Potential of rainwater harvesting and uses in the coastal savannah zone of Ghana – A case study of Nmai Djorn households

By

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CERTIFICATION

I hereby declare that this submission is my own work towards the M.Sc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

To God Almighty, my family and friends

ABSTRACT

This dissertation aimed at developing potential rainwater harvesting in the coastal savannah zone of Ghana. Using monthly rainfall data from Ghana Meteorological Agency the monthly supply was estimated. Sample of 100 selected household determining the existing storage tank being used in the selected houses. Techo meter was used to determine the roof catchment area of the houses involved with 100 m² to 200 m² ranges being the highest area in the study area. Supply side approach method was used under different scenarios (100%, 50%) to determine the storage capacity of fully or partially dependency on rainwater harvested of average household of 5 persons with daily water consumption of 76 litres per person per day in each of the ten years rainfall data collected.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Water scarcity is becoming one of the most alarming global crises as the population in cities grows water to supply industry, agriculture and domestic grow exponentially. Rainwater harvesting appears to be one of the most promising alternatives for supplying freshwater in the face of increasing water scarcity and escalating demand. Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, the land surface or rock catchments using simple techniques such as jars, pots as well as more complex techniques such as underground check dams. The techniques usually found in Asia and Africa arise from practices employed by ancient civilizations within these regions and still serve as a major source of drinking water supply in rural areas.

Rainwater harvesting is an accepted freshwater augmentation technology in Asia. While the bacteriological quality of rainwater collected from ground catchments is poor, that from properly maintained rooftop catchment systems, equipped with storage tanks having good covers and taps, is generally suitable for drinking. That notwithstanding, such water generally is of higher quality than most traditional, and many of improved, water sources found in the developing world. Contrary to popular beliefs, rather than becoming stale with extended storage, rainwater quality often improves as bacteria and pathogens gradually die off (Wirojanagud *et al*., 1989). Rooftop catchment, rainwater storage tanks can provide good quality water, clean enough for drinking, as long as the rooftop is clean, impervious, and made from non-toxic materials (lead paints and asbestos roofing materials should be avoided), and located away from over-hanging trees since birds and animals in the trees may defecate on the roof. Experience shows that, about 95% of houses in rural Africa harvest rainwater during storms. In Ghana, the challenges posed by dry wells, as well as excessive levels of contaminants especially minerals in the groundwater resources of some geological formations make harnessing of rainwater for household use unavoidable (Siabi *et. al,* 2005). Whilst researchers are looking for efficient ways of dealing with contaminants associated with these water sources, focus is gradually shifting to the development of enhanced methods for rainwater harvesting. Small communities are increasingly accepting rainwater harvesting as a technology choice capable of meeting their water demands. The resource if properly harnessed has benefits, which would contribute to meeting the millennium development goals (MDG) on water and environmental sanitation by the year 2015 in Ghana (Siabi *et. al,* 2005). Rainwater harvesting in Ghana has gone through several stages of development ranging from the use of primitive techniques (including bamboo and raffia fronds with collectors normally household equipment of different capacities) to modern techniques using aluminum gutters, P.V.C pipes with galvanized steel, ferrocement, metal as well as plastic tanks as rainwater cisterns/reservoirs.

Rainwater harvesting technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are also readily available. Rainwater harvesting is convenient in the sense that it provides water at the point of consumption, and family members have full control of their own systems, which greatly reduces operation and maintenance problems. Running costs are almost negligible. Water collected from roof catchments usually is of acceptable quality for domestic purposes. As it is collected using existing structures not specially constructed for the purpose, rainwater harvesting has few negative environmental impacts compared to other water supply project technologies. Although regional or other local factors can modify the local climatic conditions, rainwater can be a continuous source of water supply for both the rural and urban. Depending upon household capacity and needs, both the water collection and storage capacity may be increased as needed within the available catchment area.

1.2 Problem Statement

Aqua Vie ten Rand Limited (AVRL) distributes about $372,000m^3$ of water a day to the Accra-Tema Metropolitan Area (AVRL, 2009). Due to inadequate production levels, Aqua Vie ten Rand Limited has resorted to rationing the available water to ensure equitable distribution of water. The inhabitants of Accra therefore do not receive water every day of the week. Households respond by storing water for later use. Intermittent supply has also led to a thriving business of water vending, which, whilst it is a support to households without connections, it also contributes to exploitation of the poor. These vendors mostly source their water from the urban pipe-borne network. There are essentially two types: large scale enterprises requiring a capital outlay for purchase of tankers that supply water in large volumes to richer households situated in water scarce neighbourhoods, and small scale vendors who sell water in smaller volumes to individual households at the community level. Despite the efforts of AVRL to manage the water supply in such a way that people receive a fair amount of water on designated days, locations in Accra and its peri-urban areas still do not receive water at all. This problem annually worsens during the dry season, when there is no rainwater to complement the pipe water source.

In Accra today, tanker services have become a key component of the water delivery system, especially in areas of low pressure and un-served areas. Price of the water supply by the water tankers in the communities has become high. This case study focuses on the rainwater harvesting as the supplement.

1.3 Aim

The study was aimed at assessing the potential for rainwater harvesting system for coastal savannah zone of Ghana.

1.4 Specific Objectives

In order to achieve the above aim, the following specific objectives were pursued:

1. Conduct a survey of existing roof catchment characteristics and storage tank sizes as is practiced in the study area.
2. To determine suitable tank sizes to meet the water demand at the study area under different water use scenarios.
3. To examine the sufficiency of the tank sizes used to meet the water demand at the study area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Resources Potential and Utilization in Ghana

Ghana's water resources are derived from two main sources namely surface and groundwater. The surface water resources are mainly from three river systems draining the country namely; the Volta, South Western and Coastal river systems – constituting 70%, 22% and 8% respectively of the total land area of about 240,000 square kilometres of Ghana. Apart from this the only important freshwater source is the Lake Bosomtwi, which is a meteoritic crater located in the forest zone, with a surface area of 50 square kilometres and a maximum of 78 metres depth (Ministry of Works and Housing, 2005).

The total annual runoff is 56.4 billion m^3 with River Volta accounting for 41.6 billion m^3. Wide disparities between the wet season and dry season flows characterize the runoffs. The total water resources available from surface water sources are 39.4 billion m^3 per annum (Ministry of Works and Housing, 2005).

2.2 Water Harvesting

Rainwater harvesting (RWH) primarily consists of the collection, storage and subsequent use of captured rainwater as either the principal or as a supplementary source of water. Both potable and non-potable applications are possible (Fewkes, 2006). Examples exist of systems that provide water for domestic, commercial, institutional and industrial purposes as well as agriculture, livestock, groundwater recharge, flood control, process water and as an emergency supply for firefighting (Gould & Nissen-Peterson,1999; Konig).

2.2.1 Water harvesting techniques

1. ***Rainwater harvesting:*** This is generally defined as accumulating and storing rainwater. According to Gould (1999) and Lundgren and Åkerberg (2006), rainwater harvesting is a general term which describes the small scale concentration, collection, storage, and use of rainwater runoff for both domestic and agricultural purposes from rooftops, the land surface, steep slopes, road surfaces or rock catchments using simple techniques such as pots, tanks or cisterns as well as more complex systems such as underground check dams. In relation to domestic water supply, roof catchment systems are by far the most common form of rainwater harvesting technique used, although in many developing countries rainwater runoff is also collected from the ground or rock surfaces. This technology according to Lundgren and Åkerberg (2006) is based on collecting the rainwater immediately it falls before large evaporation losses occur.

2. ***Flood water harvesting*** is defined by Gupta and Ashok (2007), as the collection and storage of creek flow for irrigation use. Flood water harvesting, also known as 'large catchments water harvesting' or 'Spate Irrigation', may be classified into following two forms:

   a) In case of 'floodwater harvesting within stream bed', the water flow is dammed and thus, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.

   b) In case of 'floodwater diversion', the wade water is forced to leave its natural course and conveyed to nearby cropping fields. It is practiced in Africa and Middle East Asian regions.

3. ***Groundwater Recharge***: According to Gupta and Ashok (2007), groundwater recharge is a term that covers traditional as well as unconventional ways of ground water extraction. They obstruct the flow of ephemeral streams in a river-bed and thus the water is stored in the sediment below ground surface and can be used for aquifer recharge. Examples of groundwater harvesting techniques include qanats systems, underground dams, subsurface dams and sand storage dams. Moreover, the sand filled reservoirs have the following advantages:

   a) Evaporation losses are reduced,

   b) No reduction in storage volume due to saturation

2.3 The Growing Global Interest in Rainwater Harvesting

The development of modern 'conventional' water supply systems in the first half of last century resulted in many traditional water sources going out of favour (Gould, 1999). This was the case with rainwater harvesting technologies which came to be considered only as an option of last resort when all other water sources have been eliminated (Gould, 1999; Lundgren and Åkerberg, 2006). While the exploitation of rainwater was considered appropriate in certain extreme situations such as on coral islands or at remote farms for which reticulated supplies were uneconomic, little serious consideration was given to the more general use of the technology. During the 1980s, however, things changed and there were numerous grassroot initiatives supported by enlightened government and donor agencies promoting and implementing rainwater harvesting technologies. This has partly been a response to the growing technical feasibility of using roof catchment systems in the south due to the spread of impervious roofing materials in rural areas. It has also been motivated by a paradigm shift regarding global attitudes to the environment and the growing realization that water resource utilization has to become more sustainable (Gould 1999).

This century has seen a very keen growing interest in rainwater harvesting technologies especially in most developing countries globally. According to Smet (2003), rainwater utilization is now an option along with more 'traditional' water supply technologies, particularly in rural areas. It is of particular importance and relevance for arid and semi-arid lands, small coral and volcanic islands, and remote and scattered human settlements. This increased interest has been facilitated by a number of external factors, including:

- the shift towards more community-based approaches and technologies participation, ownership and sustainability
- the increased use of small-scale water supply for productive and economic purposes (livelihoods approach)
- the decrease in the quality and quantity of ground and surface water
- the failure of many piped water supply systems due to poor operation and maintenance
- the flexibility and adaptability of rainwater harvesting technology
- the replacement of traditional roofing (thatch) with impervious materials (e.g. tiles and corrugated iron) and
- the increased availability of low-cost tanks (e.g. made of ferro-cement or plastics).

2.4 History of Rainwater harvesting

Gould and Nissen-Peterson (1999) provide a detailed history of rainwater harvesting systems. The authors state that, whilst the exact origin of RWH has not been determined, the oldest known examples date back several thousand years and are associated with the early civilizations of the Middle East and Asia. In India, evidence has been found of simple stone-rubble structures for impounding water that date back to the third millennium BC (Agarwal and Narain,1997). In the Negev desert in Israel, runoff from hillsides has been collected and stored in cisterns to be used for agricultural and domestic purposes since before 2000 BC (Evenari, 1961). There is evidence in the Mediterranean region of a sophisticated rainwater collection and storage system at the Palace of Knossos which is believed to have been in use as early as 1700 BC (Hasse, 1989). In Sardinia, from the 6th century BC onwards, many settlements collected and used roof runoff as their main source of water (Crasta *et al*, 1982). Many Roman villas and cities are known to have used rainwater as the primary source of drinking water and for domestic purposes (Kovacs, 1979).

In the 1980's the world community embarked on the worthy challenge of endeavouring to provide access to clean water and sanitation to all by 1990. Even at the start of the International Drinking Water Supply and Sanitation (IDWSS) Decade (1981-1990) during which hundreds of millions of people were supplied with improved water , it came to light that the goal of "water for all" was unattainable. This was due mainly to a lack of political will both in the North and the South. Another major obstacle was an unrealistic faith in modern technologies and implementation strategies which in the event proved inappropriate in many rural and peri-urban communities of the South (Gould, 1999). At the same time, another billion people have access to both abundant water and the fruits of irrigation, both of which are delivered to them at affordable and often highly subsidized prices.

2.5 Advantages and disadvantages of Rainwater Harvesting

Advantages of rainwater harvested are as follows

- Rainwater harvesting provides a source of water at the point where it is needed. It is owner operated and managed.

- It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters.
- The construction of a rooftop rainwater catchment system is simple, and local people can easily be trained to build one, minimizing its cost.
- The technology is flexible. The systems can be built to meet almost any requirements. Poor households can start with a single small tank and add more when they can afford them.
- It can improve the engineering of building foundations when cisterns are built as part of the substructure of the buildings, as in the case of mandatory cisterns.
- The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources.
- Running costs are low.
- Construction, operation, and maintenance are not labor-intensive.

The disadvantages are as follows

- The success of rainfall harvesting depends upon the frequency and amount of rainfall; therefore, it is not a dependable water source in times of dry weather or prolonged drought.
- Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water in a low rainfall period. Increased storage capacities add to construction and operating costs and may make the technology economically unfeasible, unless it is subsidized by government.
- Leakage from cisterns can cause the deterioration of load bearing slopes.
- Cisterns and storage tanks can be unsafe for small children if proper access protection is not provided.

- Possible contamination of water may result from animal wastes and vegetable matter.
- Where treatment of the water prior to potable use is infrequent, due to a lack of adequate resources or knowledge, health risks may result; further, cisterns can be a breeding ground for mosquitoes.
- Rainfall harvesting systems increase construction costs and may have an adverse effect on home ownership. Systems may add 30% to 40% to the cost of a building.
- Rainfall harvesting systems may reduce revenues to public utilities

2.6 Rainwater harvesting techniques in Ghana

2.6.1 Open Catchment

This is the case whereby containers are placed in the rain during storms to collect water. In this system only a few litres of water can be collected depending on the intensity and duration of the rain making the system less efficient (Kyei-Baffour, 1987). The advantages of this system are that it can be practiced anywhere by everybody and also it does not involve any complex system which makes it very cheap to be adopted.

2.6.2 Roof catchment without gutters

This form of rainwater harvesting is a way of harvesting rain from the roof without guttering as in the case of many rural settlements. In this system, containers are placed under the spout of a roof catchment of a structure to collect water during storms. This system is an improvement over the simple open catchment system of harvesting rainwater. However, the collected water may often miss the catching container as it falls from the roof and hence containers have to be pushed to follow the dropping rain. In order to ensure clean, pure harvested water, the first few drops are not collected but allowed to go waste before containers are placed under the roof to collect the water (Kyei-Baffour, 1987).

2.6.3 Roof catchment with gutters (guttered catchment)

This is an improvement of the roof catchment without gutters. It consists of using aluminium or ion sheets as gutters to direct the water into storage containers (Kyei-Baffour, 1987). With this system, enough quantities are harvested depending on the duration and intensity of the rains. However, there is the need to divert the first few drops away from the storage tank to avoid contamination by dust, leaves, blooms, twigs, insect bodies, animal faeces, pesticides, and other airborne residues deposited on the roof or catchment area (Krishna, 2005).

2.6.4 Block masonry tank catchment systems

Another technique which can be used to catch enough water for many days is block masonry tank which form part of the building or is placed underground. The major disadvantage is the fact that the foul flush is not diverted and these tanks are often uncovered. Sediments are allowed to settle before the taps or hand pumps provided are used. The purity of the water in such tanks is very bad. Often mosquitoes breed in them and algal growth is a common phenomenon since light is not excluded. However it represents a bold attempt at providing large storage containers (Kyei-Baffour, 1987).

