These include:

- ❖ Rainfall quantity (mm/year)
- ❖ Rainfall pattern
- ❖ Collection surface area (m^2)
- ❖ Storage capacity (m^3)
- ❖ Daily consumption rate (litres /capita/day or lpcd)
- ❖ Number of users

- ❖ Cost
- ❖ Alternative water sources
- ❖ Water Management strategy

Source: Report A1(part1), Eng. Warwick

2.8 DOMESTIC ROOF WATER HARVESTING SYSTEM (DRWH)

The typical DRWH system that is used in a typical developing country usually comprise a collection surface, roof tank and guttering to transport the water from the roof to the storage tank. Other peripheral equipment sometimes incorporated is first flush systems (to divert the dirty water which contains roof debris after prolonged dry periods), filtration equipment and settling chambers to remove debris and contaminants before water enters the storage tank or Cistern . The water tank usually represents the biggest capital investment element of DRWH system. It therefore usually requires the most careful design - to provide optimal storage capacity while keeping the cost as low as possible. There are many options for storing water. In developing countries, common vessels used for storing water on a small scale include - plastic bowls and buckets, jerry cans, clay or ceramic jars, cement jars, old oil drums, empty food container etc. for storing larger quantities of water, the system will usually require a tank or a Cistern and the design of such tanks is the focus of this thesis.

Fig.2.1 and 2.2 shows typical domestic roof water harvesting system main components and the application of domestic roof water harvesting system for small scale vegetable garden respectively.

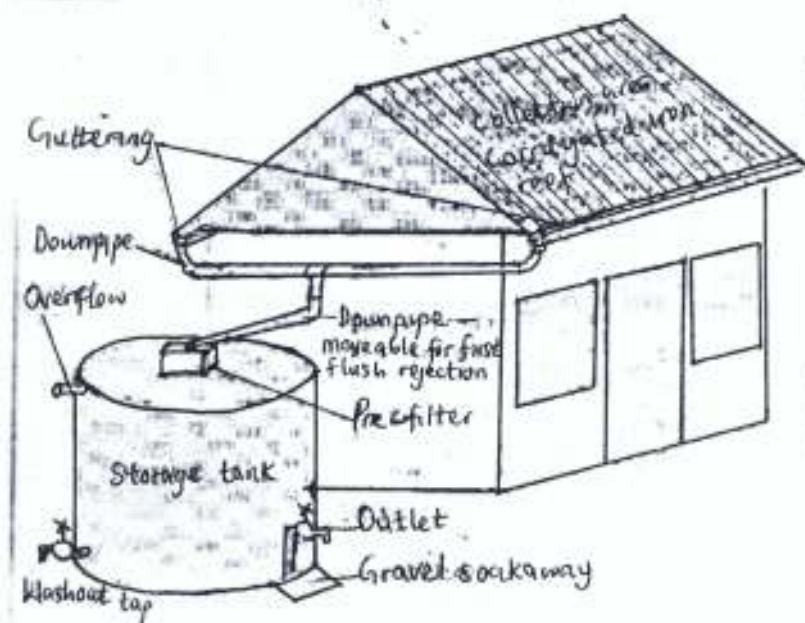


Figure 2.1: Typical Domestic Roofwater Harvesting System showing the main component of the system

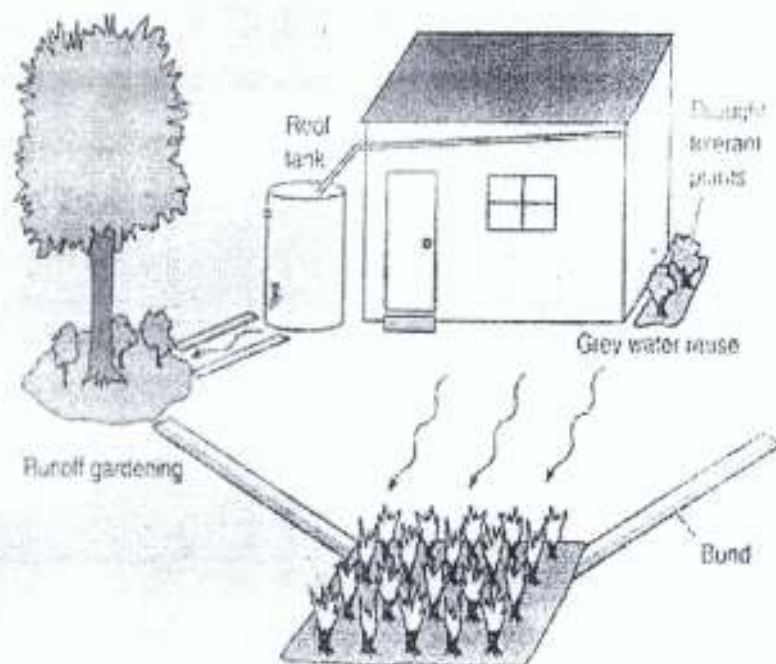


Figure 2.2: Domestic roof water harvesting system for a vegetable garden.

2.9 DESIGN CONSIDERATION FOR RWH STORAGE TANKS

Design is the process of preparing specifications on type, make and proper measurement in constructing structures. The design is very important in order that construction of these infrastructures to be strong, accurate and durable. Ideally, the RWH collection system should involve basic construction techniques, be inexpensive to maintain and have a long functional span if well designed (Pacey 1996). The design of rainwater storage tank is not merely an abstract engineering problem; it is related to the type of assistance, the sort of materials and other resources that are locally available.

The two important decisions that a designer will be faced with are: what storage method and size should be used, how problems associated with storage tank should be avoided. The intended use of the harvested water will determine the type and size of storage structure. Another determinant of the need for storage is the frequency of rainfall. The factors that are considered for designing cheap and affordable tank are:

- ❖ Water demand,
- ❖ quantum of rainwater that can be harvested,
- ❖ appropriate sizing,
- ❖ optimal shape and
- ❖ materials.

2.9.1 Water Demand

Water demand is the expected daily rate of water use in the community for domestic, agricultural, and other uses as the case may be. The determination of the per capita daily

demands involves estimating the population to be served and their per capita consumption together with an analysis of the factors that may operate to affect consumption (Steel & McGhee, 1979).

Fresh water needs to be harnessed and supplied to meet variety of consumptive use water demands of the human population. This work is concerned with the four basic needs for drinking, cooking sanitation and bathing and in addition small scale vegetable garden. Gleik (1996) reported that varied amount of water ranging between 27 and 200 litres per capita per day (lpcd) have been proposed as minimum standards for domestic use. Falkenmark and Windstrand (1992) recommend a figure of 100lpcd as the amount needed for a minimally acceptable standard of living in developing countries. The world Health Organization (WHO) has stipulated a per capita demand of 120lpcd for rural areas. In Nigeria this requirement is far from being met and in urban areas, it has been shown to be lesser than WHO's rural area stipulation. The water demand of the study area is limited to 25lpcd based on findings from the questionnaire administered to the rural communities.

2.9.2 Quantum of Rainwater Harvested

The task of quantifying the amount of rainwater that can be harvested from the rooftop is a simple straight forward exercise (Gould, 1991). It has been shown that the quantum of rainwater that can be actually harvested and supplied with a rooftop rainwater harvesting system is limited more by the size of the storage tank that is practically feasible than by the rainfall that is actually available.

2.9.3 Appropriate Sizing

In many Rainwater Harvesting designs, the size of tank is limited by the cost of materials and construction of the tank rather than available rainfall. Therefore medium tank size is recommended for the following reasons;

- ❖ ease of recycling
- ❖ ease of replication
- ❖ ease of cleaning
- ❖ ease of maintenance

In cases where water demand is high, more than one tank of medium sizes is recommended. In southwest Nigeria, Rainwater Harvesting for supplemental use can be met with a medium tank size as rainwater can be collected during the two wet season, as we have bimodal rainfall pattern.

The main calculation when designing a Rainwater Harvesting system will be to size the water tank correctly to give adequate storage capacity. Storage requirement will be determined by a number of interrelated factors. They include:

- ❖ Local rainfall data and weather patterns
- ❖ Roof (or other) collection area
- ❖ Runoff coefficient (this varies between 0.5 and 0.9 depending on roof material and slope).
- ❖ User numbers and consumption rates

Basically, the volume of the tank should be sufficient to store water for the whole dry season.

2.9.4 Sizing of System Components

The available methods that can be used for sizing storage tank are: demand size approach, supply size approach and computer model. Information collected from the rainfall data and administered questionnaires were used to calculate the size.

Demand size approach was used to calculate the largest storage requirement based on the consumption rates and number of persons. It is a method for acquiring rough estimates of tank.

The **supply size approach** is a typical field approach to rainwater harvest

Computer Model is another method of sizing water storage tank. There are several computer based programme for calculating tank size accurately.

Two of them will be described below;

Sim Tanka

The Sim Tanka computer model was developed by an Indian Organisation (Ajit foundation).

This requires at least 15 years of monthly rainfall records for the place at which the rainwater harvesting system is located. It is appropriate for drought prone areas. It takes into account the fluctuations in the rainfall, giving each fluctuation its right importance for determining the size of the rainwater harvesting system. The result of the simulation allows the design of a rainwater system that will meet demands reliably that is it allows one to find the minimum catchments area and the smallest possible storage tank that will meet demand with probability of up to 95% in spite of the fluctuations in the rainfall (University of Warwick, report A1, Part 1).

The "Rainwater Tank Performance Calculator"¹¹

The programme requires 10 years of monthly data (i.e. for 120 values). It calculates the approximate system reliability and efficiency for a selection of tank sizes including one that can be defined using monthly rainfall data and roof area. One can also define how the rainwater will be used by giving a nominal daily demand and choosing between their water management strategies.

To start the calculation one will fill an estimated tank size and the programme will give the values for other tank sizes as well. The parameters could be varied to suit a particular condition.

2.9.5 Optimal Tank Shape

The shape of a tank affects both the volume - to - surface ratio and the distribution of forces. It also has effect upon the material requirement. Straight sides are much easier to manufacture than curved sides but straight sides require larger materials than curved sides. There are different tank shapes and they include square or box type, water jar shape. The shapes of other jars are spherical, oval, cylindrical etc. Examples of some tank shapes are shown below.



