PERFORMANCE EVALUATION OF RAIN WATER HARVESTING FOR PADDY PRODUCTION IN TANZANIA.

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
AGRICULTURAL ENGINEERING OF THE SOKOINE UNIVERSITY OF
AGRICULTURE, MOROGORO, TANZANIA.

1992.

ABSTRACT

The major problem inherent of the rain-water harvesting system for paddy production in North-West regions of Tanzania is low runoff efficiency and high rate of loss of stored water due to seepage and evaporation, which result in low yields and sometimes total crop failure. The present research was conducted in Shinyanga region with the objective of assessing the performance of the rain water harvesting system for paddy production. In order to achieve this objective the historical climatic and runoff data together with data from experimental runoff plots were analysed.

From historical rainfall data the results showed that:

- It is possible to receive 60mm of rainfall within 24 hours once every two years and within wet season dry spells of unpredictable length and timing are common.
- The variations in yearly rainfall is some 25% over a period of 10 years.
- At an annual rainfall of 800 mm water deficit in the paddies will amount to 1560 mm.

The experimental results showed that:

- Uncompacted rain catchment with ground slope of less than 5% has an average surface runoff of 30.3 mm per month with mean runoff efficiency of less than 30%.

-A compacted rain catchmet with ground slope of less than 5% has an average surface runoff of 66.4 mm per month with mean runoff efficiency between 45% and 60%.

- Uncompacted rain catchment with ground slope greater than 5% has an average surface runoff of 66.4 mm per month with mean runoff efficiency between 50% and 65%.

-A compacted rain catchment with ground slope of greater than 5% has an average surface runoff of 71.7 mm per month with mean runoff efficiency greater than 65%.

-And also the study showed that most of catchments used are large areas of between 10 to 100 km^2 feeding runoff to ephemeral streams at a runoff yield efficiency of 12%.

Therefore from the major findings it was concluded that the rain water harvesting system used in Tanzania has very wide potential but is currently inefficient, mainly due to the low control and inadequate management of the catchment area by the farmers. It is proposed that more research work is required to: quantify the yield benefits attributable to rain water harvesting; establish economically viable design parameters for catchments under different topographical and assess the erosion risks inherent of the system.

DECLARATION

I, SHADRACK SAKAI MWAKALILA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently being submitted for a degree in any other University.

Date. 26/11/1992
Signature.......................

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ACKNOWLEDGEMENTS

I wish to acknowledge my sincere and profound gratitude to my supervisor Dr. N. Hatibu for his generous guidance, invaluability suggestions, encouragement and expertise in the planning, execution and writing of this work without which it would have been difficult to undertake and complete this study.

Special appreciation is due to the people in shinyanga region who directly or indirectly, contributed invaluably to the success of this study.

I would like to acknowledge the understanding, patience and constant encouragement I received from my wife Jane, and children Essau, Janeth and Enock.

My parents, Mzee Sakai Mwakalila and Mama Raheli Mwantyala and my brothers and sisters: Ellen, Erica, Ezekiah, Watson and Misaka, who since my childhood, assisted and encouraged me to acquire higher academic qualifications and thus tirelessly prayed for my well being throughout the study. I acknowledge their efforts.

I owe a debt of gratitude to the staff of the Directorate of meteorology, Shinyanga for the provision of standard meteorological materials and technical help in the execution of the field work.

I am very thankful to the Germany Technical Co-operation and the Southern African Countries Centre for Agricultural Research (GTZ/SACCAR), Botswana, for their sponsorship which have enabled me complete this study.

I wish to thank the Ministry for Agriculture, Livestock Development and Cooperatives, Tanzania, for granting me a study leave.

Last but not least, I wish to thank Dr. H.F. Mahoo for his effort in assisting me in completing my research successfully. I acknowledge with gratitude his extensive comments which he made to the drafts, which led me to substantial improvements of various sections in this dissertation.

CHAPTER I INTRODUCTION

1.1 DEFINITIONS OF RAIN-WATER HARVESTING

Rain-Water Harvesting (RWH) has been defined as the interception and concentration of local rainfall runoff from a catchment area for various purposes(Dutt, 1981). The process include inducement, collection, storage and conservation of local surface runoff. The harvested water can be used for agricultural or domestic purposes.

RWH system for crop production consists of a catchment or water collecting area and a cropped area where the collected runoff is used to grow crops (Reij et al, 1988).

Water collected from the catchment area treated to increase runoff from rainfall is either stored in reservoirs or concentrated on small areas where percolation into the root zone temporarily stores water for later use by plants. Therefore rain water harvesting enables a greater percentage of rainfall to be put to beneficial use.

RWH is restricted to methods which are entirely dependent on local rainfall (overland flow and ephemeral stream flow) and thus differentiates it from "true" irrigation system.

Therefore RWH is feasible at any place where water runs off a surface and could be collected. RWH is of great interest in the arid and semi-arid regions, where agricultural production is limited primarily by low and erratic rainfall.

The methods of RWH can be split into two main categories: Micro-catchment water harvesting and Runoff farming water harvesting(Boers and Ben-Asher, 1982).

(a) MICRO-CATCHMENT WATER HARVESTING

This is a method of collecting surface runoff from a catchment area over a flow distance of less than 100m and storing it for consumptive use in the root zone of an adjacent cropped area. According to Boers and Ben-Asher (1986), the design parameters for this method are :

- -The ratio of catchment area to the cropped area. This ratio depends on climate, soil conditions and crop water requirement.
- -The ratio of the length to the width of the catchment. This ratio depends on rainfall characteristics, topography, and water properties of the soil.

(b) RUN OFF FARMING WATER HARVESTING.

This is a method of collecting surface runoff from a catchment area using channels, dams or diversion system, and storing it in reservoirs for later application to cropped area. The limitation of reservoirs lies with the investment needed for the construction of reservoirs and the system to distribute the water to the cultivated area. For this reason, this system can only be used where high valued crops are to be grown.

1.2 RAIN-WATER HARVESTING IN TANZANIA.

In Tanzania elaborate RWH is mainly practised in the North-West part, comprising of Shinyanga, Tabora and Mwanza region (Figure 1.1). There are no records to show how the system started, but farmers have been developing it by trial and error since early 1940s.

The system is used for growing paddy. Rain-water collected from the catchment is being stored in bounded fields which mostly are rectangular in shape with earth bunds. The bunds are built with simple provisions for entry and egress of water. These rectangular bounded fields are locally called "Majaruba" (Figure 1.2). The height of bunds varies from 25 to 100 cm.

Water from runoff is led into the " Majaruba" and may be channelled from "Jaruba" to "Jaruba" (see Figure 1.2). Most farmers cultivate on average 15 to 25 "Majaruba" of a total of about 0.3ha. Initial cultivation of paddies is almost entirely with oxen, though about half the farmers then level by hand. Yields are very variable but average 1.5 tons per hectare, and crop failures, due to inadequate rainfall or late floods are common.

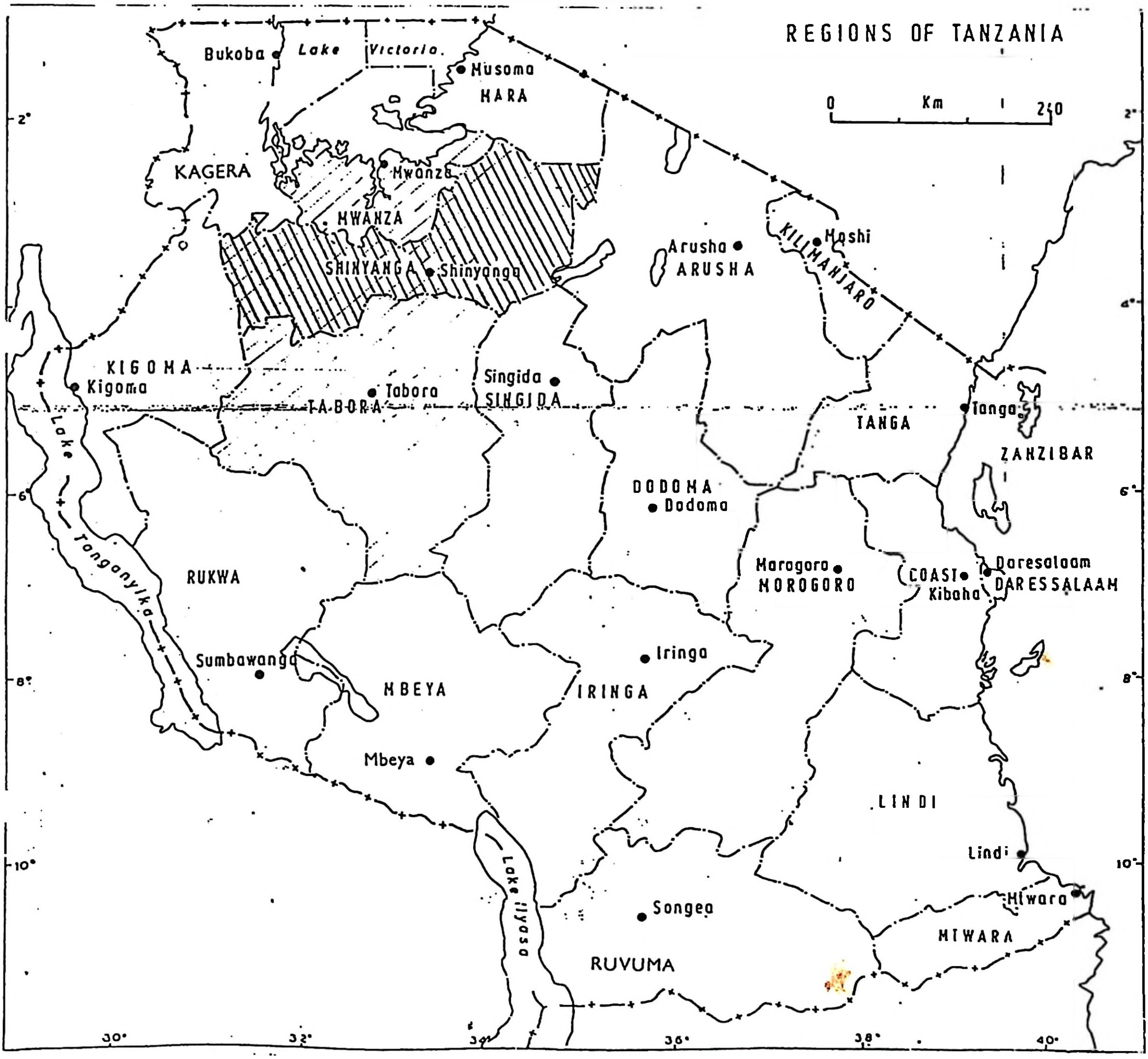


FIGURE 1.1 Locational map of North-West Tanzania.

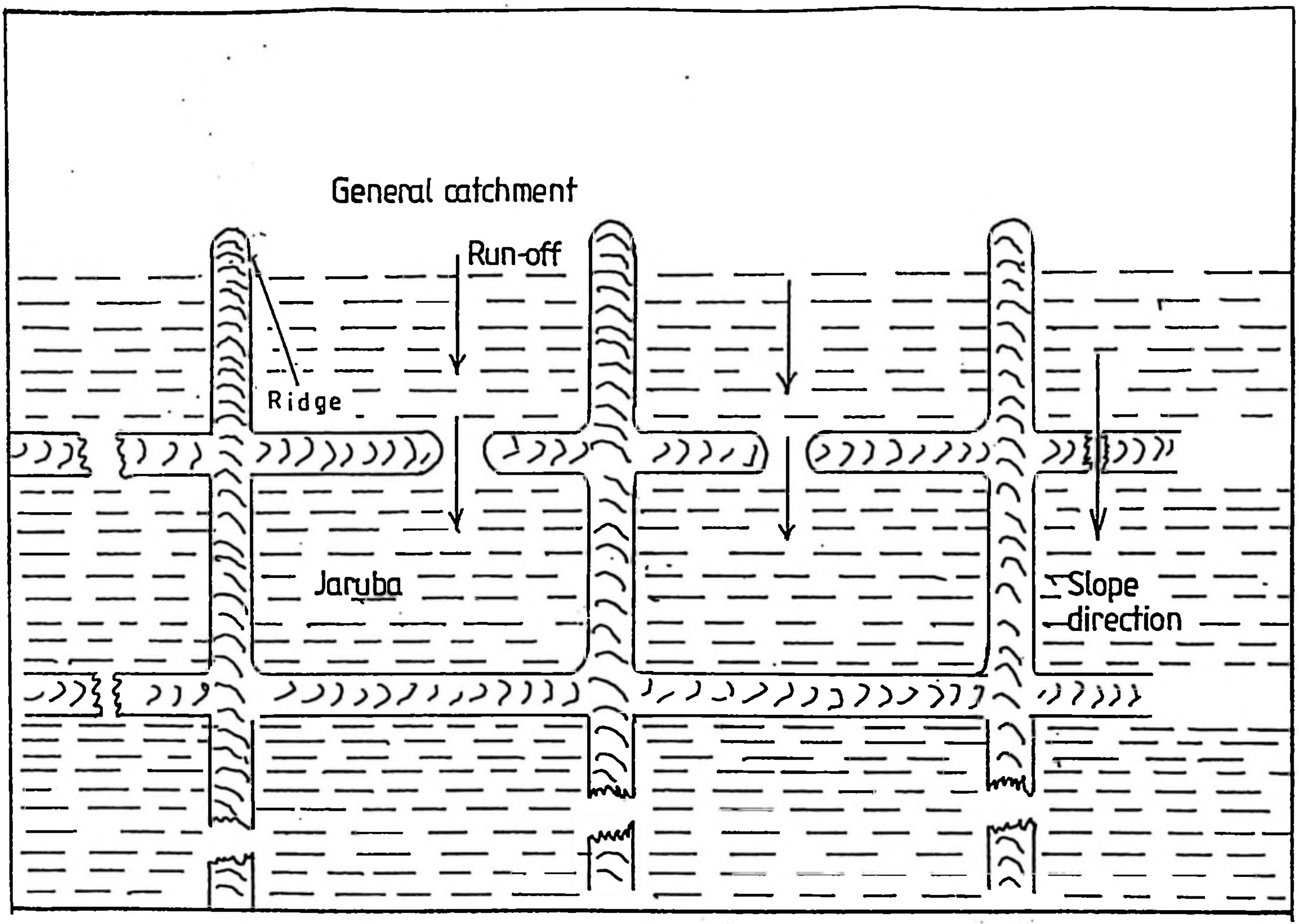


FIGURE 1.2 Preparation of "Majaruba".

The main constraints inherent of the traditional RWH system practised in North-West regions of Tanzania have been identified as:

(a) Limited period when soils are workable by hand making bund construction difficult and restricting expansion of cultivated area.

(b) Low structural stability of the prepared bunds making them to be subjected to frequent flood and erosion damage.

(c) Low runoff collection efficiency and high rate of loss of stored water due to seepage and evaporation, which result in low yields and sometimes total crop failure.

(d) Un-levelled paddies causing variable crop performance and bund breaching due to un-even distribution of flood water.

Therefore present research was conducted in Shinyanga region to investigate the problem of low runoff collection efficiency and high rate of loss of stored water due to seepage and evaporation.

1.3 SCOPE OF THE EVALUATION:

The main objective of this research was to assess the performance of the rain water harvesting system in Shinyanga region.

The specific objectives of this research were as follows:

(1) To assess the rainfall status of the Shinyanga region.

(2) To assess the runoff yield from different rain catchment systems.

(3) To asses the extent of losses of soil water from the paddy fields through evapotranspiration and deep percolation.

(4) To use the data collected in (1) through (3) to evaluate the effectiveness and efficiency of the RWH system in Shinyanga.

(5) To propose possible actions that can be taken in order to improve the local techniques of rain water harvesting and the adaptation of these techniques to other semi-arid areas of Tanzania.

In order to achieve the objectives above historical rainfall and runoff data together with data from experimental plots were analyzed.

CHAPTER 2. BACKGROUND AND LITERATURE SURVEY.

2.1 CLIMATE IN TANZANIA

In general, Tanzania has a tropical subhumid to semi-arid climate, with variations of altitude which influencing both rainfall and temperature in different parts of the country. The main problem of water supply for agricultural production in marginal/ or semi-arid areas of Tanzania is that rainfall does not always occur at the right place and /or at the right time. The possibilities of irrigation to supplement rainfall for crop production are limited for reasons of both expense and the lack of perennial sources of surface water. The key to mitigating the effects of low and un-reliable rainfall and stabilising food production in the semi-arid areas will be more effective management of rain water. One method is rain-water harvesting.

According to Saouma, (1978), the country can be divided into five major climatic regions (Figure 2.1 and 2.2).

(a) Dry season savanna

This region covers nearly the whole of the country. The rainfall maxima months coalesce to a short 5 - 6 months rainy season followed by a severe and prolonged dry season.

The rainfall varies between 500 - 1000 mm per annum. The characteristic vegetation is woodland and large parts are unhibited.

(b) Semi-arid twin-season

This is relatively a small area comprising the low-lands of north-eastern mountain ranges. It has twin rain seasons with rainfall varying between 250 - 750 mm per annum.

(c) Coastal climate

This stretches half of Tanzanians coast. It is relatively humid but bounded by a drier interior. Rainfall rarely exceeds 1250 mm and is less efficient than the corresponding amount of rainfall would be in the highlands due to high evaporation rate.

(d) Highlands

Highland climates has rainfalls ranging between 1250 - 1750 mm per annum.

(e) Rainy season savanna.

This region lies around lake victoria. It has two periods of overhead sun close together in one half of the year so that a prolonged season of 7 - 10 months of rainy season is created with a marked but relatively short dry season in between.

The rainfall is substantial, 750 - 1500 mm per annum and gives rise to a rich savanna of broad leafed trees.

(f) Rungwe

This lies at the northern end of lake Nyasa and has a remarkably high rainfall of 2500 mm or more per annum.

Temperatures are not an important constraint to agricultural production. Rainfall is the most important climatic element in Tanzania.

Over 50% of the country have a low average rainfall and the amount of rainfall received each year is very variable. Many parts suffer from long dry season with relatively few rain days. Since more than three quarters of the country receives less than 1000 mm average annual rainfall. Therefore, for this reason nearly two thirds of Tanzania can be described as arid or semi-arid on the basis of having probability of less than 25% of receiving 750 mm of rainfall per year (Niewolt, 1973 and Riise 1971).

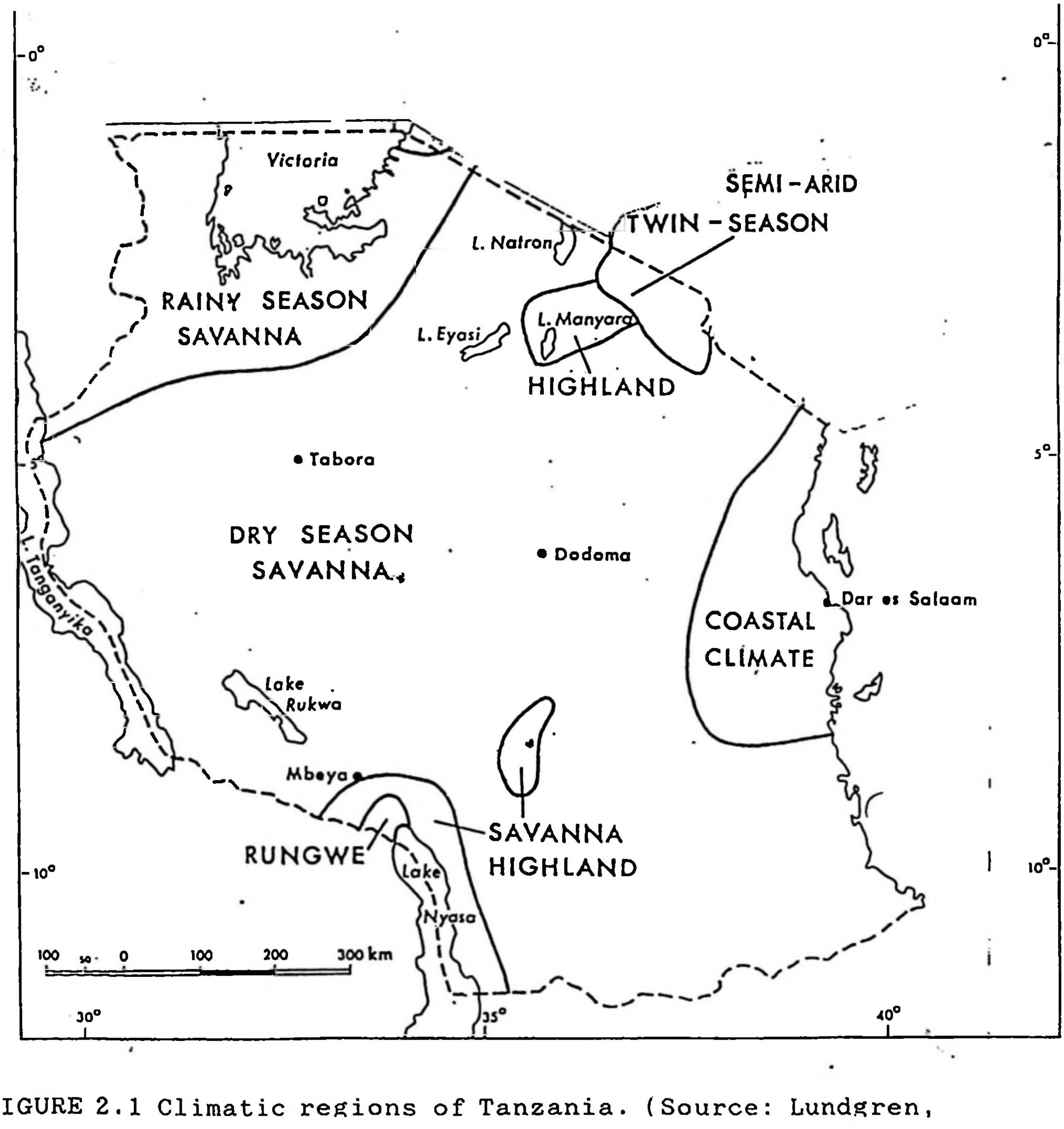


FIGURE 2.1 Climatic regions of Tanzania. (Source: Lundgren, 1975)

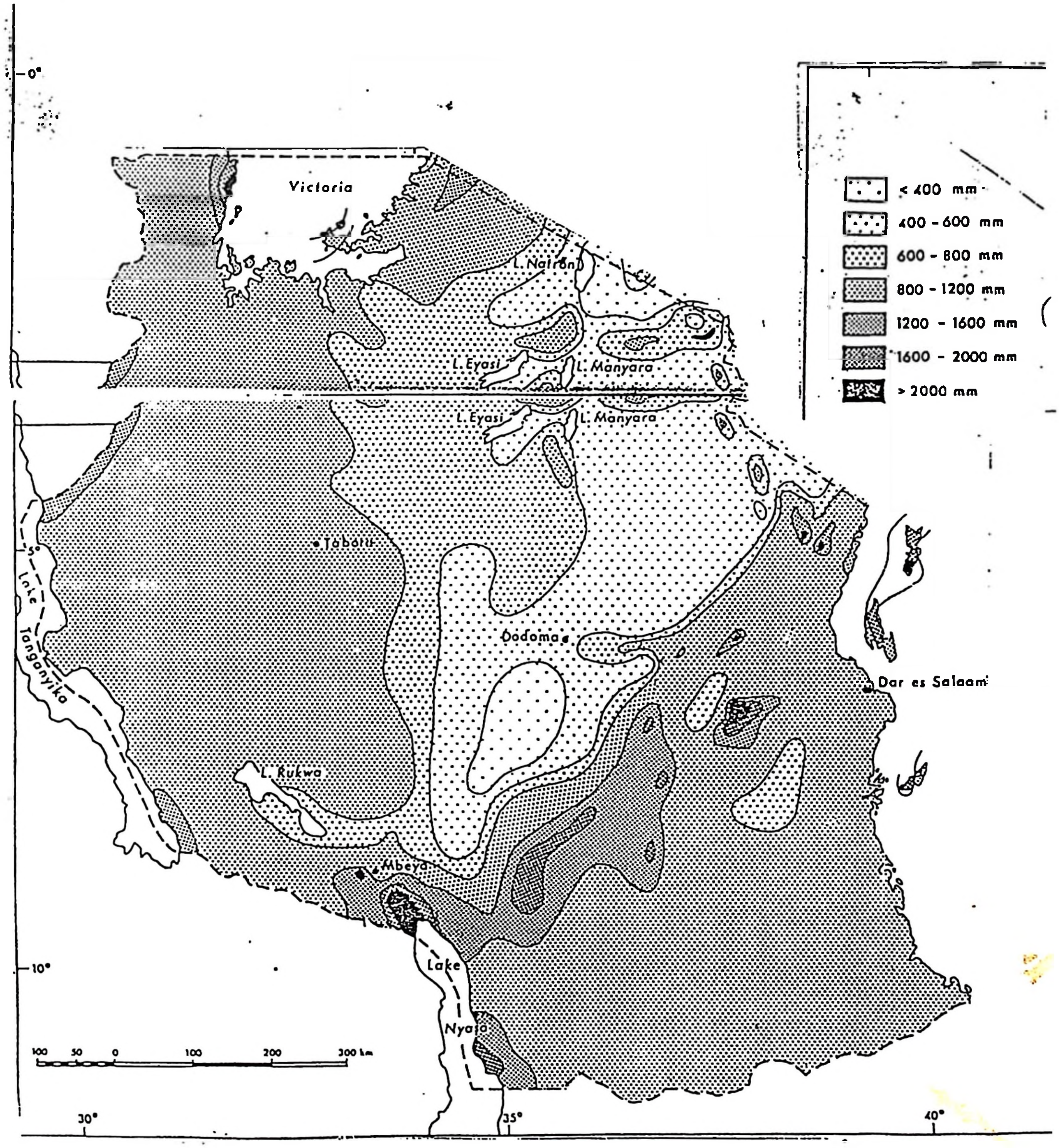


FIGURE 2.2 Average annual rainfall. (Source: Lundgren,1975)

2.2 PAST PERFORMANCE OF CONVENTIONAL IRRIGATION PROJECTS IN TANZANIA

Irrigation projects in Tanzania are carried out by river diversion and furrow distribution of water.
Past investments in irrigation, particularly for rice production have been in capital intensive fully developed irrigation projects. The National Agricultural and Food Co-operation (NAFCO) operates four mechanized state farms at Mbarali, Madibira, Ruvu and Dakawa with very mixed success. The most successful, Mbarali, has suffered declining yields over the past few years from an average of 7 tons/ha to 4.5 tons/ha of paddy production. The most recent, the 2,00 ha Dakawa Scheme, completed in 1982 at a cost in excess of $ 10,000/ha, has never been fully cropped and has difficulty in meeting its operating costs (Saouma, 1990).