2.7 Components of a rainwater harvesting system

A rainwater harvesting system regardless of its complexity consists of six basic components namely:

- Catchment surface: the collection surface from which rainfall runs off
- Gutters and downspouts: they channel water from the roof to the tank
- Leaf screens, first-flush diverters, and roof washers: components which remove debris and dust from the captured rainwater before it goes to the tank
- Storage tanks, also called cisterns

- Delivery system
- Treatment/purification: for potable systems, filters and other methods

2.7.1 Catchment surface

For domestic rainwater harvesting the most common surface for collection is the roof of the dwelling. Many other surfaces can be, and are, used: courtyards, threshing areas, paved walking areas, plastic sheeting, trees, etc. Most dwellings, however, have a roof. The style, construction and material of the roof affect its suitability as a collection surface for water. Typical materials for roofing include corrugated iron sheet, asbestos sheet; tiles (a wide variety is found), slate, and thatch (from a variety of organic materials). Most are suitable for collection of roofwater, but only certain types of grasses e.g. coconut and anahaw palm (Gould and Nissen Peterson, 1999); thatched tightly, provide a surface adequate for high quality water collection. The rapid move towards the use of corrugated iron sheets in many developing countries favours the promotion of RWH.

2.7.2 Gutters and downspouts

Guttering is used to transport rainwater from the roof to the storage vessel. Guttering comes in a wide variety of shapes and forms, ranging from the factory made PVC type to home-made guttering using bamboo or folded metal sheet. In fact, the lack of standards in guttering shape and size makes it difficult for designers to develop standard solutions to, say, filtration and first flush devices. Guttering is usually fixed to the building just below the roof and catches the water as it falls from the roof.

2.7.2.1 Gutter Sizing and Installation

The size and capacity of gutters depends on the roof area, slope, and hydraulic radius, time of concentration of the rain and rainfall intensity (Kyei-Baffour, 1987; Thomas, 1997). When using the roof of a house as a catchment surface, it is important to consider that many roofs consist of one or more roof "valleys". The roof valley tends to concentrate rainfall runoff from two roof planes before the collected rain reaches a gutter (Krishna, 2005).

Gutters should be installed with slopes towards the downspout; also the outside face of the gutter should be lower than the inside face to encourage drainage away from the building wall to prevent sagging which promotes pools that provide breeding places for mosquitoes (Kyei-Baffour, 1987; Cunliffe, 1998; Martinson and Thomas, 2003).

2.7.2.2 Gutter types

There is a staggering variety of guttering available throughout the world. This may include gutters made from prefabricated plastics to simple gutters made on-site from sheet metal and even bamboo.

- **Plastic**

Gutters made from extruded plastic are popular in high-income countries; they are durable and relatively inexpensive. Mounting is usually by way of purpose built brackets and there is an array of hardware for joining, downpipe connection and finishing ends. They are less available in low-income countries and tend to be expensive, however, in countries with a good industrial base, such as Mexico, India and Sri Lanka, plastic gutters are readily available for reasonable prices (Martinson, 2007).

- **Aluminium**

Aluminium guttering is extremely popular in countries such as Australia and the USA where it dominates the market. It is rolled on-site from coils of sheet metal in lengths to suit the house, eliminating in-line joints. Aluminium is naturally resistant to corrosion and so the gutters should last indefinitely. In low-income countries where it is available, the cost of the sheet is over 1.5 times the cost of steel of the same gauge and the material is less stiff so for a similar strength of gutter a larger gauge of material is required, resulting in gutters up to three times the price. This makes aluminium gutters prohibitively expensive; however aluminium sheet is growing in markets in low-income countries so the price will come down over time (Martinson, 2007).

- **Steel**

In Africa galvanised sheet steel gutters dominate. They are either made in small workshops in lengths and joined together or can even be made on-site by builders. Workshop-made gutters usually have square section and can employ an upstand to aid interception whereas on-site gutters are usually of a v-shape as described by Nissen-Peterson (1990). The shape is quite efficient but reportedly has a tendency to block with debris. Mounting the v-shape is also more difficult and they are usually tied directly under the roof or onto a splashguard (Martinson, 2007).

- **Wood and bamboo**

Wooden planks and bamboo gutters are widely described in literatures. They are usually cheap (or even free) and all money tends to stay in the community. They do, however, suffer from problems of longevity as the organic material will eventually rot away and leak. The porous surface also forms an ideal environment for accumulation of bacteria that may be subsequently washed into the storage tank (Martinson, 2007).

- **Half pipe**

Half pipes have been proposed as an inexpensive form of guttering and are used in many areas. It is relatively simple to be manufactured and the semi-circular shape is extremely efficient. The cost of these gutters depends on the local cost of PVC pipe, which may be more expensive than an equivalent sheet metal gutter and the opening size at the top is fixed to the standard sizes of pipe available which may not be appropriate. A variant on the half pipe is a full pipe with a slit or groove cut into it and mounted over the edge of the roof enclosing the edge.

2.7.3 First-flush diverters, Leaf screens, and roof washers

2.7.3.1 First-Flush Diverters

Debris, dirt, dust and droppings will collect on the roof of a building or other collection area. When the first rains arrive, this unwanted matter will be washed into the tank. This will cause contamination of the water and the quality will be reduced. Many RWH systems therefore incorporate a system for diverting this 'first flush' water so that it does not enter the tank. The simpler ideas are based on a manually operated arrangement whereby the inlet pipe is moved away from the tank inlet and then replaced again once the initial first flush has been diverted. This method has obvious drawbacks in that there has to be a person present who will remember to move the pipe. Other systems use tipping gutters to achieve the same purpose. The most common system uses a bucket which accepts the first flush and the weight of this water off-balances a tipping gutter which then diverts the water back into the tank. The bucket then empties slowly through a small-bore pipe and automatically resets. The process will repeat itself from time to time if the rain continues to fall, which can be a problem where water is really at a premium. In this case a tap can be fitted to the bucket and will be operated manually. The quantity of water that is flushed is dependent on the force required to lift the guttering. This can be adjusted to suit the needs of the user.

2.7.3.2 Leaf washers

Removal of debris that gathers on the catchment surface ensures high quality water for either potable use or to work well without clogging irrigation emitters. Essentially, mesh screens remove debris both before and after the storage tank. Leaf screens must be regularly cleaned to be effective. If not maintained, leaf screens can become clogged and prevent rainwater from flowing into a tank. Built-up debris can also harbour bacteria and the products of leaf decay (Krishna, 2005).

2.7.3.3 Roof Washers

The roof washer, placed just ahead of the storage tank, filters small debris for potable systems and also for systems using drip irrigation. Roof washers consist of a tank, usually between 136 – 227 litres in capacity, with leaf strainers and a filter. One commercially available roof washer has a 30-micron filter. All roof washers must be cleaned. Without proper maintenance they not only become clogged and restrict the flow of rainwater, but may themselves become breeding grounds for pathogens (Krishna, 2005).

2.7.4 Rainwater Cisterns/storage facilities

The water storage tank usually represents the biggest capital investment element of a domestic RWH system. It therefore usually requires careful design – to provide optimal storage capacity while keeping the cost as low as possible. The catchment area is usually the existing rooftop or occasionally a cleaned area of ground and guttering can often be obtained relatively cheaply, or can be manufactured locally.

There are an almost unlimited number of options for storing water. Common vessels used for very small-scale water storage in developing countries include such examples as plastic bowls and buckets, jerry cans, clay or ceramic jars, cement jars, old oil drums, empty food containers, etc. For storing larger quantities of water the system will usually require a tank or a cistern. For the purpose of this document we will classify the tank as an above-ground storage vessel and the cistern as a below-ground storage vessel. These can vary in size from a cubic metre or so (1000 litres) up to hundreds of cubic metres for large projects, but typically up to a maximum of 20 or 30 cubic metres for a domestic system. In some areas sand or pea gravel over well-compacted soil may be sufficient for a small tank otherwise a concrete pad should be constructed. The tank must also be positioned so that run-off will not undermine or erode the place where it is sited (Lundgren and Åkerberg, 2006). It is very necessary that all tanks (aboveground and belowground) must have vents to expel air as rainwater enters the tank and draw air in as rainwater is pumped out of the tank. If the tank overflow does not have a water trap, air can be displaced through the overflow as rainwater enters the tank. In these cases, the vent only needs to be as big in diameter as the water supply line leaving the tank. If air cannot leave the tank through the overflow, the vent diameter should be 1 ½ times the diameter of the inlet pipe (Brand *et. al.*, 2009).

2.7.4.1 Rain barrel

Rain barrel is one of the simplest and commonest rainwater storage tanks used by many rural households in Ghana. According to Martinson (2007), some commercially available rain barrels are manufactured with overflow pipes linking a series of barrels. It is, however, fairly expensive in most instances compared to the other designs since the cost of the joined barrels is dominated by welding.

2.7.4.2 Galvanised steel tanks

The most common material used in the manufacture of rainwater tanks is galvanised steel. Galvanised steel is not inherently resistant to corrosion but it is available with rust-resistant coatings such as Zincalume or Aquaplate. Initial corrosion of galvanised steel normally leads to the production of a thin adherent film that coats the surface of the tank and provides protection against further corrosion. It is important when cleaning such tanks not to disturb this film. New tanks may leach excess concentrations of zinc, which could affect the taste of the stored rainwater, but is not a health risk. These tanks may need to be flushed before use.

2.7.4.3 Ferrocement tanks

Concrete and ferro-cement tanks are strong and long lasting and can be installed underground. New tanks may impart tastes and may leach lime, thereby increasing the pH of water. These tanks may need to be flushed before use.

2.7.4.4 Bamboocrete tanks

Bamboocrete is a composite material consisting of thinly formed cement mortar matrix which is highly reinforced with small-sized bamboo splints (Kyei-Baffour, 1987). The bamboo tanks usually have a large storage capacity (1,000 to 2,000 litres), are quite inexpensive and easy to clean. However, bamboo reinforced tanks have been tried but were quickly attacked by termites, bacteria and fungus (Kyei-Baffour, 1987; Martinson and Thomas, 2007).

2.7.4.5 Corrugated iron sheet tanks

These can be constructed with special roller machines. The soldered joints have strength limitation to carry water which is very heavy. However, these tanks can be bought and installed. They are affected by rough handling and transportation and after some years leakage occur due to corrosion. This can be prevented by coating tanks with bitumen and placing them on reinforced concrete foundation with an extension for ferrocement coating of the outside wall of the tank (Kyei-Baffour, 1987).

2.7.4.6 Brick or stone masonry tanks

Tanks constructed of brick or stone masonry are used and are usually larger than the metal tanks. The walls are cylindrical and bounded by cheap lime mortar or more expensive cement mix. For heights above 2m, reinforcement along the outer side edges becomes necessary. This can be provided by one or more steel bands around the outer circumference of the tank (Kyei-Baffour, 1987).

2.7.4.7Clay pots

Clay and concrete tiles are both porous. Easily available materials are suitable for potable or non-potable systems, but may contribute to as much as a 10 % loss due to texture, inefficient flow, or evaporation (Lundgren and Åkerberg, 2006). In order to reduce water loss, there is the need to improve upon its glazing techniques (Kyei-Baffour, 1987).

2.7.4.8 Fibreglass

Fibreglass tanks suitable for collecting rainwater are available. These tanks are manufactured with a food-grade coating on their interior surface. The coating is cured before the tanks are offered for sale. The tanks should also be manufactured to prevent the entry of light, which could encourage algal growth.(Chapman, 1985). Guidance on use of rainwater tank.

2.7.4.9 Plastic tanks and tanks with plastic liners

Increasing ranges of tanks manufactured from synthetic polymers including polyethylene are becoming available. Plastic tanks and plastic liners should be constructed of materials that are at least of a food-grade standard (compliant with AS 2070) and preferably that comply with the requirements of AS/NZS 4020. Plastic tanks should be manufactured to prevent the entry of light. (Chapman, 1985). Guidance on use of rainwater tank.

2.7.5 Treatment/purification

For a non-potable system used for hose irrigation, if tree overhang is present, leaf screens on gutters and a roof washer 0.09 square metres of roof is sufficient. If drip irrigation is planned, however, sediment filtration may be necessary to prevent clogging of emitters. As standards differ, the drip irrigation manufacturer or vendor should be contacted regarding filtering of water (Krishna, 2005).

For potable water systems, treatment beyond the leaf screen and roof washer is necessary to remove sediment and disease-causing pathogens from stored water. Treatment generally consists of filtration and disinfection processes in series before distribution to ensure health and safety (Krishna, 2005).

2.8 Water Requirements (Per capita consumption)

Basically, water requirements or per capita consumption of water varies from one geographical region to another. In very advance economies where water is abundant and cheap, per capita consumption of water can be as high as 1,000 litres a day per household whereas in water scarce regions and rural communities in the tropics, its use might be as little as 12 litres a day for a household which is below the WHO recommendations of 100 litres a day (Martinson and Thomas, 2003). According to Cunliffe (1998), water demand depends on:

- the number of people using the water,
- average consumption per person,
- the range of uses (drinking, cooking, bathroom, laundry, toilet, irrigation, etc), and
- the use of water conservation devices.

However, the purpose for which water is needed and the quantity of water needed are very paramount. Furthermore, Kyei-Baffour (1987) grouped the types of water needed as:

- clean water for use in the house
- fairly clean water for livestock, poultry, etc.
- unclean water for irrigating crops.

It should however, be noted that clean water can be used for all purposes, but since it is most difficult to collect and store, it is not reasonable to use it when more easily accessible water can be utilized (Kyei-Baffour, 1987).

2.9 Sizing the Storage Tank

There are several methods for sizing storage reservoirs. These methods vary in complexity and sophistication.

- demand side approach (dry season demand versus supply)
- supply side approach (graphical methods)

The first method is the simplest method and most widely used. The second method uses statistical indicators of the average rainfall for a given place.

If rainfall is limited and shows large fluctuations then a design based on only one single statistical indicator can be misleading.

Method 1: Demand side approach (dry season demand versus supply)

According to Chapman (1985), this is the simplest method to calculate the storage requirement based on the required water volume (consumption rates) and occupancy of the building. This approach is only relevant in areas with a distinct dry season. The tank is designed to meet the necessary water demand throughout the dry season. To obtain required storage volume the following equation can be used:

$Dd = C \times N \times Nd\ (365\ days)\ Eq[2.1]$

Dd = Demand

C = Water use

N = Household Members

Nd = Number of days in a year

This equation provides the water demand in litres per year. Dividing by 12 months will give the required water demand in litres/month. The required monthly water demand multiplied by the dry period will give the required storage capacity for a given household size.

$RS = Dd \times Dp\ Eq[2.2]$

RS = Required storage capacity

Dd = demand

Dp =*dry period*

This simple method can be used in situations where there is sufficient rainfall in the rainy season that can be harvested and an adequate roof or catchment area. It is a method for calculating rough estimates of the monthly required tank size and it does not take into account variations between different years, such as the occurrence of drought years. The method is easy to understand and is sufficient in many cases. It can be used in the absence of any rainfall data.