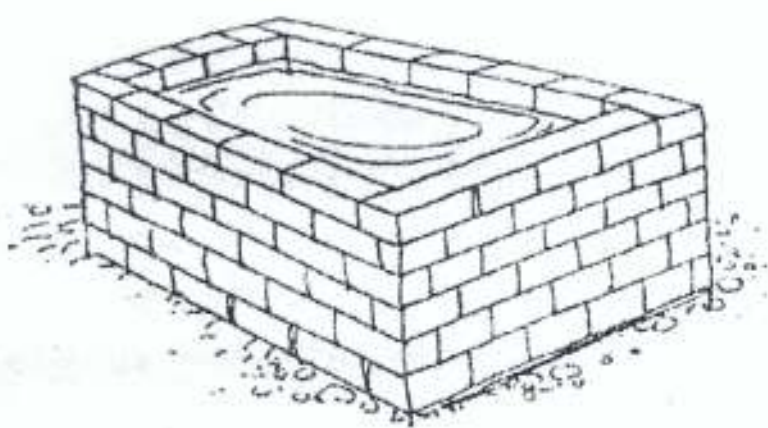


Figure 2.3: Square or Box Shaped

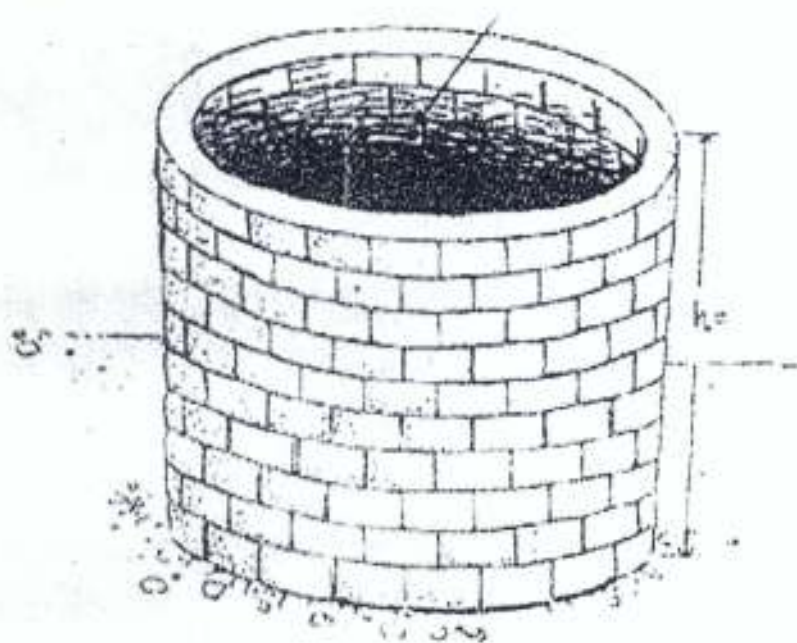


Figure 2.4: Cylindrical

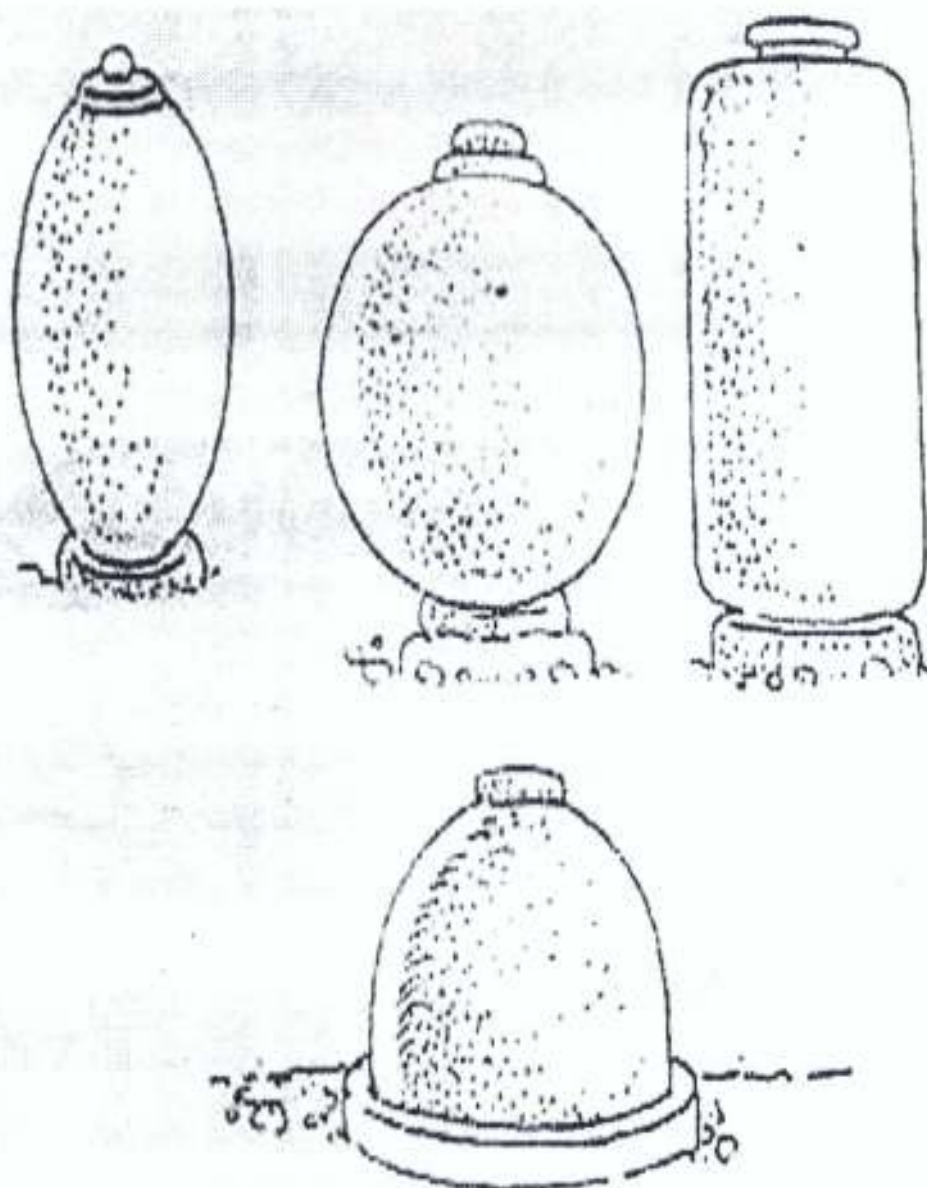


Figure 2.5: Different shapes of RW Storage Tanks

The relative merits of cuboid, the cylindrical and doubly curved tank are shown in the Table 2.1

Table 2.1: Relative Merits of Some Tank Shapes

Tank shape Or type	Stresses	Material usage	Construction
Cuboid	Stresses are merely distributed around the structure bending stresses are especially high near the edges	The ratio between material usage and storage capacity is higher than for a cylindrical or doubly curved tank	Construction is quite simple using most materials
Cylindrical	Stresses are more evenly distributed with bending stresses only near the bottom	There is an improvement in the material use to storage capacity ratio (a saving of 7.5% over a similarly proportioned cuboid)	Construction becomes more difficult with some materials e.g bricks, but the shape is well suited to construction with materials that can be bent e.g ferro cement and GI sheeting or built in sections
Doubly curved tanks e.g Thai jar	Stresses are well distributed. The base of the tank is of smaller diameter reducing both hoop stresses and bending stresses there	Material usage to capacity ratio is very good (saving of up to 20% over a cuboid)	Construction can be difficult, often relying on specialized moulds. Materials must be pliable and able to curve in two directions e.g ferrocement and clay.

Source: Recommendations for Designing Rainwater Harvesting System Tanks O-DEV contract No ERBICI8CT9B027, Milestone A6 : Report A4 January 2001

2.9.6 Materials

The cost of materials used for storage tanks can be reduced by:

- ❖ using cheaper, local and available materials e.g clay ,sawdust etc
- ❖ removing material where it is not needed
- ❖ reducing overall material use by reducing safety factors if they are unnecessarily high
- ❖ making use of some existing structure (e.g the wall of a house or the ground itself)
- ❖ building the tank underground

Reasonable materials savings can be made from underground tank because if the soil is suitable it can take the weight of the water and the walls can be made considerably thinner as they will simply be used as a water proof layer stopping the water seeping into the soil. The hemispherical geometry can also be very efficient as the ground will act as a form for construction on and the tank do not need to stand up on its base like an above ground tank. The soil dug from the hole could also be used for the construction if suitable.

Surface tanks for roof water storage are commonly made of brick, ferrocement, concrete blocks, plastics and galvanized iron (Milestone A6: Report A4, DTU Warwick 2001).

Bricks, Stabilized Soil and Rammed Earth

Burned bricks are often made locally and are available much more cheaply than materials that have to be imported into an area such as plastics or cement. Tanks made from bricks can be cheaper than those of “imported” materials and will also keep more of the money spent on the tank.

Another “earth technology” is to use a small amount of cement to hold together (stabilise) an otherwise soil based block. This technique can dramatically reduce the quantity of cement needed to make a tank of equivalent strength. The wet strength of stabilized soil is

considerably lower than cement so the designer must either balance the cement content to ensure the wet strength is sufficient or employ some water proof barrier to prevent water soaking into the blocks.

Ramming earth between two walls ("shutters") compacting it, give the wall a stiffness that simple soil building does not have. The technique uses only local materials. It does not require specialized labour but require some specialized tooling such as the shutters and a tamper to ram the earth into place but these can be made locally and used to make several tanks spreading their costs.

Wattle and Daub

A traditional technique for house building in many parts of the world, wattle and daub used mud to fill in a structure made from collected round wood. The technique is well known and practiced at a village level and requires no specialised tooling or knowledge to implement. All materials are available locally and usually need only be collected, thus the only capital requirement is labour making it extremely suitable for "self help" projects. The technique results in a structure that is not waterproof and so a method of holding the water must be employed one excellent example of this is the Rwandan "tarpaulin tank" which utilise an UNHCR tarpaulin in an excavation to hold the water with a wattle and daub enclosure.

Plastics Sheetting

Plastic sheeting is becoming available in many parts of the world and can be used for lining otherwise permeable tanks to render them waterproof. At a basic level, this could be simple polythene sheet but this tends to have a short life span.

2.10 REVIEW OF EXISTING TANK DESIGNS

Rainwater Harvest Research Group (RHRG) investigated tank designs and presented it as case studies (Milestone A6: Report A4, DTU Warwick 2001).

The case studies described includes

- ❖ The Pumpkin Tank, Srilanka was developed by community water supply and sanitation programme between 1995 and 1998 with a catchments of 32m^2 , storage capacity of $5\text{-}7\text{m}^3$ and a storage cost of £112). The typical characteristic of this tank is that it has doubly curved structures, there is economy of materials, requires specialized techniques and the tanks required the use of mould.
- ❖ Underground brick dome tank, Srilanka is another RWH system which was developed by the CWSS programme in Srilanka. The tank is an underground brick built tank with a storage capacity of 5m^3 , a catchment area of 28m^2 . It has a brick dome roof, require less skill for construction and a low cost pump is installed for extraction.
- ❖ Brick built storage tank, Srilanka is an example of local initiative in design and manufacture in DRWH. The tank was constructed in the village of Ahaspokuna, near Kandy, in the highlands area of Srilanka. The tank has a storage capacity of 3m^3 , a catchment area of 90m^2 and it is made from brick with cement render at a cost of £80.