In the small holder sector there has also been a concentration on capital intensive fully developed irrigation schemes, particularly the 2,300 ha lower Moshi Project which was implemented with Japanese support at a cost of $ 15,000/ha. On going projects of this nature are the African Development Bank (ADB) supported Schemes at Mwamapuli and Kitivo, and the Food and Agriculture Organization/United Nations Development Projects (FAO/UNDP) supported Majengo Scheme in Mbeya Region.

Although the capital costs of these latter schemes are less than the lower Moshi Project, the latest estimate for Majengo being about $ 8,000/ha, their economic viability depends on the rapid adopting by farmers of more sophisticated farming techniques, and the availability of effective support and extension services (Saouma, 1990).

This type of development also suffers the disadvantage of benefiting relatively few people at high cost, and often being incompatible with the objectives, abilities and resources of beneficiaries.

2.3 RAIN-WATER HARVESTING PRACTICE AROUND THE WORLD.

Rain-water harvesting is practiced in several countries around the world such as: Middle East (Israel), South America, India, Pakistan, North Africa, Australia and Sub-Saharan Africa.

According to Evenari et al (1971), the Middle East has been referred to by many authors as being of outstanding importance in the history of water harvesting. He describes systems in the Negev desert, which are thought to have started around 2500 years BC. By harvesting rain the Nabataeans were able to provide sufficient food for themselves and for the caravans that crossed the Negev

Desert. Generating technologies to collect rainfall where precipitation was as little as 100 mm, they collected and directed runoff from the hills towards lower areas to irrigate established crops. They also built mediterranean in small riverbeds to collect runoff from hills. These technologies, as well as the use of cisterns can still be seen in the region of Beersheba in Avdat, Israel, where various mediterranean countries still use them in agriculture and livestock production. According to Dutt (1981) evidence indicates that rain was harvested in Mexico and South American countries for agricultural, livestock, and human purposes before the arrival of the Spaniards.

Reij et al (1988) reports that in Jaisalmer district of West Rajastanin India, which is located in the Thar desert and receives an average annual rainfall of only 167 mm, large bunds were constructed as early as the 15th century to store runoff from rocky catchments. In the mountainous and dry province of Baluchistan in Pakistan, bunds are traditionally constructed across the slope of the land to force the runoff to infiltrate. Also examples of RWH techniques can be found in North Africa such as the southwestern Anti-Atlas in Morocco, in large parts of Tunisia, on many single sites in the predesert of Libya, the foothills of the Jebel Nefusa (Libya) and the northwest coastal zone of Egypt . In Australia water harvesting is widely practised, the techniques are implemented by commercial farmers using heavy duty equipment. And in Sub-Saharan Africa, various techniques to conserve soil and water have been and in many cases still are applied in semi-arid regions.

2.4 PREVIOUS RESEARCH ON RWH FOR CROP PRODUCTION

Research on RWH have been conducted in Australia, Israel, and United States of America.

According to Dutt (1981), a number of water-harvesting systems have been developed to suit given regions, crops and rainfall pattern. Desert strip-farming experiments to grow two crops per year began in November 1978 and continue to this date at the University of Arizona page Trow bridge Experiment-Farm. Desert-Strip farming is similar to conservation bench-terrace farming and conservation dryland-strip farming in that crops are planted along contours . Laing (1980) reports that, extensive research has been carried out in Israel and the results shows that units of water-harvesting systems depend in part upon site specific soil characteristics. The soil usually must perform as a collection surface and a medium for plant growth. To shed water, soils used for untreated catchments should be relatively impermeable or have tendency to crust during rainfall. Soils best suited to such catchments are fine to medium textured with significant percentages of clay. Also according to Fink and Ehrlier (1980), laboratory and field test have been developed to evaluate water-harvesting treatments at U.S. Water Conservation Laboratory. A promising new water-repellent treatment composed of soil stabilizer, residual wax, and antistripping agent has been developed. This water-harvesting treatment, as well as others, is currently being applied in run-off farming studies. Frasier (1977) report that catchments with slopes greater than 8% have serious erosion problems. Shanan and Tadmor (1979) write that "greatly sloping plains (1%-3%) gradients) without gullies, channels and local depressions are ideal". They add that catchments with slopes that are steeper than 7% can lead to erosion problems where the length of overland flow exceeds 10 m. Also Dutt (1980) reports that, the ratio of catchment area to cropped area can be reduced, thus, making catchments more efficient by removing plant growth from catchment, treating them with sodium salt, and compacting them and also the catchment should be shaped to conform to the natural slope of the land

According to Frasier (1980), Methods and materials are available for constructing water harvesting systems for supplying drinking water and water for runoff farming applications, of the various types of catchments and storage facilities which are potentially suitable, no single method or material is universally the best. Each system must be individually designed to satisfy onsite needs .

Reij et al (1988) reports that, much has been written about the rain-water harvesting but most concerns Israel, the Middle East, Northern Africa, India and the South-Western part of the USA as well as North Mexico. There is, however, little information available on water harvesting in Sub-Sahara Africa (SSA), and the little information available has not been collected or analyzed systematically. The basic problem is that the knowledge of traditional soil and water conservation in sub-saharan Africa is extremely limited and fragmentary. No studies have been made of traditional soil and water conservation/water harvesting systems in, for example, Niger, Somalia and Sudan, despite the fact that in each of these countries farmers have treated several thousand hectares with these techniques.

Important soil and water conservation projects have been carried out in Niger (Ader Doutchi Maggia) and in Burkina Faso (Plateau central). The emphasis in these projects was on soil conservation rather than water conservation. Rainfall in the Sahel was relatively abundant in the

196os, but the occurrence of a series of drought in years did not quickly lead to an adaptation of the techniques. Only since the 1980s can a shift be observed toward the use of water harvesting techniques . Now the emphasis is on those water harvesting systems which collect and concentrate rainfall runoff for the purpose of improving plant production in the arid and semi-arid areas of SSA.

2.5 PADDY PRODUCTION UNDER RWH IN SHINYANGA.

2.5.1 CULTURAL PRACTICES

The system of rain water harvesting for paddy production in Shinyanga is essentially practised in areas of land which are subject to seasonal flooding. They can occur in the lower parts of undulating terrain or as fans at the end of flooded areas. The soils are vertic, black-grey cracking clays of reasonable fertility. These areas are locally called "Mbugas".

In Shinyanga region about 43,000 ha are used for producing rice under RWH system. During the rainy season most farmers collect surface runoff from catchment area using channels or diversion systems into "Majaruba" which are located down stream of the runoff area (catchment area). Then the "Jaruba" is ploughed with about 5-7 cm of standing water. After repeated ploughing the soil becomes puddled and paddy seedlings are then transplanted to the field. Normally during the growing season prolonged dry spells occur. However the water which is stored in the rootzone below the basin after each rain event is used to cover the water requirement of the crop during dry spells.

In order to make the bunds more stable against erosion damage, grasses are planted along the bunds. The plant 'cynodon dactylion' which is locally called Lugobi is used to stabilize the bunds against erosive effect of flowing water.

During bund construction animal drawn plough is used to cultivate and loosen the soil, then the soil is moved by hand to build up the bund. In trying to maximise water storage in order to cover the loss of stored water due to seepage and evaporation, some farmers construct bunds of heights between 100-125 cm so as to increase the storage capacity of the basin.

2.5.2 VARIETIES OF PADDY GROWN

In Shinyanga region the following varieties of paddy are adopted: Kahogo Red, Afaa mwanza, Supa India, Gamti, Faya Thereza, IR8, IR579, Taiwan 14 and surinaam.

2.5.3 CROP WATER REQUIREMENTS

Crop water requirements are defined here as the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop, growing in a large field under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977). Crop water requirements for paddy, depending on the climate and soil are between 1000 to 1500 mm for a 6 month crop (Chatterjee and Maiti, 1983).

After the paddy has germinated and has become established after transplanting, water is kept in the fields until a month before harvesting. This is important for the following two reason:-(a) to meet the water demand of the paddy plant and to obtain the highest possible yield, and (b) and second to suppress the weeds.

The time when the paddy plant is most sensitive to a water deficit is during flowering and the second half of the vegetative growth stage. Paddy yields decline when the soil moisture content decreases to 70-80% of the saturation point. At 50% saturation, the yield expectancy drops to 50%-70% at 30% saturation no yield is expected and at 20% the paddy plants die of draught stress. Paddy roots can grow to a depth of 1 m. The fibrous root system gradually increases from transplanting up to the heading stage. It then decreases after flowering. At maturity most of the roots are dead. The most important characteristic of these roots is that they grow under a low oxygen content in the soil. During and immediately after transplanting the depth of water allowed in the basin should be about 10 cm. This can be decreased to 3-4 cm during the talloring stage. After tillering, the water depth can be increased to another 10 cm during the heading and flowering stages. During the ripening periods the field should be gradually drained up to harvesting. Paddy can tolerate complete submergence for one day or two only but any prolonged submergence will kill the plant.

Total water requirement of a transplanted paddy crop includes water needed to raise seedlings, prepare land and to grow the crop from transplanting to harvest. The amount of requirement will vary due to many factors: Soil type, topography, depth of water table, duration of the crop, evaporative demand of the growing season etc.

2.5.4 AVERAGE PADDY YIELDS

The performance of the traditional RWH system in terms of crop yield can be summarized as it shows in Table 2.1

TABLE 2.1 AVERAGE PADDY YIELDS IN SHINYANGA

PERIOD (YEAR)	AREA CULTIVATED (HECTARES)	PADDY YIELD (TONS)	AVERAGE YIELDS (TONS/HACTARE)
1982-83	59 729	59 729	1.0
1983-84	86 702	86 702	1.0
1984-85	35 747	52 715	1.5
1985-86	42 500	48 099	1.1
1986-87	58 350	106 682	1.8
1987-88	54 406	81 609	1.5
1988-89	76 182	185 743	2.4
1989-90	94 031	169 255	1.8
1990-91	89 024	158 048	1.8

Source: Regional Agricultural and Livestock Development Officer in Shinyanga region (1991).

2.5.5 CROPPING CALENDER

Land preparation for paddy starts immediately after early (first) rains, and the first rains normally starts early November or late October. Rice nurseries are established near the villages in December, either on rainfall or by hand watering. Depending on water availability in the paddies, seedlings are transplanted in January and February. Harvesting time depends on the variety grown and the date of transplanting. However, in larger parts of the region harvesting is done between May and July (Table 2.2).

TABLE 2.2 THE CROPPING CALENDER FOR GROWING PADDY

ACTIVITY	OCT-DEC	DEC-FEB	MAR-APR	MAY-JULY
LAND AND NURSERY PREPARATION	----------			
TRANSPLANTING		----------		
WEEDING			----------	
HARVESTING				----------

2.5.6 MAJOR ARRANGEMENTS OF RWH SYSTEM

The system of RWH can be divided into 3 categories depending on the way the water is harvested and moved into the "Jaruba"

(1) The system may be arranged in such away that several "Jaruba" are laid parallel to each other down a slope [Figure 2.3 (a)], but with common catchment for capturing runoff and also provision is available to allow runoff to pass into the lower "Jaruba."

(2) The system may be arranged in such away that the general catchment run down the slope and when there is rain these form some sort of a stream. Provision is made for capturing runoff by small ridges built into the water path which leads water through an opening into the "Jaruba". [Figure 2.3. (b)].

(3) The system may be arranged in such away that runoff is diverted from an ephemeral stream which become flooded during heavy

rains whereas in other arrangements the surface runoff is harvested directly from the catchment which is located adjacent to the farmed area (basin). Therefore in this arrangement farmers collect surface runoff from these streams, using channels or diversion systems and storing it in the farmed area. Also ridges forming the basin in this technique may be breached to allow runoff to pass into lower basins [Figure 2.3 (c)].

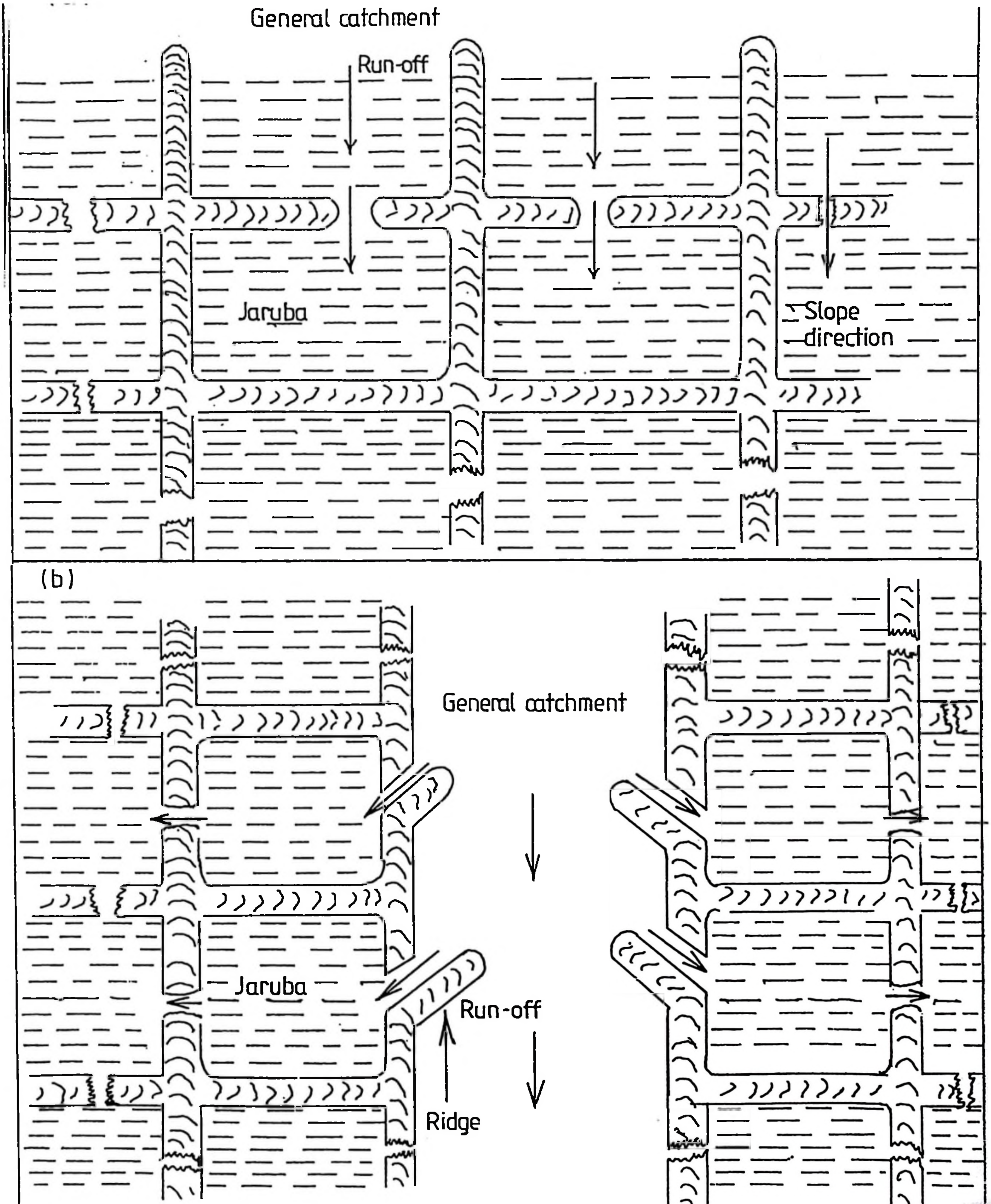


Figure 2.3(a) & (b) Arrangements of Rain-Water Harvesting system.

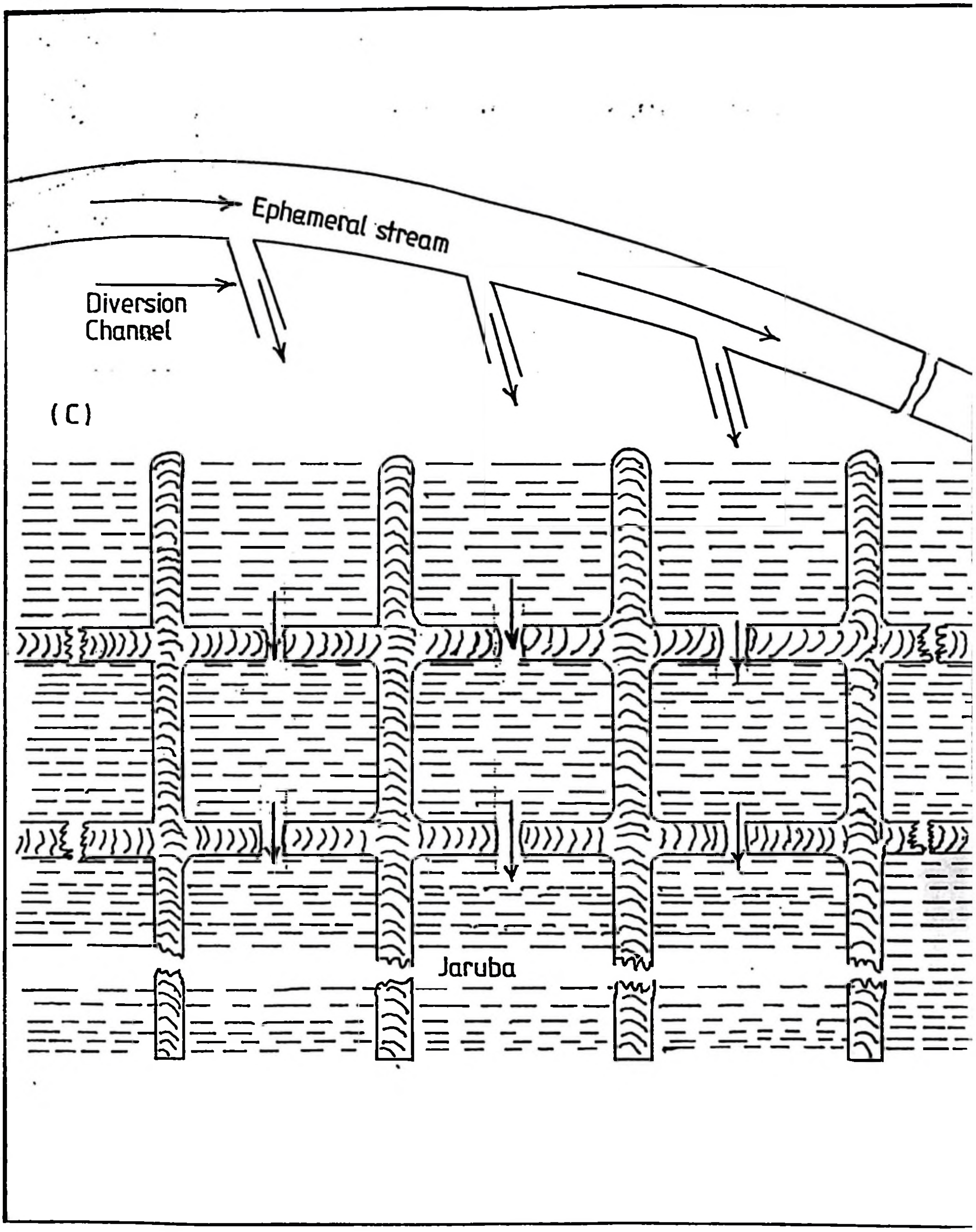


Figure 2.3(c) Arrangement of Rain-Water Harvesting system.

CHAPTER 3. MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

Shinyanga region is located in North-West of central Tanzania and lies between 31^0 and 35^0 East longitude and 2^0 and 4^0 south latitude (Figure 3.1). This region has an area of about 50,704 km^2 and the area suitable for agriculture and livestock is about 31,000 km^2. The landscape is mostly bare soil with small bushes.

The average annual precipitation amounts to some 750 mm in most of the Shinyanga, Maswa and Bariadi districts. This increases in the western part of the Shinyanga district and reaches about 1000 mm in Kahama(Figure 3.2). The variation in yearly rainfall is some 25% over a period of 10 years. However, variations in monthly rainfall during the entire wet season are in the order of 60% or even more.