Method 2: Supply side approach (graphical methods)

Supply side implies catching whatever available water there is from the source during the surplus period to be used in the deficit period. To estimate the most appropriate storage tank capacity for maximising supply is to represent roof run-off and daily consumption graphically. This method will give a reasonable estimation of the storage requirements. Daily or weekly rainfall data is required for a more accurate assessment. In low rainfall areas where rainfall has an uneven distribution there may be an excess of water during some months of the year, while at other times there will be a deficit. If there is sufficient water to meet the demand throughout the year, then sufficient storage will be required to bridge the periods of scarcity. As storage is expensive, this should be calculated carefully to avoid unnecessary expenses. This method will give an estimation of the storage requirements. (Chapman, 1985), Guidance on use of rainwater tank.

2.10 Rainfall patterns in Ghana

The climate of Ghana is tropical, but temperatures vary with season and elevation. Except in the northern part of Ghana, two rainy seasons occur, from March to July and from September to November. In the northern part of Ghana, the rainy season begins in April and lasts until September. Annual rainfall ranges from about 1,100 mm in the north to about 2,100 mm in the southwest. The harmattan, a dry desert wind, blows from the northeast from December to March, lowering the humidity and creating hot days and cool nights in the north. In the south the effects of the harmattan are felt in January. In most areas the highest temperatures occur in March, the lowest in August. In the tropical and humid; the whole country; average low 20.5 °C, average high 26 °C, Accra; average daily temperature is 30 °C . The coolest time of year is between June and September when the main rainfall occurs. Variations in temperature both annually and daily are quite small. The minimum temperature is around 23 °C. Warm and comparatively dry along southeast coast; hot and humid in southwest; hot and dry in north. Ghana web, Ghana, geography, location and climate.

CHAPTER THREE

METHODOLOGY

3.1 Methods

The research method was based on interview that used systematic random sampling technique and it involved 100 respondents. The survey was carried out with the aim of obtaining the roof catchment area for rainwater harvesting in the study area.

Secondary data (sources) which include the rainfall data over 10 years was collected at Ghana Meteorological Agency, Accra.

3.1.1 Study Area

The study was carried out in Nmai Djorn, Accra; which is part of Adenta Municipal Assembly. The population of the study area is seventy eight thousand two hundred and fifteen (78215) as of 2010 Adenta Municipal Assembly. The area lies located at latitude 5°33" 00" N and longitude 0° 12" 00" W.

3.2 Design of Rainwater harvesting system

3.2.1 Introduction

The design of rainwater harvesting facilities for domestic use is often traditionally approached from only water demand point of view rather than the rainfall intensity and pattern, and available roof surfaces that allow for rainwater collection and storage. This approach has left the resource under exploited in both urban and rural communities because structures have not been put in place to maximize rainwater collection and storage and usage. Currently, non-availability of large roof surfaces in rural communities place some limitation on the quantity of rainwater that can be harvested during the rainy season.

For any given roof surface area, the quantity of water collected during a rainstorm, Q is given as:

$Q = I \times A \times C \; Eq[3.1]$

Where,

I is the rainfall intensity (mm/h)

A is the surface area of the roof (m^2)

C is the runoff Coefficient.

3.2.2 Average annual rainfall of the study area

Daily rainfall data for the study was collected from the weather station at Ghana Meteorological Agency Accra. The average annual rainfall of 830.89 mm for period of ten years (2001 – 2010) was estimated from the daily rainfall data. The average monthly rainfall is also estimated as 69.24 mm.

3.2.3 Number of days without rainfall in the study area

The number of days without rain was estimated from the rainfall data obtained from the Ghana Meteorological agency Accra. The length of the dry season was estimated as 180 days.

3.2.4 Number of people to be served (Population to be served)

Since the system to be designed is intended for use by individual households, the average number of people in the household was estimated to be five (5) .The average daily water consumption was estimated at 76 litres per person per day (**Ernest Mensah Abraham** ***et al.*** 2007). The first step in designing a rainwater harvesting system is to consider the annual household water demand.

$ADd = C \times N \times Nd \; (365days) \; Eq[3.2]$

ADd = Annual Household Water Demand

3.2.5 Roof Catchment area

The effective area of the catchment surface was estimated from the area in plan under consideration. The odometer wheel was used to estimate the lengths and widths of the individual structures and a factor 'f', applied to the catchment surfaces considered. For the purpose of this research, f was chosen as (0.9) since almost all the catchment surfaces considered were corrugated sheets and impermeable with low level of losses.

3.2.6 Sizing the storage tank

Method 1: Demand side approach (dry season demand versus supply)

To obtain required storage volume using method1the following equation was used:

$$Dd = C \times N \times Nd\ (365\ days)\ Eq[3.3]$$

This equation provides the water demand in litres per year. Dividing by 12 months will give the required water demand in litres/month. The required monthly water demand multiplied by the dry period will give the required storage capacity.

$$Rs = Dd \times Dp\ Eq[3.4]$$

Method 2: Supply side approach (graphical methods)

Another method to estimate the most appropriate storage tank capacity for maximising supply is to represent roof run-off and daily consumption graphically. This method will give a reasonable estimation of the storage requirements. Daily or weekly rainfall data is required for a more accurate assessment. In low rainfall areas where rainfall has an uneven distribution there may be an excess of water during some months of the year, while at other times there will be a deficit. If there is sufficient water to meet the demand throughout the year, then sufficient storage will be required to store water.

3.2.7 Gutter slope

For the purpose of the study, a slope of 19°or a gradient of (0.344) was adopted and used for all calculations.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

Chapter 4 of the study presents the results of the survey conducted; the keys words are roof catchment and storage characteristics, cumulative water harvested and cumulative demand and relationship between the tank sizes.

4.2 Result of survey

4.2.1 Roof catchment and storage characteristics

From the results as shown in Table4.1, is the roof catchment area characteristic of the selected houses of the study area and. The results show that 41% out of the 100 selected houses have roof catchment area between 100 and 200 m^2. 26% of the selected houses have roof catchment area between 200 and 300 m^2 and 21% of the selected houses have roof catchment area between 300 and 400 m^2.

Table 4.1.Rroof catchment area characteristics and frequency

Roof catchment sizes of the selected houses	Frequency
< 100	4
100-200	41
200-300	26
300-400	21
400-500	3
≥500	5
Total	100

From the survey conducted, Figure 4.1 shows that most of the houses have roof catchment area greater than 350 m^2 and use poly tank of size 7000 litres and less than 300 m^2 uses poly tank of size 5000 litres and few of the roof catchment areas are greater than 400 m^2 use 10000 litres.

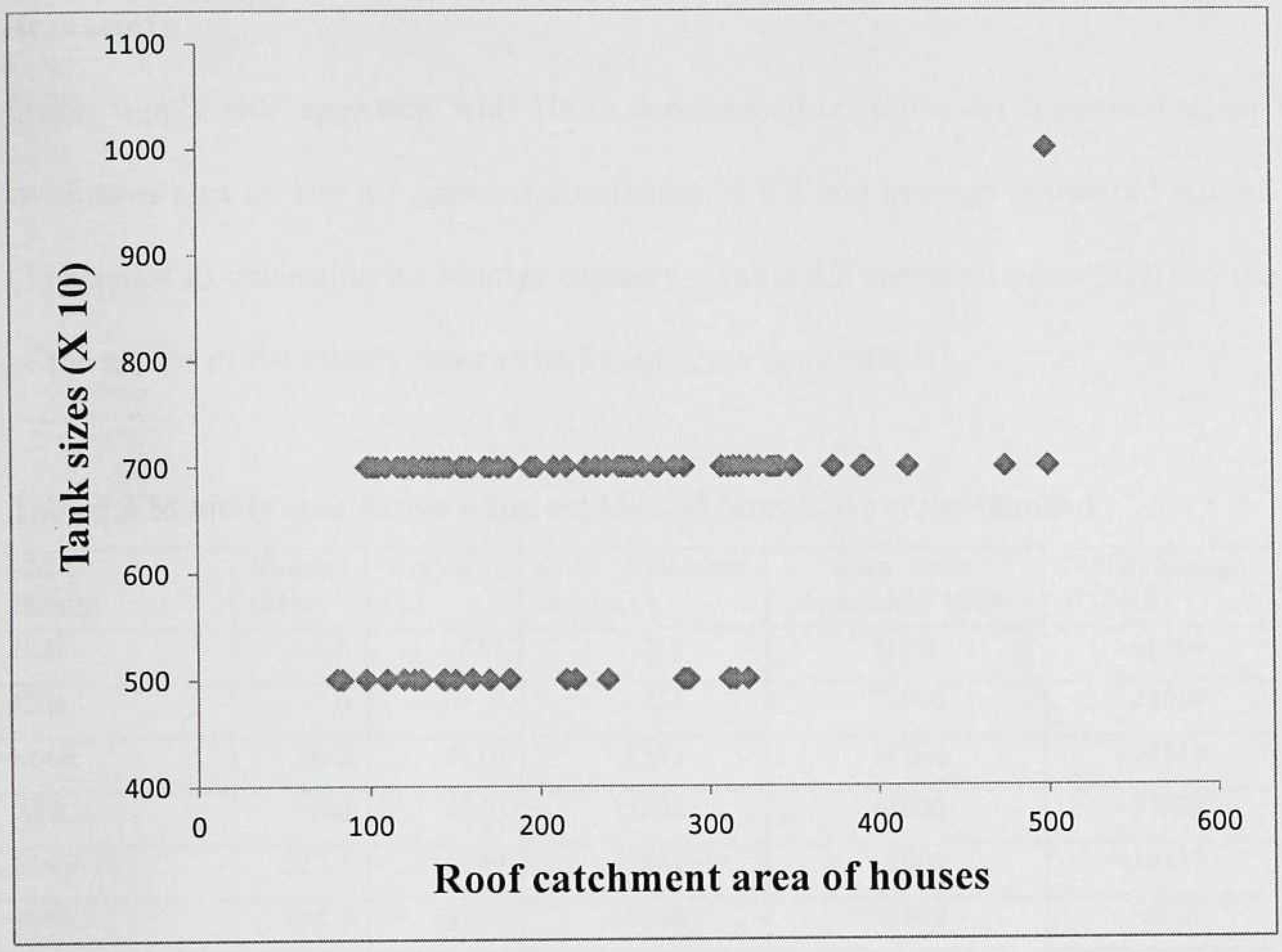

Figure 4. 1: The relationship between the roof catchment area of houses and the storage tank characteristics

The graph indicates the existing size of the roof catchment area in the study area and the storage tank that are currently in use of the households.

4.2.2 Supply side approach (graphical methods)

During some months of the year, there may be an excess of harvested water over demand, while at other times there will be a deficit. If there is enough harvested water throughout the year to meet the demand according to roof catchment size, then sufficient storage capacity will be required to bridge the periods of scarcity. This is a scenario used to determine the storage capacity.

Scenario1a

Using supply side approach with 100% dependency on rainwater harvested under roof catchment area of 100 m², run-off coefficient of 0.9 and average household size of five (5) persons to determine the storage capacity . Table 4.2 represent year 2001and the rest of the results of the other years can be found at the Appendix III.

Table4.2 Monthly cumulative water supply and cumulative water demand

2001 Months	Rainfall (MM)	Supply (L)	Cum. Rainwater supply(L)	Cum. water demand(L) 100%	Deficit/Storage 100%(L)
JAN	2.6	234	234	11400	-11166
FEB	0	0	234	22800	-22566
MAR	90.2	8118	8352	34200	-25848
APR	106	9540	17892	45600	-27708
MAY	222.1	19989	37881	57000	-19119
JUN	246.7	22203	60084	68400	-8316
JUL	16.3	1467	61551	79800	-18249
AUG	3.6	324	61875	91200	-29325
SEP	77.7	6993	68868	102600	-33732
OCT	20.7	1863	70731	114000	-43269
NOV	29.8	2682	73413	125400	-51987
DEC	21.5	1935	75348	136800	-61452

Table 4.2 shows the comparison of cumulative water harvested and cumulative water demand of 2001. It can be noted that there is a deficit in all of the months, meaning that supply cannot meet the demand under a scenario of 100 m² roof area and 100% dependency of 5 persons on rainwater usage.

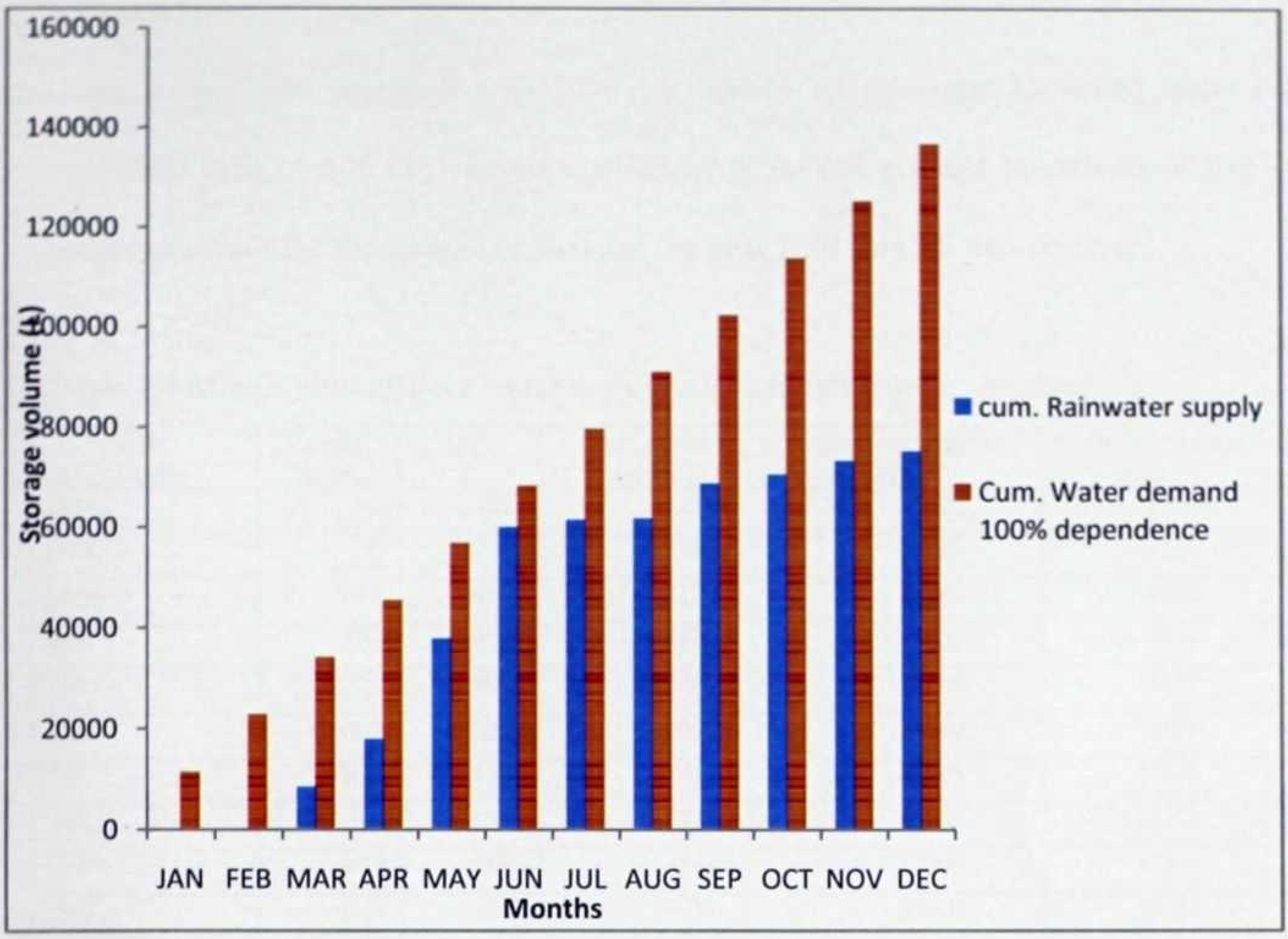

Figure 4.2: The predicted cumulative water supply (inflow) and cumulative water demand (outflow) under 100m²of 100% dependency

There was no excess water to be stored in that particular year. The cumulative demand far exceeds the cumulative supply.