- ❖ Partially below ground brick built tank, Srilanka was built by Mr. G. Victor. A Goonetilleke in the hill town of Kandy after experiencing difficulty in sinking a well to sufficient depth to have a reliable perennial source of groundwater at the site of his newly built home. The tank has a storage capacity of 10m^3 and is built using brick with cement render at a cost of £550.
- ❖ Underground Storage Cistern tank was also developed for use in Uganda by members of the Development Technology unit, Warwick University and members of the Uganda Rural Development and Training Programme (URDT), between 1995 and 1997. The material used for the construction of the tank is cement mortar at a cost of £90 for 8m^3 ; the size ranges from 4 - 10m^3 with a varying catchments. It was observed that with underground tanks; very thin walls are possible in appropriate soil. The unreinforced mortar dome roof lowers the cost due to no steel and the ground as a formwork reduced the cost of amortisation of formwork.
- ❖ Ferrocement water tank has been used for many years in parts of Africa. The tank has a storage capacity of 10m^3 with varying catchments. The storage cost of 8m^3 is £90. It has a reusable formwork with built – in depth gauge (corrugations), wire reinforcement graded through structure (more on bottom) and has reinforcing from base to walls and filleted base join to avoid cracking at base.
- ❖ RWH in the barrios of Tegucigalpa, Honduras is carried out by using recycled or scavenged materials. 0.2m^3 used barrels (up to 3) or 1.2m^3 of open concrete tanks are used. The storage cost is £10 for drum and £18 for small tank. The lessons learned was that available containers can be used to store water though at a small

scale to improve well being and reduce a number of water related diseases which residents in the area suffers.

- ❖ Thai Jar is a type of water vessel originally developed for a large countrywide programme in Thailand that has installed over 10 million jars. It became successful business by companies in Thailand with companies producing up to 30 jars per day. The design has also been adopted in East Africa and South Asia. The vessel is made with pottery or cement at a storage cost of £30 for a 2m^3 jar. The size ranges between $0.5\text{-}2\text{m}^3$. The lesson learned from this initiative is that small tanks are used modularly with several houses having more than one and up to ten, which are used commercially. The mass production of the tank lead to much cheaper tank and the programme grew exponentially and became self-sustaining within a few years.
- ❖ Plastic lined tanks are made using plastic sheets as a waterproof membrane in an otherwise wholly traditional structure. Examples are bamboo tank developed by ARTI in Pune India, which uses a polythene sheet in a basket structure that is traditionally used for grain storage. Also in East Africa, Rwandan refugees have used a tarpaulin distributed by UNHCR as liner for an underground tank over which a wattle and daub enclosure is built to protect the water. The lesson learnt from this type of initiative is that small, portable imported input bolstering principally local technique greatly reduced cost however it raises questions of durability.

2.11 WOOD

The quality and stability of wood and cement end product depend on the wood physical and chemical characteristics as well as its behaviour under compression.

The wood materials can be obtained in two main ways:

- (i) Round logs, thinning, branches
- (ii) Industrial wood – residues as slabs, peeler cores, veneer trimmings, off cuts and edgers (Chittenden et al, 1975; Bison-werke, 1981, Elten Engineering & Co. 1981; Badejo, 1983)

Wood properties vary considerably both within and between species. The choice of wood species depends on chemical and physical characteristics. Chemical characteristics are important because chemicals in hardwood slow down the setting of cement or completely prevent it from setting. The chemical has the tendency to hinder wood cement relationship. The low level of wood – cement compatibility is due to natural incompatibility existing between wood, which is an organic substance and cement, an inorganic binder (Vilela and Pasquier, 1968). Researchers have observed that the hardening characteristics of cement mixed with wood, varies considerably among the 27 wood species studied.

The problem of covalent formation of sound adhesive bonds of wood/cement combination in the wood – cement bonded board manufacture is due to the presence of chemical deposits in wood. These wood constituents interfere with the hardening process of cement and the number of wood species suited for processing is limited. The chemical deposits, which hinder cement setting, include sugars, hemi-cellulose content of sapwood and the extractives components of the heartwood mainly phenolic compounds (Sandermann et al, 1960; Sandermann and Kohler, 1964; Simatupang, 1988).

Many researches have detailed the influence of species on properties of wood-cement bonded board (Simatupang, 1983; Lange and Simatupang, 1985). A large number of wood

species, especially hardwoods, contain large amounts of sugars and tannin that decisively retard the setting of cement (Lahtinen, 1991). This means that special attention must be paid to the choice of suitable wood specie when cement particleboard is manufactured with the conventional methods.

Softwood is known to be better than hardwood because hardwood in particular contains plenty of chemicals, which slow down the setting of the cement or even completely prevent it from setting. The chemical has the tendency to hinder wood cement relationship. The low level of wood-cement incompatibility is due to natural incompatibility existing between wood, which is an organic substance and cement, an inorganic binder (Vilela and pasquier, 1986). Researches have observed that the hardening characteristics of cement mixed with wood, varies considerably among the 27 wood specie studies, studied. Lee (1991) confirmed that traditionally, hardwoods are not suitable and less preferred for CEB or cement bonded particleboard due to their greater inhibiting effect on cement curing. Boards made from such wood usually crumble into bits immediately following removal from the press. Only wood that has been tested and found suitable is used. Lee (1991) pointed out that the initial storage of the wood causes a reduction in moisture content as well as sugar content which may likely retard or prevent the curing of the cement. TRADA (1985), Simatupang, (1988), Simatupang and Geimer, (1990) indicated that logs are stored for about two to three months to neutralize extractive in the wood that may retard cement curing.

Weatherwax and Tarkow (1964, 1967) summarized the major drawback in the development of wood-cement boards' technology as the difficulties encountered in the hardening of cement mixed with wood particle. The degree of difficulty is noted to vary

from species with some completely blocking cement hydration. Owing to the variation in chemical composition between individual trees, a great variation was to be expected in the suitability of woods – cement boards.

2.11.1 Chemicals in Wood

The problem of covalent formation of sound adhesive bonds of wood/cement combination in the wood-cement bonded board manufacture is due to the presence of chemical deposits in wood. These wood constituents interfere with the hardening process of cement and the number of wood species suited for processing is limited. The limitation is caused by setting effect on the furnish regardless of time allowed for setting to occur. This also determines the success or failure of the final products. Simatupang, et al. (1978) supported this claim and reported that the hydration of Portland cement is retarded by about 0.5% of wood starch or 0.25% of free monosaccharides or oligosaccharides or phenolic compound (based on the weight of cement) making de-molding within a reasonable length of time impracticable.

In general, softwoods are more suitable than hardwood because of the high deposit of chemical substances, which hinder cement setting. These chemical deposits include sugar, hemi-cellulose content of sapwood and the extractives component of the heartwood mainly the phenolic compounds (Sandermann, et. al, 1960; Sandermann and Kohler, 1964; Simatupang, 1988). Weatherwax and Tarkow, (1964) stated that the extractive components responsible for the failure in setting of cement bonded excelsior board are hemi-cellulose starches, sugars, phenols, hydroxylate carboxylic acids. Kossatz, et. al, (1994) in their submission stated that the monomeric and dimeric carbohydrates as well as phenolic constituents are so-called “cement poisons”. Interferences of the hydration of portland

cement and, as a consequences, its hardening process are attributable to the fact that calcium hydroxide in contact with water constitutes water-insoluble calcium salts under action of carbohydrates and phenolic compounds contained in wood.

These salts settle at the surface of cement grains forming a barrier and thus interfere with the progress of hydration. Simatupang, et. al, (1991) observed that the glucose and hydrolysable tannin compounds, when present at the concentration of 0.25 percent, severely retard the setting of Portland cement pastes. They further discovered that these inhibitory substances include tannins, hemicellulose, simple sugar and phenolic compounds.

However, organic acids, such as acetic and tannin, and other extractives may not only inhibit setting of cement but may also slowly attack and destroy the cement bond resulting in a reduction in board strength (Fraser, 1977). The lower compatibility was attributed in part to the inhibiting effect of hydrolysable hemicellulose and some extractive present in hardwood (Miller, et. al, 1989). Other researchers have investigated which of the components of wood are responsible to cement setting inhibition (Sandermann and Kohler, 1964; Badejo and Simatupang 1985; Badejo 1985).

The general chemical identified to be influencing cement setting includes the carbohydrates, the phenols, the hemicelluloses and the extractives. Sandermann and Brendel (1956) classified carbohydrates into three groups as they affect wood-cement mixtures. Vis-à-vis: water-soluble sugars; water-soluble higher carbohydrates; and water-soluble constituents formed from water insoluble carbohydrates due to action of the alkaline cement. The carbohydrate group is made up of xylose, fructose, glucose, sucrose

and saccharose. Starch cellobiose were found to be inhibitory to cement setting (Sandermann and Kohler 1963; Sandermann, 1966). Generally, the sugars in wood appear to significantly inhibit cement setting (Biblis and Lo, 1968). However, it is not all of these carbohydrates that hinder cement setting. For instance, Sandermann and Brendel (1956) pointed out that sugar additions of about 0.125% increased the strength of cement appreciably while an addition of 0.25% of most sugars causes complete setting inhibition. This shows that the degree of inhibition of wood chemical substances on cement setting depends on the types and concentration of its constituents (Sandermann and Brendel, 1956; Sandermann and Kohler, 1963; Biblis and Lo, 1968). Small concentrations of certain chemical may retard cement setting, while others may not do so even at higher concentrations. Glucose hydrolyzable tannin and pinosylvin are phenolic compounds and when present at certain concentration are reported to severely retard cement setting (Sanderman and Kohler, 1963; Simatupang and Geimer 1990; Simatupang, et. al, 1991).

Organic acids such as acetic, tannin, fatty and glucuronic amino do not favour cement setting (Weather waxand Tarkow, 1964; Fraser, 1977; Blankenhorn, et. al, 1991; Simatupang, et. al, 1991).Hydrolysable hemicellulose that gives out sugars particularly in hardwoods were found to inhibit cement setting (Weatherwax and Tarkow, 1964. 1967; Moslemi, 1989). Portland Cement is found to be more sensitive to wood extractive than either gypsum or magnesia cement that is, in most cases, the hydration times is the longest. Simatupang and Geimer (1990) have confirmed that wood extractives retard the hydration of the inorganic binders and alter the crystalline structures. Normal calcium sulphate

dehydrates or gypsum crystals are relatively long and have hexagonal form. Under the influence of wood extractives, the form and dimension of the crystal are altered.

In another study, Simatupang, et. al, (1991) confirming their previous work indicated that wood extractives that retard gypsum hydration caused an alteration of the gypsum crystals especially in the interfacial layer between wood and gypsum. The conclusion therefore was that wood species with wood extract that caused retardation of the gypsum hardening would result in weaker boards. Cement setting inhibition by wood extractives is caused by a protective membrane wrapping the particle of cement (Sandermann and Kohler 1963).