The spacial variation of rainfall is also very important. Showers are mostly formed insitu and as a result rainfall intensity varies considerably even within a small area.

Taking into account the characteristic of rainfall and temperature Shinyanga region has a Semi-arid tropical climate (Kopper, 1958).

A distinct dry season lasting three to six months is followed by a distinct wet season, usually from November to the beginning of May.

The mean daily air temperature (22^0C) is fairly constant throughout the year although a period of heat (22^0-30^0C) usually comes in October, just before the rainy period. The amount of cloud during the rainy season that follows prevents part of the solar radiation from reaching the earth so that the temperature at that time average several degrees lower (21^0-23^0C). After the rainy period a cooler dry season ensues, coinciding with the months of lowest elevation of the sun (20^0-23^0C). The minimum daily temperature varies from 15^0C in June-July to 19^0C in the last three months of the year, where as the maximum daily temperature varies from 28^0C to 32^0C.

Evaporation ranges between 4mm/day and 5mm/day in west part of the region, 5mm/day and 6mm/day in central and eastern part and between 6mm/day and 7mm/day in south east part of the region (Figure 3.3a to 3.3c).

Relative humidity is lowest during the day. It ranges from 30% in the dry season to 40% in the wet season. At night relative humidity increases to about 90% throughout the year.

The elevations in the region vary between 1500 m above sea level and 1100 m. The macro relief can be described as gently sloping. The micro relief is characterized by undulating landscape in the major part of the region.

There is a wide variation of soils within each of the rainfall zones. In general, it can be said that south and West Kahama consist of sandy non-alluvial soils of poor quality, while in East Kahama, the central and Northern parts of Shinyanga and Maswa Districts, and the Bariadi Districts there is a mixture of non-alluvial sandy loam and alluvial heavy clay areas of variable quality (Ridep, 1975).

Traditionally , rice, sorghum and bulrush millet are the staple food crops. Maize is becoming increasingly important and is now grown over significant areas. Other crops include sweet potatoes, and cassava. Groundnuts, soyabeans and cotton are mainly used as a cash crop.

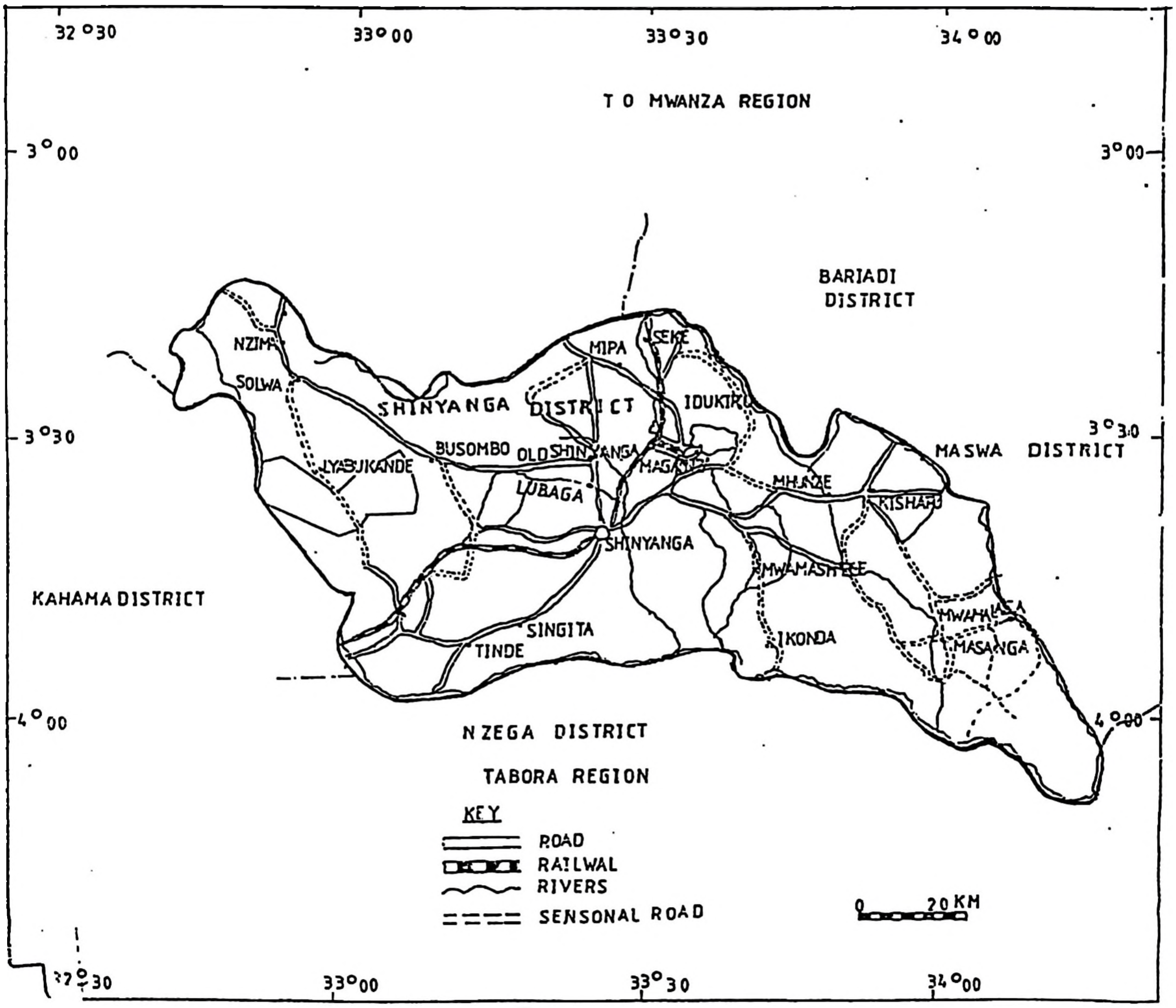


FIGURE 3.1 Locational map of the study area.

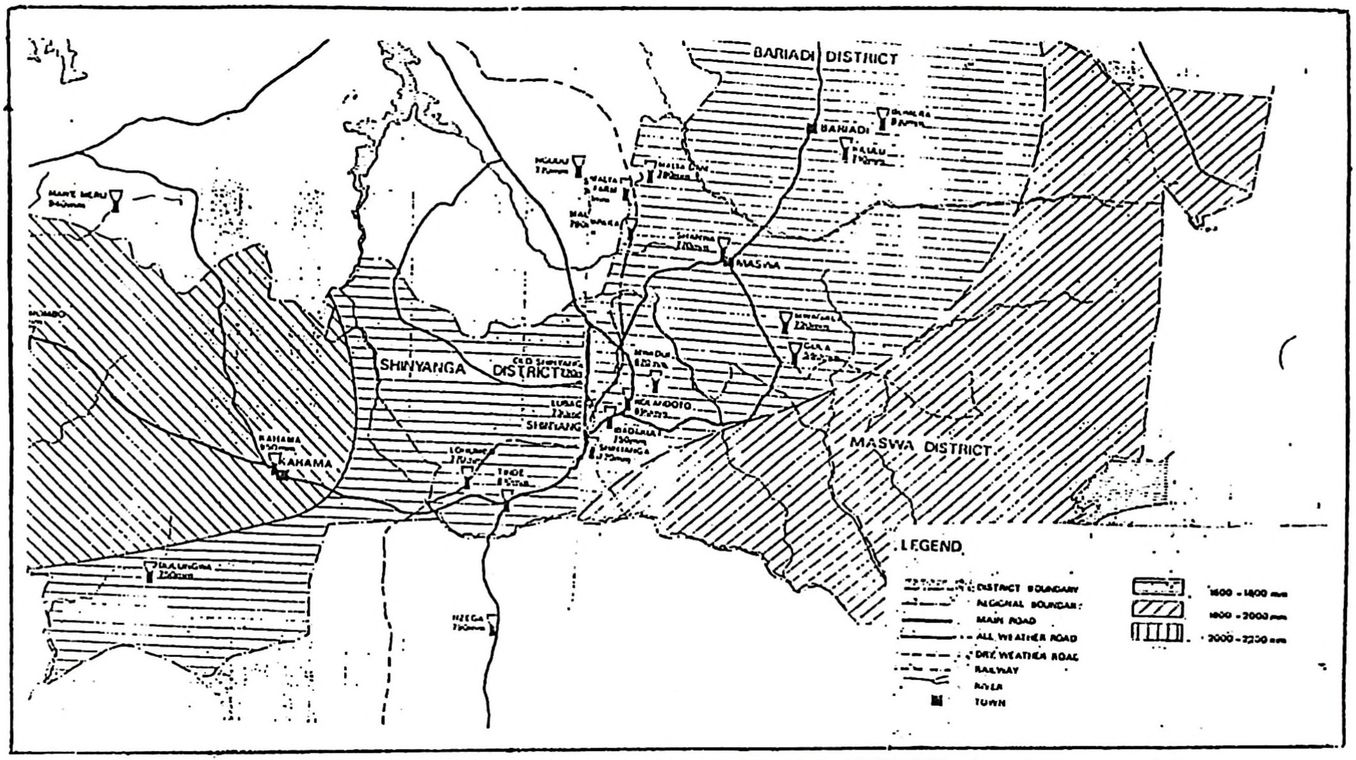


FIGURE 3.2 Mean annual rainfall. (Source: Ridep, 1975)

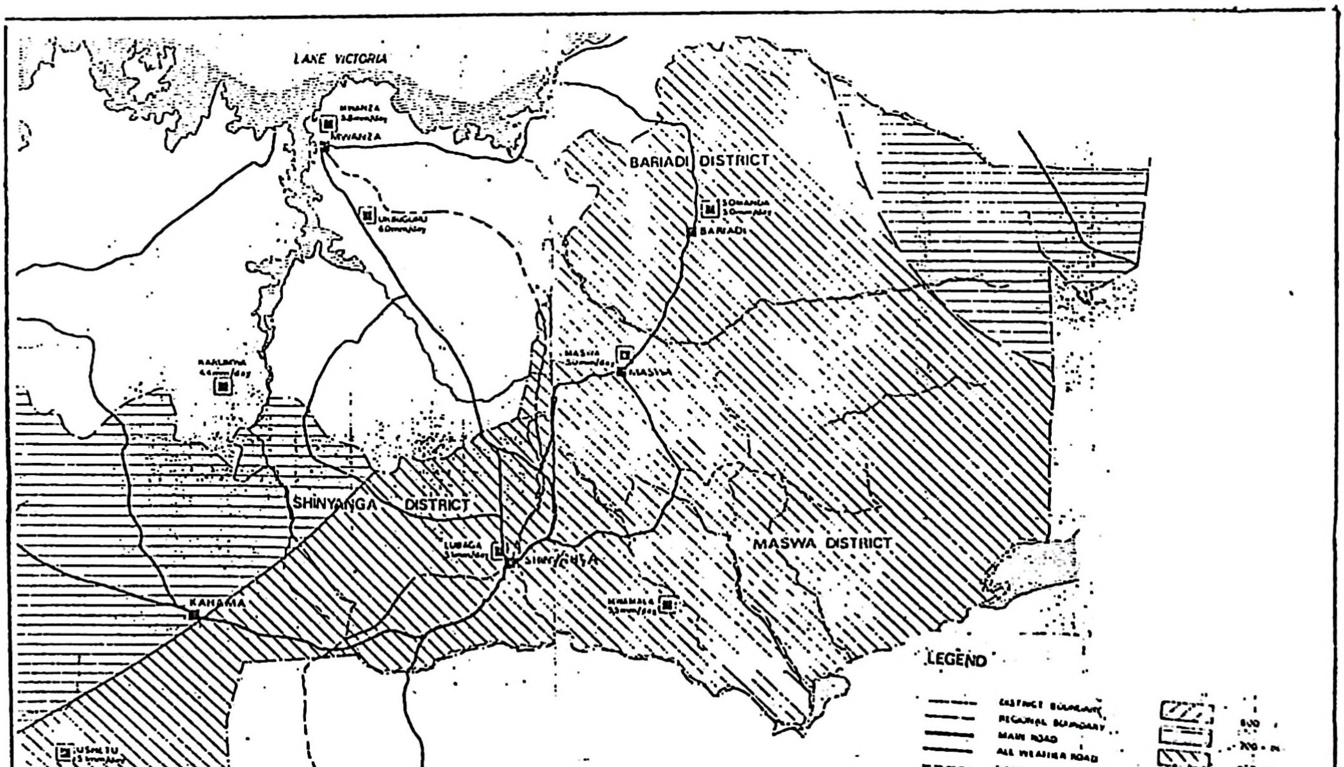


FIGURE 3.3 (a) Mean daily evaporation (Source: Ridep, 1975)

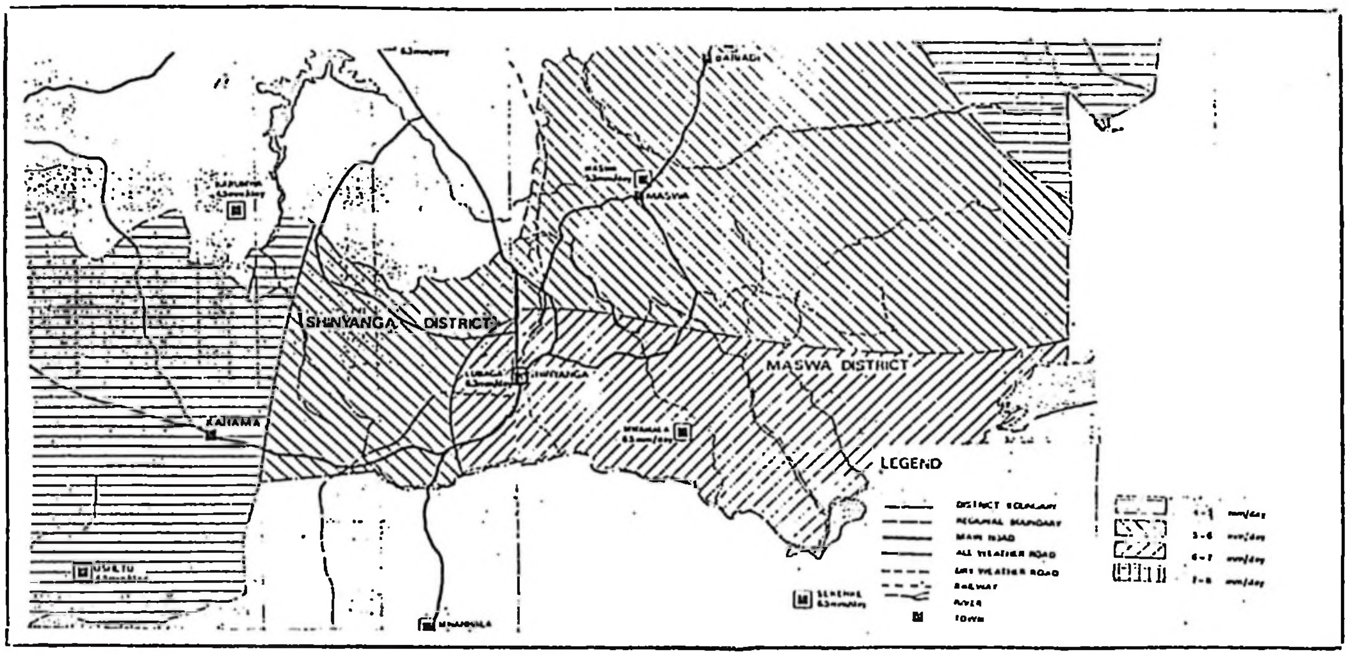


FIGURE 3.3 (b) Mean daily evaporation(Source: Ridep, 1975)

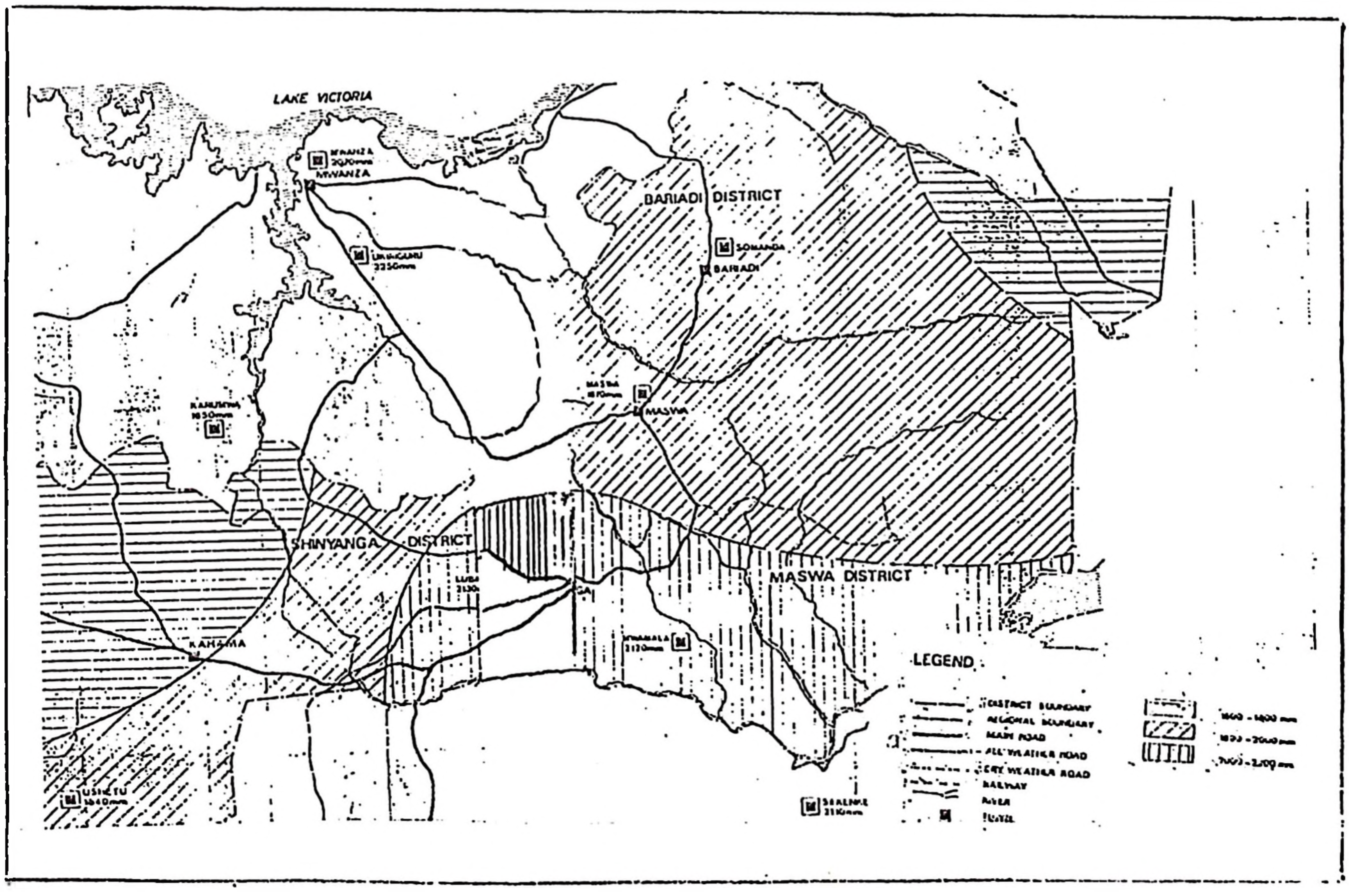


FIGURE 3.3 (c) Mean annual evaporation(Source: Ridep, 1975)

3.2 DATA COLLECTION

3.2.1 RAINFALL CHARACTERISTICS

In order to assess the suitability of RWH system in Shinyanga region from the rainfall point of view, the historical data analysis was used.

Record of annual rainfall data from 1971 to 1991 seasons were obtained from Lubaga meteorological station. This data represents very well the annual rainfall records of central part of Shinyanga which covers the Shinyanga urban and rural districts. Lubaga is located in Shinyanga District about 5km from Shinyanga town (Figure 3.2).

3.2.2 SURFACE RUN-OFF COLLECTION

3.2.2.1 SITE SELECTION

The rate and quantity of the surface runoff is affected by many properties of the catchment area, such as size and shape of the catchment, slopes, soil permeability and type of vegetation. Therefore the study area was surveyed and twelve (12) rain-catchments of different characteristics were selected for run-off collection at Lubaga. These catchments were classified according to the different characteristics as shown in Table 3.1. These catchments were selected such that the surface of the runoff plots represent that of the expected water harvesting system (i.e. treatment, slope and soil).

TABLE 3.1 RAIN CATCHMENTS OF DIFFERENT CHARACTERISTICS

Class	Description of catchment	Number of catchments
A	uncompacted, clay soils and slope < 5%	3
B	compacted, clay soils and slope < 5%	3
C	uncompacted, clay soils and slope > 5%	3
D	compacted, clay soils and slope > 5%	3

3.2.2.2 INSTRUMENTATION

The runoff plots were first instrumented with dividing tanks for runoff collection (Figure 3.4). Dividing tanks are two or more empty drums of 200 litres and they are arranged in such away that one tank is used for collecting surface runoff direct from the rain catchment where as the second drum is used to collect overflow from the first tank.

To minimize the number of empty tanks or to reduce the cost, the first tank was drilled 10 holes 5 millimetres from the top level (open end), and the holes were evenly spaced on the same level, then a piece of pipe about 30 cm was welded all around to one of the 10 holes, this implies that during the runoff collection, if there is overflow from the first tank only one tenth of the overflow will be collected in the second tank.

These dividing collecting tanks were buried in the ground for measuring runoff water. The catchment areas were bordered in all sides with runoff water to be collected and measured at the lower end.

Unfortunately before data collection started, these drums were stolen, then another alternative design had to be attempted this was to dig and construct a pit of the capacity approximately 1000 litres.

These excavated earth tanks were constructed at the lower end of the catchments and were lined with a thin layer of cement mortar so as to prevent seepage/leakage (Figure 3.5).

3.2.2.3 RUN-OFF COLLECTION

Surface runoff from different rain catchments were collected during the rain season (from November 1991 to march 1992).

The layout of a run-off test plot used in the study for runoff collection is as shown in Figure 3.6. After measurements has been done runoff water from the tank was emptied. This exercise was done after each rain event.

3.2.3 LOSSES OF RAIN WATER FROM THE PADDY FIELDS

3.2.3.1 EVAPOTRANSPIRATION (ET)

The penman formula has found widespread acceptance for determination of evapotranspiration. It is based on a combination of aerodynamic and energy balance equations. Reliable estimates of daily or monthly evapotranspiration with this formula require information of the relevant meteorological factors: solar radiation, hours of sunshine, air temperature, air humidity and windrun.

To overcome the computational labour involved in solving the Penman equation, tables which enable rapid estimates were drawn up (see Appendix - A) .

In addition to the use of the formulae, the open water evaporation was estimated by a correlation with the results of an evaporation pan. The U.S. Class A evaporation pan which is commonly used in East Africa, was used to assess the evaporation in Shinyanga region.

3.2.3.2 DEEP PERCOLATION

Equations 4.6, 4.7 and 4.8 established by Nedeco, (1974) were used to asses the losses of water through deep percolation. However, taking into account the rain season from November 1991 to April 1992, the soil profile was investigated by measuring the soil-moisture content up to about 1m depth after each rain event , and the gravimetric method was used for this purpose (Dutt, 1981). These measurements were taken from one of the rain-fed plots (plot-3).