Table 4.3: shows the summary of the deficit and storage for the ten years period of rainfall data of 100% dependency on rainwater usage under 100 m² roof catchment area.

Table 4.3: The summary of the deficit and storage for the ten years period of rainfall

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-11166	-1275	-11166	-10077	-11400	-10617	-11400	-11184	-10959	-8655
FEB	-22566	-10488	-21720	-19884	-22125	-21477	-21234	-22584	-21009	-13278
MAR	-25848	-18441	-30861	-30807	-22095	-30555	-27009	-29205	-25335	-21744
APR	-27708	-17853	-22911	-39831	-30588	-38625	-30813	-22101	-26673	-31668
MAY	-19119	-16770	-27903	-39936	-32178	-28731	-29100	2076	-31548	-33303
JUN	-8316	9684	-36423	-40851	-28530	-29502	-25560	810	-24435	-18153
JUL	-18249	1128	-44511	-48777	-35745	-37113	-26349	1218	-26340	-21615
AUG	-29325	-9669	-53580	-58521	-44652	-47064	-31440	-7554	-36813	-30594
SEP	-33732	-19035	-61398	-60903	-53532	-52065	-34821	-16308	-47853	-37134
OCT	-43269	-24999	-63564	-64428	-56742	-56661	-40272	-22200	-59019	-41361
NOV	-51987	-35193	-71265	-73794	-60447	-67053	-47676	-22953	-69519	-47433
DEC	-61452	-136800	-81270	-84762	-66807	-78444	-58716	-31977	-76842	-53640

Scenario1b

Using supply side approach with 50% dependency on rainwater harvested under roof catchment area of 100 m², run-off coefficient of 0.9and average household of five (5) people to determine the storage capacity of the year 2001 rainfall data collected.

Table 4.4 Monthly cumulative water supply and cumulative water demand

2001 Months	Rainfall (MM)	Supply L	Cum. Rainwater supply (L)	Cum. water demand 50% (L)	Deficit/Storage 50% (L)
JAN	2.6	234	234	5700	-5466
FEB	0	0	234	11400	-11166
MAR	90.2	8118	8352	17100	-8748
APR	106	9540	17892	22800	-4908
MAY	222.1	19989	37881	28500	9381
JUN	246.7	22203	60084	34200	25884
JUL	16.3	1467	61551	39900	21651
AUG	3.6	324	61875	45600	16275
SEPT	77.7	6993	68868	51300	17568
OCT	20.7	1863	70731	57000	13731
NOV	29.8	2682	73413	62700	10713
DEC	21.5	1935	75348	68400	6948

Table 4.4 shows the comparison of cumulative water harvested and cumulative water demand of the 2001 when the household dependency is 50%. It can be noted that for some of the months, the demand exceed the supply which then becomes the deficit and the excess water can be store to meet the water shortage.

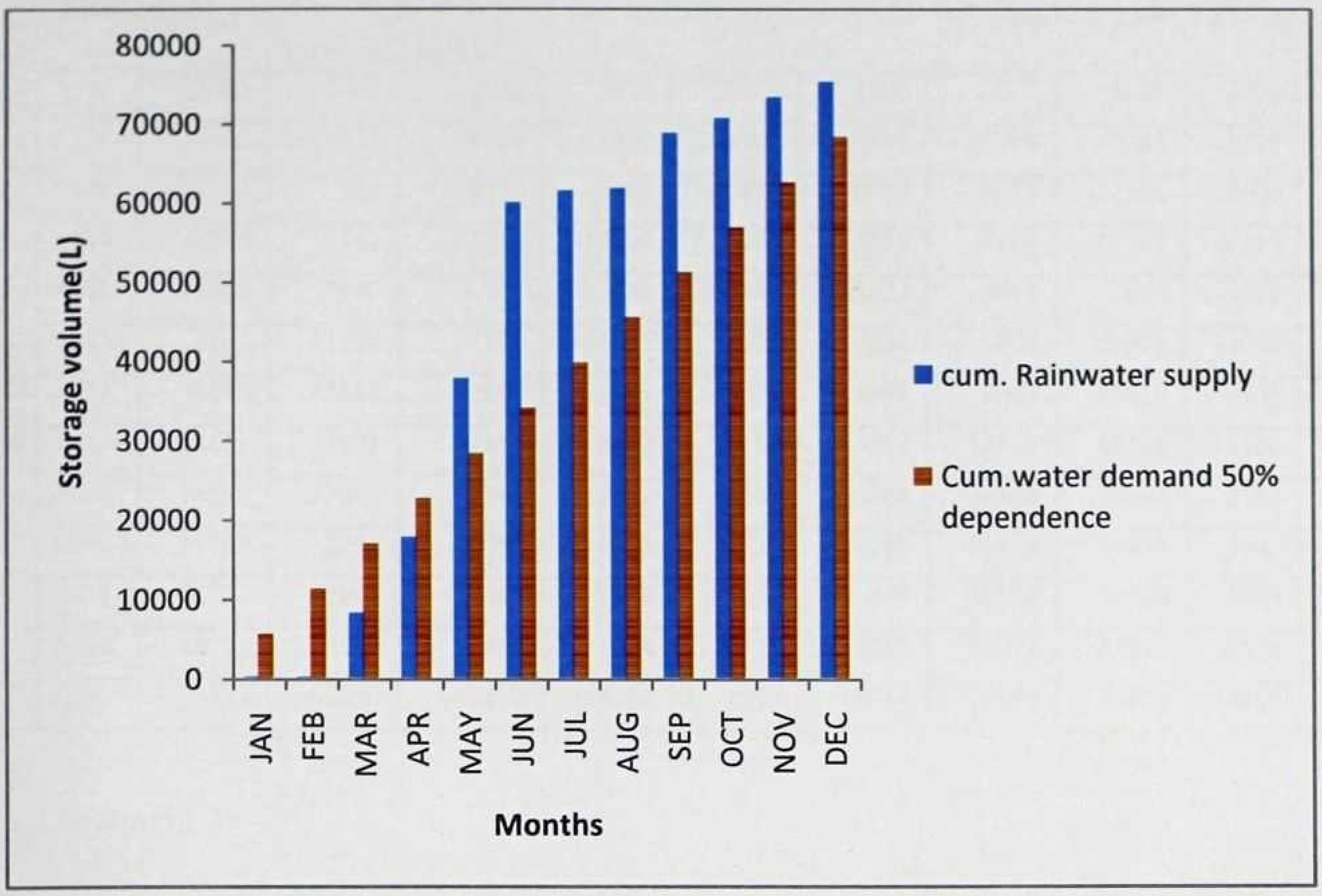

Figure 4.3: The predicted cumulative water supply (inflow) and cumulative water demand(outflow) under 100m²of 50% dependency

Figure 4.3 shows the predicted cumulative water supply (inflow) and cumulative water demand (outflow) from the tank. The maximum storage requirement occurs in June at 25884 litres. All this water will have to be stored to cover the shortfall during the dry period. In this case the storage capacity of the year 2001 when the household dependency on rainwater harvested is 50% will be 25884 litres or 25.9 cubic meters tank.

Table4. 5 shows the summary of the deficit and storage for the ten years period of rainfall data of 50% dependency on rainwater usage under 100 m² roof catchment area.

Table4. 5: The summary of the deficit and storage for the ten years period of rainfall data

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-5466	4425	-5466	-4377	-5700	-4917	-5700	-5484	-5259	-2955
FEB	-11166	912	-10320	-8484	-10725	-10077	-9834	-11184	-9609	-1878
MAR	-8748	-1341	-13761	-13707	-4995	-13455	-9909	-12105	-8235	-4644
APR	-4908	4947	-111	-17031	-7788	-15825	-8013	699	-3873	-8868
MAY	9381	11730	597	-11436	-3678	-231	-600	30576	-3048	-4803
JUN	25884	43884	-2223	-6651	5670	4698	8640	35010	9765	16047
JUL	21651	41028	-4611	-8877	4155	2787	13551	41118	13560	18285
AUG	16275	35931	-7980	-12921	948	-1464	14160	38046	8787	15006
SEP	17568	32265	-10098	-9603	-2232	-765	16479	34992	3447	14166
OCT	13731	32001	-6564	-7428	258	339	16728	34800	-2019	15639
NOV	10713	27507	-8565	-11094	2253	-4353	15024	39747	-6819	15267
DEC	6948	-68400	-12870	-16362	1593	-10044	9684	36423	-8442	14760

Scenario 2a

Using supply side approach with100% dependency on rainwater harvested under roof catchment area of 200 m², run-off coefficient of 0.9 and average household of five (5) to determine the storage capacity. This represent year 2001, the rest of the years can be found at the Appendix III.

Table4. 6: Monthly cumulative water supply and cumulative water demand

2001 Months	Rainfall (mm)	Supply (L)	Cum. Rainwater supply(L)	Cum. Water demand 100%(L)	deficit/storage 100%(L)
JAN	2.6	468	468	11400	-10932
FEB	0	0	468	22800	-22332
MAR	90.2	16236	16704	34200	-17496
APR	106	19080	35784	45600	-9816
MAY	222.1	39978	75762	57000	18762
JUN	246.7	44406	120168	68400	51768
JUL	16.3	2934	123102	79800	43302
AUG	3.6	648	123750	91200	32550
SEP	77.7	13986	137736	102600	35136
OCT	20.7	3726	141462	114000	27462
NOV	29.8	5364	146826	125400	21426
DEC	21.5	3870	150696	136800	13896

Table 4.6 shows the comparison of cumulative water harvested and cumulative water demand of 2001 when the household dependence is 100%. It can be noted that some of the

months the demand exceed the supply which then becomes deficit(minus) and some of the months supply exceed the demand, so the excess water can be store to meet the water shortage.

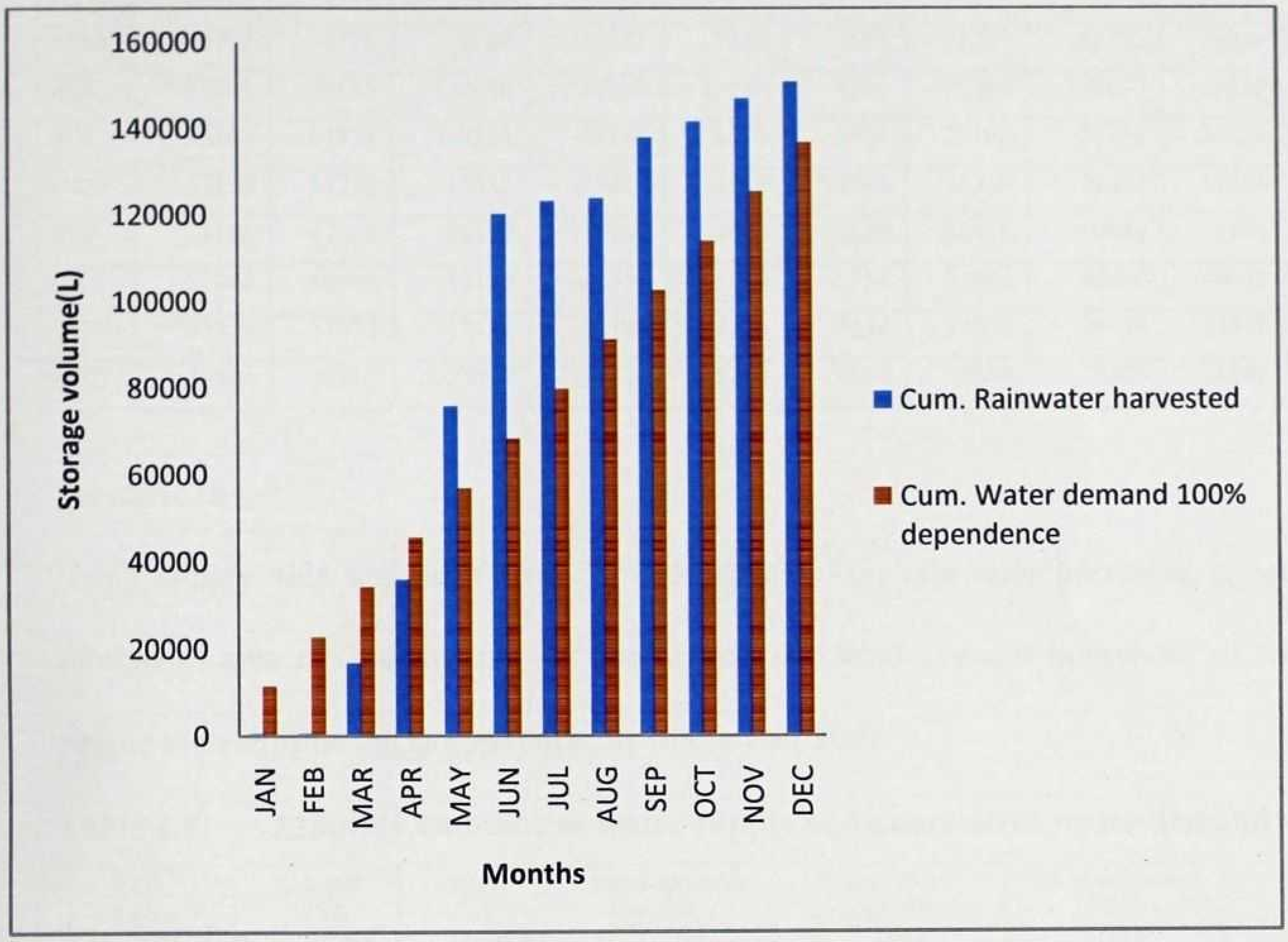

Figure 4.4: The cumulative water supply (inflow) and cumulative water demand (outflow) under 200 m²of 100% dependency

Figure 4.4 shows the cumulative water supply (inflow) and cumulative water demand (outflow) from the tank. The maximum storage requirement occurs in June at 51768 litres. All this water will have to be stored to cover the shortfall during the dry period. In this case the storage capacity of the year 2001 when the household dependence of the rainwater harvested is 100% under roof catchment area of 200 m² will be 51768 litres or 51.8 cubic meters tank.

Table 4.7 shows the summary of the deficit and storage for the ten years period of rainfall data of 100% dependency on rainwater usage under 200 m² roof catchment area.