2.11.2 *Gmelina arborea*

Sawdust from *Gmelina arborea*, a hardwood species is used for this study. Planting of *Gmelina arborea* significantly increased in Nigeria when it was intended to use it as a raw material for Iwopin Paper Mill (FORMECU/FDF, 1991). *Gmelina arborea* could not be used in construction and furniture works because of its weak composition and nature (Ajayi 2000). There is therefore the need to find alternative use for it because of its relative abundance in comparison to other species from the natural forest, finding a use for *Gmelina arborea* particularly in water storage structure would be helpful to encourage its growth. The sample used for this study was collected from the Ondo State Afforestation Project at Epemakinde in Oluwa forest reserve, Ondo State. The choice of *Gmelina* for this study is influenced by previous research results which showed that it formed better flakeboard and also has flake retaining ability compared to other wood species such as *Leucaena leucophala* (Ajayi 2000).

2.11.3 Preparation of wood raw materials

Gmelina arborea sawdust is obtained from the wood processing plant at Epemakinde. The material is pretreated to improve the binding compatibility of the wood – cement mix. This process is carried out by preheating the sample in hot water at 80°C. To preheat, the *Gmelina* sawdust is soaked in hot water and stirred continuously for 10 minutes and thereafter allowed to further remain in the hot water for another 30 minutes. The temperature of the water is maintained at 80°C by continuously adding boiled water. After the expiration of 40-minutes soaking in hot water, the water containing chemical substances from the sawdust were drained. The sample was further treated with hot water also at 80°C for 10 minutes and later drained. Treatment of wood with hot water brings down the hydration time. The sample was air dried for two weeks until it attained moisture content of about 12%. The air-dried sawdust will then be stored in polythene bags and ready for use. The wood raw materials was prepared using the method by Badejo, 1984 and Ajayi, 2000.

Chemical treatments have been widely used to improve the bonding of wood and cement to improve the strength of the wood – cement - bonded material. The setting time of cement - bonded materials is reduced by the addition of additives. The admixture also known as mineralizing agents can be any of the following: Aluminium sulphate in combination with Calcium hydroxide (lime water) or water glass solution $\{(Al_2SO_4)_3$ and $Ca(OH)_2\}$, Calcium hydroxide $Ca(OH)_2$, Calcium chloride ($CaCl_2$), Magnesium Chloride $MgCl_2$, Aluminium Chloride (Al_2Cl_3) (Simatupang et al 1991). In this study, ($CaCl_2$) is used as an additive because of its availability.

2.12 WATER QUALITY REQUIREMENT

The problems in the world with regard to water supply are that there is either too little of it available or if there is sufficient, it is polluted Schalekemp (1982). A water supply that is adequate is the one that provides safe water in quantities sufficient for drinking, domestic and other household purposes. A sufficient quantity should be available on a reliable, year round basis near to or within the household where the water is to be used. Clean water only exists briefly in nature and is immediately polluted by prevailing environmental factors and human activities. Rain water harvested from rooftop is generally of good quality, however, the rain may contain dissolved contaminants such as carbondioxide and particulate matter and when it falls on the roof it may be contaminated with materials used in the construction of the roof, and bird droppings (Milne, 1979). The World Health Organisation has given the minimum standards for potable water supply see (Table 2.2).

Table 2.2: World Health Organisation minimum standards for drinking water

SUBSTANCE	MAX ACCEPTANCE	MAX ALLOWANCE
Total Solids	500mg/l	1500 mg/l
Colour	6 Units	50units
Turbidity	<1' unit	25Units
Taste	Unobjectionable	-
Odour	Unobjectionable	-
Iron (Fe)	0.3 mg/l	1.0 mg/l
Manganese (Mn)	0.1 mg/l	0.5 mg/l
Copper (Cu)	1.0 mg/l	1.5 mg/l
Zinc (Zn)	5.0 mg/l	15 mg/l
Calcium (Ca)	75 mg/l	200 mg/l
Magnesium (Mg)	50 mg/l	150 mg/l
Sulphate (SO ₄)	200 mg/l	400 mg/l
Chloride (Cl)	200 mg/l	250 mg/l
PH Range	7.0	6.5 to 9.2
Magnesium + Sodium Sulphate	500 mg/l	1000 mg/l
Phenolic Substance (as Pheno)	0.01 mg/l	0.02 mg/l
Nitrates	45 mg/l	-
Carbon Chloroform Extract CCE	0.2 mg/l	0.5 mg/l
Organic (Pollutants)		
Alkyl Benzyl Suphonets ABS	0.5 mg/l	1.0 mg/l
Fluorides	1.0 mg/l	1.5 mg/l

Source: As reported by Obatayo

CHAPTER THREE



3.0 RESEARCH METHODOLOGY

3.1 RAINFALL INFORMATION

Weather data for fourteen years (14) years (1980-1993) for Akure in Southwestern Nigeria were collected from the International Institute for Tropical Agriculture(IITA), Ibadan to determine the number and length of wet and dry days, the critical dry periods and the quantum of harvestable rainwater. This rainfall information was used to determine the size of the water tank required to give adequate storage capacity.

3.2 DETERMINATION OF HOUSEHOLD WATER USE PATTERN

A set of questionnaire (35) was administered on rural dwellers (Ibule and Oda) and some parts of Akure metropolis (Oke aro and Ijoka) to establish water needs for domestic and agricultural uses, types of rainwater storage structure, general perception about rainwater, average population per household, roof construction materials and roof area. All the questionnaires were collected and analysed. The data collected were used to establish household water use pattern using statistical method (see Appendix I & II).

3.3 METHODS OF SIZING SYSTEM COMPONENTS

There are a number of different methods for sizing system components. The methods used in this study are the demand size approach and supply size approach.

Demand size approach

This is a very simple method used to calculate the largest storage requirement based on the consumption rates and number of persons in this study, the following parameters based on analysis of questionnaire and weather data are used for the design.

Consumption – 25litres per day

Requirement – 25×7

$$= 175 \text{ litres per day}$$

$$= 175 \times 30 = 5250 \text{ litres per month}$$

$$= 5.25 \text{ m}^3 \text{ per month}$$

Roof area – 70 m^2

Runoff coefficient – 0.9 (for corrugated roof)

$$\begin{aligned} \text{Annual available water (assuming all is collected)} &= 70 \times 1.46 \times 0.9 = 91.98 \text{ m}^3 \\ &= 92 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Average daily available water} &= \frac{92}{365} = 0.2521 \text{ m}^3 / \text{day} \\ &= 7.56 \text{ m}^3 / \text{month} \end{aligned}$$

So if we want to supply harvest water throughout the rainy season to meet this need, the demand cannot exceed 175litres per day. If the available harvested water cannot meet the expected demand, careful management will therefore be required.

3.4 DESIGN AND CONSTRUCTION OF FORMWORK

The formwork for the water storage structure is cylindrical in shape. The 0.3m in height formwork is made from a metal sheet 2mm thick. It has an outer diameter of 0.25m and inner diameter of 0.2m, giving a capacity of 6litres of water. Between the edges of the outer cylinder is placed a wedge that is pulled out to allow the formwork to be dismantled. The

formwork is assembled before pouring the mixture into it. The formwork design is shown below.

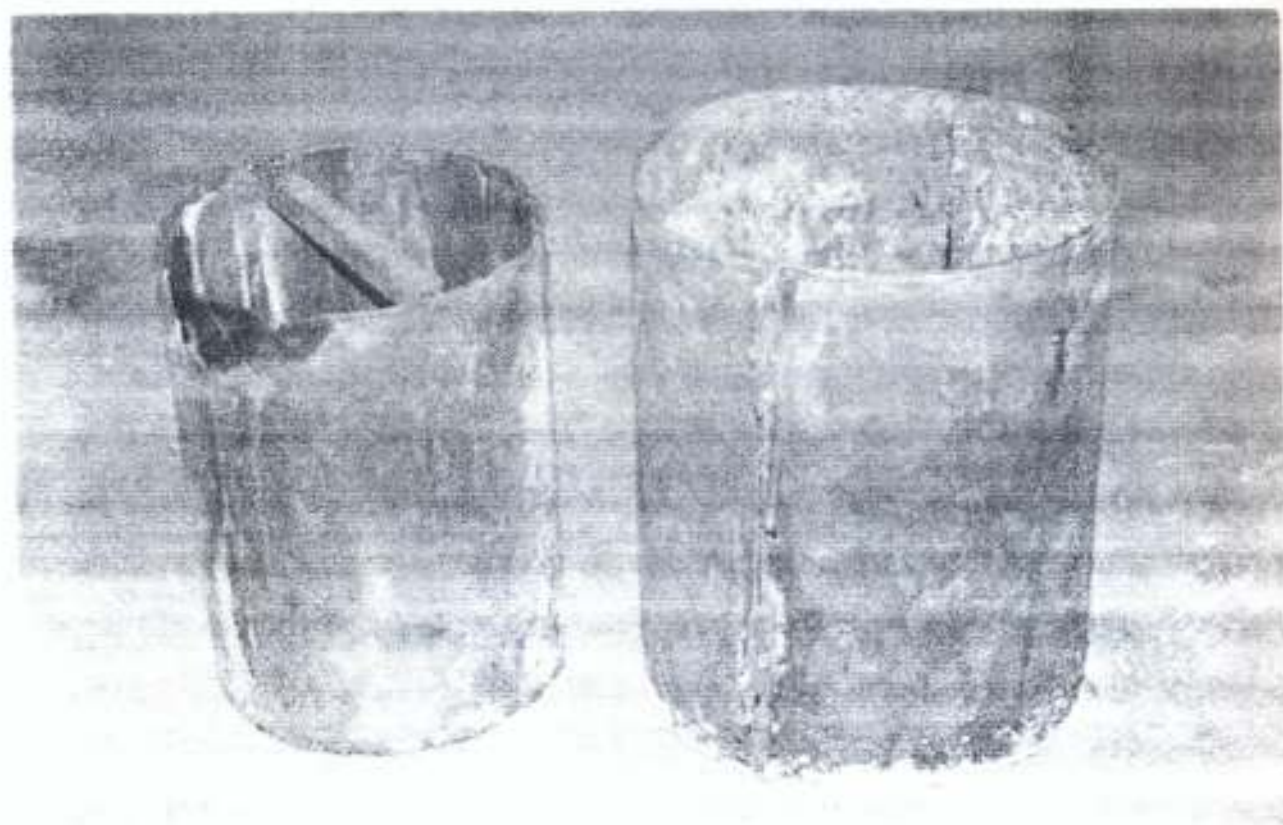


Plate 1: Picture of the Formwork

3.5 PRETREATMENT OF WOOD RAW MATERIAL

The sawdust of *Gmelina arborea* specie is collected and preheated in hot water at 80°C. The Gmelina sawdust were dipped in the hot water and stirred continuously for 10 minutes and thereafter allowed to further remain in the hot water for 30 minutes. The temperature of the water was maintained at 80°C by continuously adding boiled water. After the expiration

of 40-minutes immersion in hot water, the water containing chemical substances from the sawdust were drained off. The sawdust were further treated with hot water also at 80°C for 10 minutes and later drained off. The sawdust was air dried for two weeks until it attained moisture content of about 12%. The air-dried sawdust was stored in polythene bags and ready for use.