3.2.3.3 CROPPED AREA DATA

Three plots (paddy fields) were prepared and planted with paddy for the purpose of continuous measurement of water depth in the jaruba during the growing season. From these laid out plots, one plot was used as control such that no provision was made for runoff entry, thus it was just a rainfed plot. In the other plots provisions were made for entry of runoff from the adjacent catchments. These microcatchments were classified as shown in Table 3.2.

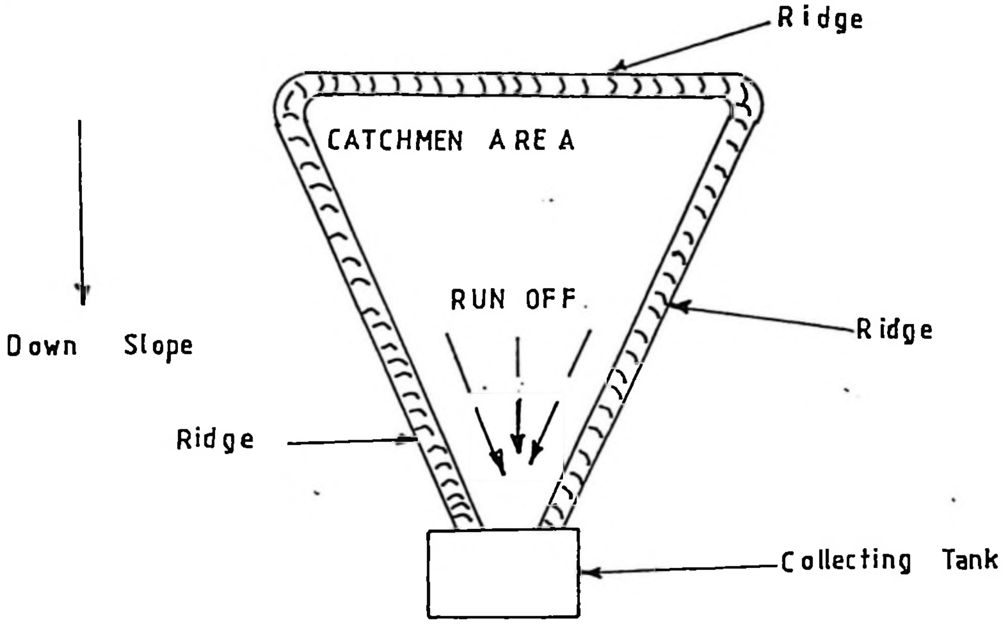
Therefore the water holding capacity were investigated in all plots by continuous measurements of water depth in the jaruba using a graduated stick. These measurement was carried out throughout the rain season (1st December 1991 to 1st April 1992)

TABLE 3.2 RAIN-CATCHMENT CLASSIFICATION

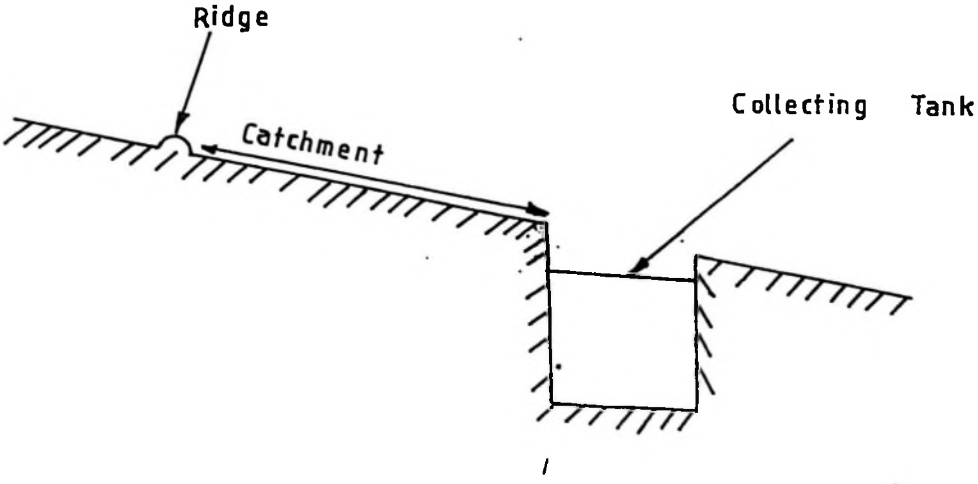
Type of plot	Description of the catchment
Plot 1 (PTI) (AREA = 332 m^2)	smoothed, compacted and slope < 5% (AREA = 236 M^2)
Plot 2 (PT2) (AREA = 173.6m^2)	grassed, compacted and slope < 5% (AREA = 63.44 M^2)
Plot 3 (PT3) (AREA = 105.1M^2)	no catchment for runoff entry

FIGURE 3.4 General view of Dividing collecting tanks.

FIGURE 3.5 General view of Excavated collecting tank.



TOP VIEW



CROSS SECTION

FIGURE.3.6 Layout of the runoff plot used in the study

FIGURE 3.7 General view of the paddy field with a rain-catchment.

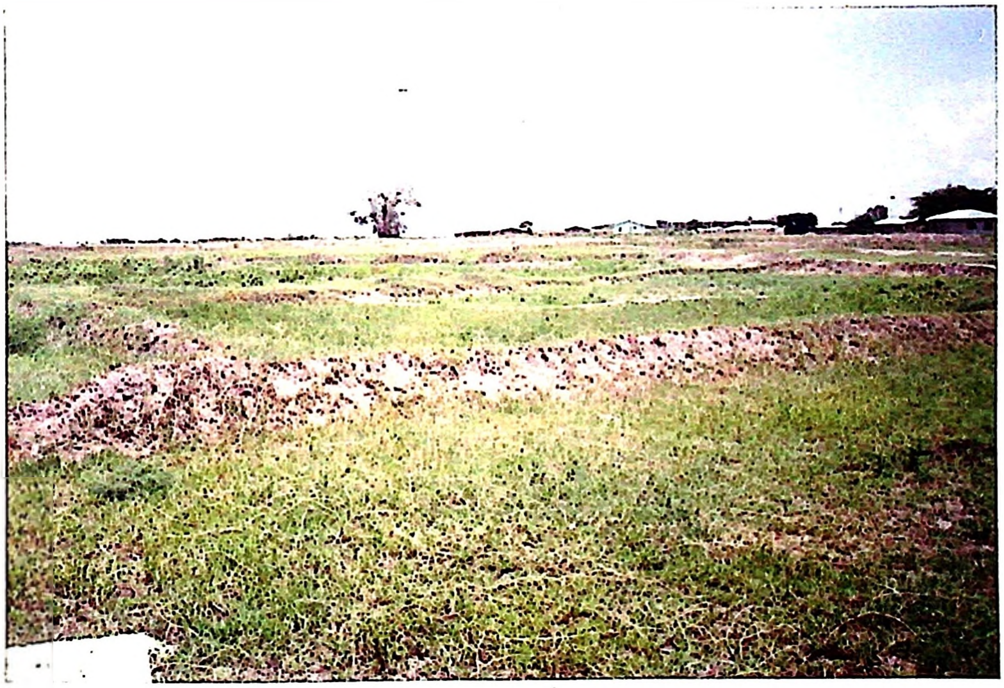


FIGURE 3.8 General view of paddy field without a rain-catchment.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 RAINFALL STATUS IN SHINYANGA REGION

Historical rainfall data were collected from different stations and analysed as follows.

4.1.1 FREQUENCY OF ANNUAL RAINFALL

The long term rainfall data of 4 stations in the region, Ushirimbo, Kahama, Old Shinyanga and Shanwa and of 2 Stations just outside the Region, Ngudu (Mwanza region) and Nzega (Tabora Region) has been used to determine the mean annual rainfall and extreme values with their frequencies for each station. These values are listed in Table 4.1 and plotted in Figure 4.1.

4.1.2 FREQUENCY OF MONTHLY RAINFALL

Monthly precipitation data of Lubaga and the stations used for the calculation of the annual rainfall frequencies have been analyzed. The mean monthly rainfall and extreme values with their frequencies are listed in Table 4.2 and plotted in Figure 4.2.

4.1.3 CUMULATIVE RAINFALL

Cumulative rainfall in successive months Stating in November has been plotted in Figure 4.3.

4.1.4 FREQUENCY OF DAILY RAINFALL

The diurnal variation of the precipitation in Shinyanga District is computed from the charts of the rain gauge recorders at Shinyanga, Chibe and Usia. The data are plotted in Figure 4.4.

4.1.5 RAINFALL INTENSITY

For Tabora Region a relation was developed between the maximum rainfall intensity (I) that occurred and the period (t) over which this intensity was measured (McCallum 1965). It was therefore expressed in the formula:

$$I = 61t^{-0.89} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

where: I is rainfall intensity in mm/hour

t is period in hours

The relation appears to be valid for periods ranging from 1 hour to 24 hours

In Figure 4.5 the observations of the recording rain gauge at Chibe are plotted against the above formula. The results suggest a good validity of the Tabora formula for the Shinyanga Region.

TABLE 4.1 Annual rainfall in Shinyanga region(in millimetres).

Station	Probability of non-exceedence						
	2 %	10 %	20 %	60 %	80 %	90 %	98 %
Ushirombo	520	620	700	870	1100	1250	1530
Kahama	660	750	820	950	1100	1200	1390
Old Shinyanga	460	580	640	775	950	1050	1280
Maswa (Shanwa)	440	540	610	790	1070	1090	1360
Nzega	460	560	620	790	950	1070	1300
Ngudu	420	520	600	750	980	1100	1400

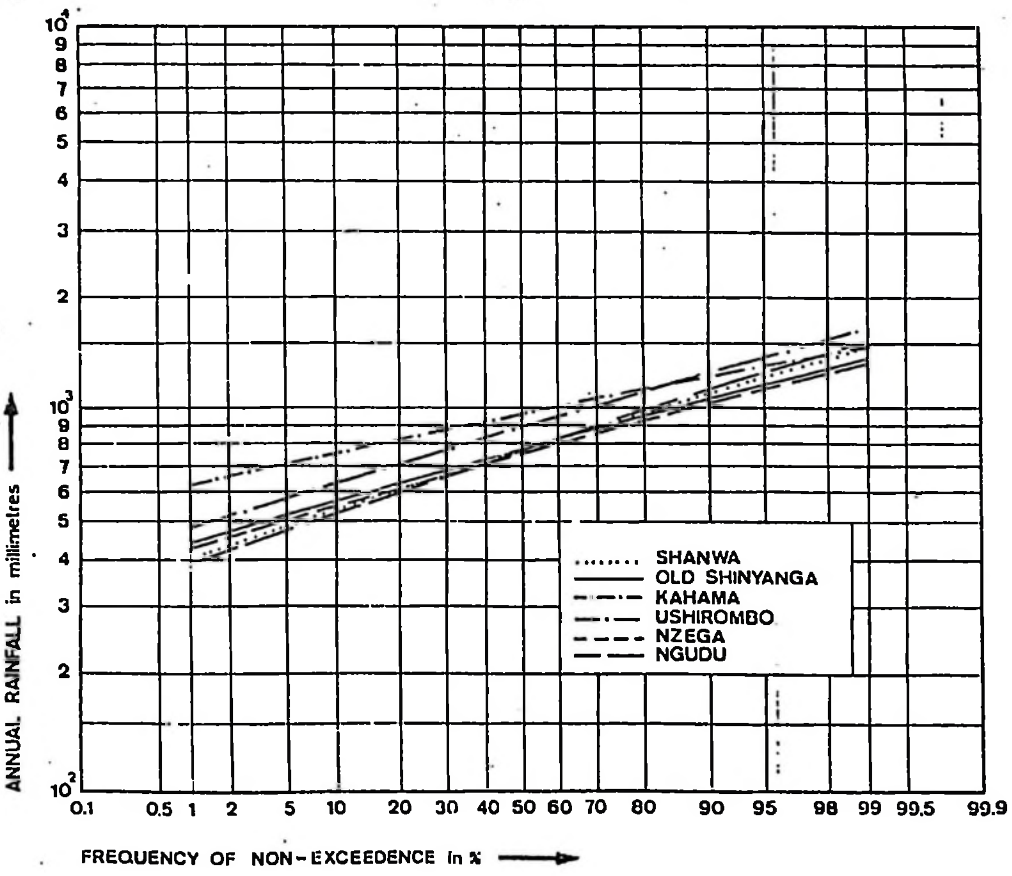


FIGURE 4.1 Frequency of annual rainfall.

TABLE 4.2 Monthly rainfall in millimetres with probability of non-exceedence.

Station	Freq	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Lubaga	10 %					19	87	70	50	95	75	0	
	50 %	4	4	5	25	56	135	120	90	150	110	20	4
	90 %					170	210	200	160	230	162	80	
Kahama	10 %				0	45	85	75	65	105	50	0	
	50 %	3	3	15	32	100	130	115	100	150	110	34	3
	90 %				70	220	210	180	160	230	230	110	
Maswa (Shanwa)	10 %				0	50	55	60	50	50	70	0	
	50 %	4	4	10	16	93	110	112	105	110	130	36	4
	90 %				50	170	210	165	210	240	230	66	
Ushirombo	50 %	7	7	15	48	100	120	124	97	133	150	78	7
Old Shinyanga	50 %	4	4	5	25	60	133	120	95	131	136	62	4
Ngudu	50%	9	9	14	28	102	115	96	95	128	151	64	9
Nzega	50 %	2	2	6	17	87	114	124	115	140	130	29	2

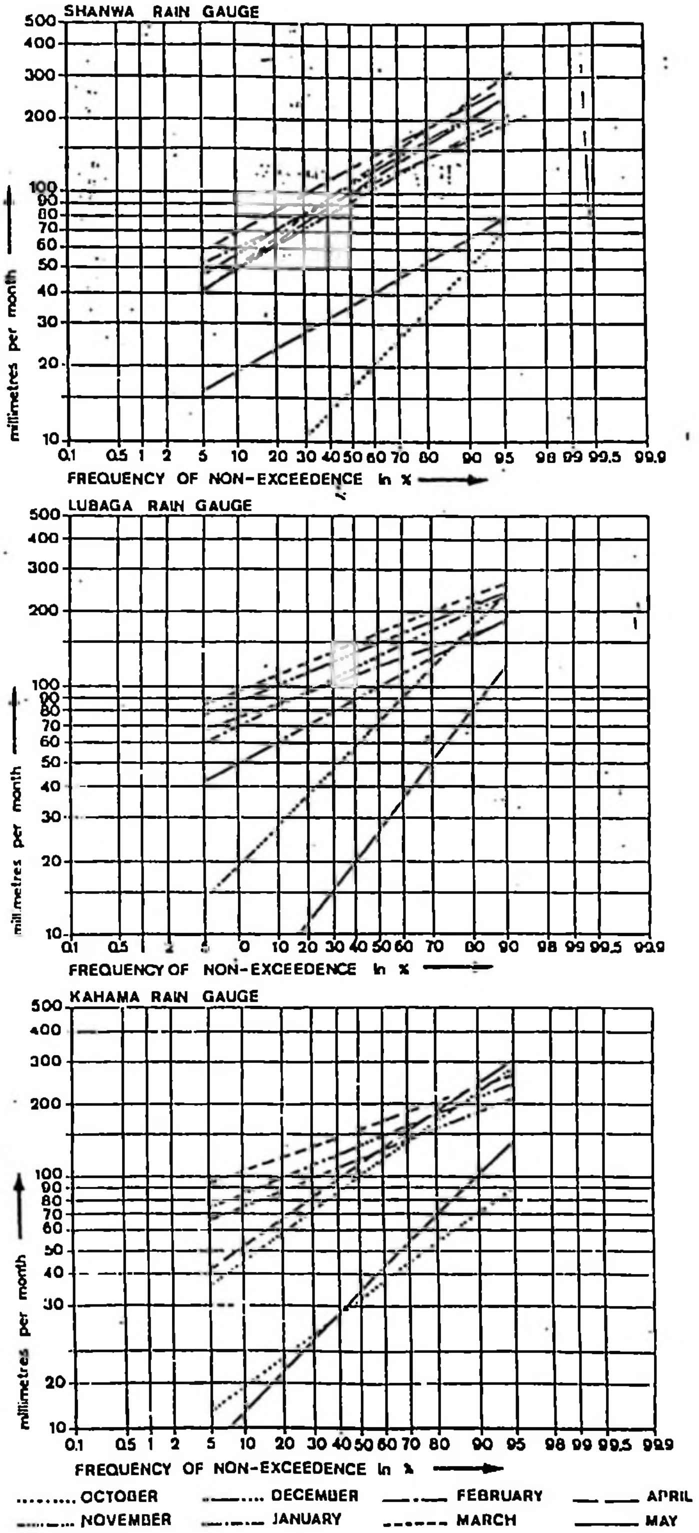


FIGURE 4.2 Frequency of monthly rainfall.

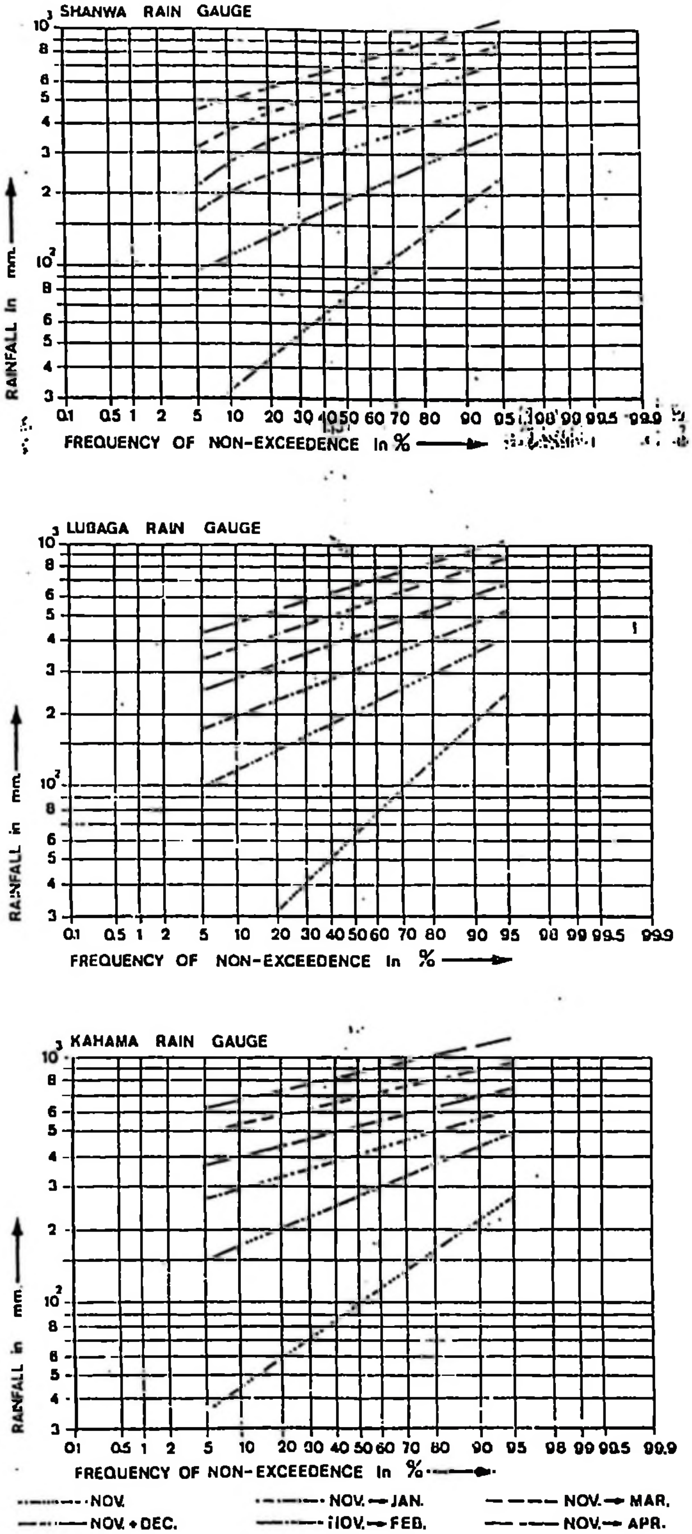


FIGURE 4.3 Cumulative rainfall in successive months starting November.

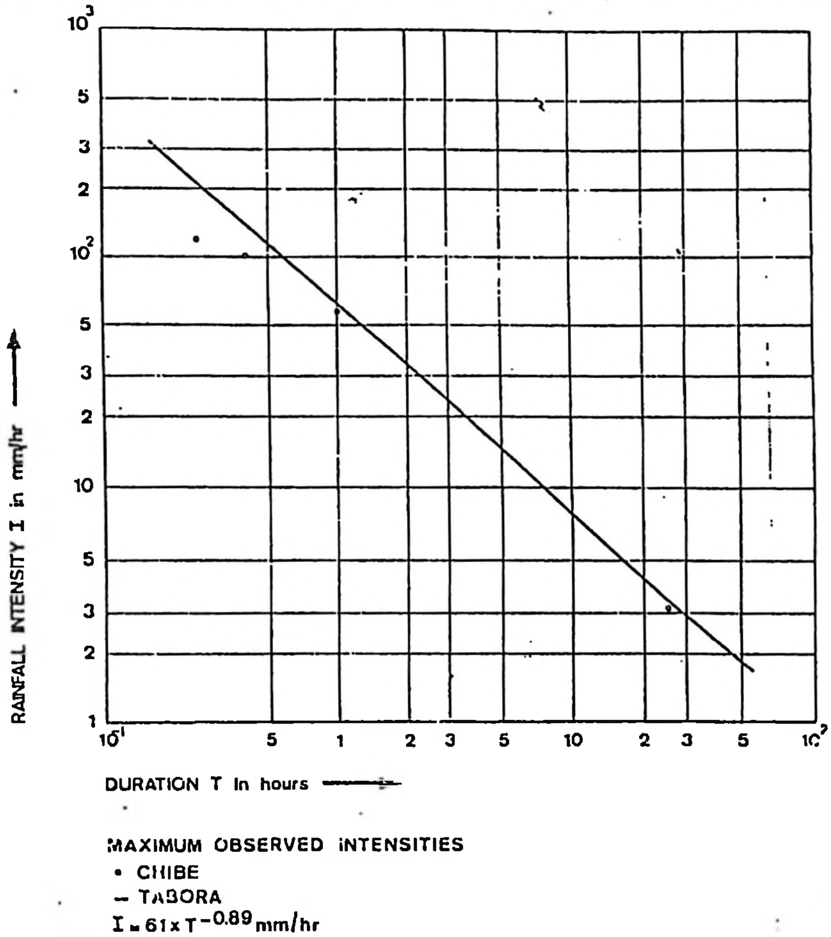


FIGURE 4.4 Rainfall intensity

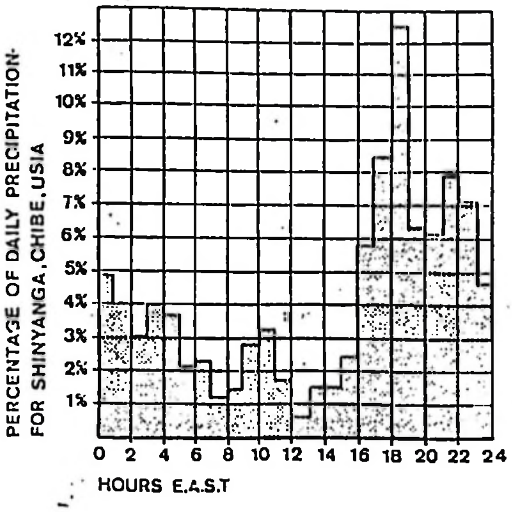


FIGURE 4.5 Frequency of daily rainfall in Shinyanga district.