Table 4.7:**The summary of the deficit and storage for the ten years period of rainfall**

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-10932	8850	-10932	-8754	-11400	-9834	-11400	-10968	-10518	-5910
FEB	-22332	1824	-20640	-16968	-21450	-20154	-19668	-22368	-19218	-3756
MAR	-17496	-2682	-27522	-27414	-9990	-26910	-19818	-24210	-16470	-9288
APR	-9816	-7188	-222	-34062	-15576	-31650	-16026	1398	-7746	-17736
MAY	18762	6378	1194	-22872	-7356	-462	-1200	61152	-6096	-9606
JUN	51768	70686	-4446	-13302	11340	9396	17280	70020	19530	32094
JUL	43302	64974	-9204	-17754	8370	5454	27102	82236	27120	36570
AUG	32550	54780	-15942	-25842	1956	-3048	28320	76092	17574	30012
SEP	35136	47448	-20178	-19206	-4404	-1650	32958	69984	6894	28332
OCT	27462	46920	-13110	-14856	576	558	33456	69600	-4038	31278
NOV	21426	37932	-17112	-22188	4566	-8646	30048	79494	-13638	30534
DEC	13896	27918	-25722	-32724	3246	-20028	19368	72846	-16884	29520

Scenario2b

Using supply side approach with 50% dependency on rainwater harvested under roof catchment area of 200 m², run-off coefficient of 0.9and average household of five (5) people to determine the storage capacity of the year 2001.

Table 4.8: Monthly cumulative water supply and cumulative water demand

2001 Months	Rainfall (MM)	Supply (L)	Cum. Rainwater supply(L)	Cum .Water demand 50%(L)	Deficit/Storage 50%(L)
JAN	2.6	468	468	5700	-5232
FEB	0	0	468	11400	-10932
MAR	90.2	16236	16704	17100	-396
APR	106	19080	35784	22800	12984
MAY	222.1	39978	75762	28500	47262
JUN	246.7	44406	120168	34200	85968
JUL	16.3	2934	123102	39900	83202
AUG	3.6	648	123750	45600	78150
SEP	77.7	13986	137736	51300	86436
OCT	20.7	3726	141462	57000	84462
NOV	29.8	5364	146826	62700	84126
DEC	21.5	3870	150696	68400	82296

Table4. 8 shows the comparison of cumulative water harvested and cumulative water demand of the 2001 when the household dependence is 50% under roof catchment. It can be noted that in some of the months the demand exceed the supply which then becomes

deficit(minus) and some of the months supply exceed the demand, so the excess water can be store to meet the water shortage/ deficit in some other months.

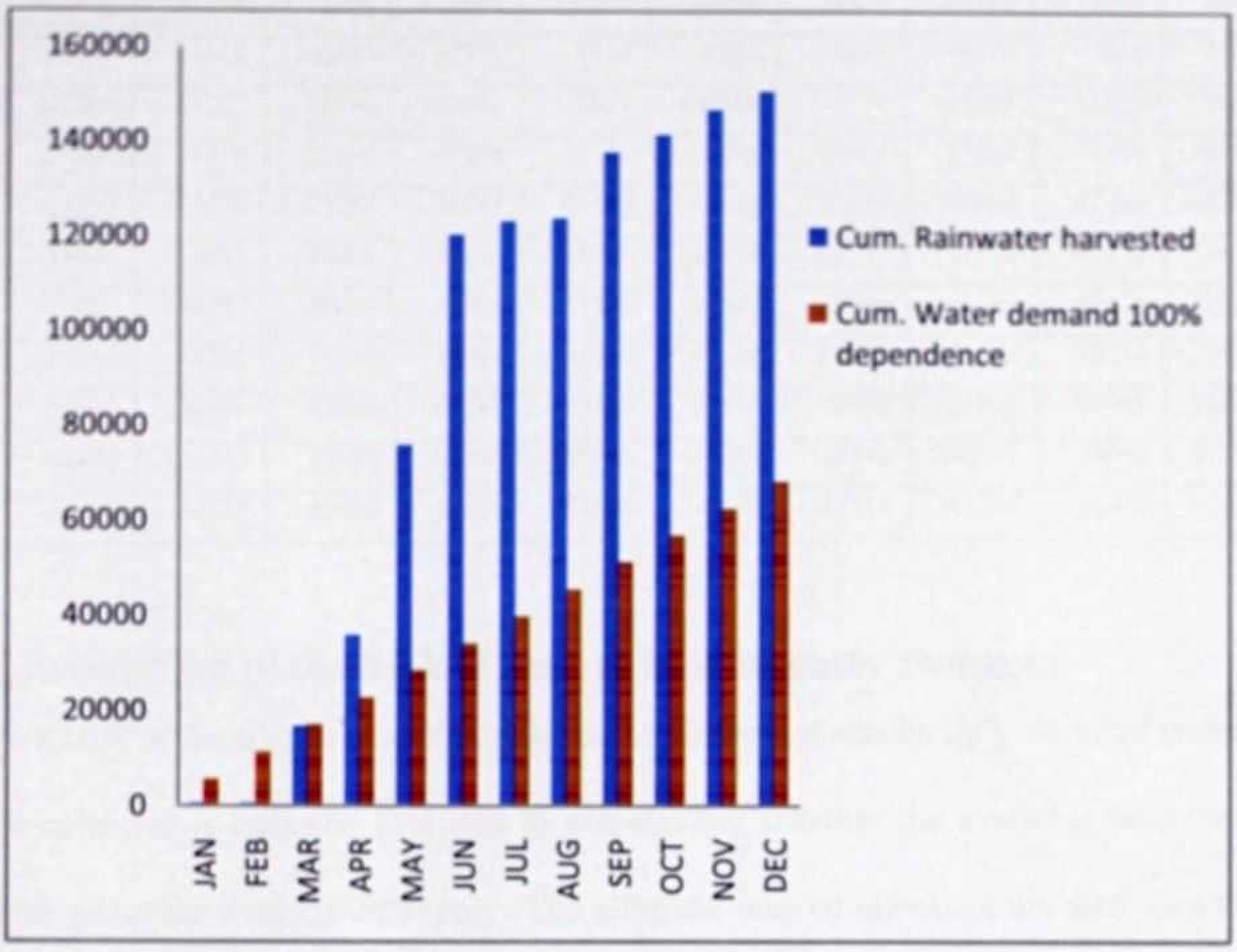

Figure 4.5: The predicted cumulative water supply (inflow) and cumulative water demand (outflow) under 200m²of 50% dependency

Figure 5 shows the predicted cumulative water supply (inflow) and cumulative water demand (outflow) from the tank. The maximum storage requirement occurs in June at 86436litres. All this water will have to be stored to cover the shortfall during the dry period. In this case the storage capacity of the year 2001 when the household dependency on the rainwater harvested is 50% under roof catchment area of 200 m²will be 86436litres or 86.4 cubic meters tank.

Table4. 9 shows the summary of the deficit and storage for the ten years period of rainfall data of 50% dependency on rainwater usage under 200 m² roof catchment area.

Table 4.9: The summary of the deficit and storage for the ten years period of rainfall data

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-5700	14550	-5232	-3054	-5700	-4134	-5700	-5268	-4818	-210
FEB	-11400	13224	-9240	-5568	-10050	-8754	-8268	-10968	-7818	7644
MAR	-17100	14418	-10422	-10314	7110	-9810	-2718	-7110	630	7812
APR	-22800	15612	22578	-11262	7224	-8850	6774	24198	15054	5064
MAY	-28500	34878	29694	5628	21144	28038	27300	89652	22404	18894
JUN	-34200	104886	29754	20898	45540	43596	51480	104220	53730	66294
JUL	-39900	104874	30696	22146	48270	45354	67002	122136	67020	76470
AUG	-45600	100380	29658	19758	47556	42552	73920	121692	63174	75612
SEP	-51300	98748	31122	32094	46896	49650	84258	121284	58194	79632
OCT	-57000	103920	43890	42144	57576	57558	90456	126600	52962	88278
NOV	-62700	100632	45588	40512	67266	54054	92748	142194	49062	93234
DEC	-68400	96318	42678	35676	71646	48372	87768	141246	51516	97920

4.2.3 Estimation of the Risk of Failure of Rainwater Storages

Where a tank is the sole source of supply, determining the maximum volume of water that can be collected is only the first step to determining whether the available tank capacity provides adequate security of supply. The simplest way of checking the tank size that is estimated to provide sufficient water throughout an average year is to use monthly rainfall data and assume that at the start of the wetter months the tank is empty. The following formula should then be used for each month:

$$Vt = Vt - 1 + C.A.Pt - D.N.dt \quad Eq[4.1]$$

V_t = theoretical volume of water remaining in the tank at the end of the month.

V_{t-1} = volume of water left in the tank from the previous month.

C = rainwater catchment run-off coefficient.

A = area of the roof catchment (m^2)

P_t = historic monthly precipitation (mm)

D = daily per capita demand (L/pers/day)

N = number of household members

dt = number of days in the month t

Starting with the tank empty then Vt-1 = 0. If, after any month, Vt exceeds the volume of the tank, then water will be lost to overflow. If Vt is ever a negative figure then this indicates that demand will exceed the available water supply. Providing the calculated annual run-off exceeds the annual water demand, Vt will only be negative if periodic overflows reduce the amount of water collected so it is less than the demand. If the water is to be met throughout the year, the tank should be large enough, so that Vt is never negative.

Monthly catchment calculation

Scenario3a:

Monthly catchment calculation for roof catchment area of 100 m^2, to assess the reliability of the 5000 litres storage tank used at the study area. The rest of the calculation of the other years is provided at the Appendix IV

Table4. 10: Monthly catchment calculation measures

Measures	calculation
Average daily water demand	= 76litres× (household of five)
	= (76× 5) ×30days
	= 11400litres/month
Monthly rainfall of the area	
Catchment area	= 100 m^2
Catchment efficiency	= 90% or 0.9
Run-off formula	= 0.9(efficiency) ×rainfall (monthly) × roof area
Tank size used in the area	= 5000litres

Table 4.11 shows the monthly catchment calculation for the year 2001. Assumption was made that at the beginning of the month (January) the storage tank is taken to be empty. The deficit at the remarks shows that the supply in the tank could not meet the demand.

Table 4.11: Monthly catchment calculation for 2001

Year Months	V_{t-1}	*C.A.Pt*	*D.N.dt*	V_t	Remarks
JAN	0	234	11400	-11168	Deficit
FEB	0	0	11400	-11400	Deficit
MAR	0	8118	11400	-3282	Deficit
APR	0	9540	11400	-1824	Deficit
MAY	0	19989	11400	3589	Overflow
JUN	5000	22203	11400	10803	Overflow
JUL	5000	1467	11400	-4933	Deficit
AUG	0	324	11400	-11076	Deficit
SEP	0	6993	11400	-4407	Deficit
OCT	0	1863	11400	-9537	Deficit
NOV	0	2682	11400	-8758	Deficit
DEC	0	1935	11400	-9565	Deficit

This shows the total overflow of 14392 litres leading the demand to exceed the supply.

10 months out of the 12 months the tank failed to supply water which means that the tank is not reliable to supply water for the household throughout that year 2001.

$$\textit{The percentage of water wasted} = \frac{\text{Total overflow}}{\text{Total demand}} \times 100 \ldots Eq[4.2]$$

$$\text{Total demand} = 76 \times 5 \times 365$$

$$= 138700$$

$$\textit{The percentage of water wasted} = \frac{14392}{138700} \times 100$$

$$= 10\%$$

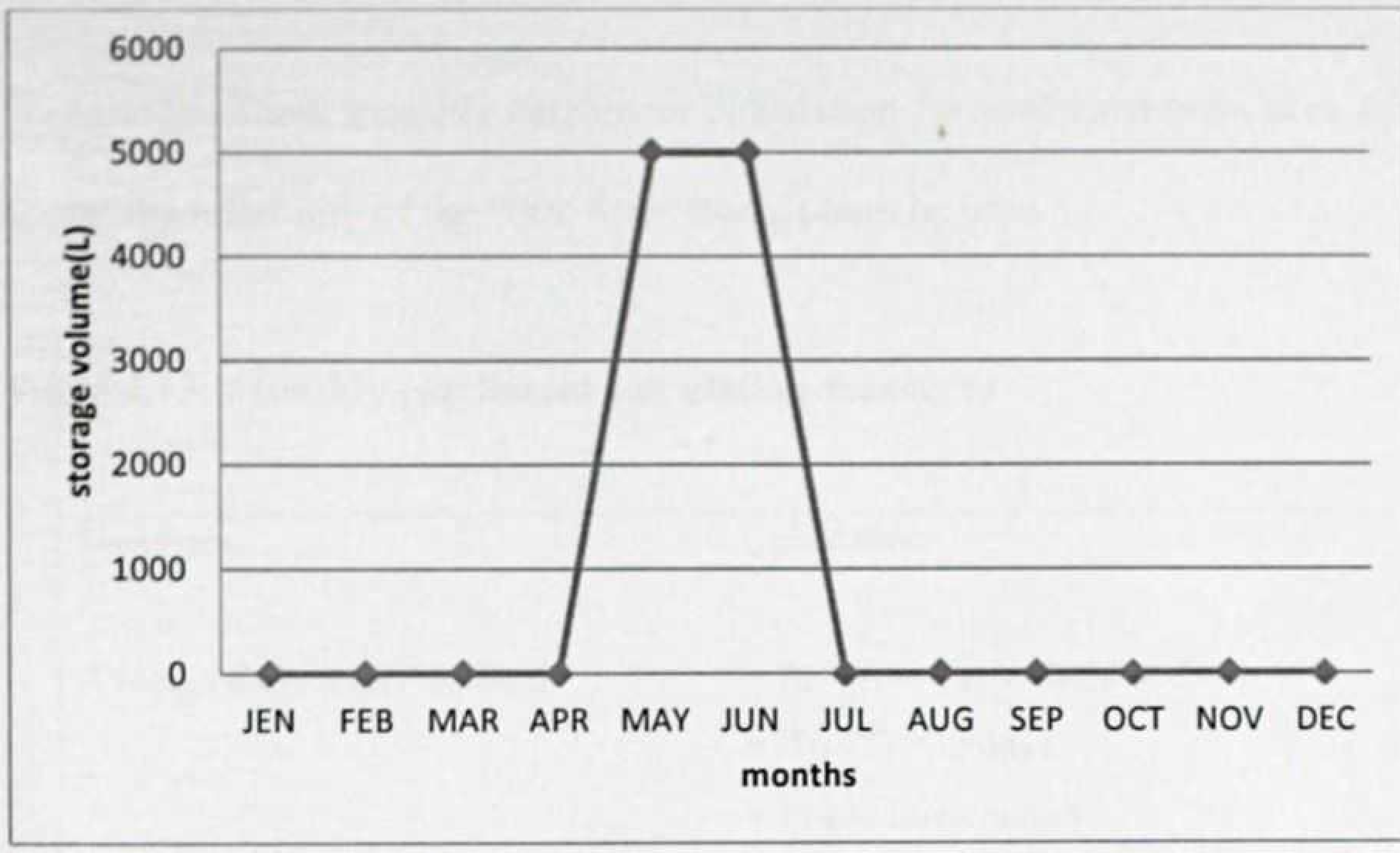

Figure 4.6: Monthly volume of stored rainwater under roof area of 100m² of 5000 litres tank

Figure 4.6 monthly volume of stored rainwater tank in 5000 litres rainwater tank for a household of 5persons for the year 2001 with the parameter values in Table4. 11, the tank supply met demand only at May and June.