3.6 CONSTRUCTION OF MODEL

Water storage tanks can be constructed from various materials, but this project will concentrate on the use of wood particles (flakes of *Gmelina arborea*) and cement. Cement serves as a filler and reinforcement that fills the existing gaps between the wood particles. Cement is responsible for high resistances to weathering, fire, insects and fungus attack. The reason for the attribute above is that the entire wood particles are coated by the cement thereby forming a substrate difficult for agents of degradation to penetrate into it. Once the tank is constructed, its performance should be monitored. Attention must be paid to deficiencies in maintenance such as keeping gutters clean, as well as any other defect the tank may develop.

The quantity of production variables required to produce the storage tank was calculated and measured out according to the level of combination in the experiment. Such variables are wood density (dry weight), cement and additives. Wood and cement were calculated based on the mixing ratio of the materials comprising the mass of the tank. Chemical additive used was based on the percentage weight of the chemical in relation to the weight of cement. Amount of water was then calculated.

In calculating the quantity of water to be used for mixing the aggregates of the wood-cement storage structure, the formula derived by Ajayi 2000 was used.

$$V_{water} = 0.6C + (0.30 - MC)W_{wood}$$

Where

$$V_{water} = \text{volume of water}$$

C = weight of cement

W_{wood} = Weight of oven dry wood (kg) and

MC = Moisture content (%)

The Cement-Wood mixing ratios for the study are 2.0:1.0; 2.5:1.0; 3.0:1.0.

For each of the sample mixed, 3.5% of the weight of Cement is added as additive.

The prescribed quantity of additives was dissolved in the water used for the mixture. The quantity of pretreated wood sawdust was measured and poured into a plastic bowl. Water containing chemical additives (Calcium Chloride: $CaCl_2$) was added and mixed with the wood aggregates to retard the inhibiting effect of the remnant sugars and accelerate setting (curing) of the cement. Thereafter, the prescribed quantity of Cement was slowly added to the wet sawdust and thoroughly mixed until a well blended homogenous saw dust – water - cement- chemical additives paste free of wood cement lumps was obtained. The paste was then poured into the formwork and shaken thoroughly to remove any void space(s).

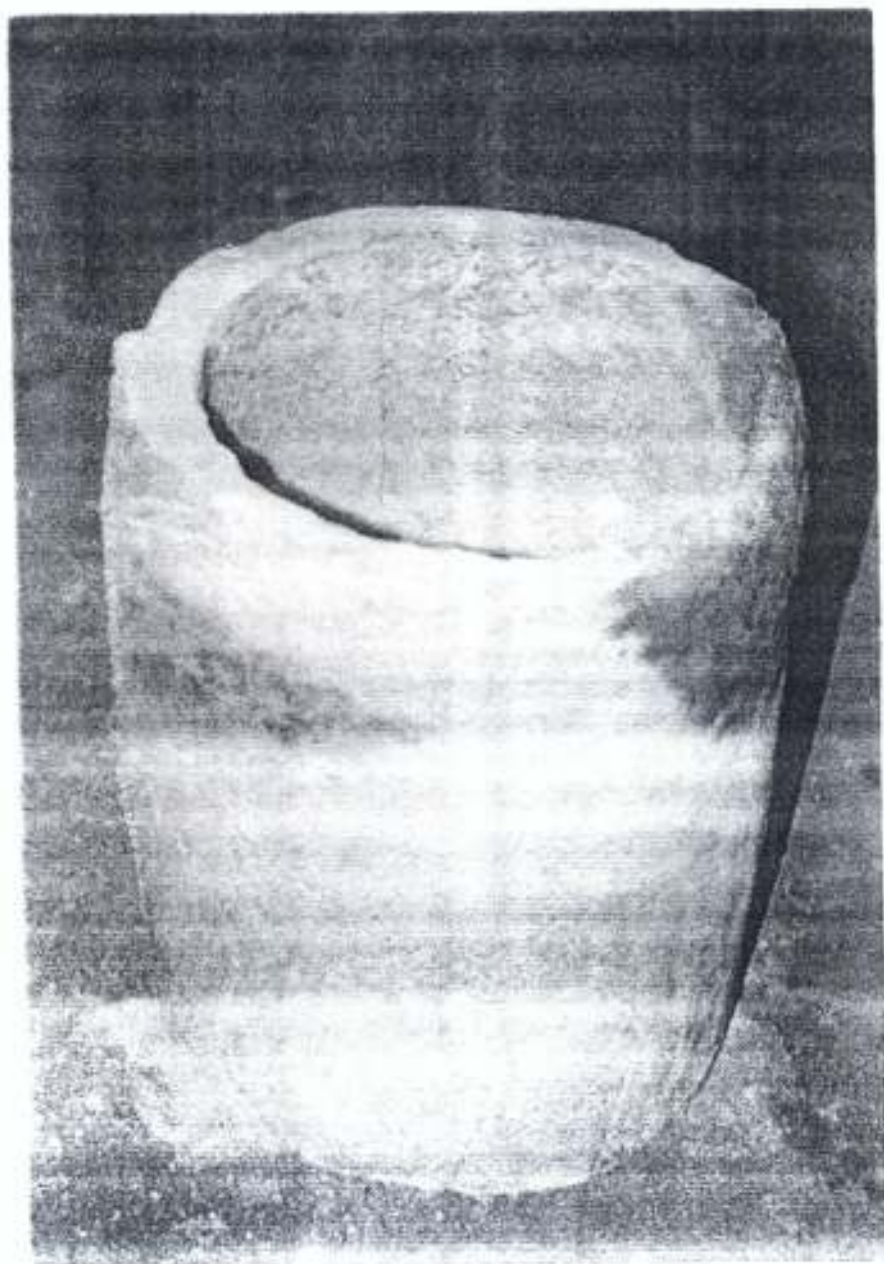


Plate 2: Picture of Model Tank

3.7 BILLETS FORMATION

The cement-sawdust mixture was formed into a uniform mat inside a wooden – metal cauls plate of 350mm X 350mm and pre-pressed using wooden plate. The steel plate was covered with polythene sheet before board formation by hand to prevent the sticking of the board on to the plate. After board formation, the wooden plate was removed; another polythene sheet was placed on the mat before placing the upper plate. This mould was transferred to the press and pressed to a thickness of 6mm and left for 24 hours under the press for it to cure. After this, the upper plate was removed from the board for post-curing. Thereafter, the boards were trimmed to remove edge effects on specimens, cut into test specimens (50mm X 50mm X 6mm) and kept under laboratory environment for some days as part of the curing process after which billets produced were subjected to various tests.

3.8 TEST OF ENGINEERING PROPERTIES

3.8.1 Internal Bonding Test

Small billets of the cement-sawdust mixture were tested for tensile strength using the Universal Tensile Machine, model SM 100 at the Federal Polytechnic, Ado Ekiti. Stress was applied to the specimen comprising of three different mix ratios until failure occurs within test specimen. The direction of loading is perpendicular to the faces and the centre of load passed through the centre of the specimen. Loading was done continuously and at uniform speed of the testing machine until failure occurred and the location of the line of failure was noted.

$$I_b = \frac{F_f}{A}$$

where:

I_b is the internal Bond; F_f =Failure force in (N) and A is the cross sectional area (mm^2)



Plate3: Billet Compression Process



Plate 4: Billet Cutting



3.8.2 Bending Strength

Small billets of the cement-sawdust mixture were tested for bending strength using the Universal Tensile Machine, model SM 100 at the Federal Polytechnic, Ado Ekiti.

3.8.3 Crushing Strength

Billets of the materials used for the construction of the storage tank were subjected to different loads using a Siedner machine, model 794 Riedingen West-Germany at the Ondo State Ministry of Works and Housing, Akure. The loads under which compression occurred were recorded.

3.8.4 Water Absorption Test

Three billets of different mix ratio (3.0:1.0, 2.5:1.0 and 2.0:1.0) were soaked in water for 48 hours. After submersion, specimens were suspended to drain for 10 minutes so as to remove the excess surface water. Thereafter specimens were weighed and water absorption determined. This was calculated from the increase in weight of specimen to the same degree of accuracy before soaking.

$$W_a = \frac{W_2 - W_1}{W_1} \times 100$$

Where W_a = Water Absorption (%)

W_2 = Final weight (g)

W_1 = Initial weight (g)

3.8.5 Accelerated Aging Test

Accelerated aging is a simulated weathering test, used to obtain a measure of the inherent ability of sawdust-cement-bonded tank to withstand severe exposure conditions. The intention is to know how the tank will withstand aging conditions. Such exposure is intended to simulate long-time exterior-exposure in a short time. It can also provide insight to degradation that could occur in service and thereby reducing the risk of investing so much in sawdust-cement water storage tank. This treatment maximizes the effect of three important influences that cause degradation such as heat, moisture swelling and shrinkage stresses.

The condition under which the specimens were subjected to was a simulated one. The simulated condition adopted (Sharman and Vautier, 1986) comprised one complete cycle of accelerated aging test as stated below:

- i. immersed in water at 30°C for 48hours
- ii. exposed to boiled water for 1hour
- iii. stored inside freezer for 24hours
- iv. oven dry at 180°C for 1hour

After the completion of these abnormal and intensive treatments, specimens were weighed.

3.9 WATER QUALITY TEST

Rainwater was collected after twenty minutes of downpour. The fresh sample was analysed and also samples from the tanks of three different mix ratio 3.0:1.0, 2.5:1.0 and 2.0:1.0 were equally analysed after two months of storage. The analysis was carried out in the Crop, Soil and Pest Management Laboratory of the Federal University of Technology,

Akure. The physio-chemical properties tested in the analysis of the water sample are listed below:

- i. pH
- ii. Total Hardness
- iii. Alkalinity Determination
- iv. Acidity Determination
- v. Total suspended solid
- vi. Dissolved free CO₂

3.9.1 pH

The pH of the water sample was determined using Jenway 3015 pH meter at room temperature. The standard of the pH was prepared using buffer tablet 7 and 9 in determining the pH of the sample.