To assess the suitability of RWH system, it is not so much the mean precipitation which is important as the frequency of occurrence of relatively dry and/or wet years.

From historical annual rainfall data shows that, in the Shinyanga, Maswa and Bariadi Districts will exceed 1050 mm and in Kahama District will exceed 1200 mm on an average of once in every decade. Rainfall of less than 550 mm per year for the Shinyanga, Maswa and Bariadi Districts and rainfall of less than about 700 mm per year

To assess the suitability of RWH system, it is not so much the mean precipitation which is important as the frequency of occurrence of relatively dry and/or wet years.

From historical annual rainfall data shows that, in the Shinyanga, Maswa and Bariadi Districts will exceed 1050 mm and in Kahama District will exceed 1200 mm on an average of once in every decade. Rainfall of less than 550 mm per year for the Shinyanga, Maswa and Bariadi Districts and rainfall of less than about 700 mm per year for Kahama District have an average recurrence period of ten years. From Figure 4.1, it appears that the rainfall is quite uniformly distributed over the wet season November through April in Kahama District, and December-April for the remaining Districts with an average of 120 mm per month. Monthly rainfall (December to April) for all stations will exceed 200 mm on an average of once every ten years. Rainfall of less than 70 mm per month has an average recurrence period of ten years. Depending on the District, once in every 3-5 years there are periods of 30 days during the wet season with an average of less than 1 mm rainfall per day. Periods of 30 days with an average of less than 2 mm a day occur each second year in Kahama District and at least once a year in other

Districts. From Figure 4.2, it reveals that an average of once in 20 years a total rainfall of 100 mm is not reached before the end of December. The computation of frequencies of extreme daily rainfall show that for Shinyanga District 90 mm/day may occur on an average of once every 10 years. And a maximum daily rainfall of 60 mm has an average recurrence period of 2 years for the entire Region. Figure 4.3, shows that most of the daily precipitation occurs between 16.00 hours East African standard Time (EAST) and midnight, with the most favourable period being 18.00-19.00 hours, when 12% of the observed rainfall occurred.

4.2 RAINFALL STATUS IN SHINYANGA DISTRICT

In order to evaluate the runoff efficiency of the experimental plots, rainfall data under the area of study (Shinyanga district) were analyzed. The runoff efficiency is the percent of rainfall collected, also is the equivalent depth of runoff water divided by the rainfall depth expressed as a percent.

Therefore rainfall data are listed in Table 4.3, and Table 4.4 and are plotted in Figure 4.6 and 4.7.

TABLE 4.3 ANNUAL RAINFALL (mm) IN SHINYANGA DISTRICT.

RAIN - SEASON	TOTAL RAIN FALL RECEIVED (mm)
1971	698.3
1972	932.1
1973	906.0
1974	952.5
1975	748.7
1976	795.5
1977	830.6
1978	955.1
1979	861.8
1980	861.0
1981	696.0
1982	992.9
1983	586.0
1984	699.0
1985	652.0
1986	1062.2
1987	666.4
1988	793.6
1989	903.3
1990	734.7
1991	710.2

TABLE 4.4 MEAN MONTHLY RAINFALL (mm) IN SHINYANGA DISTRICT
(1971 - 1991)

MONTH	JAN	FEB	MAR	APR	MAY	JUN	AUG	SEP	OCT	DEC	TOTAL
MEAN RAINFALL	121.5	97.3	139.4	112.1	30.4	13.8	1.6	9.0	32.0	149.0	810.6

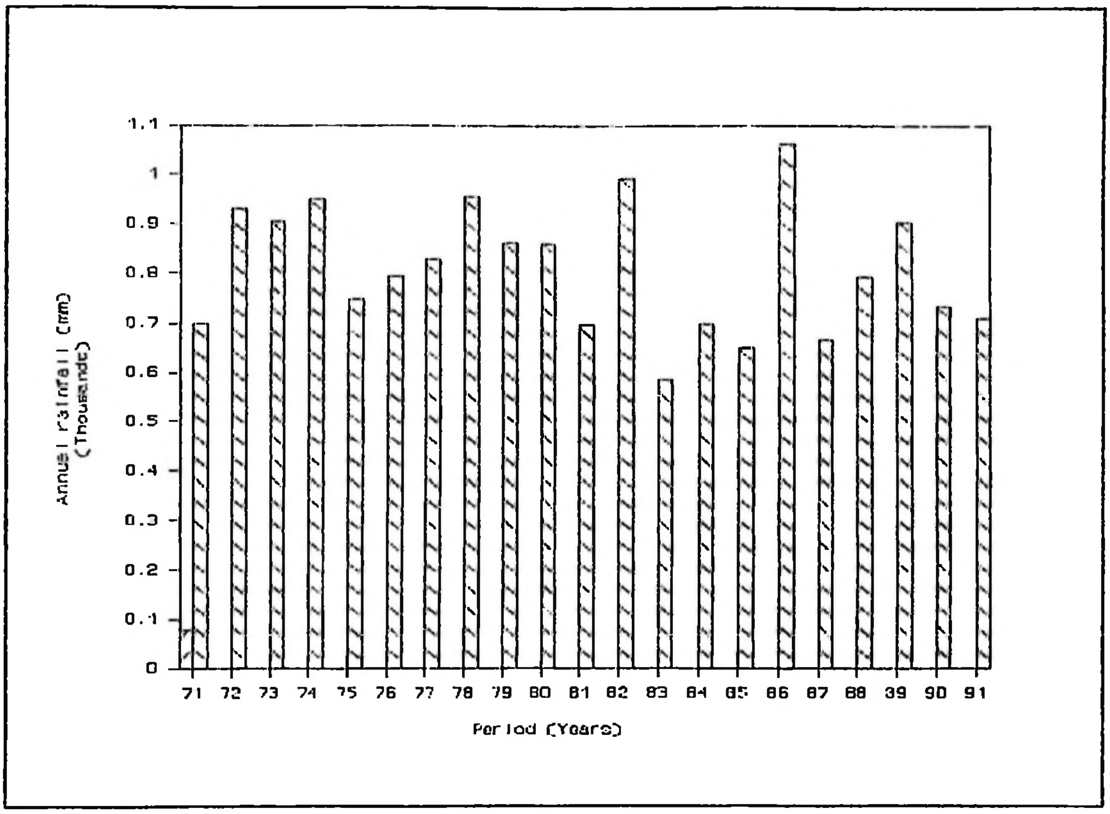


Figure 4.6 Annual rainfall in Shinyanga district

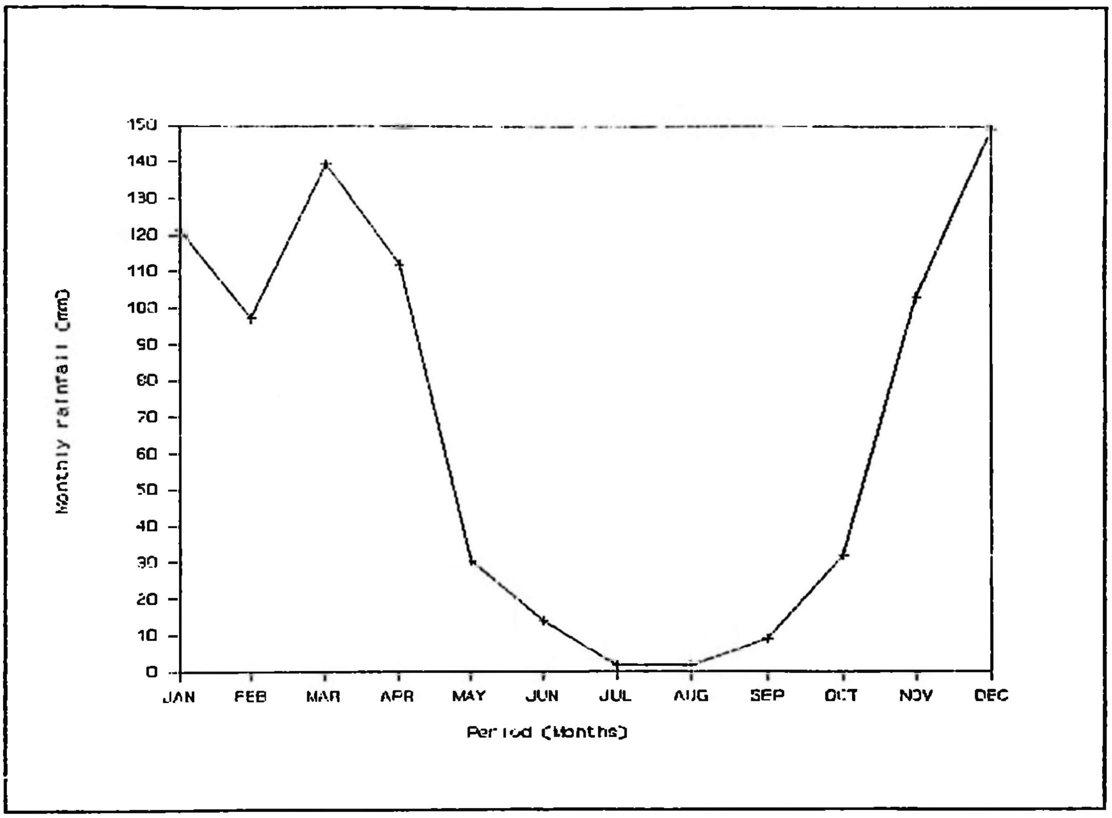


Figure 4.7 Distribution of rainfall in Shinyanga

Annual rainfall in semi-arid areas often follows a long term trend (Bruce and Clack, 1966). A number of years with relatively highly rainfall is followed by a number of relatively dry years. This phenomenon also applies to the Shinyanga district (Figure 4.6).

In Table 4.3, shows that the mean annual rainfall at Lubaga is approximately 811 mm, also it shows the actual mean monthly rainfall. Of the twenty one (21) years shown in Figure 4.6, three years (1983, 1984, 1985) indicated consecutive years of severe drought. One year (1986) had a total rainfall approximately 31% greater than normal. Since the growing season of paddy in Shinyanga is from December to April, thus in Figure 4.7 shows that in February the crop requires the greater amount of supplemental water with January having the second highest demand. December had lower requirements of supplemental water because of higher amounts of rainfall.

4.3 SURFACE RUN-OFF

4.3.1 SURFACE RUN-OFF FROM EPHEMERAL STREAMS

Using the empirical formular established by Nedeco (1974), the monthly surface runoff from different ephemeral streams at the hydrometric stations in

Shinyanga region, were calculated and compared with the total precipitation on the catchment area of about 100 km^2 during the corresponding month. According to a long-term series of data on rainfall and surface runoff, the relationship between the monthly areal precipitation and the surface runoff were established. It was found that there was no runoff where the precipitation was less than 70 mm. Where precipitation was between 70 and 265 mm the runoff was shown to be given by the relation:

$R = 0.01\ (P-70)^{1.77}$ ....(4.2)

and where precipitation was above 265 mm the runoff was shown to be given by the relation:

$R = (P-138)$ ....(4.3)

Where: P = the monthly areal precipitation on the catchment in mm.

R = the monthly surface run-off expressed in mm of water depth over the whole catchment area.

The data for monthly surface runoff from streams are listed in appendix-B.

To establish the relationship between the monthly areas precipitation and the surface runoff the following two principles have been adopted.

1) There is a threshold value for the monthly areas precipitation under which no run-off occurs (Bruce and clark, 1966). This valued is assumed to be 70 mm/month for a 100 km^2(see figure 4.8).

2) During months of abundant rainfall the actual evapotranspiration equals, the potential evapotranspiration and the infiltration amounts to the infiltration capacity of the soil. Thus the losses of the monthly precipitation are constant and consequently on increasing monthly precipitation above a certain rate results in an increase of the run-off with an equal value.

The graph which best fits the precipitation and run-off data for the area in between the above limits was found by means of trial and error.

Satisfactory results concerning the relationship between the monthly rainfall and runoff as plotted in figure 4.8 are obtained if the curve is shifted along the precipitation axis until a threshold value of 90 mm/month is reached (see figure 4.9). The equations 4.2 and 4.3 were changed, and it was found that there was no runoff where the precipitation was less than 90 mm. Where precipitation was between 90 and 285 mm the runoff was shown to be given by the relation:

$R = 0.01(P - 90)^{1.77}$................................(4.4)

and where precipitation was above 285 mm the runoff was shown to be given by the relation:

$R = P - 158$ ....(4.5)

The annual surface runoff from ephemeral streams were simulated by entering the monthly rainfall in the equations 4.2 and 4.3, and the results are listed in Table 4.5.

TABLE 4.5 SIMULATED ANNUAL RUN-OFF AT MHALE RIVER, LUBAGA.

RAIN SEASON	TOTAL RAIN RECEIVED (mm)	ANNUAL RUN-OFF (mm)	RUN OFF EFFICIENCY
1971-72	672.0	42.0	16.2
1972-73	864.3	130.5	15.1
1973-74	871.9	135.8	15.7
1974-75	715.0	70.5	10.0
1975-76	632.3	27.0	4.3
1976-77	670.9	40.0	6.0
1977-78	985.5	281.6	28.6
1978-79	785.0	104.2	13.1
1979-80	556.7	31.2	5.6
1980-81	563.1	138.0	24.5
1981-82	619.0	34.2	5.5
1982-83	824.0	119.8	14.5
1983-84	583.8	27.4	4.7
1984-85	593.7	23.6	4.0
1985-86	882.3	154.0	17.5
1986-87	638.4	44.8	7.0
1987-88	679.7	43.0	6.3
1988-89	819.7	65.2	8.0
1989-90	817.0	93.1	11.4
1990-91	679.9	88.7	13.0
MEAN	723.0	85.0	12.0

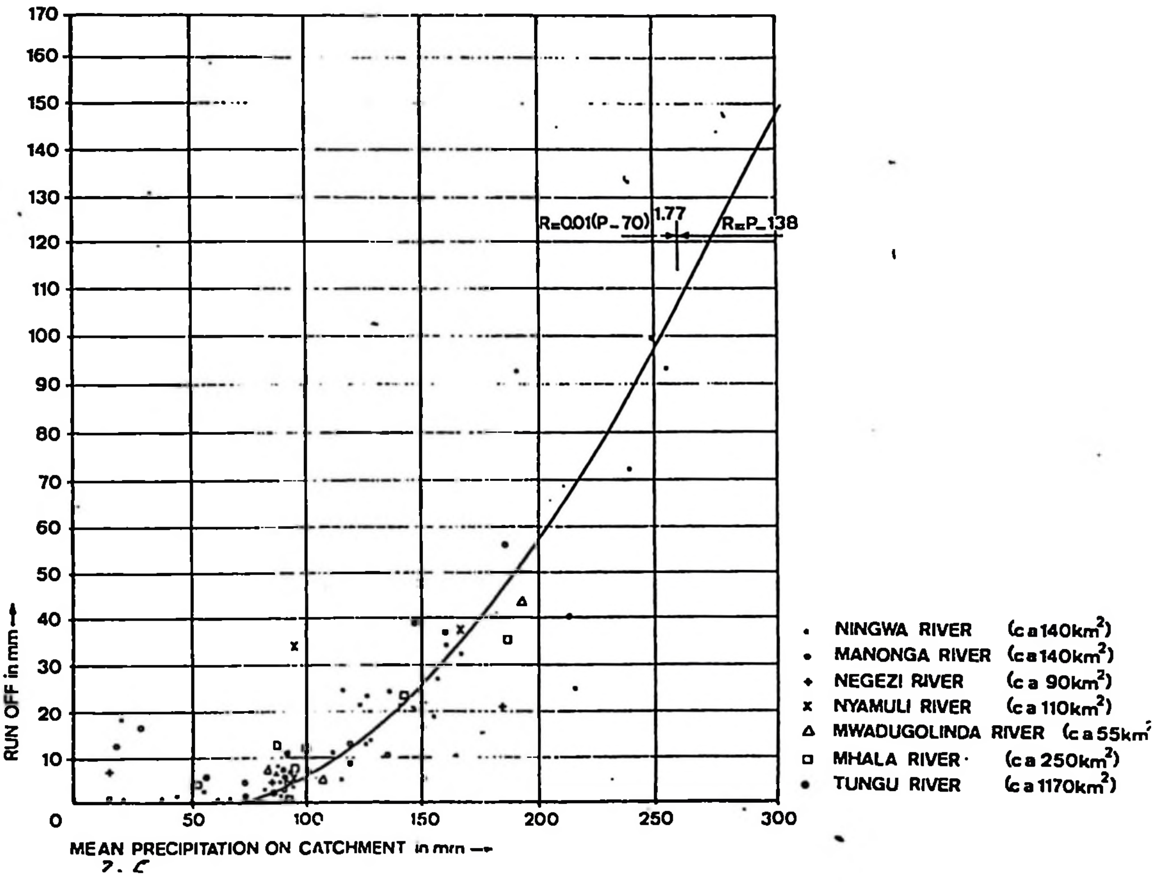


FIGURE 4.8 Monthly run-off from ephemeral streams.

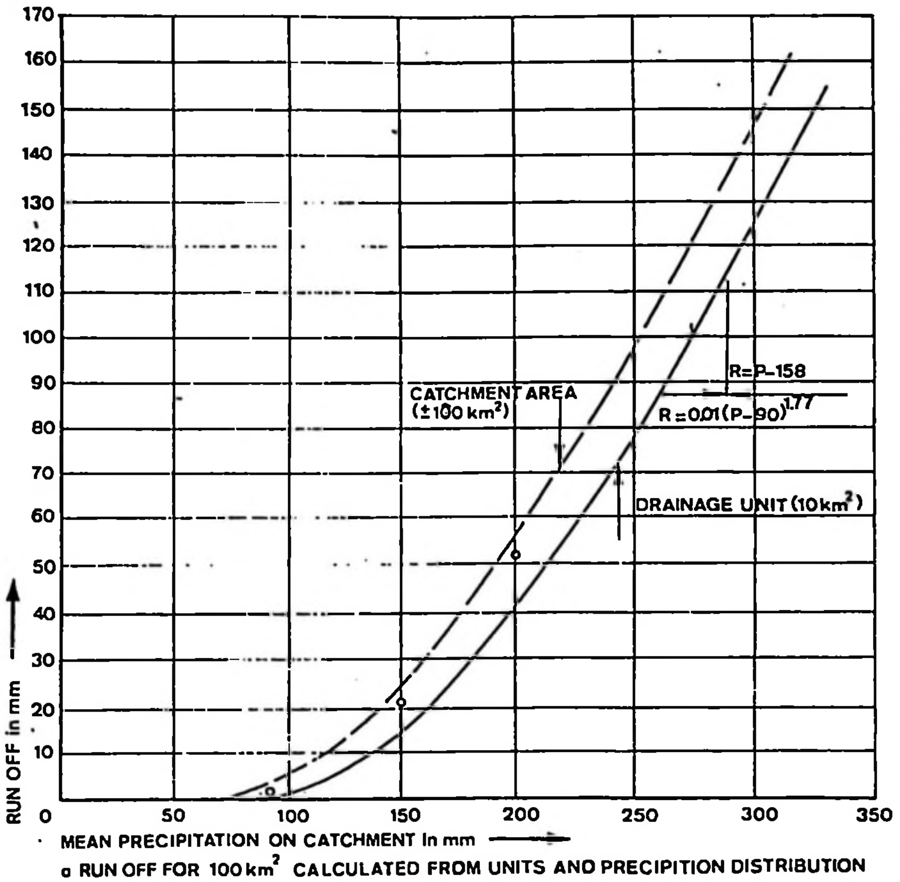


FIGURE 4.9 Relationship between monthly rainfall and run-off.

4.3.2 SURFACE RUNOFF FROM RUNOFF TEST-PLOTS

The monthly surface runoff from runoff test-plots are listed in table 4.6.

TABLE 4.6 THE MONTHLY SURFACE RUN-OFF YIELD FROM RUN OFF TEST-PLOTS

PERIOD (Months)	RAINFALL (mm)	RUN-OFF YIELD FROM CATCHMENTS (mm/per unit area)			
		A	B	C	D
NOVEMBER	45.4	8.5	23.2	31.3	25.9
DECEMBER	104.9	19.6	70.2	82.0	59.1
JANUARY	38.7	9.2	29.8	29.5	29.0
FEBRUARY	134.5	26.4	48.5	29.5	47.0
MARCH	84.5	87.8	160.3	159.7	197.5
MEAN	81.4	30.3	66.4	66.4	71.7

A = UNCOMPACTED CATCHMENT WITH SLOPE < 5%

B = COMPACTED CATCHMENT WITH SLOPE < 5%

C = UNCOMPACTED CATCHMENT WITH SLOPE > 5%

D = COMPACTED CATCHMENT WITH SLOPE > 5 %

It should be noted that the values for catchment-A are the mean values from catchment A-1, A-2, and A-3.The values of catchment-B are the mean values of catchment B-1, B-2 and B-3. The values of catchment-C are the mean values of catchment C-1, C-2 and C-3. And the values of catchment-D are the mean values of catchment D-1, D-2 and D-3. Also it was assumed that the catchment-D represents the standard catchment for rain-water harvesting for paddy production.

From Table 4.5 shows that a surface runoff of less than 15 mm has as average return period of ten years and a run-off of less than 8 mm may occur on an average of once every 20 years. This is about 3% and 1.5% respectively of the

corresponding precipitation. The mean annual run off of the catchment area (1o km^2) is 85 mm/year, being 11% of the mean annual rainfall.

The result from Table 4.5 also shows that the mean annual surface runoff from catchment area is 85 mm/year but with mean annual run-off efficiency of 12%. Also it indicates that annual surface runoff of less than 270 mm may occur on average of once every 10 years , which is about 4.5% of the corresponding precipitation.

The Table 4.6, indicates that lowest runoff yield is obtained from the catchment-A (30.3 mm/month),this is due to the fact that the catchment-A is uncompacted as result some amount of runoff infiltrates in the soil , also the slope of the catchment is less than 5%, this again reduces the speed of flow of runoff, and hence most of runoff infiltrates in the soil. The catchment-D contributes more runoff yield than other catchments because is compacted and is steep.

The relation between monthly rainfall and runoff established in equations 4.2 and 4.3 concerns catchment areas of about 100 km^2 The actual rainfall on this area is not evenly distributed, but should be regarded so the average or total rainfall on a number of smaller units, each equal to the area for which a certain point rainfall represents the areal average.

Instead, the relationship for a catchment of 10 km^2 is determined and for further calculations larger catchment areas is assumed to consist of appropriate number of drainage units. It is assumed that the slope of the rainfall run-off graph in Figure 4.9, remain the same for drainage units of 10 km^2.

From Figure 4.8, the runoff data concerns basins of different terrain classes. The manonga river and the mwadugolinda river represent the flat country, where as the other basins are situated in hilly and rolling country. Presumably, the slope of the catchment influences the travelling time of the run-off, but reduces its total volume to only a minor extent. More over, the infiltration, will influence the total volume of the surface run-off.

However, Figure 4.8, reveals that the relation between rainfall and runoff is not clearly influenced by catchment characteristics. This is shown by the fact that points of one basin or corresponding basins are not clustered and do not show any clear tendency. It should also be noted that the rivers mentioned in Figure 4.8 are seasonal (ephemeral streams) rivers.