Table 4.12: shows the summary of the deficit and overflow of the monthly catchment calculation of the ten years period of rainfall data using 5000 litres tank size under 100 m² roof area catchment size.

Table 12: The summary the deficit and overflow of the monthly catchment calculation

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-11168	-3556	-11166	-1007	-11400	-10617	-11400	-11184	-10959	-8655
FEB	-11400	-9213	-10554	-9807	-10725	-10860	-9834	-11400	-10050	-4623
MAR	-3282	-7953	-9141	-10923	30	-9078	-5775	-6621	-4326	-8466
APR	-1824	597	2950	-9024	-8407	-8070	-3804	2104	-1338	-9924
MAY	3589	1680	8	-465	-1590	4894	1713	24177	-4875	-1635
JUN	10803	23134	10788	-915	3648	4229	253	3734	2113	10150
JUL	-4933	-3556	-3088	-7926	-3567	-3382	4221	4124	3095	1538
AUG	-11076	-10797	-9069	-9744	-8907	-9951	-880	-4630	-7378	-7441
SEP	-4407	-9366	-7818	-2382	-8880	-5001	-3381	-8754	-11040	-6540
OCT	-9537	-5964	-2202	-3525	-3210	-4596	-5451	-5892	-11166	-4227
NOV	-8758	-10194	-7701	-9366	-3705	-10392	-7404	-753	-11400	-6072
DEC	-9565	-10707	-10005	-10968	-6342	-11391	-11040	-24	-7323	-6207

Scenario3b: Show monthly catchment calculation for roof catchment area of 100 m^2, to access the reliability of the 7000 litres storage tank be used.

Table 4.13: Monthly catchment calculation measures

Measures	Calculation
Average daily water demand	= 76 litres× (household of five) = (76× 5) ×30 days = 11400 litres/month
Month rainfall of the area	
Catchment area	= 100 m²
Catchment efficiency	= 90% or 0.9
Run-off formula	= 0.9(efficiency) ×rainfall (monthly) × roof area
Tank size used in the area	= 7000 litres

Table 4.14 shows monthly catchment calculation for the year 2001. Assumption was made that at the beginning of the month (January) the storage tank is taken to be empty.

Table 14: Monthly catchment calculation for the year 2001

Year/ Months	V_{t-1}	*C.A.Pt*	*D.N.dt*	V_t	Remarks
JAN	0	234	11400	-11168	Deficit
FEB	0	0	11400	-11400	Deficit
MAR	0	8118	11400	-3282	Deficit
APR	0	9540	11400	-1824	Deficit
MAY	0	19989	11400	1589	Overflow
JUN	7000	22203	11400	10803	Overflow
JUL	7000	1467	11400	-2933	Deficit
AUG	0	324	11400	-11076	Deficit
SEP	0	6993	11400	-4407	Deficit
OCT	0	1863	11400	-9537	Deficit
NOV	0	2682	11400	-8758	Deficit
DEC	0	1935	11400	-9565	Deficit

This show the total overflow of 12392 litres 10 months out of the 12 months the tank supply water to supply water which means that the tank is not reliable to supply water for the household throughout that year 2001.

$$\text{The percentage of water wasted} = \frac{\text{Total overflow}}{\text{Total demand}} \times 100\%$$

$$= \frac{12{,}392}{138{,}700} \times 100\%$$

$$= 8.9\%$$

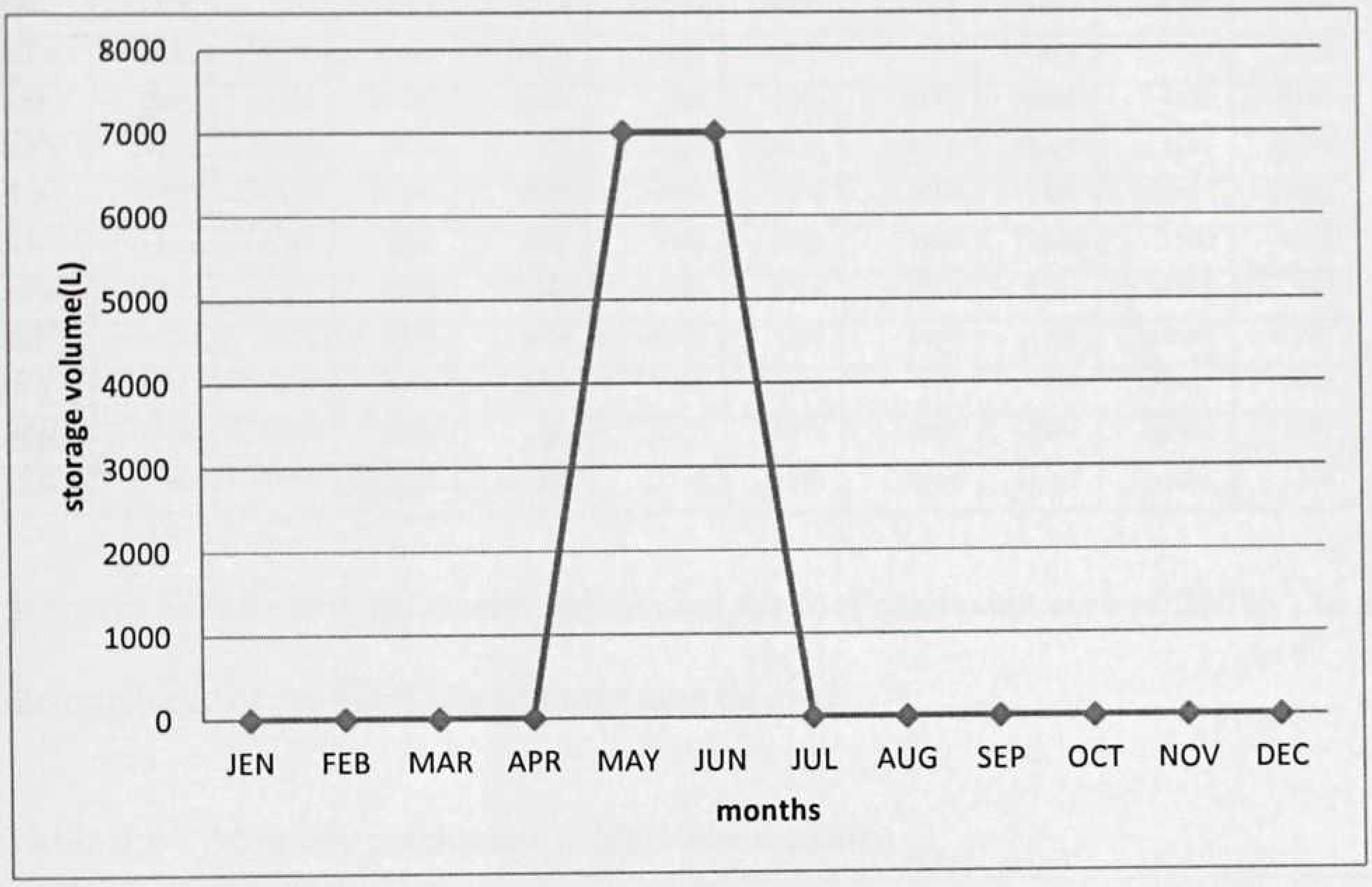

Figure 4.7: Monthly volume of stored rainwater under roof area of 100m² of 7000 litres tank

Figure 4.7 monthly volume of stored rainwater tank in 7000 litres rainwater tank for a household of 5 persons for the year 2001 with the parameter values in Table 4.14, the tank supply water to the household at May and June.

Table 4.15 shows the summary of the deficit and overflow of the monthly catchment calculation of the ten years period of rainfall data using 7000 litres tank size under 100 m² roof area catchment size

Table 15: The summary of the deficit and overflow of the monthly catchment calculation

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-10932	1850	-10932	-8754	-11400	-9834	-11400	-10968	-10578	-5910
FEB	-11400	-26	-9708	-8214	-10050	-10320	-8268	-11400	-8700	2154
MAR	4836	-4506	-6882	-10446	4460	-6750	-150	-1842	2748	-3378
APR	5594	5594	20300	-6648	-586	-4740	3792	18608	6472	-8448
MAY	28578	13566	1416	3470	1220	24188	11618	59754	1650	3130
JUN	33006	64308	42960	9570	18696	9858	18480	8868	25626	34700
JUL	-1466	1288	2224	2548	1970	3178	9822	12216	7590	4476
AUG	-10752	-8906	-4792	-3540	-4444	-5324	1218	3144	-2546	442
SEP	2586	-7332	-4230	6636	-6360	1398	4638	-4108	-10680	-1238
OCT	-5080	-528	6996	3986	4980	3606	498	-384	-10932	2946
NOV	-6036	-8988	2994	-332	1970	-5778	3592	2894	-11400	2202
DEC	-7530	-10014	-5612	-10536	3716	-11382	-7088	11352	-3246	1188

Scenario 4a: Monthly catchment calculation for roof catchment area of 200 m^2, to access the reliability of the 5000 litres storage tank be used.

Table 4.16: Monthly catchment calculation measure

Measures	Calculation
Average daily water demand	= 76 litres× (household of five)
	= (76× 5) ×30 days
	= 11400 litres/month
Month rainfall of the area	
Catchment area	= 200 m²
Catchment efficiency	= 90% or 0.9
Run-off formula	= 0.9(efficiency) ×rainfall (monthly) × roof area
Tank size used in the area	= 5000 litres

Table 4.17 shows monthly catchment calculation for the year 2001. Assumption made was that at the beginning of the month (January) the storage tank is taken to be empty. The deficit at the remarks shows that the storage tank is empty at that month.

Table 4.17 shows monthly catchment calculation for the year 2001, assumption made was that at the beginning of the month (January) the storage tank is taken to be empty.

Table 17: Monthly catchment calculation for the year 2001

Year Months	V_{t-1}	*C.A.Pt*	*D.N.dt*	V_t	Remarks
JAN	0	468	11400	-10932	Deficit
FEB	0	0	11400	-11400	Deficit
MAR	0	16222	11400	4836	No overflow
APR	4836	19080	11400	7594	Overflow
MAY	5000	39978	11400	28578	Overflow
JUN	5000	44406	11400	33006	Overflow
JUL	5000	2934	11400	-3466	Deficit
AUG	0	648	11400	-10752	Deficit
SEP	0	13986	11400	2586	No overflow
OCT	2586	3726	11400	-5080	Deficit
NOV	0	5364	11400	-6036	Deficit
DEC	0	3870	11400	-7530	Deficit

This show the total overflow of 69172 litres7 months out of 12 months the tank failed to supply water.

$$\text{The percentage of water wasted} = \frac{\text{Total overflow}}{\text{Total demand}} \times 100$$

$$= \frac{69{,}172}{138{,}700} \times 100$$

$$= 49.9\%$$

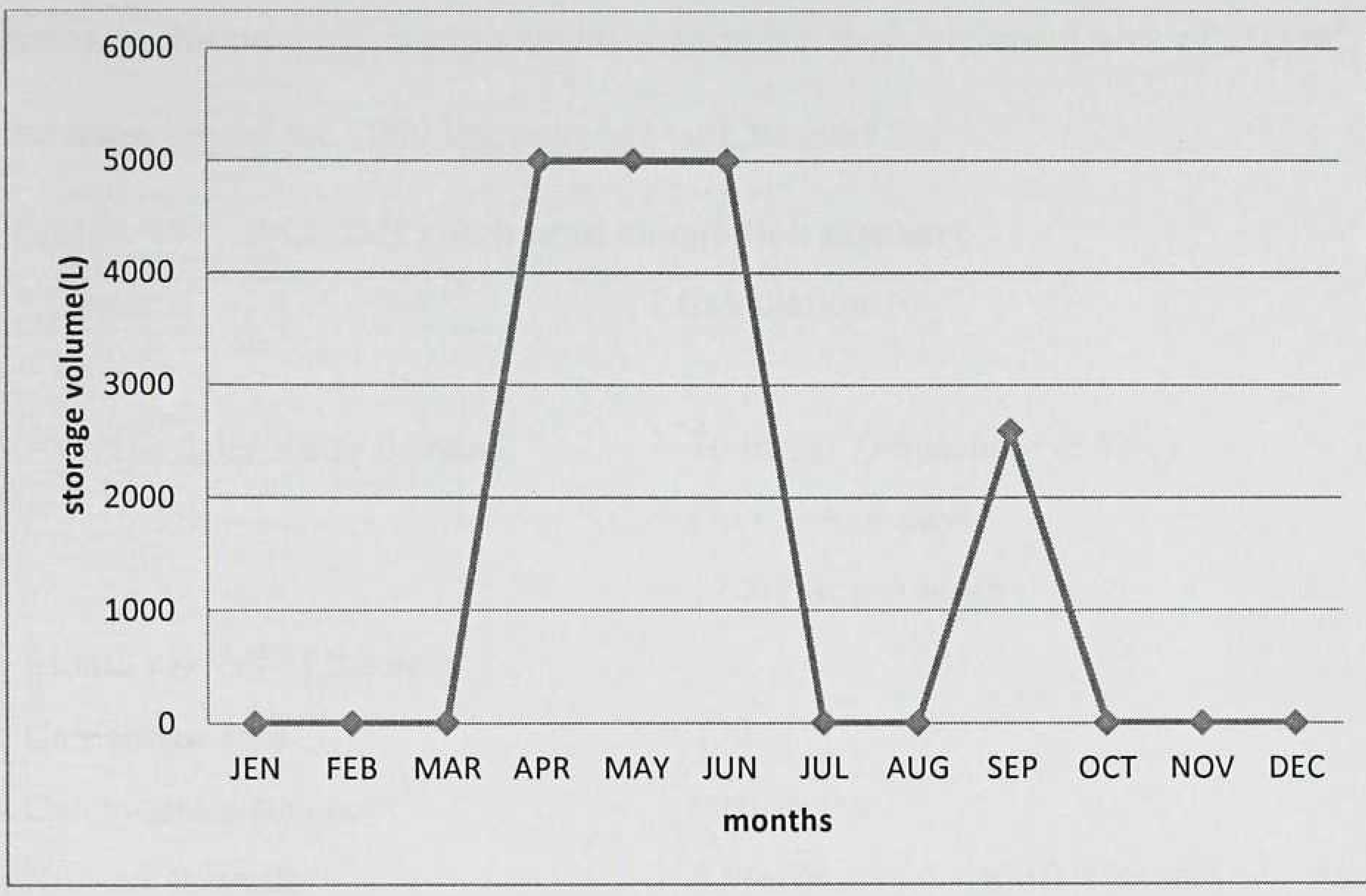

Figure4. 8: Monthly volume of stored rainwater under roof area of 200m² of 5000 litres tank

Figure4. 8 monthly volume of stored rainwater tank in 5000 litres storage tank for a household of 5persons for the year 2001 with the parameter values in Table 4.17.