3.9.2 Total Hardness

0.01M EDTA solution was put in the burette and titrate 20ml of the sample into 250ml conical flask with 100ml distilled water and 15ml conc. Ammonia solution or NH₄Cl + NH₃ with 10 drops of 5% OH. NH₂. HCl .5 drops of Erich Rome Black "T" as an indicator was added to give a deep blue end point. Hardness of water is at the presence of calcium.

$$CaCO_3 = \frac{\text{Titre Value}}{V_s} \times 1000$$

CaCO₃ in Mg/litre and V_s is the Volume of sample

3.9.3 Alkalinity Determination

50ml of water sample was pipetted into 250ml conical flask, and 2-3 drops of phenolphthalein indicator was used titrating with 0.1M H_2SO_4 until pink colour disappears and the value is recorded as P change (phenolphthalein change). In case no colour is produced by phenolphthalein indicator, or the colour has changed to colourless, 1-2 drops of methyl orange indicator was used recorded as MO (methyl orange change). If the solution is that which change to colourless and methyl orange is added, the value of alkalinity is recorded as P+MO which is Total Alkalinity but if it is a new solution, the alkalinity is MO.

$$T = P + MO$$

Total or Phenolphthalein alkalinity MG/L as:

$$\text{CaCO}_3 = \frac{A \times M}{V_s} \times 1000$$

Where A = Volume of Acid (titre value); M = Molarity of H_2SO_4 and V_s is the Volume of sample.

3.9.4 Acidity Determination

Acidity of water is usually due to the presence of uncombined CO_2 , mineral acid and salts of strong acids and weak base in water. 50ml of the rain water sample was pipetted into 250ml conical flask and 2-3 drops of phenolphthalein as indicator was added and titrated with 0.5% Na_2CO_3 and pink colour was observed as the end point.

Acidity = Volume of the 0.5% Na_2CO_3

3.9.5 Total Suspended Solids

The filter paper used was first weighed say f_i and 50ml of the water sample was poured into the filter paper and was then oven dried at 180°C , allowed to cool inside a desiccator and later re-weighed, this was done for periods until a constant weight was observed say f_{ii} . The difference in weight $F_{ii} - F_i$ (filter paper + solid – filter paper only), the result represent total suspended solid expressed in Mg/litre.

$$\text{CaCO}_3 = \frac{Y}{V_i} \times 1000$$

where Y is the difference in $F_{ii} - F_i$

3.9.6 Determination of Dissolved Free CO_2

Free CO_2 is due to dissolved CO_2 in water as a result of the presence of carbonic water. It affects water taste. 50ml of the rain water sample was pipetted into 250ml conical flask and 5 drops of phenolphthalein indicator was added and titrated with 0.01M of NaOH and pink colour indicates the end point.

CHAPTER FOUR

4.1 OVERVIEW OF RAINFALL PATTERN AND DISTRIBUTION IN AKURE

A plot of 14 year (1980 - 1993) average rainfall data for Akure shows a weakly bimodal distribution that characterize most sub-humid zone of Nigeria (Akintola,1986). A plot of some selected 7 years data from the data set, 1980 - 1993 showed the high degree of inter-annual variability in rainfall distribution in Akure (figure 4.1). The break and peak period of the years slightly differ from one another and is usually a month interval but most of the break occurs in August. In fact the peak of rainfall of a particular year was the break of another that makes the pattern not uniform, a pattern which means in a particular year we can have rainfall that will just be enough and in the following year a deficit. This shows that rainfall in that year is extremely low. In this analysis, the period of scarcity remains the same.

Onset of rain is usually between the months of March and April, though occasional rainstorms are sometimes recorded in the early months. Those events represent a false start of rainfall and the quality of water that is harvested from rooftop during these events is very poor. This results from the accumulated dirt and dust on the roof during the dry season. Also during this period, and the level of water in the wells will still be very low, even though this is a period of severe scarcity during which harvested rainwater, if of good quality, would have been a relief to the people

Detail analyses of the 14years weather data (1980 - 1993) for Akure showed pronounced intraseasonal variability. This is clearly depicted by the average monthly rainfall shown in (figure 4.2) which confirms studies by (Barron et al, 2003) that inter and intra seasonal variability is a critical problem in sub-Saharan Africa.

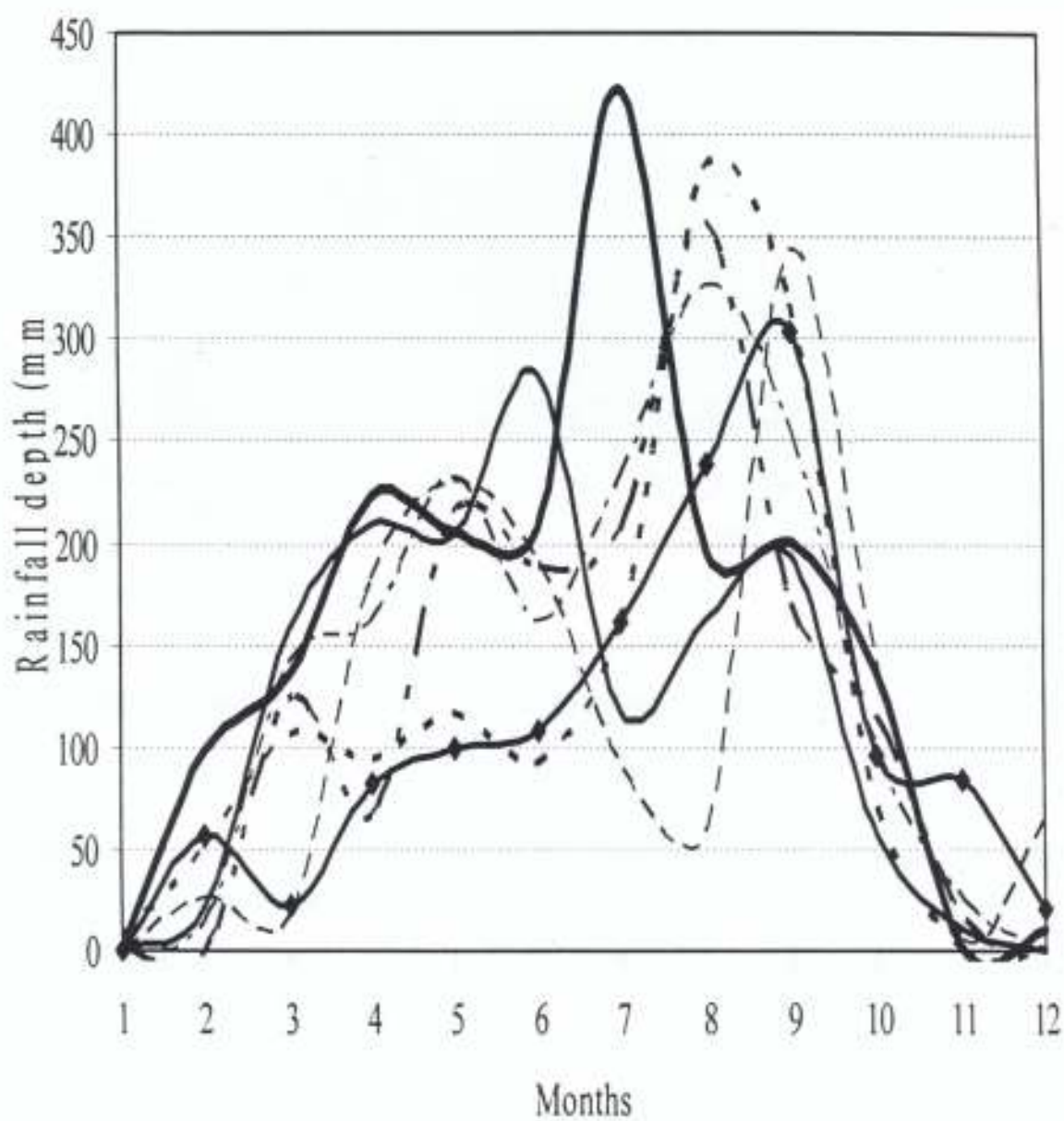


Figure 4.1: Average monthly rainfall for Akure for Seven selected years (1981, 1983, 1985, 1987, 1989, 1991, 1993)

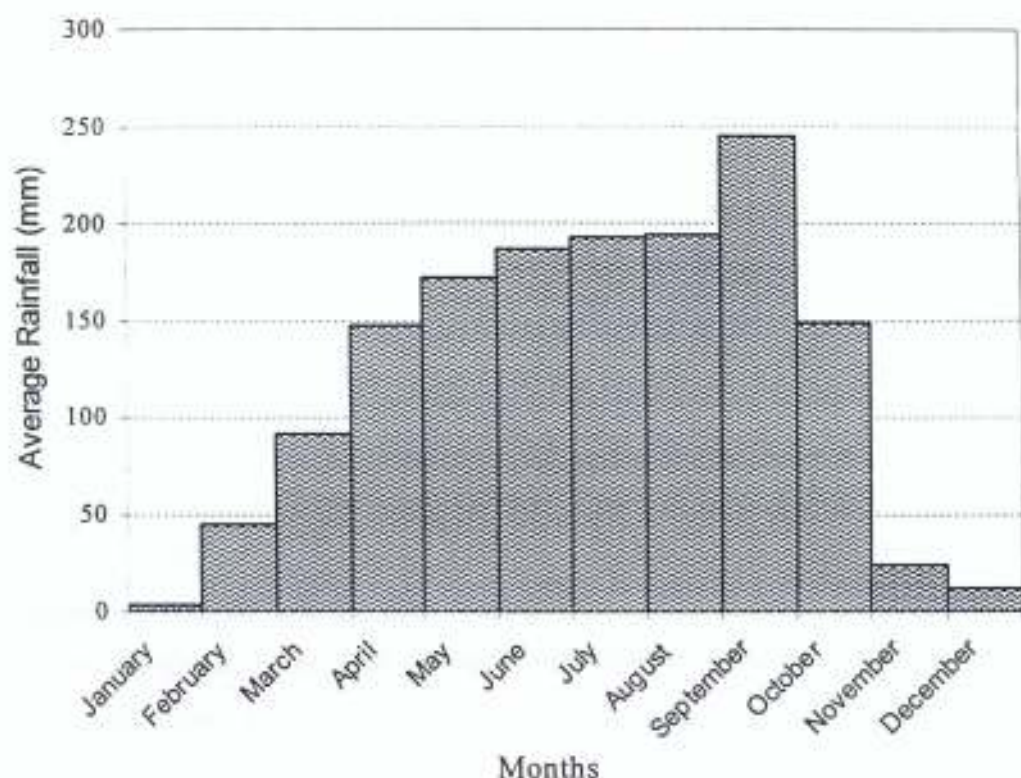


Figure 4.2: Average monthly rainfall for Akure for 14 years (1980-1993)

There is a gradual rise in rainfall from January until May, it levels up in July and August, there is always a break between July and August but mostly August which gives prolonged days without rain during which most crops must have consumed the available moisture in the soil and tending towards wilting. Also during this period, we must have used part of the water being stored for critical periods. There is a sharp rise in September during which we store back what we have used and crops begin to pick up again, that is, the month of September experiences heavy rainfall throughout, thereafter, the rain begins to reduce both in frequency, duration, and intensity until it eventually diminishes at the latter part of November. The month of December is almost generally scarce of rainfall. January is a period of very little or no rain.