4.4 WATER BALANCE IN THE PADDY FIELDS

Precipitation falling on the area will be discharged as surface runoff, or will evaporate or infiltrate in the soil. Part of the infiltrated water percolates downwards until it reaches the zone of saturation at the phreatic surface, the other part is stored as soil moisture which supplies the vegetation during the next period.

Therefore, the following elements of water balance can be distinguished for the paddy field, assuming no overflow from a "Jaruba".

(a) the precipitation (p), being the inflow to the soil profile

(b) the surface run-on (R), being the stream-flow to the soil profile

(c) the evapo-transpiration (ET), being the evaporation from water surfaces and from the leafy part of the plant.

(d) the change in storage (CS) in the ground water over the period under consideration.

(e) the percolation (I), being the recharge of the ground water (outflow from the soil profile).

Assuming the storage in the ground water is constant therefore the water balance in the soil profile during the growing season, may be written as the equation

$$WB = P + R - ET - I \quad \ldots\ldots\ldots\ldots\ldots (4.9)$$

Where: WB = water balance in the soil profile.

The mean monthly precipitation, surface runoff and evapotranspiration has been calculated from the data collected at Lubaga meteorological station for the purpose of determining the water losses from the paddy fields during the growing season.

4.4.1 EVAPOTRANSPIRATION (ET)

The penman estimate of the evapo-transpiration during periods of rain season/growing season has been calculated for the purpose of estimating the crop water requirement during the growing season(Doorenbos and Pruitt, 1977). The detail calculations are given in Appendix - A. The climatic data used for calculating evapotranspiration are listed in Table 4.7. The data for mean daily evapotranspiration are listed in Table 4.11 The data for crop (paddy) water required during the growing season are listed in Table 4.12 . The results obtained from pan evaporation has been compared with calculated mean daily pen man evapotranspiration (see Table 4.9), also the results from pan evaporation has been used to estimate the water deficit under the study area.

Data for mean monthly rainfall, evaporation and water deficit in central Shinyanga are listed in Table 4.13 and plotted in Figure 4.10. Also the climatic data for pan evaporation in Shinyanga district are listed in Table 4.8 and 4.9.

4.4.2 DEEP PERCOLATION (I)

According to a long-term series data the monthly percolation as a function of the monthly precipitation was established for 10 km^2. The results was found that there was no percolation for precipitation of less than 90 mm. Where precipitation was between 90 and 180 mm the percolation was shown by the relation:

$$I = P-120 + 4x10^{-5} (180-P)^3 -0.01 (P-90)^{1.77} \quad ...(4.6)$$

and where precipitation was between 180 and 285 mm the percolation was shown by the relation:

$I = P-120-0.01\ (P-90)^{1.77}$...................(4.7)

Where precipitation was above 285 mm the percolation was shown to be given by the relation:

$I = 38$....................................(4.8)

where:

I is monthly percolation in mm.

P is monthly precipitation in mm.

Therefore by taking into account the rain season for the particular period 1991/92 deep percolation can be assumed to be negligible . This is due to the fact that, by using the equations 4.6, 4.7 and 4.8 the monthly precipitation for this period was less than 90mm, also the results of soil moisture content measured before and after rain event has been shown in Table 4.14.

Thus the following equation holds for the particular rain season (November 1991-April 1992).

$WB = P+R - ET$................(4.10)

Where: WB = Water Balance in the soil
P = Precipitation
ET = Evapotranspiration

TABLE 4.7 MEAN DAILY CLIMATIC DATA IN SHINYANGA DISTRICT.

1989	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
AIR TEMPERATURE	22.0	23.3	24.0	24.0	22.6	22.0	23.4	23.4	25.3	26.1	26.1	30.5	24.4
RELATIVE HUMIDITY	78.9	79.1	65.0	69.6	64.1	54.9	49.7	47.4	44.5	40.5	52.2	72.0	60.0
WIND RUN (KM/DAY)	109.1	94.7	119.4	146.2	168.2	180.3	222.4	222.4	204.1	199.0	199.2	137.2	166.9
HOURS OF SUNSHINE	8.0	7.6	2.6	8.8	8.6	9.9	10.0	9.8	9.5	9.4	7.9	6.5	8.6

1990	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
AIR TEMPERATURE	23.4	24.0	24.3	23.5	23.4	22.3	21.7	23.3	24.8	25.9	25.6	23.9	23.8
RELATIVE HUMIDITY	63.5	70.0	72.2	73.3	60.0	50.2	46.4	46.7	42.4	42.7	51.0	64.4	57.0
WIND RUN (KM/DAY)	130.0	117.8	107.6	105.0	127.7	151.7	165.3	210.0	225.0	207.0	190.4	135.0	156.0
HOURS OF SUNSHINE	8.4	6.4	6.6	7.4	10.4	10.4	10.7	9.9	9.4	9.7	8.7	7.2	8.3

1991	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
AIR TEMPERATURE	24.1	24.4	24.5	24.0	24.2	23.4	22.5	23.4	25.0	24.3	25.0	24.0	24.1
RELATIVE HUMIDITY	67.6	64.3	62.4	64.3	58.5	49.6	46.0	43.6	39.7	56.0	52.0	60.0	55.3
WIND RUN (KM/DAY)	119.4	117.6	111.1	116.2	147.4	138.0	194.0	172.0	187.0	150.0	200.0	195.0	154.0
HOURS OF SUNSHINE	7.7	7.0	7.8	8.8	8.5	9.0	9.5	9.8	8.7	7.6	7.6	7.5	8.3

TABLE 4.8 MEAN ANNUAL EVAPORATION IN SHINYANGA DISTRICT

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1989	107.6	137.6	178.6	172.0	176.7	196.5	245.5	266.2	246.3	305.6	251.5	160.9	2445.1
1990	178.8	144.6	138.1	149.4	176.9	190.0	215.5	243.7	276.8	278.6	236.1	179.1	2407.6
1991	166.0	159.4	192.1	160.0	150.8	194.2	241.5	238.9	255.9	201.5	240.1	186.0	2386.4
MEAN	150.8	147.2	169.6	160.5	168.1	193.6	242.7	249.6	259.7	274.8	242.6	175.3	2413.0

TABLE 4.9 MEAN DAILY EVAPORATION IN SHINYANGA DISTRICT

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MEAN
1989	3.5	4.9	5.8	5.7	5.7	6.6	7.9	8.6	8.2	9.9	8.4	5.2	6.7
1990	5.8	5.2	4.5	5.0	5.7	6.3	6.9	7.9	9.2	9.3	7.9	5.7	6.6
1991	5.4	5.7	6.2	5.3	4.9	6.5	7.8	7.7	8.5	6.5	7.5	5.5	6.5

TABLE 4.10 LOSSES OF RAIN WATER FROM PADDY FIELDS .

PERIOD (Month)	DEPTH OF WATER IN THE PADDY FIELD (MM)		
	PLOT-1	PLOT-2	PLOT-3
DECEMBER	148.5	122.0	0.0
JANUARY	47.4	42.5	0.0
FEBRUARY	13.4	2.6	0.0
MARCH	1.2	0.5	0.0
APRIL	0.0	0.0	0.0

TABLE 4.11 MEAN DAILY EVAPOTRANSPIRATION (ET): (MM/DAY)

GROWING SEASON	DEC	JAN	FEB	MAR	APR	MEAN DAILY EVAPO-TRANSPIRATION (mm/day)	MEAN DAILY EVAPORATION (mm/day)
1988/89	5.3	5.3	5.3	5.6	5.1	5.3	5.0
1989/90	5.6	5.2	5.2	5.2	5.0	5.2	5.1
1990/91	4.5	5.4	5.4	5.9	5.7	5.4	5.3
1991/92	4.2	4.8	5.6	6.0	5.5	5.2	5.1
MEAN	4.9	5.2	5.4	5.7	5.3		

TABLE 4.12 CROP (PADDY) WATER REQUIREMENT ETc (MM/DAY)

GROWING SEASON	DEC	JAN	FEB	MAR	APR
1988-89	5.8	5.7	6.4	6.7	4.6
1989-90	6.2	6.2	6.2	6.2	4.5
1990-91	5.0	6.5	6.5	7.1	5.1
1991-92	4.6	6.7	6.7	7.2	5.0
MEAN	5.4	5.7	6.5	6.8	3.6

TABLE 4.13 WATER DEFICIT IN SHINYANGA DISTRICT

MONTH	MEAN MONTHLY RAINFALL (MM)	MEAN MONTHLY EVAPORATION (MM)	MEAN MONTHLY WATER DEFICIT (MM)
JANUARY	121.5	155.0	33.5
FEBRUARY	97.3	148.0	50.7
MARCH	139.4	167.4	28.0
APRIL	112.1	168.0	55.9
MAY	30.4	176.7	146.3
JUNE	13.8	187.0	175.2
JULY	1.5	214.0	212.5
AUGUST	1.6	245.0	243.4
SEPTEMBER	9.0	276.0	267.0
OCTOBER	32.0	244.9	212.9
NOVEMBER	103.0	237.0	134.0
DECEMBER	149.0	151.9	2.9
TOTAL	810.6	2372.9	1562.3

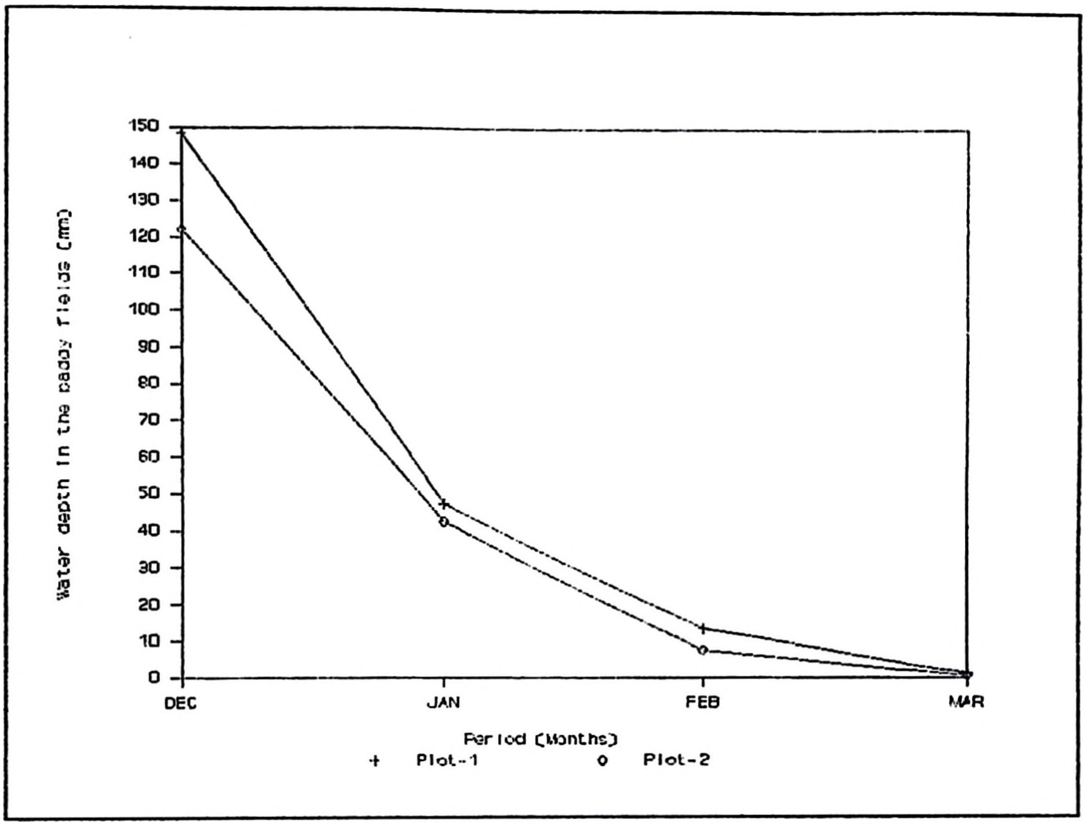


Figure 4.10 Decrease of water depth in the paddy fields during the growing period

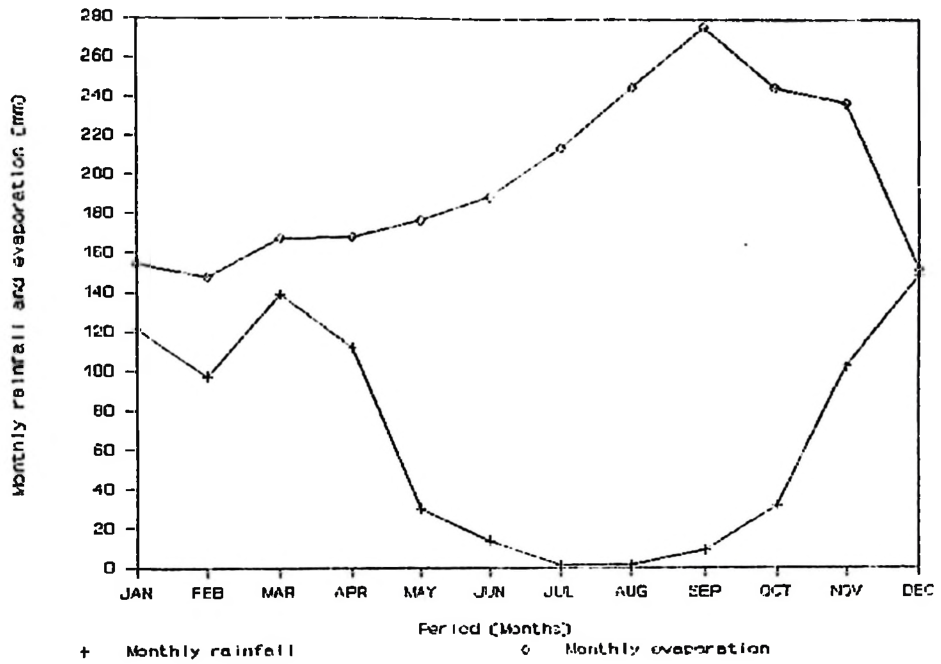


Figure 4.11 Water deficit in Shinyanga district

TABLE 4.14 MEAN MONTHLY SOIL-MOISTURE CONTENT IN PLOT-3

PERIOD 1991/92	RAINFALL (mm)	SOIL-MOISTURE CONTENT BELOW 50 CM DEPTH (%)	
		BEFORE RAIN EVENT	AFTER RAIN EVENT
NOVEMBER	45.4	1.2	1.2
DECEMBER	104.9	1.8	1.81
JANUARY	38.9	1.6	1.6
FEBRUARY	134.3	2.0	2.02
MARCH	83.5	1.7	1.71

The results obtained from the calculations of evapotranspiration, evaporation and percolation, shows that losses of soil water is mainly attributed to the daily evaporation this is due to the fact that evapotranspiration is a combination of evaporation from water surfaces and transpiration which is the losses of water from the leafy parts of the plants and by comparing the calculated mean daily evapotranspiration and mean daily evaporation (see Table 4.11) the difference is very small (0.1 mm/day). Also by using the relations of rainfall and percolation established in equations 4.6, 4.7 and 4.8 it shows that the losses of water by deep percolation is negligible compared to that of evapotranspiration. On top of that the nature of soil (mainly clay) is impermeable in sense that it has high retention capacity of soil water.

Therefore the main losses of soil water is through evaporation, and the only way to compensate these losses is to supply more water to the paddy fields during the rain season, this can only be achieved by improving the rain harvesting system.

From Table 4.12, indicates that the amount of water to be supplied to the paddy field should not be less than 152 mm in December. This is because during this month, the amount of water (152 mm) is required for paddling the land, in January the amount of water required for initial and establishment of the transplanted rice should not be less 171 mm. In mid season (February) the amount of water required should not be less than 190 mm (It is a vegetative stage), in march the amount of water required should not be less than 204 mm, this is due to the fact that during the weeding and flowering stage (March) the crop (paddy) requires more water, and during the ripening period (starting April up to May), the field should be gradually drained up to harvesting time.

It should be noted that the total water requirement for paddy production includes water needed to raise seedlings, prepare land and to grow the crop from transplanting to harvest. Therefore in order to increase paddy production in Shinyanga the total amount of water to be supplied in paddy field should not be less than 1000 mm.

From Figure 4.10, indicates that during and immediately after transplanting the depth of water in the paddy field (Jaruba) was about 150 mm for plot-1 (PT1) and about 130 mm for plot-2 (PT2). The transplantation was done during December 23rd; During the tillering stage (January) the depth of water decreased up to about 50 mm for plot-1 (PT1), and up to about 40 mm for plot-2 (PT2). After tillering, the water depth continued to decrease up to the flowering stage (February) when the depth of water was about 15 mm and 10 mm in plot PT1 and PT2 respectively. It should be noted that the plot-3 (PT3) was a rainfed plot such that no provision for runoff entry was made, as result this plot, during the transplanting stage there was no water in the plot for puddling the soil, that is to say in this particular growing period the plot-3 (PT3) remain untransplanted because of lack of water in the basin.

Also it should be noted that during the growing period the distribution of rainfall was poor in such away that during the flowering stage up to the ripening stage the paddies were dry. Normally after tillering stage (January) the depth of water in the paddy field is supposed to be increased at least up to 100 mm, this is because during the flowering stage the paddy requires more water than in the tillering stage. Therefore during February and March water depth in the field should not be less than 100 mm.

Also Figure 4.10, indicates that initialy more water was available in plot-1 compared to plot-2 this is due to the fact that the amount of water in both plots was mainly affected by the nature of the catchments; Generally speaking the catchments of both plots were almost flat in such away that during the rainfall the catchment failed to contribute sufficient runoff yield. The catchment for plot- 1 was smoothed, and compacted while that for plot-2 was grassed though was also compacted, thus the presence of grass on the catchment reduces the speed of overland flow of water (run off) that is why more water was found in plot-1 than in plot-2.

Figure 4.12 and Figure 4.13, both indicates the paddy crop at tillering stage. Also shows that in plot-1 plants has more tillers with good growth compared to the plot-2. Therefore this fact shows the importance of water in the field during the tillering stage.

The need of more water supply to the paddy fields can also be justified by results presented in Table 4.13 and Figure 4.10, both indicates that the annual water deficit is 1562.3 mm, this is from the fact that the annual rainfall is 810.6 mm whereas the annual evaporation is 2372.9 mm. These results indicates that the amount of water required to be harvested (by runoff collection) should not be less than 1562.3 mm per year in order to meet the water demand for crop production in Shinyanga. It should be noted that the water demand is not constant throughout the region, therefore the water deficit of 1562.3 mm covers the central Shinyanga region (Urban and rural Shinyanga Districts).

From Table 4.14 shows that the soil below 50cm is dry even after rain event, while the top layer is moist. This shows that the loss of rain water through deep percolation for this period was negligible compared to other losses attributed to the evapotranspiration.

Figure 4.12 Paddy crop of plot-1 at tillering stage.

Figure 4.13 Paddy crop of plot-2 at tillering stage

4.5 RUN-OFF YIELD

The RWH techniques were evaluated for 5-months (rain-season period), from November 1991 tO March 1992, for runoff yield of the system.

A comparative evaluation of the total yield of the RWH system from the runoff test plots was carried out by measuring the water volume in the tanks (in litres) over a 5-month period and comparing them to the theoretic volumes (in litres) received after each rainfall. Theoretic volumes were obtained by multiplying the number of square meters in the harvesting area by the millimeters of raifall registered on a rain gauge. These measurements are listed in Table 4.15.

The effects of size and the length-width ratio of the catchment on runoff efficiency has been tabulated in Table 4.17 and 4.18 and plotted in Figure 5.14 and 5.15.

4.6 EFFECTIVENESS OF THE RWH SYSTEM

A comparative evaluation of the effectiveness of the RWH techniques was carried out by computing the total rain-water harvested (rainfall + runoff) during the rain season from the catchment area (in mm) over a 5-month period and comparing them to the total water required for paddy during the growing season. The crop water requirements were obtained by multiplying the calculated evapotranspiration by the crop coefficient. Detail calculations are in Appendix-A. The data for effectiveness of the RWH techniques are listed in Table 4.16.