Table4.18 shows the summary of the deficit and overflow of the monthly catchment calculation of the ten years period of rainfall data using 5000 litres tank size under 200 m² roof area catchment size.

Table 4.18: The summary of the deficit and overflow of the monthly catchment calculation

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-10932	3850	-10932	-8754	-11400	-9834	-11400	-10968	-10578	-5910
FEB	-11400	-2026	-9708	-8214	-10050	-10320	-8268	-11400	-8700	2154
MAR	4836	-4506	-6882	-10446	6460	-6750	-150	-1842	2748	-3378
APR	7594	7594	22300	-6648	-586	-4740	3792	20608	8472	-8448
MAY	28578	13566	1416	5470	3220	26188	13618	59754	1650	3130
JUN	33006	64308	42960	9570	18696	9858	18480	8868	25626	41700
JUL	-3466	-712	224	548	1970	1178	9822	12216	7590	4476
AUG	-10752	-10194	-6738	-7540	-4444	-7324	1218	1144	-4546	-1558
SEP	2586	-7332	-4230	1636	-6360	1398	4638	-6108	-10680	-1680
OCT	-5080	-528	1996	4350	4980	3606	498	-384	-10932	2946
NOV	-6036	-8988	998	-2332	3970	-5778	1592	4894	-11400	2202
DEC	-7530	-10014	-7612	-10536	3716	-11382	-9088	11352	-3246	1188

Scenario 4b: monthly catchment calculation for roof catchment area of 200 m^2, to access the reliability of the 7000 litres storage tank be used.

Table4. 19: Monthly catchment calculation measure

Measures	Calculation
Average daily water demand	= 76 litres× (household of five) = (76× 5) ×30 days = 11400 litres/month
Month rainfall of the area	
Catchment area	= 200 m²
Catchment efficiency	= 90% or 0.9
Run-off formula	= 0.9(efficiency) ×rainfall (monthly) × roof area
Tank size used in the area	= 7000 litres

Table 4.20 shows monthly catchment calculation for the year 2001, assumption made was that at the beginning of the month (January) the storage tank is taken to be empty.

Table4. 20: Monthly catchment calculation for the year 2001

Year/ Months	V_{t-1}	*C.A.Pt*	*D.N.dt*	V_t	Remarks
JAN	0	468	11400	-10932	Deficit
FEB	0	0	11400	-11400	Deficit
MAR	0	16222	11400	4836	No overflow
APR	4836	19080	11400	5594	Overflow
MAY	7000	39978	11400	28578	Overflow
JUN	7000	44406	11400	33006	Overflow
JUL	7000	2934	11400	-1466	Deficit
AUG	0	648	11400	-10752	Deficit
SEP	0	13986	11400	2586	No overflow
OCT	2586	3726	11400	-5080	Deficit
NOV	0	5364	11400	-6036	Deficit
DEC	0	3870	11400	-7530	Deficit

This show the total overflow of 67172 litres. 7 months out of 12 months the tank failed to supply water to the household throughout that year.

$$\text{The percentage of water wasted} = \frac{\text{Total overflow}}{\text{Total demand}} \times 100$$

$$= \frac{67172}{138700} \times 100\%$$

$$= 48.4\%$$

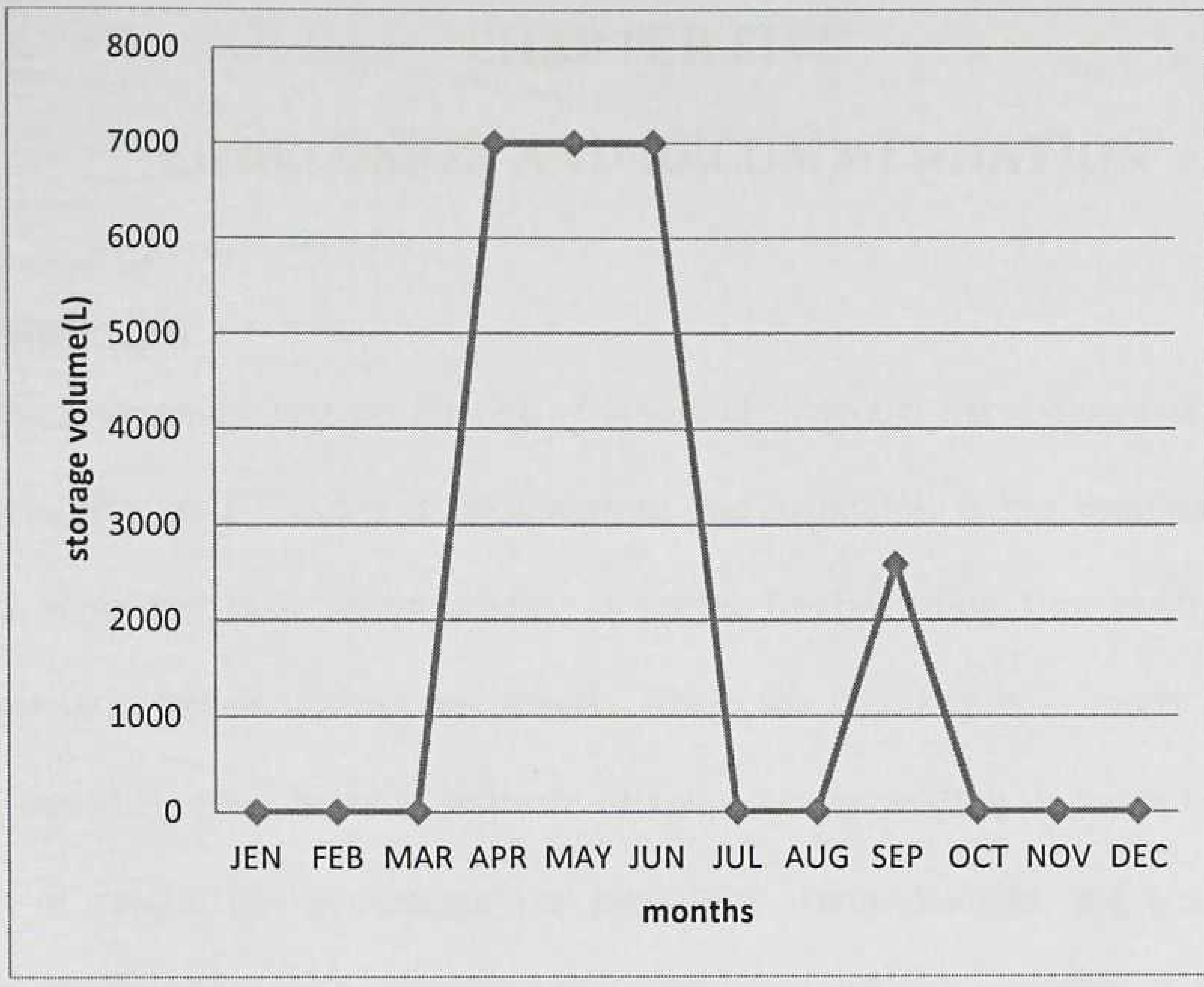

Figure 4.9: Monthly volume of stored rainwater tank under roof area of 200m² of 7000 litres tank

Figure4. 9 monthly volume of stored rainwater tank in 7000 litres rainwater tank for a household of 5 persons for the year 2001 with the parameter values in Table4. 20

Table 4.21 shows the summary of the deficit and overflow of the monthly catchment calculation of the ten years period of rainfall data using 7000 litres tank size under 200 m² roof area catchment size.

Table 4.21: The summary of the deficit and overflow of the monthly catchment calculation

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	-10932	1850	-10932	-8754	-11400	-9834	-11400	-10968	-10578	-5910
FEB	-11400	-26	-9708	-8214	-10050	-10320	-8268	-11400	-8700	2154
MAR	4836	-4506	-6882	-10446	4460	-6750	-150	-1842	2748	-3378
APR	5594	5594	20300	-6648	-586	-4740	3792	18608	6472	-8448
MAY	28578	13566	1416	3470	1220	24188	11618	59754	1650	3130
JUN	33006	64308	42960	9570	18696	9858	18480	8868	25626	34700
JUL	-1466	1288	2224	2548	1970	3178	9822	12216	7590	4476
AUG	-10752	-8906	-4792	-3540	-4444	-5324	1218	3144	-2546	442
SEP	2586	-7332	-4230	6636	-6360	1398	4638	-4108	-10680	-1238
OCT	-5080	-528	6996	3986	4980	3606	498	-384	-10932	2946
NOV	-6036	-8988	2994	-332	1970	-5778	3592	2894	-11400	2202
DEC	-7530	-10014	-5612	-10536	3716	-11382	-7088	11352	-3246	1188

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The estimations made here on the risk of failure of rainwater harvesting and storage in the study area rely on a number of assumptions and estimates. It has been assumed that a monthly rainwater tank water balance is useful for providing first order estimates of rainwater tank failure during dry periods. There are five key parameters on which the simple, monthly mass balance estimate of rainwater harvesting depends which are: the number of people per household; the per capita water demand; the area of the roof catchment; the roof catchment runoff coefficient; and the capacity (volume) of the rainwater storage.

Using the assumed baseline parameter values and the historic monthly rainfall record for the study area from 2001 to 2010, estimates of the risk of failure of rainwater tanks were found for an assumed constant rate household demand by varying one parameter at a time with the others held constant. It was found that for the average household size of 5person in the study area, using water for daily demand at 76 litres/pers/day that if the household had a 5,000 litres and 7000 litres rainwater tank need a larger roof area of about 200 m^2 and large rainwater tank was required to prevent rainwater tank failure at a per capita demand of 76 litres/pers/day.

The monthly water balance predicted the capacity of rainwater tanks necessary to prevent failure for a specified demand and roof catchment area. The conclusion from the monthly water balance that, due to frequent dry period, rainwater harvesting and storage in the study area can only supplement household water requirements.

5.2 Recommendations

Implementing rainwater harvesting within a household, the sizing of the roof catchment collection area supplying rainwater harvesting is importance and appropriate sizing of the storage tank

Rainwater harvesting can be a supplementary water supply for family to reduce the cost of water supply.

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APPENDIX I

Table 1.Effective area in plan of sampled houses in the community

LENGTH(m)	WIDTH(m)	AREA(m^2)	POLYTANK size (litres x10)
22.0	7.0	154.0	700
14.5	11.0	159.5	700
19.60	11.0	215.6	500
22.0	9.0	198.0	700
50.0	10.0	500.0	700
24.0	7.0	168.0	700
35.0	10.0	350.0	700
14.7	7	102.9	700
18.7	7.0	126.0	500
15.0	8	120.0	500
19.0	9.0	171.0	700
22.0	9.0	198.0	700
18.0	8.0	144.0	500
28.0	14.0	392.0	700
24.0	7.0	168.0	700
21.0	15.0	315.0	500
8.0	7.5	60.0	500
15.0	10.0	150.0	500
50.0	10.0	500.0	700
12.7	11.0	139.7	700
24.0	13.0	312.0	700
19.3	14.0	270.2	700
20.0	12.0	240.0	500
17.0	8.0	136.0	700
34.0	10.0	340.0	700
19.0	18.0	342.0	700
21.0	12.0	252.0	700
12.0	11.0	132.0	700
21.0	7.0	147.0	700
13.0	9.0	117.0	700
19.0	11.0	209.0	700
16.0	15.0	240.0	700
24.0	13.0	312.0	500
50.0	10.0	500.0	1000
33.0	10.0	330.0	700
18.0	8.0	144.0	700
13.0	11.0	143.0	500
17.0	13.0	221.0	500
38.0	11.0	418.0	700
19.0	13.0	247.0	700
18.0	12.0	216.0	700
21.0	14.0	249.0	700

22.0	19.0	418.0	700
19.0	15.0	285.0	500
19.0	13.0	247.0	700
50.0	10.0	500.0	700
14.0	10.0	140.0	700
23.0	17.0	391.0	700
29.0	9.0	261.0	700
12.0	7.0	84.0	500
9.0	9.0	81.0	500
8.0	7.0	56.0	700
11.0	9.0	99.0	700
10.0	7.0	70.0	700
19.0	12.0	228.0	700
17.0	10.0	170.0	500
22.0	17.0	374.0	700
14.0	9.0	126.0	700
17.0	15.0	255.0	700
13.0	10.0	130.0	500
12.0	10.0	120.0	700
15.0	13.0	195.0	700
25.0	19.0	475.0	700
22.0	14.0	308.0	700
21.0	15.0	315.0	700
20.0	14.0	280.0	700
18.0	14.0	198.0	700
18.0	13.0	234.0	700
18.0	18.0	324.0	700
15.0	10.0	150.0	500
12.0	12.0	144.0	500
18.0	14.0	252.0	700
24.0	14.0	336.0	700
26.0	14.0	364.0	700
16.0	10.0	160.0	500
19.0	17.0	323.0	500
24.0	12.0	288.0	500
21.0	16.0	336.0	700
26.0	11.0	286.0	500
19.0	18.0	324.0	700
24.0	13.0	312.0	700
24.0	10.0	240.0	700

18.0	8.0	144.0	500
16.0	11.0	176.0	700
27.0	10.0	270.0	700
50.0	10.0	500.0	700
29.0	11.0	319.0	700
11.0	11.0	121.0	700
13.0	12.0	156.0	700
11.0	10.0	110.0	700
12.0	11.0	132.0	700
26.0	11.0	132.0	700
24.0	13.0	312.0	500
17.0	15.0	255.0	700
19.0	9.0	171.0	700
14.0	13.0	182.0	500
21.0	12.0	252.0	700
14.0	13.0	182.0	700
11.0	10.0	110.0	500
21.0	14.0	294.0	700
total		23545.7	
average		235.457	

APPENDIX II

MONTHLY RAINFALL DATA OVER ACCRA AIRPORT

Table 2. Show monthly rainfall values (mm)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2001	2.6	tr	90.2	106.4	222.1	246.7	16.3	3.6	77.7	20.7	29.8	21.5
2002	112.5	24.3	38.3	133.2	138.7	420.6	31.6	6.7	22.6	60.4	13.4	7.7
2003	2.6	9.4	25.1	215.0	71.2	302.0	36.8	25.9	39.8	102.6	41.1	15.5
2004	14.7	17.7	5.3	26.4	121.5	116.5	38.6	18.4	100.2	87.5	22.6	4.8
2005	tr	7.5	127.0	32.3	109.0	167.2	46.5	27.7	28.0	91.0	85.5	56.2
2006	8.7	6.0	25.8	37.0	236.6	118.1	42.1	16.1	71.1	75.6	11.2	0.1
2007	0.0	17.4	62.5	84.4	145.7	166.0	117.9	70.1	89.1	66.1	44.4	4.0
2008	2.4	0.0	53.1	205.6	395.3	112.6	131.2	29.2	29.4	61.2	118.3	126.4
2009	4.9	15.0	78.6	111.8	72.5	205.7	105.5	10.3	4.0	2.6	0.0	45.3
2010	30.5	75.3	32.6	16.4	108.5	295.0	88.2	26.9	54.0	79.7	59.2	57.7

NB: TR= Means trace, that is rainfall amount less than 0.1 of a millimeter

APPENDIX III

Scenario1a using supply side approach with100% dependence and 50% dependence of rainwater harvested under roof catchment area of 100m² to determine the tank size of (2001-2010) years rainfall data collected.