From this graph we are able to know the most critical periods when all other alternatives to water supply must have ceased, hence the need for the use of stored water

Majority of the rainfall is between May and October with two peaks – one in July and the other one in September. Cessation of rainfall in Akure is often between the months of November and January.

Rainfall here is unevenly distributed; more care has to be taken to size the storage properly. During some months of the year, there was an excess of rain water, while at other times, there are deficit. Based on the sampling of the opinion of Akure township dwellers, they depend mostly on wells which go down drastically during the dry period, .Groundwater in the basement complex formation is virtually absent and when it is available, it occurs in very small yield and often rather difficult to locate; in fact, this is a depletion of the groundwater potential The dry days can last for 15 days or more, no crop can withstand as many days without water. Due to the failure of some boreholes that are to supplement water supply, there is a need to harvest and store the rainwater we have during the wet period.

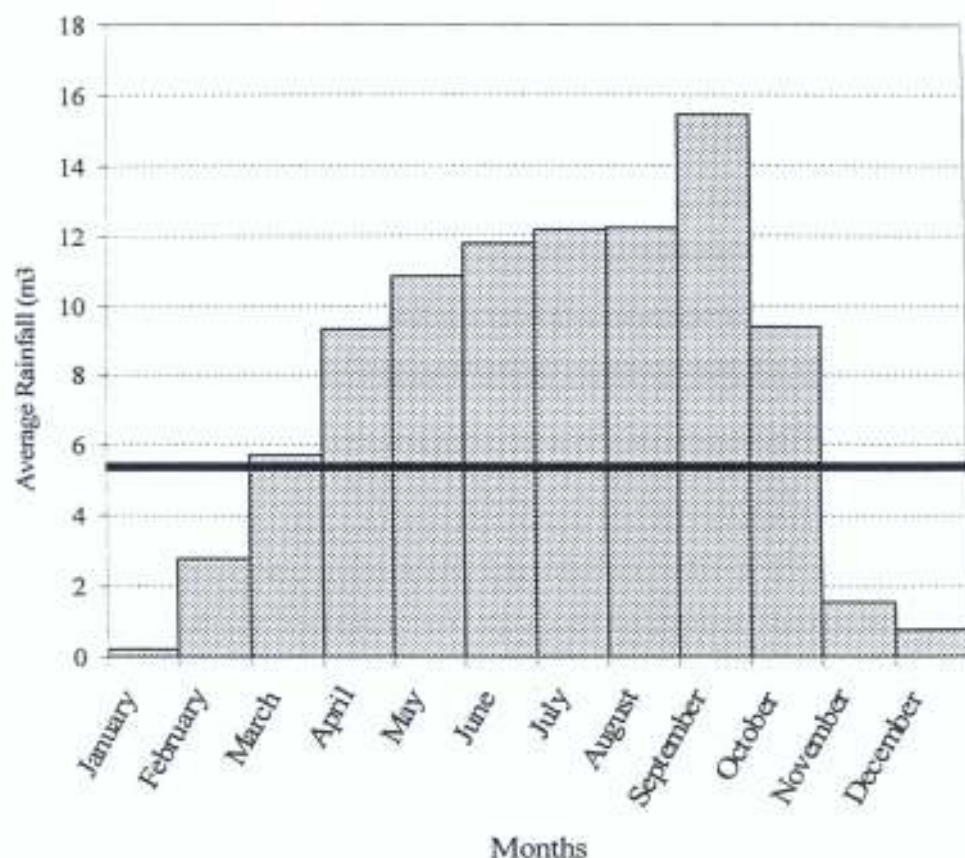


Fig 4.3 comparison of harvestable water and the demand for each month

4.1.1 Comparison of Harvestable water and demand

Based on the opinion of Akure rural dwellers that was sampled, it was found out that an average of one person would consume 25litres of water per day. So 7 people per household will consume 175 litres per day, that is, 5.25m^3 per month. The demand line is shown in Fig. 4.3

It is then clearly shown from fig.4.3 that the first time that rainfall starts to meet the demand of the people is in towards the end of March, even the rain then is barely enough because it follows a prolonged dry period and we have nothing to harvest. But despite the fact that rainfall stabilizes from April to October during which there is excess, people still lack water; and down for the few dry days in-between (August break) just because they fail to manage the one available very well. So with effective rainwater harvesting from April to

October, there is not likely to be any problem whatever is stored from April to October will be used to augment supply during the critical dry period.

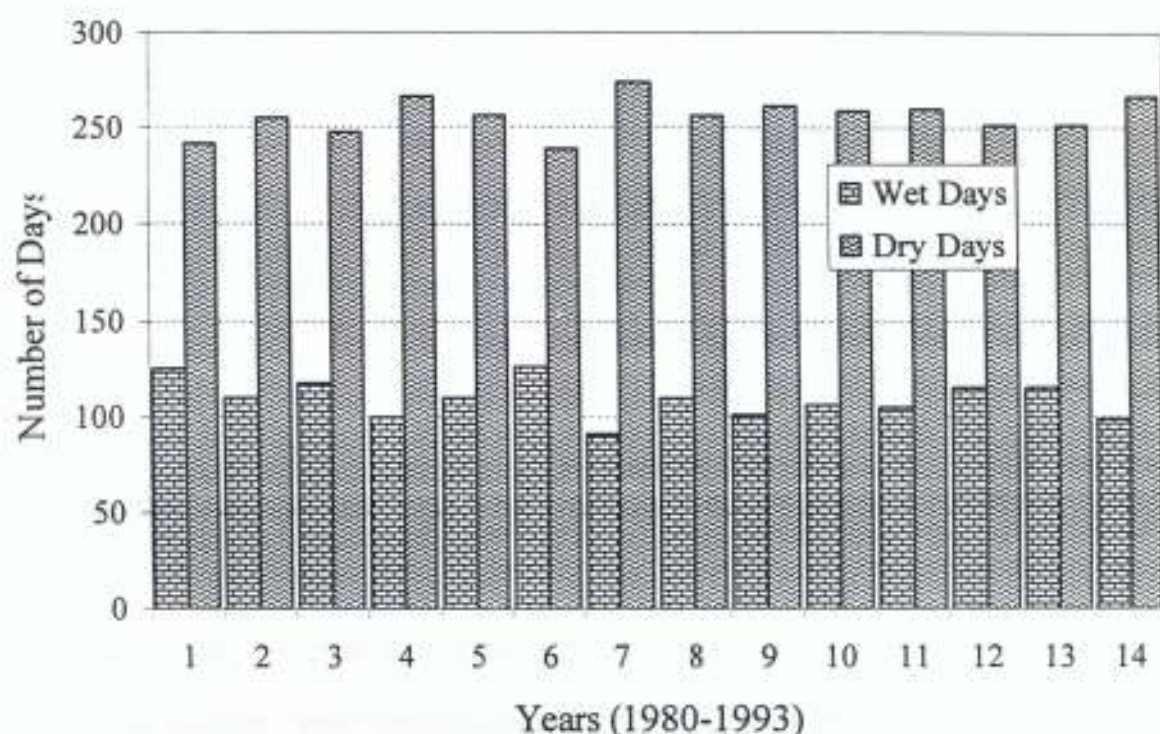


Figure 4.4: Comparison of average number of wet and dry days (1980-1993)

The analysis of the 14years data (1980 - 1993) presents an average annual rainfall of 1462.2mm, average total days with rain is 109days while dry days is 256 days (Fig. 4.4). This shows that there has never being a time when the numbers of rainy days up to the number of dry days let alone being more than it. This shows the level of water scarcity in the absence of rainwater collection and that there is always a need to harvest rainwater.

4.2 ANALYSES OF RESULTS

4.2.1 Questionnaires

The analysis of the Questionnaires returned by residents showed that the mean number of persons per building is 7 (actually 6.68) with the percentages of men: women: children

population being 25%: 26%: 49% respectively. 55% of the sampled population wanted Government to provide potable water while 45% still believe so much in rainwater

4.2.2 Sawdust – Cement Structure

The sawdust from *G. arborea* was pre-treated in Hot water. The hot water treatment was done in an aluminium bowl, which contains hot water at 80°C. The quantity of additives required was dissolved in the quantity of water needed. The quantity of wood flakes were measured out and poured inside a plastic bowl. Water containing chemical additives (Calcium Chloride: CaCl_2) was added and mixed with the wood aggregates to retard the inhibiting effect of the remnant sugars and accelerate setting (curing) of the cement.

Cement was slowly added to the wet sawdust and thoroughly mixed until a well blended homogenous sawdust - water-cement- chemical additives paste free of wood cement lumps was obtained. The mixture was then poured into the formwork and shaken thoroughly to remove any void space.

The quantity of cement used in the construction of the storage tank was 2.4kg and sawdust, 0.8kg in the ratio 3:1. Using the formula derived by Ajayi (2000), the volume of water used was calculated to be 1.6litres and additives (CaCl_2) was 0.084kg. This was used in making the tank, which came out in the shape of the formwork that is cylindrical. The tank produced has a volume capacity of 0.006m³ with an outer diameter of 0.25m, inner diameter of 0.20m and a height 0.3m. It was discovered that the more the cement, the

stronger the structure but at ratio 3:1, the structure came out very strong and for more effective result, the structure can be plastered with cement.

4.2.3 Construction of Tank Model

The quantity of production variables required to produce the model storage tank were calculated and measured out according to the design mix ratio earlier calculated. The mix typically consists of sawdust (dry), cement and additives. The amount of chemical additive used for each combination of the model tank was calculated as a function of the weight of cement. Appropriate quantity of water is there after added to the mixture to form a good paste. Table 4.1 presents the detail quantity of material that was used for the three different models used in this study.

Table 4.1: Quantities of Materials used

Ratio	Wt. of Sawdust (kg)	Wt. of Cement (kg)	Wt. of Additives	Wt. of Water (L)
3.0:1.0	0.8	2.4	0.084	1.6
2.5:1.0	0.8	2.0	0.070	1.3
2.0:1.0	0.8	1.6	0.056	1.1

4.3 ENGINEERING PROPERTIES TEST

4.3.1 Internal Bonding (IB) Test

Table 4.2 presents the result of the Internal Bonding Test (IB) conducted on the billet sample produced from the different mix ratio used for the experiment. Two states of the billet were also tested viz. dry (naturally cured samples) and wet (by soaking in water for 48Hours). The average internal bond varied from 95 – 110N/mm² for dry billets and 93 –

105N/mm² for wet samples. The dry ratio 3.0:1.0 billet had higher IB value compared with the wet sample of the same ratio. This trend was observed in all the different mix-ratios. The wet billet from the mix ratio 2.0:1.0 gave the least value of IB values. Thus it could be inferred that the internal bonding strength is positively correlated with the quantity of cement in the sample. Also, moisture state affect the strength of the structure produced from the entire different mix ratio.