TABLE 4.15 5-MONTH AVERAGES OF MEASUREMENTS MADE TO EVALUATE RUNOFF EFFICIENCY OF RWH SYSTEM

TYPE OF RAIN-CATCHMENT	A			B			C			D		
	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	D-1	D-2	D-3
MEAN RAINFALL (MM)	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4
HEIGHT OF WATER IN THE COLLECTING TANK (MM)	317.2	399.8	374.0	1030.2	948.6	971.0	850.0	641.2	687.5	1086.0	956.1	1249.2
SIZE OF HARVESTING AREA, A(m^2)	34.6	80.64	45.36	54.0	43.2	40.32	40.32	24.96	26.04	58.3	34.56	80.64
THEORETICAL VOLUME, V, RECEIVED (litres)	2815.1	6560.9	3690.5	4393.4	3514.8	3280.4	3280.4	2030.7	2118.6	4743.3	2811.8	6560.9
ACTUAL VOLUME, V2 COLLECTED (litres)	634.4	799.7	748.0	2060.4	1897.2	1942.1	1698.0	1282.5	1375.0	2172.0	1912.2	2498.4
RUNOFF EFFICIENCY, E (V2/V1 x 100%)	22.5	12.2	20.3	46.9	54.0	59.1	51.8	63.2	64.9	45.8	68.0	38.1
TANK CAPACITY (Litres)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
SLOPE OF THE CATCHMENT (%)	4.5	4.6	3.7	5.0	5.0	5.3	19.0	50.0	53.3	25.0	30.0	29.0
LENGTH-WIDTH RATIO OF THE CATCHMENT (L/W)	1.5	1.1	2.5	0.9	1.7	2.0	2.0	1.0	1.0	2.0	2.7	1.0

TABLE 4.16 EFFECTIVENESS OF THE RWH SYSTEM

PERIOD 1991-92	A	B	C	D	E
RAINFALL (MM)	407.0	407.0	407.0	407.0	407.0
RUNOFF (MM)	151.5	332.0	332.0	358.5	85.0
RUNOFF + RAINFALL (MM)	558.5	739.0	739.0	765.5	492.0
AMOUNT REQUIRED (MM)	1000.0	1000.0	1000.0	1000.0	1000.0
EFFECTIVENESS (%)	55.9	73.9	73.9	76.6	49.2

TABLE 4.17 The effects of catchment area on Runoff efficiency

A		B		C		D	
A	E	A	E	A	E	A	E
34.6	22.5	54.0	46.9	40.32	51.8	58.3	46.9
80.64	12.2	43.2	54.0	24.96	63.2	34.56	68.0
45.36	20.3	40.32	59.1	26.04	64.9	80.64	38.1

Table 4.18 The effects of length-width ratio of the catchment on runoff efficiency

Catchment B		Catchment D	
Ratio	Efficiency	Ratio	Efficiency
0.9	46.9	2.0	45.8
1.7	54.0	2.7	68.0
2.0	59.1	1.0	38.1

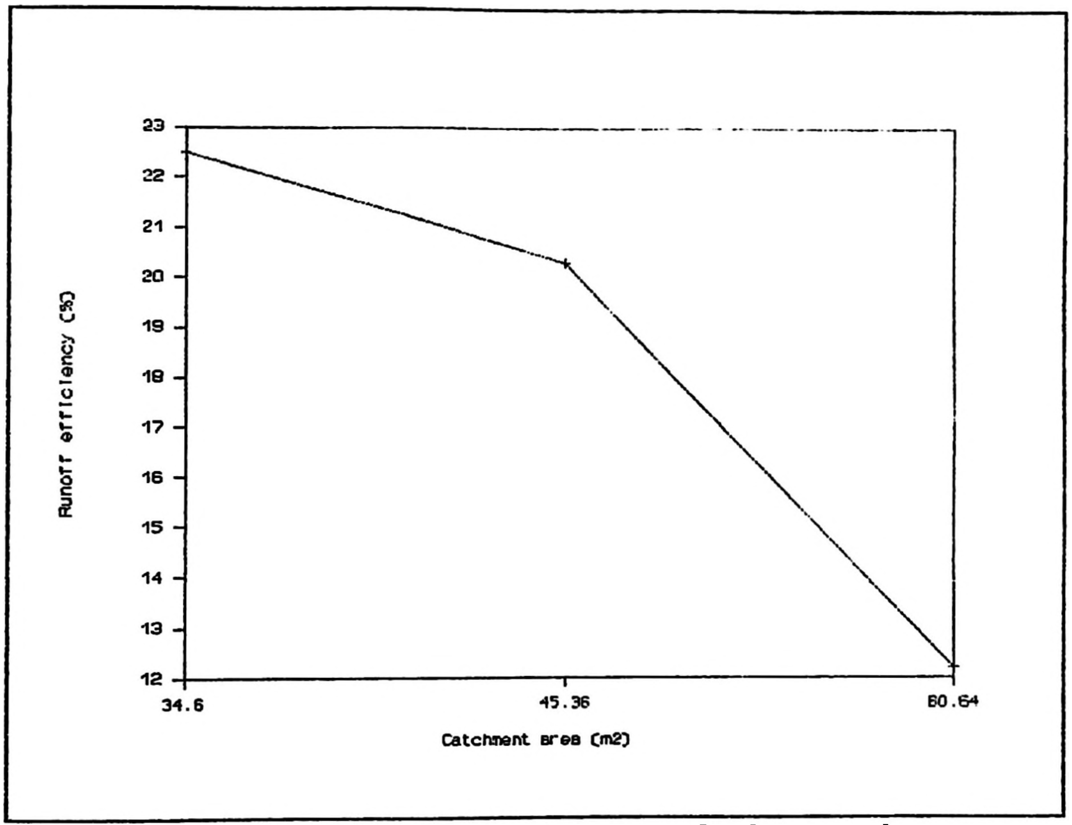


Figure 4.14 (a) The effect of size of the catchment-A on the runoff efficiency

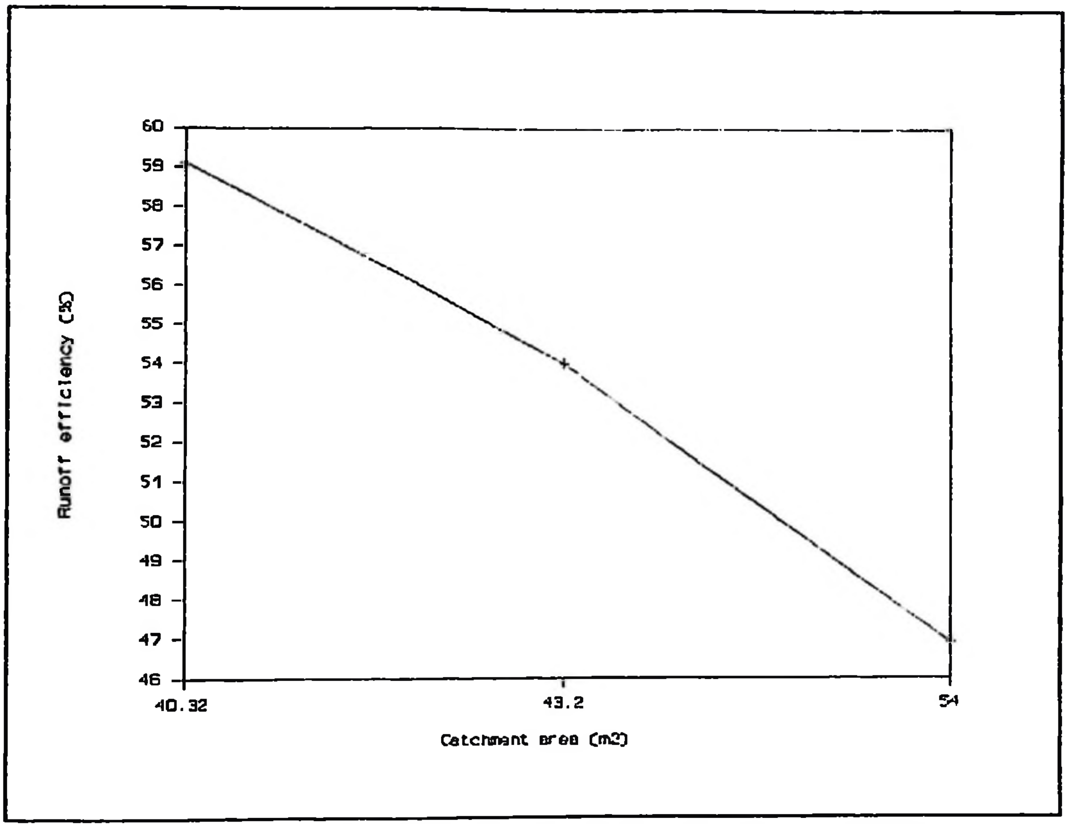


Figure 4.14 (b) The effect of size of the catchment-B on the runoff efficiency

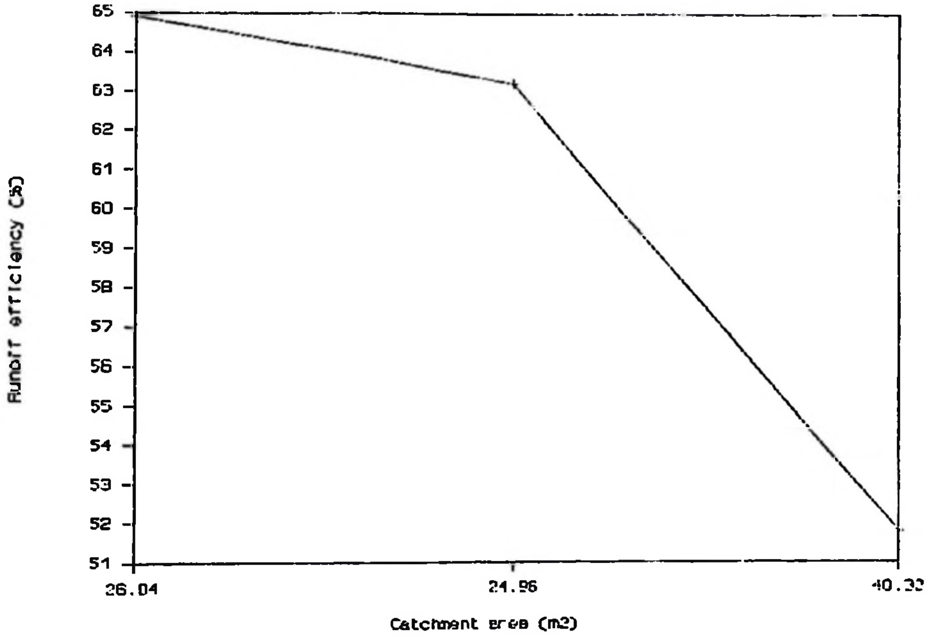


Figure 4.14 (c) The effect of size of the catchment-C on the runoff efficiency

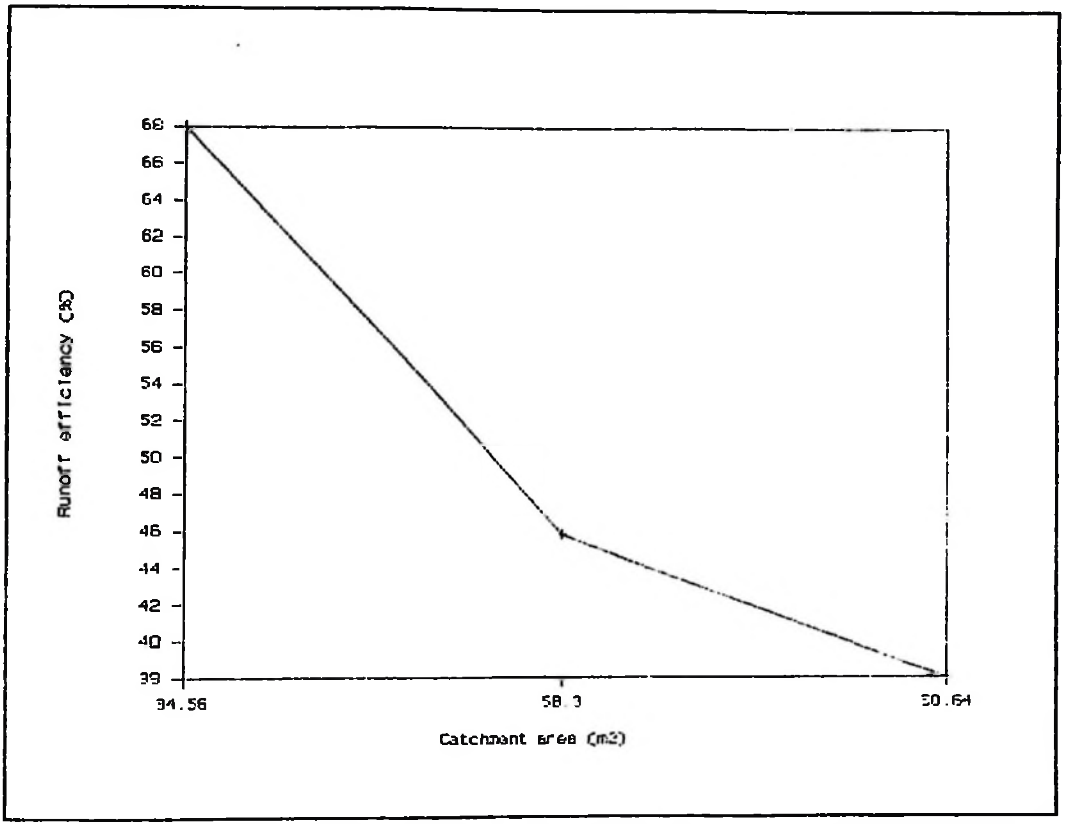


Figure 4.14 (d) The effect of size of the catchment-D on the runoff efficiency

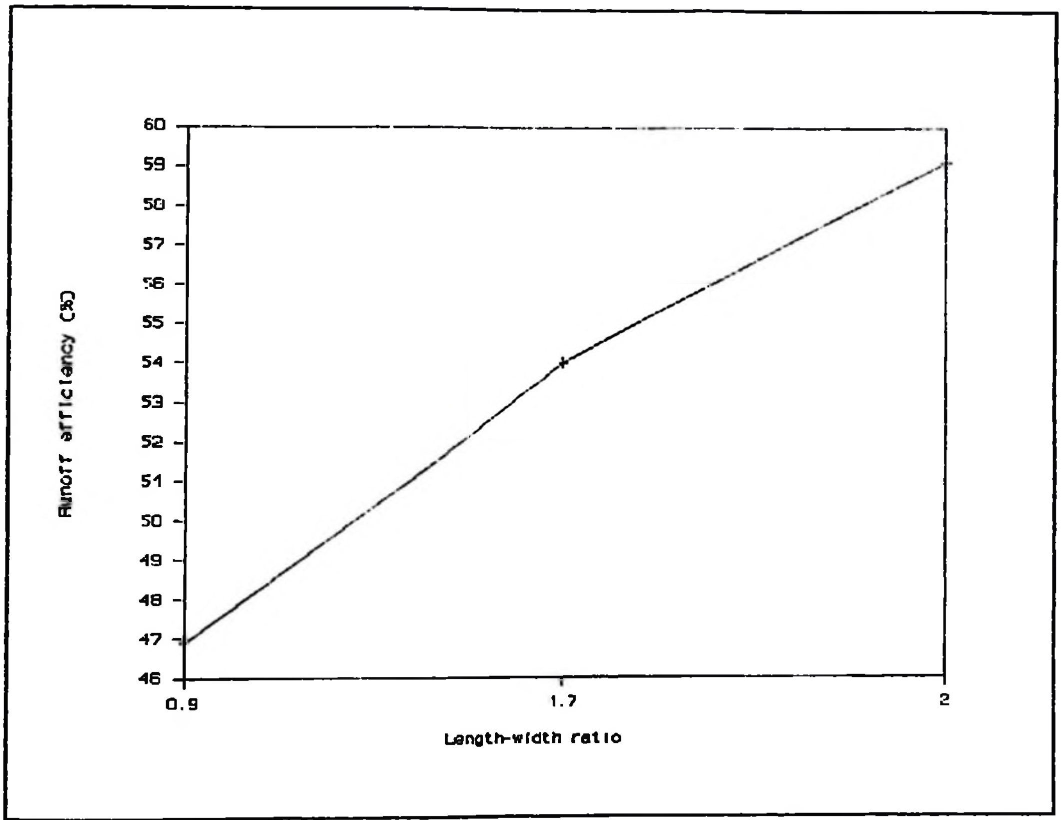


Figure 4.15 (a) The effect of length-width ratio of the catchment-B on the runoff efficiency

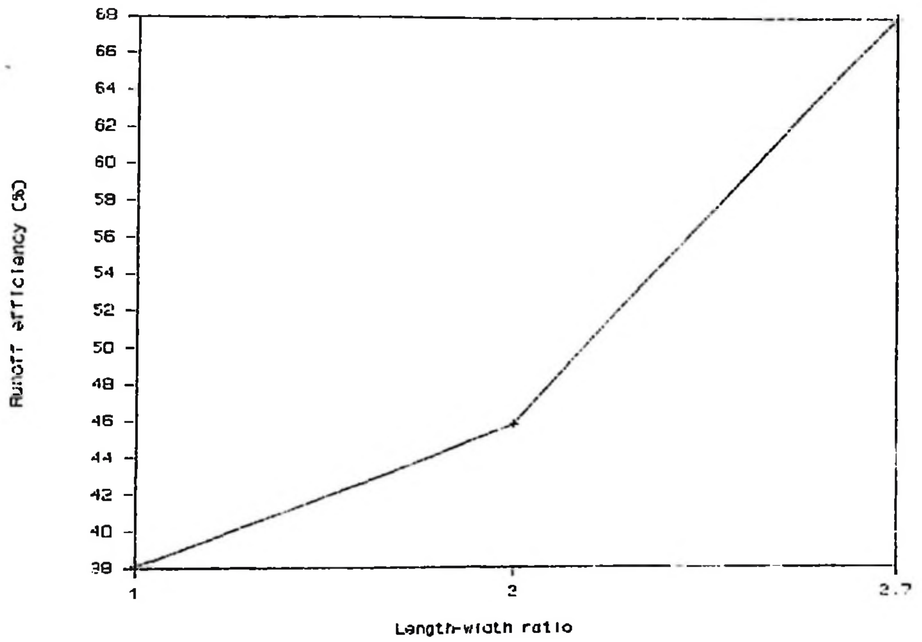


Figure 4.15 (b) The effect of length-width ratio of the catchment-D on the runoff efficiency

Table 4.15 indicates that the A-2 had the lowest runoff efficiency (12.2%), the A-3 the second lowest (20.3%) and the A-1 the third lowest (22.5%). The low efficiency of the A-2 catchment was attributed mainly to the size of harvesting are (catchment) which was too large (80.64 m^2) and the length-width ratio (L/w) of the catchment area which was small, in the case of the A-3 the low efficiency was attributed to the slope of the catchment are which was small (3.7%) and in the case of A-1 the low efficiency was mainly attributed to the nature of the catchment which was grassed with a slope of 4.5% and L/W ratio of 1.5.

The most efficient catchments were the D-2 (68.0%); C-3 (64.9%) and C-2 (63.2%). The high efficiency of these catchments were due to the following facts. The D-2 catchment was very steep (30.0%) with smallest harvesting area (34.56 m^2) compared to other areas of D-1 and D-3. The C-3 catchment was uncompacted but with largest slope (53.3%) and the harvesting area was small (26.04 m^2) and in the case of C-3 though the catchment was uncompacted but had the largest slope (50.0%), also had smallest area (24.96 m^2). The D-3 with runoff efficiency of (38.1%) and the D-1 with efficiency of 45.8% indicates the effect of rise of the harvesting area on runoff efficiency due to the fact that D-3 catchment and D-1 catchment were compacted with large slope of 29% and 25.0% respectively, but still had low efficiency compare 1 to D-2 because D-3 and D-1 had large areas (80.64 m^2 and 58.3 m^2 respectively) compared to that of D-3 catchment (34.56 m^2).

It should be noted that Table 4.15, does not tell anything on surface runoff from the ephemeral streams. However, Table 4.5 shows that the mean annual surface runoff from ephemeral streams is 85 mm. By dividing this annual surface runoff with annual rainfall (407 mm) the results shows that the annual runoff efficiency for ephemeral streams is 20.9%. The low efficiency for this RWH technique is mainly attributed to the length of run (conveyance distance) which is normally large in such away that the time the runoff takes to flow from the catchment to the field is large, thus the losses of water by evaporation and infiltration along its way to the field is very significant, and hence amount of runoff received to the field is relative small.

The runoff efficiency is affected by many factors such as area and shape of the catchment, ground slopes of the catchment, the ratio of length to the width of the catchment (the length coinciding with the direction of flow and the width perpendicular to it), the ratio of catchment area to the farmed area, soil permeability and type of vegetation.

However, the following factors were taken into account during the research; the area of the catchment, slopes, the length/width ratio and soil permeability.

From Figure 4.14, shows that the rain-harvesting efficiency (E) decreases as the size of the harvesting area (catchment) increases. Therefore high runoff yield per unit area is obtained from small catchment compared to large catchments.

Figure 4.15, indicates that rain-harvesting efficiency increases as the length/width ratio of the catchment increases. The length of the catchment here refers to that which is coinciding with the direction of flow and the width perpendicular to it. The ratio depends on rainfall characteristics, topography, and water-spreading properties of the soil. Therefore in the design of RWH layout, topography plays an important role.

The Table 4.16 indicates that the effectiveness of the RWH system in catchment-A is less than 60%. Most rain-catchment used in Shinyanga fall under catchment-A which is uncompacted with ground slope of less than 5%. That is to say the amount of water supplied to the paddy field is less than 60% of the amount required and this is the one of the factors which causes the low production of paddy in Shinyanga region.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

On the basis of the analysis presented in chapter-5 the following conclusions can be made:

(1) Once in 3 to 5 years there are periods of 30 days during the wet season with an average of less than 1 mm rainfall per day. Periods of 30 days with average ofless than 2 mm a day occur at least once a year in Shinyanga region.

(2) Once in 20 years a total rainfall of 100 mm is not reached before the end of December. Rainfall of less than 70 mm per month has an average recurrence period of 10 years. And daily rainfall of 60 mm has an average recurrence period of 2 years for the Shinyanga region.

(3) The variations in yearly rainfall is some 25% over a period of 10 years. Variations in monthly rainfall during the entire wet season are in the order of 60% or even more.

(4) The losses of soil water from the paddy fields is mainly attributed to evapotranspiration which ranges between 5 mm and 6 mm per day, during the growing season (from December to April).

(5) The mean annual surface runoff from ephemeral streams is 85mm per year with mean annual runoff efficiency of 12%.

(6) Uncompacted catchment with ground slope of less than 5% has an average surface runoff of 30.3 mm per month with mean runoff efficiency of less than 30%. A compacted catchment with ground slope of less than 5% has an average surface runoff of 66.4 mm per month with mean runoff efficiency between 45% and 60%. Uncompacted catchment with ground slope greater than 5% has an average surface runoff of 66.4 mm per month with mean runoff efficiency between 50% and 65%. And compacted catchment with ground slope of greater than 5% has an average surface runoff of 71.7 mm per month with mean runoff efficiency greater than 65%.

(7) From paddy water requirement point of view, the RWH system is effective by less than 60% to most farmers due to the fact that their rain-catchment are not compacted with slope ofless than 5%.

Currently the rain-water harvesting systems in Shinyanga collect about 20% to 50% of the precipitation for paddy production, while a more elaborate RWH system can collect more than 95%. And it should be noted that water-harvesting systems can require up to 200 mm annual rainfall to support one crop per year, that is to say if the system of water-harvesting in Shinyanga will be improved, the annual rainfall in Shinyanga is adequate for paddy production by rain water harvesting.

5.2 RECOMMENDATIONS FOR IMPLEMENTATION

In order to improve the local techniques of rain water harvesting and the adaptation of these techniques to other semi-arid areas of Tanzania, the following possible actions should be taken into account.

1) Since it is generally less expensive to improve catchments than to reduce evaporation; extra catchment improvement such as land clearing, shaping, smoothing and compacting can be used to compensate for expected evaporation losses. Catchment area slopes should be steep enough to maximize runoff and minimize surface storage but flat enough to prevent erosion. According to the soil type of the Shinyanga region, gently sloping plains (3%-7%) gradients without gullies, channels and local depressions are ideal.

2) In designing the RWH system the following parameters should be kept in mind:

(a) The ratio of the catchment Area (CA) to the cropped Area (FA) should not be too large in order to reduce deep percolation and not be too small in order to reduce direct evaporation losses. The ratio of $1 < CA/FA < 1.5$ is ideal.

(b) The ratio of length to the width for the catchment should be highly considered during the design of the RWH system, this is due to the fact that large length/width ratio of the catchment may create problems in earth work and erosion. The ratio of 2.0 to 3.5 for the catchment is recommended.

3) More research should be carried out to quantify the yield benefits attributable to RWH; establish economically viable design parameters for catchments under different topographical and soil conditions and assess the erosion risks inherent of the system.

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APPENDICES

APPENDIX-A

1.0 CALCULATIONS FOR EVAPOTRANSPIRATION (ET) BY PENMAN METHOD

The calculations for daily evapotranspiration were based on climatical data collected at Shinyanga Meteorological station which is located at 3° 39's Latitude and 33° 24'E Longitude, with altitude of 1200m above sea level. Also the calculations covers the growing period of paddy (December-March).

1.1. ASSUMPTIONS

The main assumptions in the calculations are as follows:

(a) The day and night wind speeds are just about equal.

(b) Albedo (α) is taken to be = 0.25 (Doorenbos and Pruitt, 1977).

(c) The crop coeffient for rice are:
1.1 for December and January, 1.2 for February and March and 0.9 for April and May.

1.2 DEFINITIONS OF SYMBOLS USED

SYMBOLS	DESCRIPTIONS	UNITS
n	actual sunshine hours	hrs
N	Maximum possible sunshine hours	hrs
e_a	Saturation vapour pressure	mbar
ed	Actual vapour pressure	mbar
f(u)	wind function	km/day
W	Weighting factors	-
R_a	extra terrestrial radiation	mm/day
	mean air temperature	c°
R_s	short wave radiation	mm/day
R_{ns}	net short wave radiation	mm/day
R_{nl}	net long wave radiation	mm/day
R_n	net radiation	mm/day
RH	Relative Humidity (mean)	%
u	mean wind speed	km/day
c	adjustment factor	-
k_c	crop coefficient	-

Appendex-A (cont.)