This represents the deficit and the storage

2001 months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	2.6	234	234	11400	5700	-11166	-5466
FEB	0	0	234	22800	11400	-22566	-11166
MAR	90.2	8118	8352	34200	17100	-25848	-8748
APR	106	9540	17892	45600	22800	-27708	-4908
MAY	222.1	19989	37881	57000	28500	-19119	9381
JUN	246.7	22203	60084	68400	34200	-8316	25884
JUL	16.3	1467	61551	79800	39900	-18249	21651
AUG	3.6	324	61875	91200	45600	-29325	16275
SEP	77.7	6993	68868	102600	51300	-33732	17568
OCT	20.7	1863	70731	114000	57000	-43269	13731
NOV	29.8	2682	73413	125400	62700	-51987	10713
DEC	21.5	1935	75348	136800	68400	-61452	6948

Year 2002/ Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	112.5	10125	10125	11400	5700	-1275	4425
FEB	24.3	2187	12312	22800	11400	-10488	912
MAR	38.3	3447	15759	34200	17100	-18441	-1341
APR	133.2	11988	27747	45600	22800	-17853	4947
MAY	138.7	12483	40230	57000	28500	-16770	11730
JUN	420.6	37854	78084	68400	34200	9684	43884
JUL	31.6	2844	80928	79800	39900	1128	41028
AUG	6.7	603	81531	91200	45600	-9669	35931
SEP	22.6	2034	83565	102600	51300	-19035	32265
OCT	60.4	5436	89001	114000	57000	-24999	32001
NOV	13.4	1206	90207	125400	62700	-35193	27507
DEC	7.7	693		136800	68400	-136800	-68400

Year 2003/ Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/ Storage 50%
JAN	2.6	234	234	11400	5700	-11166	-5466
FEB	9.4	846	1080	22800	11400	-21720	-10320
MAR	25.1	2259	3339	34200	17100	-30861	-13761
APR	215	19350	22689	45600	22800	-22911	-111
MAY	71.2	6408	29097	57000	28500	-27903	597
JUN	32	2880	31977	68400	34200	-36423	-2223
JUL	36.8	3312	35289	79800	39900	-44511	-4611
AUG	25.9	2331	37620	91200	45600	-53580	-7980
SEP	39.8	3582	41202	102600	51300	-61398	-10098
OCT	102.6	9234	50436	114000	57000	-63564	-6564
NOV	41.1	3699	54135	125400	62700	-71265	-8565
DEC	15.5	1395	55530	136800	68400	-81270	-12870

Year 2004/ Months	**rainfall**	**supply**	**cum. Rainwater supply**	**cum.water demand 100%**	**cum.water demand 50%**	**Deficit/Storage 100%**	**Deficit/Storage 50%**
JAN	14.7	1323	1323	11400	5700	-10077	-4377
FEB	17.7	1593	2916	22800	11400	-19884	-8484
MAR	5.3	477	3393	34200	17100	-30807	-13707
APR	26.4	2376	5769	45600	22800	-39831	-17031
MAY	125.5	11295	17064	57000	28500	-39936	-11436
JUN	116.5	10485	27549	68400	34200	-40851	-6651
JUL	38.6	3474	31023	79800	39900	-48777	-8877
AUG	18.4	1656	32679	91200	45600	-58521	-12921
SEP	100.2	9018	41697	102600	51300	-60903	-9603
OCT	87.5	7875	49572	114000	57000	-64428	-7428
NOV	22.6	2034	51606	125400	62700	-73794	-11094
DEC	4.8	432	52038	136800	68400	-84762	-16362

Year 2005/ Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	0	0	0	11400	5700	-11400	-5700
FEB	7.5	675	675	22800	11400	-22125	-10725
MAR	127	11430	12105	34200	17100	-22095	-4995
APR	32.3	2907	15012	45600	22800	-30588	-7788
MAY	109	9810	24822	57000	28500	-32178	-3678
JUN	167.2	15048	39870	68400	34200	-28530	5670
JUL	46.5	4185	44055	79800	39900	-35745	4155
AUG	27.7	2493	46548	91200	45600	-44652	948
SEP	28	2520	49068	102600	51300	-53532	-2232
OCT	91	8190	57258	114000	57000	-56742	258
NOV	85.5	7695	64953	125400	62700	-60447	2253
DEC	56	5040	69993	136800	68400	-66807	1593

Year 2006 Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	8.7	783	783	11400	5700	-10617	-4917
FEB	6	540	1323	22800	11400	-21477	-10077
MAR	25.8	2322	3645	34200	17100	-30555	-13455
APR	37	3330	6975	45600	22800	-38625	-15825
MAY	236.6	21294	28269	57000	28500	-28731	-231
JUN	118.1	10629	38898	68400	34200	-29502	4698
JUL	42.1	3789	42687	79800	39900	-37113	2787
AUG	16.1	1449	44136	91200	45600	-47064	-1464
SEP	71.1	6399	50535	102600	51300	-52065	-765
OCT	75.6	6804	57339	114000	57000	-56661	339
NOV	11.2	1008	58347	125400	62700	-67053	-4353
DEC	0.1	9	58356	136800	68400	-78444	-10044

Year 2007/ Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	0	0	0	11400	5700	-11400	-5700
FEB	17.4	1566	1566	22800	11400	-21234	-9834
MAR	62.5	5625	7191	34200	17100	-27009	-9909
APR	84.4	7596	14787	45600	22800	-30813	-8013
MAY	145.7	13113	27900	57000	28500	-29100	-600
JUN	166	14940	42840	68400	34200	-25560	8640
JUL	117.9	10611	53451	79800	39900	-26349	13551
AUG	70.1	6309	59760	91200	45600	-31440	14160
SEP	89.1	8019	67779	102600	51300	-34821	16479
OCT	66.1	5949	73728	114000	57000	-40272	16728
NOV	44.4	3996	77724	125400	62700	-47676	15024
DEC	4	360	78084	136800	68400	-58716	9684

Year 2008 Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	2.4	216	216	11400	5700	-11184	-5484
FEB	0	0	216	22800	11400	-22584	-11184
MAR	53.1	4779	4995	34200	17100	-29205	-12105
APR	205.6	18504	23499	45600	22800	-22101	699
MAY	395.3	35577	59076	57000	28500	2076	30576
JUN	112.6	10134	69210	68400	34200	810	35010
JUL	131.2	11808	81018	79800	39900	1218	41118
AUG	29.2	2628	83646	91200	45600	-7554	38046
SEP	29.4	2646	86292	102600	51300	-16308	34992
OCT	61.2	5508	91800	114000	57000	-22200	34800
NOV	118.3	10647	102447	125400	62700	-22953	39747
DEC	26.4	2376	104823	136800	68400	-31977	36423

Year 2009/ Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	4.9	441	441	11400	5700	-10959	-5259
FEB	15	1350	1791	22800	11400	-21009	-9609
MAR	78.6	7074	8865	34200	17100	-25335	-8235
APR	111.8	10062	18927	45600	22800	-26673	-3873
MAY	72.5	6525	25452	57000	28500	-31548	-3048
JUN	205.7	18513	43965	68400	34200	-24435	9765
JUL	105.5	9495	53460	79800	39900	-26340	13560
AUG	10.3	927	54387	91200	45600	-36813	8787
SEP	4	360	54747	102600	51300	-47853	3447
OCT	2.6	234	54981	114000	57000	-59019	-2019
NOV	10	900	55881	125400	62700	-69519	-6819
DEC	45.3	4077	59958	136800	68400	-76842	-8442

Year 2010 Months	rainfall	supply	cum. Rainwater supply	cum.water demand 100%	cum.water demand 50%	Deficit/Storage 100%	Deficit/Storage 50%
JAN	30.5	2745	2745	11400	5700	-8655	-2955
FEB	75.3	6777	9522	22800	11400	-13278	-1878
MAR	32.6	2934	12456	34200	17100	-21744	-4644
APR	16.4	1476	13932	45600	22800	-31668	-8868
MAY	108.5	9765	23697	57000	28500	-33303	-4803
JUN	295	26550	50247	68400	34200	-18153	16047
JUL	88.2	7938	58185	79800	39900	-21615	18285
AUG	26.9	2421	60606	91200	45600	-30594	15006
SEP	54	4860	65466	102600	51300	-37134	14166
OCT	79.7	7173	72639	114000	57000	-41361	15639
NOV	59.2	5328	77967	125400	62700	-47433	15267
DEC	57.7	5193	83160	136800	68400	-53640	14760

APPENDIX IV

Scenario 2 shows monthly catchment calculation for roof catchment area of $100m^2$, to access the reliability of the 5000litres and 7000litres storage tank be used.

Year 2001/ Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	234	11400	-11168	Deficit
FEB	0	0	11400	-11400	Deficit
MAR	0	8118	11400	-3282	Deficit
APR	0	9540	11400	-1824	Deficit
MAY	0	19989	11400	3589	Overflow
JUN	5000	22203	11400	10803	Overflow
JUL	5000	1467	11400	-4933	Deficit
AUG	0	324	11400	-11076	Deficit
SEP	0	6993	11400	-4407	Deficit
OCT	0	1863	11400	-9537	Deficit
NOV	0	2682	11400	-8758	Deficit
DEC	0	1935	11400	-9565	Deficit

Year 2002 Months	**Vt-1**	**C.A.Pt**	**D.N.dt**	**Vt**	**Remarks**
JAN	0	10125	11400	-3556	Deficit
FEB	0	2187	11400	-9213	Deficit
MAR	0	3447	11400	-7953	Deficit
APR	0	11988	11400	597	No overflow
MAY	597	12483	11400	1680	No overflow
JUN	1680	37854	11400	23134	Overflow
JUL	5000	2844	11400	-3556	Deficit
AUG	0	603	11400	-10797	Deficit
SEP	0	2034	11400	-9366	Deficit
OCT	0	5436	11400	-5964	Deficit
NOV	0	1206	11400	-10194	Deficit
DEC	0	693	11400	-10707	Deficit

Year 2003 Months	**Vt-1**	**C.A.Pt**	**D.N.dt**	**Vt**	**Remarks**
JAN	0	234	11400	-11166	Deficit
FEB	0	846	11400	-10554	Deficit
MAR	0	2259	11400	-9141	Deficit
APR	0	19350	11400	2950	Overflow
MAY	5000	6408	11400	8	No overflow
JUN	8	2880	11400	10788	Overflow
JUL	5000	3312	11400	-3088	Deficit
AUG	0	2331	11400	-9069	Deficit
SEP	0	3582	11400	-7818	Deficit
OCT	0	9234	11400	-2202	Deficit
NOV	0	3699	11400	-7701	Deficit
DEC	0	1395	11400	-10005	Deficit

Year 2004/ Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	1323	11400	-1007	Deficit
FEB	0	1593	11400	-9807	Deficit
MAR	0	477	11400	-10923	Deficit
APR	0	2376	11400	-9024	Deficit
MAY	0	11295	11400	-465	Overflow
JUN	0	10485	11400	-915	Overflow
JUL	0	3474	11400	-7926	Deficit
AUG	0	1656	11400	-9744	Deficit
SEP	0	9018	11400	-2382	Deficit
OCT	0	7875	11400	-3525	Deficit
NOV	0	2034	11400	-9366	Deficit
DEC	0	432	11400	-10968	Deficit

Year 2005/ Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	0	11400	-11400	Deficit
FEB	0	675	11400	-10725	Deficit
MAR	0	11430	11400	30	No overflow
APR	30	2907	11400	-8407	Deficit
MAY	0	9810	11400	-1590	Deficit
JUN	0	15048	11400	3648	No overflow
JUL	3648	4185	11400	-3567	Deficit
AUG	0	2493	11400	-8907	Deficit
SEP	0	2520	11400	-8880	Deficit
OCT	0	8190	11400	-3210	Deficit
NOV	0	7695	11400	-3705	Deficit
DEC	0	5040	11400	-6342	Deficit

Year 2006 Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	783	11400	-10617	Deficit
FEB	0	540	11400	-10860	Deficit
MAR	0	2322	11400	-9078	Deficit
APR	30	3330	11400	-8070	Deficit
MAY	0	21294	11400	4894	Overflow
JUN	5000	10629	11400	4229	No overflow
JUL	3648	3789	11400	-3382	Deficit
AUG	0	1449	11400	-9951	Deficit
SEP	0	6399	11400	-5001	Deficit
OCT	0	6804	11400	-4596	Deficit
NOV	0	1008	11400	-10392	Deficit
DEC	0	9	11400	-11391	Deficit

Year 2007 Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	0	11400	-11400	Deficit
FEB	0	1566	11400	-9834	Deficit
MAR	0	5625	11400	-5775	deficit
APR	30	7596	11400	-3804	Deficit
MAY	0	13113	11400	1713	No overflow
JUN	1713	14940	11400	253	Overflow
JUL	5000	10611	11400	4221	No overflow
AUG	4221	6309	11400	-880	Deficit
SEP	0	8019	11400	-3381	Deficit
OCT	0	5949	11400	-5451	Deficit
NOV	0	3996	11400	-7404	Deficit
DEC	0	360	11400	-11040	Deficit

Year 2008/ Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	216	11400	-11184	Deficit
FEB	0	0	11400	-11400	Deficit
MAR	0	4779	11400	-6621	Deficit
APR	0	18504	11400	2104	Overflow
MAY	5000	35577	11400	24177	Overflow
JUN	5000	10134	11400	3734	No overflow
JUL	3734	11808	11400	4124	No overflow
AUG	4124	2628	11400	-4630	Deficit
SEP	0	2646	11400	-8754	Deficit
OCT	0	5508	11400	-5892	Deficit
NOV	0	10647	11400	-753	Deficit
DEC	0	2376	11400	-24	Deficit

Year 2009/ Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	441	11400	-10959	Deficit
FEB	0	1350	11400	-10050	Deficit
MAR	0	7074	11400	-4326	Deficit
APR	0	10062	11400	-1338	Deficit
MAY	0	6525	11400	-4875	Deficit
JUN	0	18513	11400	2113	Overflow
JUL	5000	9495	11400	3095	No overflow
AUG	3095	927	11400	-7378	Deficit
SEP	0	360	11400	-11040	Deficit
OCT	0	234	11400	-11166	Deficit
NOV	0	900	11400	-11400	Deficit
DEC	0	4077	11400	-7323	Deficit

Year 2010 Months	Vt-1	C.A.Pt	D.N.dt	Vt	Remarks
JAN	0	2745	11400	-8655	Deficit
FEB	0	6777	11400	-4623	Deficit
MAR	0	2934	11400	-8466	Deficit
APR	0	1476	11400	-9924	Deficit
MAY	0	9765	11400	-1635	Deficit
JUN	0	26550	11400	10150	Overflow
JUL	5000	7938	11400	1538	No overflow
AUG	1538	2421	11400	-7441	Deficit
SEP	0	4860	11400	-6540	Deficit
OCT	0	7173	11400	-4227	Deficit
NOV	0	5328	11400	-6072	Deficit
DEC	0	5193	11400	-6207	Deficit