Since the structure was intended for storage of water, which was observed to lower the internal bonding, another set of billet were produced to run another test. In the second experiment, the length of days allowed for the samples to cure was double (i.e. 28 days), before any soaking. The result of the experiment showed that the internal bonding values for all the samples increased very significantly. This clearly showed that storage pots produced from any of the mix ratio must be allowed a longer time to cure to enhance the stability in the presence of stored water. Allowing a longer time of curing and thorough mixing of the paste before setting will help reduce significantly the presence of voids in the pots.

The performance of the sample with the mix ratio 3.0:1.0 could be attributed to the limited or no void in the cured samples. This led to an improvement in the bonding potentials, thus the mix ratio produced, when thoroughly mixed and allowed sufficient time to cure under natural condition produces tanks with superior internal bonding characteristics.

For the cement – sawdust mix ratio of 2.0:1.0, close inspection showed the surface is rougher. This must have resulted from inadequate blending of the cement with the other material used for the formation. It is possible that the quantity of cement in the sample is lower than what would be used for producing tanks for water storage.

Detail inspection of the samples also showed high density of void compared to the samples from other mix ratio. However, the samples have the least weight in comparison to the other billet samples. In our opinion, the sample of that mix ratio will be best suited for production of ceiling tiles than for water storage tank. This was also similarly concluded by studies by Ajayi, 2000.

Table 4.2: Results of Internal Bond Test

Sample Names	Cement/Wood Mixing Ratio	Treatment	IB Values (N/mm ²)
A _d	3.0:1.0	Dry	110(120)
B _d	2.5:1.0	Dry	104(110)
C _d	2.0:1.0	Dry	95(100)
A _w	3.0:1.0	Wet	105(110)
B _w	2.5:1.0	Wet	100(106)
C _w	2.0:1.0	Wet	93(100)

Note: The numbers in the parenthesis are the value obtained for the samples that were allowed 28 days curing time

A_d is the mix ratio 3.0:1.0 that was not soaked in water

B_d is the mix ratio 2.5:1.0 that was not soaked in water

C_d is the mix ratio 2.0:1.0 that was not soaked in water

A_w is the mix ratio 3.0:1.0 that was soaked in water

B_w is the mix ratio 2.5:1.0 that was soaked in water

C_w is the mix ratio 2.0:1.0 that was soaked in water

4.3.2 Crushing Strength

In the Crushing Strength test, cement-sawdust ratio 3.0:1.0 (A_d) crushed under load 5,000KN, ratio 2.5:1.0 (B_d) crushed under load 3,000KN while ratio 2.0:1.0 (C_d) crushed under load 2,000KN. This clearly followed the pattern of behaviour observed under the internal bonding test. It is safe to conclude that the resistance of each sample under the different mix ratio is dependent on the internal bonding of the sample. Thus a weak and sparsely bonding between particles of a sample will result in low crushing strength. In this circumstance, the magnitude in performance follow this pattern $A_d > B_d > C_d$.

4.3.3 Bending Strength

In the Bending strength test, variation of the thickness of billets will affect the values of the bending strength properties of the specimen. Each specimen was supported equally at two points away from the two ends with parallel metal rollers on such a way that no crushing of the specimen will occur at the end points during the test.

$$\text{Bending stress } \delta = \frac{3PL}{2bd^2}$$

Where P = Failing load

L = Span btw centre of support (mm)

b = Width of test specimen (mm)

d = mean thickness of test specimen (mm)

Table 4.3: Results of Bending Strength Test

Sample Names	Cement/Wood Mixing Ratio	Treatment	❖ BS Values (N/mm ²)
A _d	3.0:1.0	Dry	16.57
B _d	2.5:1.0	Dry	14.02
C _d	2.0:1.0	Dry	13.40

❖ *Mean for 5 test specimens per each mix ratio.*

The range of Bending strength values obtained from the three mix ratios compared favourably with the values of MOR reported in literatures (7.22 to 14.60 Mpa Oyagade 1985, Ajayi , 2000). The highest value of bending strength was obtained at mix ratio 3.01:1.0. This is possibly due to better inter-particle contact leading to better bond formation with smoother surface.

4.3.4 Water Absorption Test

The most stable storage structure is the ratio 3.0:1.0. It has no void and the surface is smoother than other mix ratios. When it was soaked in water, it did not absorb water. In the mix ratio 2.5:1.0, less water was absorbed, but the mix ratio 2.0:1.0, the water retention ability was high enough to cause increase in weight because of the surface roughness and presence of voids. The result here shows that there is a significant difference in water absorption of the three mix ratios, that is, Water Absorption was significantly affected by the quantity (ratio) of cement used, so the mixing ratio has a strong effect on Water Absorption of the billets.

Table 4.4: Water Absorption properties under different mix ratio

Sample Names	Cement/Wood Mixing Ratio	Water Absorption (%)
A _d	3.0:1.0	0
B _d	2.5:1.0	0.42
C _d	2.0:1.0	4.17

4.3.5. Accelerated Aging Test

This test followed one – cycle treatment of 74-hour under severe conditions. The three mix ratios appeared stronger than they were originally even having gone through the severe treatments conditions. There was no powder formation in the three specimens. Although one would have thought that the severity of the treatment would have cause softening of the samples, increase in weight and cracking because of the evolution of air bubbles from the test specimens during hot water treatment. Contrarily, the different mix ratios performed better under the different tests of internal bonding and bending strength. Interestingly also, the Water Absorption was reduced for C_d after the Accelerated Aging test. This showed that the samples have the tendency to become more stabilised with age of use if used to store water, irrespective of the variation in environmental condition.

4.4 Water Quality Test

Rainwater sample were collected twenty minutes into a normal rainfall event. The delay was to ensure that the contaminants on the rooftop have been washed away in the first few minutes of the rain event. The samples were tested for their chemical properties, before storing in four different containers produced from the 3 mix ratios used for this study. The samples were thereafter analysed for their chemical properties to determine the suitability for domestic uses and possible change in chemical properties with storage time and

medium. Major parameters that determine the consumability of water were determined and the results is presented in table 4.4

Table 4.5 Physical and Chemical Analysis of rainwater samples stored in the different pot with varied mix ratio

Test	A	B	C	D	E
pH	6.85	6.90	6.90	7.0	7.2
Total Hardness	220	230	260	280	300
Alkalinity	0.7	0.7	0.8	0.85	-
Acidity	0.7	0.7	0.7	0.80	-
Total Suspended Solid	350Mg/L	350Mg/L	360Mg/L	380Mg/L	500Mg/L
Dissolved Free CO ₂	0.4	0.4	0.4	0.5	0.8

Laboratory: Crop, Soil and Pest Management Laboratory, Federal University of Technology, Akure

Samples: A - Fresh rainwater

B – Rainwater stored inside a clay pot for two months (Control)

C – Rainwater stored in constructed storage tank of mix ratio 3.0:1.0 for 2 months

D - Rainwater stored in constructed storage tank of mix ratio 2.5:1.0 for 2 months

E - Rainwater stored in constructed storage tank of mix ratio 2.0:1.0 for 2 months

In determining the Alkalinity and Acidity of sample E (water stored in a tank made from 2.0:1.0 mix ratio), when phenolphthalein indicator was added to the water sample, rather than being colourless before titrating with H_2SO_4 and Na_2CO_3 respectively to give pink colour as end point, it turned purple. This shows that the sample has increase in Alkalinity and Acidity to a point where it is no longer safe for human consumption. It is obvious that chemical reaction have occurred between the water sample and the construction material. This possibly results from the low bonding strength earlier on recorded for the sample, due to the cement-sawdust mixing ratio. The results from the samples stored in the other

storage tanks showed that there is no significant change in quality as the values fell within the WHO Standard for drinking water.



CHAPTER FIVE

Conclusions and Recommendations

5.1 Conclusions

1. The quality assessment of rainwater harvested in tank 3.0:1.0 shows that it can be used for all the four basic water needs (drinking, cooking, washing and bathing).
2. The amount of rainwater that can be harvested in Akure can meet the demand during the critical dry periods.
3. Cement and *Gmelina* sawdust can be used to produce a stable water storage structure at a mix ratio of 3:1.

5.2 Recommendations

1. There is a need for further study on the optimum mix of *Gmelina* and cement, that is, ratios 4.0:1.0, 5.0:1.0; 6.0:1.0... should be assessed.
2. Water quality after long storage should be assessed.
3. Further test on strength of tank should be re evaluated
4. Rainwater harvest should be introduced as an urgent measure to solve the critical potable water problem of marine communities in Ondo State.
5. The 3.0:1.0 *Gmelina*-cement tank should be introduced as a means of water storage.
6. Health Organization should embark on enlightenment programme to create awareness on the high quality of rainwater. The Public should be encouraged to harvest and store rainwater to meet their basic needs as studies have shown that rainwater is of better quality than stream.

7. In addition, the stored rainwater can be used to complement wells especially in the dry period when they must have almost dried up.
8. Finally, there is a need for Government to integrate rainwater harvest into National and State water policy as it is in other Countries.

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APPENDIX 1

Questionnaire on Water Resources Utilization for Ibule and Oda in Akure

Item No	Description	Items Under Description
1	Population per Household	
2	Household water consumption per day	Drinking Cooking Bathing Washing
3	Sources of Water Supply	Public Tap Borehole Well water Rain water
4	Opinion about Rain water	Suitable for all domestic uses Not suitable for Drinking Not suitable for Bathing Not suitable for Washing Not suitable for Cooking
5	Rain water Storage Capacity	5 -20 litres 20 – 100 litres 100 litres and above
6	How long do you store rain water	Day/days Week/Weeks Month/Months
7	Rain water User Regime	Occasional Intermittent Partial/Supplemental Full

APPENDIX II

Analysis of Questionnaire on Water Resources Utilization for Ibule and Oda in Akure

Item No	Description	Options Under Description	Total	Av./household	%
1	Population per Household	No. of women	69	1.97	26
		No. of men	67	1.91	25
		No. of children	130	3.71	49
		Total	266	6.68	100
2	Household water consumption per day	Drinking	4		
		Cooking	6		
		Bathing	10		
		Washing	5		
3	Sources of Water Supply	Public Tap			
		Borehole	6		
		Well water	28		
		Rainwater	10		
4	Opinion about Rain water	S for all domestic uses	20		57.1
		NS for Drinking	5		14.3
		NS for Bathing	15		42.8
		NS for Washing	-		
		NS for Cooking	-		
5	Rain water Storage Capacity	5 -20 litres	5		14.3
		20 – 100 litres	10		28.6
		>100 litres	20		57.1
		1000 litres	Nil		-

How long do you store rain water	Day/days	20	57.1
	Week/Weeks	10	28.6
	Month/Months	5	14.3
Interest in Rainwater as an alternative water supply			
		16	45
Willing to get connected to public water supply			
		19	55

Note S----Suitable

NS----Not Suitable