TABLE 1. MEAN DAILY CLIMATICAL DATA FOR SHINYANGA DISTRICT DURING THE GROWING SEASON OF PADDY CROP (DEC-MARCH)

1988-89	DEC	JAN	FEB	MAR
AIR TEMPERATURE	24.5	22.0	23.3	24.0
RELATIVE HUMIDITY	65.0	78.9	79.1	65.0
WINDRUN	135.0	109.0	94.7	119.4
HOURS OF SUNSHINE	7.0	8.0	7.6	7.6

TABLE 2: MEAN DAILY CLIMATICAL DATA FOR SHINYANGA DISTRICT

1989-90	DEC	JAN	FEB	MAR
AIR TEMPERATURE	30.5	23.4	24.0	24.3
RELATIVE HUMIDITY	72.0	63.5	70.0	72.2
WINDRUN	137.2	120.0	117.8	107.6
HOURS OF SUNSHINE	6.5	8.4	6.4	6.6

Appendix-A (cont.)

TABLE 3. MEAN MONTHLY ~~DAILY~~ CLIMATICAL DATA FOR SHINYANGA DISTRICT

1990-91	DEC	JAN	FEB	MAR
AIR TEMPERATURE	23.9	24.1	24.4	24.5
RELATIVE HUMIDITY	64.4	67.6	64.3	62.4
WINDRUN	135.0	119.4	117.6	111.[illegible]
HOURS OF SUNSHINE	7.2	7.7	7.0	[illegible]

TABLE 4. MEAN MONTHLY ~~DAILY~~ CLIMATICAL DATA FOR SHINYANGA

1991-92	DEC	JAN	FEB	MAR
AIR TEMPERATURE	24.0	25.2	24.1	25.[illegible]
RELATIVE HUMIDITY	64.3	55.0	66.8	[illegible]
WINDRUN	128.0	[illegible]	118.0	[illegible]
HOURS OF SUNSHINE	6.0	8.0	6.4	8.7

Appendix-A (cont.)

Table 5 Saturation Vapour Pressure (es) in mbar as Function of Mean Air Temperature (T) in oC 1/

Temperature °C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
es mbar	6.1	6.6	7.1	7.6	8.1	8.7	9.3	10.0	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.0	18.2	19.4	20.6	[illegible]
Temperature °C	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
es mbar	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7	37.8	40.1	42.4	44.9	47.6	50.3	53.2	56.2	59.4	62.8	66.3	[illegible]

1/ Also actual vapour pressure (ed) can be obtained from this table using available Tdewpoint data. (Example: Tdewpoint is 18°C; ed is 20.6 mbar).

Table 6 Vapour Pressure (ed) in mbar from Dry and Wet Bulb Temperature Data in °C (Aspirated Psychrometer)

Depression wet bulb T°C altitude 0-1 000 m												drybulb T°C	Depression wet bulb T°C altitude 1 000-2 000 m										
0		4	6	8	10	12	14	16	18	20	22		0	2	4	6	8	10	12	14	16	18	
73.8	64.9	56.8	49.2	42.2	35.8	29.6	24.3	19.2	14.4	10.1	6.0	40	73.8	65.2	57.1	49.8	43.0	41.8	31.0	25.6	20.7	16.2	[illegible]
66.3	58.1	50.5	43.6	37.1	31.1	25.6	20.5	15.8	11.4	7.3		38	66.3	58.2	50.9	44.1	37.9	36.7	26.8	21.8	17.3	13.2	[illegible]
59.4	51.9	44.9	38.4	32.5	26.9	21.8	17.1	12.7	8.6	4.9		36	59.4	52.1	45.2	39.0	33.3	32.1	23.0	18.4	14.3	10.4	[illegible]
53.2	46.2	39.8	33.8	28.3	23.2	18.4	14.0	10.0	6.2			34	53.2	46.4	40.1	34.4	29.1	24.1	19.6	15.4	11.5	8.0	[illegible]
47.5	41.1	35.1	29.6	24.5	19.8	15.4	11.3	7.5	4.0			32	47.5	41.3	35.5	30.2	25.3	20.7	16.6	12.6	9.1	5.8	[illegible]
42.4	36.5	30.9	25.8	21.1	16.7	12.6	8.8	5.3				30	42.4	36.7	31.3	26.4	21.9	17.7	13.8	10.2	6.9	3.8	[illegible]
37.8	32.3	27.2	22.4	18.0	14.0	10.2	6.7	3.4				28	37.8	32.5	27.5	23.0	18.9	14.9	11.4	8.0	4.9	2.1	
33.6	28.5	23.8	19.4	15.3	11.5	8.0	4.7	1.6				26	33.6	28.7	24.1	20.0	16.1	12.5	9.2	6.0	3.2	0.5	
29.8	25.1	20.7	16.6	12.8	9.3	6.0	2.9					24	29.8	25.3	21.1	17.2	13.9	10.3	7.2	4.3	1.6		
26.4	22.0	18.0	14.2	10.6	7.4	4.3	1.4					22	26.4	22.3	18.3	14.3	11.5	8.3	5.5	2.7	0.2		
23.4	19.3	15.5	12.0	8.7	5.6	2.7						20	23.4	19.5	15.9	12.6	9.5	6.6	3.9	1.3			
20.6	16.8	13.3	10.0	6.9	4.1	1.4						18	20.6	17.1	13.7	10.6	7.8	5.0	2.5	0.1			
18.2	14.6	11.4	8.3	5.4	2.7							16	18.2	14.9	11.7	8.9	6.2	3.6	1.3				
16.0	12.7	9.6	6.7	4.0	1.5							14	16.0	12.9	10.0	7.3	4.8	2.4	0.2				
14.0	10.9	8.1	5.3	2.8								12	14.0	11.2	8.4	5.9	3.6	1.4					
12.3	9.4	6.7	4.1	1.7								10	12.3	9.6	7.0	4.7	2.6	0.4					
10.7	8.0	5.5	3.1	0.8								8	10.7	8.2	5.8	3.7	1.6						
9.3	6.8	4.4	2.1									6	9.3	7.0	4.8	2.7	0.7						
8.1	5.7	3.4	1.6									4	8.1	6.0	3.6	1.8							
7.1	4.8	2.8	0.8									2	7.1	5.0	2.9	1.0							
6.1	4.0	2.0										0	6.1	4.1	2.1								

Table 6b

Vapour Pressure (ed) in mbar from Dry and Wet Bulb Temperature Data in °C (Non-Ventilated Psychrometer)

Depression wet bulb T°C altitude 0-1 000 m												drybulb T °C	Depression wet bulb T°C altitude 1 000-2 000 m											
0	2	4	6	8	10	12	14	16	18	20	22		0	2	4	6	8	10	12	14	16	18	20	22
73.8	64.7	6.2	48.4	41.2	34.4	28.2	22.4	17.0	12.0	7.4	1.0	40	73.8	64.9	56.7	49.1	42.0	35.6	29.6	34.1	18.9	14.1	9.8	5.[illegible]
66.3	57.8	0.0	42.5	36.0	29.8	24.0	18.6	13.6	9.0	4.6	0.6	38	66.3	58.0	50.5	43.4	36.9	31.0	25.4	20.3	15.5	11.1	7.0	3.[illegible]
59.4	51.6	4.4	37.6	31.4	25.6	20.2	15.2	10.6	6.2	2.2		36	59.4	51.8	44.8	38.3	32.3	26.8	21.2	16.9	12.5	8.3	4.5	1.[illegible]
53.2	45.9	9.2	33.0	27.2	21.8	16.8	12.2	7.8	3.8			34	53.2	46.1	39.7	33.7	28.1	23.0	18.2	13.9	9.7	5.9	2.4	
47.5	40.8	4.6	28.8	23.4	18.4	13.8	9.4	5.4	1.6			32	47.5	41.0	35.1	29.5	24.3	19.6	15.2	11.1	7.3	3.7	0.4	
42.4	36.2	0.4	25.0	20.0	15.4	11.0	7.[illegible]	3.2				30	42.4	36.4	30.9	25.7	20.9	16.6	12.4	8.7	5.1	1.7		
37.8	32.0	6.6	21.6	17.0	12.6	8.6	4.8	1.2				28	37.8	32.2	27.1	22.3	17.9	13.8	10.0	6.5	3.1			
33.6	28.2	3.2	18.6	14.2	10.2	6.4	2.8					26	33.6	28.4	23.7	19.3	15.1	11.4	7.8	4.5	1.4			
29.8	24.8	0.2	15.8	11.8	8.0	4.4	1.1					24	29.8	25.0	20.7	16.5	12.7	9.2	5.8	2.8				
26.4	21.8	17.4	13.4	9.6	6.0	2.7						22	26.4	22.0	17.9	14.1	10.5	7.2	4.1	1.2				
23.4	19.0	15.0	11.2	7.6	4.3	1.1						20	23.4	19.2	15.5	11.9	8.5	5.5	2.5					
20.6	16.6	12.8	9.2	5.9	2.7							18	20.6	16.8	13.3	9.9	6.8	3.9	1.1					
18.2	14.4	10.8	7.5	4.3	1.4							16	18.2	14.6	11.3	8.2	5.2	2.5						
16.0	12.4	9.1	5.9	3.0	0.1							14	16.0	12.6	9.6	6.6	3.8	1.3						
14.0	10.7	7.5	4.6	1.7								12	14.0	10.9	8.0	5.2	2.6	0.3						
12.3	9.1	6.1	3.3	0.7								10	12.3	9.3	6.7	4.0	1.6							
10.7	7.7	4.9	2.3									8	10.7	7.9	5.4	3.0	0.6							
9.3	6.5	3.9	1.5									6	9.3	6.7	4.4	2.0								
8.1	5.5	2.9	0.9									4	8.1	5.7	3.4	1.1								
7.1	4.5	2.3										2	7.1	4.7	2.5	0.3								
6.1	3.7	1.5										0	6.1	3.8	1.7									

Appendix-A (cont.)

Table 7 Values of Wind Function $f(u) = 0.27\,(1 + \frac{U_2}{100})$ for Wind Run at 2 m height in km/day

Wind km/day	0	10	20	30	40	50	60	70	80	90
	-	.30	.32	.35	.38	.41	.43	.46	.49	.51
100	.54	.57	.59	.62	.65	.67	.70	.73	.76	.78
200	.81	.84	.86	.89	.92	.94	.97	1.00	1.03	1.05
300	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32
400	1.35	1.38	1.40	1.43	1.46	1.49	1.51	1.54	1.57	1.59
500	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.84	1.90
600	1.89	1.92	1.94	1.97	2.00	2.02	2.05	2.08	2.11	2.15
700	2.16	2.19	2.21	2.24	2.27	2.29	2.32	2.35	2.38	2.40
800	2.43	2.46	2.48	2.51	2.54	2.56	2.59	2.62	2.64	2.65
900	2.70									

Appendix-A (cont.)

Table 8 Values of Weighting Factor (1-W) for the Effect of Wind and Humidity on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(1-W) at altitude m																				
0	0.57	.54	.51	.48	.45	.42	.39	.36	.34	.32	.29	.27	.25	.23	.22	.20	.19	.17	.16	.15
500	.56	.52	.49	.46	.43	.40	.38	.35	.33	.30	.28	.26	.24	.22	.21	.19	.18	.16	.15	.14
1 000	.54	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.20	.18	.17	.15	.14	.13
2 000	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12
3 000	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11
4 000	.46	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11	.10

Table 9 Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.78	.80	.82	.83	.84	.85
500	.44	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88	.89
4 000	.54	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.89	.90	.90

Appendix-A (cont.)

Table 10 Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	[illegible]
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	[illegible]
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	[illegible]
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	[illegible]
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	[illegible]
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	[illegible]
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	[illegible]
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	[illegible]
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.0
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	13	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.3	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.2	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.1	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Appendix-A (cont.)

Table 11 Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats Southern Lats	Jan July	Feb Aug	Mar Sept	Apr Oct	May Nov	June Dec	July Jan	Aug Feb	Sept Mar	Oct Apr	Nov May	Dec June
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Appendix-A (cont.)

Table 12 Conversion Factor for Extra-Terrestrial Radiation (Ra) to Net Solar Radiation (Rns) for a Given Reflection α of 0.25 and Different Ratios of Actual to Maximum Sunshine Hours $(1-\alpha)(0.25 + 0.50\ n/N)$

n/N	0.0	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0
$(1-\alpha)(0.25 + 0.50\ n/N)$	0.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.37	.39	.41	.43	.45	.47	.49*	.51	.52	.54	.56

Table 13 Effect of Temperature f(T) on Longwave Radiation (Rnl)

T°C	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(T) = \sigma Tk^4$	11.0	11.4	11.7	12.0	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15.0	15.4	15.9	16.3*	16.7	17.2	17.7	18.1

Table 14 Effect of Vapour Pressure f(ed) on Longwave Radiation (Rnl)

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed) = 0.34 - 0.044\sqrt{ed}$	0.23	.22	.20	.19	.18	.16	.15	.14	.13*	.12	.12	.11	.10	.09	.08	.08	.07	.06

Table 15 Effect of the Ratio Actual and Maximum Bright Sunshine Hours f(n/N) on Longwave Radiation (Rnl)

n/N	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9	.95	1.0
$f(n/N) = 0.1 + 0.9\ n/N$	0.10	.15	.19	.24	.28	.33	.37	.42	.46	.51	.55	.60	.64	.69	.73	.78	.82*	.87	.91	.95	1.0

Appendix-A (cont.)

Table 16 Adjustment Factor (c) in Presented Penman Equation

	RHmax = 30%				RHmax = 60%				RHmax = 90%			
Rs mm/day	3	6	9	12	3	6	9	12	3	6	9	12
Uday m/sec	Uday/Unight = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.32
6	.68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.33
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.27
	Uday/Unight = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.28
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.22
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.18
	Uday/Unight = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.69	.76	.85	.92	.83	.91	.99*	1.05*	.89	.98	1.10*	1.14*
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
	Uday/Unight = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.64	.71	.82	.89	.78	.86	.94*	.99*	.85	.92	1.01*	1.05*
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

Appendix-A (cont.)

TABLE 17 CROP COEFFICIENT FOR RICE (K_c)

STAGE OF CROP	K_c VALUES
Initial stage and establishment (1 - 2 months)	1.1 to 1.15
Vegetative, flowering and yield formation (mid - season)	1.1 to 1.3
Ripening stage	0.95 to 1.05

Appendix-A (cont.)

DECEMBER 1988

T = 24.5°C, n = 7.0 hrs/day, u = 135km/day, RH = 65% (table 1)

e_a = 26.4mbars (table 5)

$e_d = e_a * RH = 30.8 * 0.65 = 20.0$mbars

$(e_a - e_d) = 30.8 - 20.0 = 10.8$mbars

f(u) = 0.65 (table 7)

(1 - W) = 0.27 (table 8)

$(1-W)f(u)(e_a - e_d) = 0.27*0.63*10.8 = 1.84$ mm/day

Ra = 15.4mm/day (table 10)

N =12.4 hrs/day (table11)

n/N = 7.0/12.4 = 0.56

$R_s = R_a[0.25 + 0.5(n/N)] = 15.4(0.25 + 0.5 * 0.56) = 8.2$ mm/day

$R_{ns} = (1-\alpha)R_s = (1-0.25)8.2 = 6.1$mm/day

f(T) = 15.6(table 13), $f(e_d)$ = 0.14(table 14), f(n/N) = 0.64(table 15)

$R_{nl} = f(T)f(e_d)f(n/N) = 15.6*0.14*0.64 = 1.4$ mm/day

$R_n = R_{ns} - R_{nl} = 6.1 - 1.4 = 4.7$ mm/day

W = 0.73 (table 9)

$W*R_n = 0.73 * 4.7 = 3.43$ mm/day

C = 1.01 (table 16)

Therefore: $ET_0 = c[W*R_n + (1-W)f(u)(e_a - e_d)$

Crop water requirement=$k_c*ET_0 = 5.27*1.1=5.8$mm/day

JANUARY 1989

T = 22.0, n = 8.0, u = 109, RH=78.9% (table 1)'

e_a = 26.4 (table 5)

$e_d = e_a * RH = 26.4 * 0.789 = 20.8$

$(e_a - e_d = 26.4 - 20.8 = 5.6$

f(u) = 0.57 (table 7)

(1-W) = 0.27 (table 8)

$(1-W)f(u)(e_a - e_d) = 0.27 * 0.57 * 5.6 = 0.86$

R_a = 15.5 (table 10)

N = 12.3 (table 11)

n/N = 8.0/12.3 = 0.65

$R_s = R_a[0.25 + 0.5(n/N)] = 15.5(0.25 + 0.5 *0.56)=8.92$

$R_{ns} = (1-\alpha)R_s = (1-0.25)8.92 = 6.69$

f(T) = 15 (table 13)

$f(e_d)$ = 0.14 (table 14)

f(n/N) = 0.69 (table 15)

$R_{nl} = f(T)f(e_d)f(n/N) = 15*0.14*0.69 = 1.45$

$R_n = R_{ns} - R_{nl} = 6.69 - 1.45 = 5.24$

W = 0.73 (table 9)

$W * R_n = 0.73 * 5.24 = 3.83$

c = 1.1 (table 16)

$ET_0 = c[W*R_n + (1-W)f(u)(e_a-e_d)] = 1.1(3.83+0.86)=5.2$mm/day

Crop water requirement=$k_c*ET_0=1.1*5.2=5.7$mm/day.

Appendix-A (cont.)

FEBRUARY 1989
T = 23.3, n = 7.6, u = 94.7, RH = 79% (table 1)
e_a = 28.6 (table 5)
e_d = e_a * RH = 28.6 * 0.79 = 22.6
(e_a - e_d) = 28.6 -22.6 = 6.0
f(u) = 0.54 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a - e_d) = 0.25*0.54*6 = 0.8
R_a = 15.8 (table 10)
N = 12.3 (table 11)
n/N = 7.6/12.3 = 0.62
Rs = (0.25 + 0.5n/N)R_a =(0.25+0.5*0.62)15.8 = 8.83
R_{ns} = $(1-\alpha)R_s$ = (1-0.25)8.83 = 6.6
f(T)f(e_d)f(n/N) = 15.4*0.13*0.64 = 1.28
R_n = $R_{ns}-R_{nl}$ =6.6-1.28 = 5.32
W = 0.75 (TABLE 9)
W*R_n = 0.75 * 5.32 = 3.99
c = 1.1 (table 16)
ET_0 = c[W*R_n + (1-W)f(u)(e_a-e_d)] = 1.1(3.99 + 0.8) =
5.3mm/day
Crop water requirement = k_c*ET_0 = 1.2*5.3 = 6.4mm/day.

MARCH 1989
T = 24, n=7.6, u=119.4, RH=64.9% (table 1)
e_a = 29.8 (table 5)
ed = e_a * RH = 29.8*0.649 = 19.37
(e_a - e_d) = 29.8 - 19.37 = 10.43
f(u) = 0.57 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-e_d) = 0.25*0.57*10.43= 1.49
R_a = 15.6 (table 10)
N = 12.1 (table 11)
n/N = 7.6/12.1 = 0.63
R_s = (0.25+0.5n/N)R_a = (0.25+0.5*0.65)15.6 = 8.8
R_{ns} = $(1-\alpha)R_s$ = (1-0.25)8.8 = 6.6
f(T) = 15.4 (table 13)
f(e_d) = 0.14 (table 14)
f(n/N) = 0.69 (table 15)
R_{nl} = f(T)f(e_d)f(n/N) = 15.4*0.14*0.69
R_n = $R_{ns}-R_{nl}$ = 6.6-1.49 = 5.11
W = 0.75 (table 9)
W*R_n = 0.75*5.11 = 3.83
c = 1.05 (table 16)
ET_0 = c[W*R_n + (1-W)f(u)(e_a-e_d)]=1.05(3.83+1.49) =
5.6mm/day
Crop water requirement = k_c*ET_0 = 1.2*5.6 = 6.7mm/day

Appendix-A (Cont.)

DECEMBER 1989
T = 30.5, n = 6.5, u = 137.2, RH = 72% (table 2)
e_a = 43.65 (table 5)
e_d = e_a*RH = 43.65*0.72 = 31.43
(e_a-e_d) = 43.65-31.43 = 12.22
f(u) = 0.62 (table 7)
(1-W) = 0.22 (table 8)
(1-W)f(u)(e_a-e_d) = 0.22*0.62*12.22 = 1.67
R_a = 15.4 (table 10)
N = 12.4 (table 11)
n/N = 8.4/12.4 = 0.52
Rs = (0.25+0.5n/N)Ra = (0.25+0.5*0.52)15.4 = 7.9
Rns = (1-α)Rs = (1-0.25)7.9 = 5.9
f(T) = 16.7 (table 13)
f(e_d) = 0.1 (table 14)
f(n/N) = 0.55 (table 15)
R_{nl} = f(T)f(e_d)f(n/N) = 16.7*0.1*0.55 = 0.92
R_n = R_{ns}-R_{nl} = 5.9-0.92 = 4.98
W = 0.78 (table 9)
W*R_n = 0.78*4.98 = 3.9
c = 1.01 (table 16)
ET_0 = c[W*Rn+(1-W)f(u)(e_a-e_d)] = 1.01(3.9+1.67) = 5.6
Crop water requirement = 1.1*5.6 = 6.2mm/day.

JANUARY 1990
T =23.4, n = 8.4, u = 130, RH = 63.5% (table 2)
e_a = 28.78 (table 5)
e_d = e_a*RH = 28.78*0.635 = 18.28
e_a-e_d = 28.78-18.78 = 10.5
f(u) = 0.62
(1-W) = 0.25
(1-W)f(u)(e_a-e_d) = 0.25*0.62*10.5 = 1.63
R_a = 15.5 (table 10)
N = 12.3 (table11)
n/N = 8.4/12.3 = 0.68
Rs = (0.25+0.5n/N)Ra = (0.25+0.5*0.68)15.5 = 9.2
Rns = (1-α)Rs = (1-0.25)9.2 = 6.8
f(T) = 15.2 (table 13)
f(e_d) = 0.15 (table 14)
f(n/N) = 0.73 (table 15)
R_{nl} = f(T)f(e_d)f(n/N) = 15.2*0.15*0.73 = 1.7
R_n = R_{ns} - R_{nl} = 6.9-1.7 = 5.2
W = 0.75 (table 9)
W*R_n = 0.75*5.2 = 3.9
c = 0.94 (table 16)
ET_0 = c[W*R_n + (1-W)f(u)(e_a-e_d)] = 0.94(3.9+1.63) = 5.2mm/day
ement = 1.1 * 5.2 = 5.7mm/day.

Appendix-A (cont.)

FEBRUARY 1990
T=24, n=6.4, u=117.8 and RH=70% (table 2)
e_a = 29.8 (table 5)
e_d = e_a*RH = 29.8*0.70 = 20.86
e_a-e_d = 29.8-20.86 = 8.94
f(u) = 0.59 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-e_d) = 0.25*0.59*8.94 = 1.32
R_a = 15.8 (table 10)
N = 12.3 (table 11)
n/N = 6.4/12.3 = 0.52
Rs = (0.25+0.5n/N)R_a = (0.25+0.5*0.52)15.8 = 8.1
Rns = (1-α)Rs = (1-0.25)8.1 = 6.0
f(T) = 15.4 (table 13)
f(e_d) = 0.14 (table 14)
f(n/N) = 0.55 (table 15)
Rnl = f(T)f(e_d)f(n/N) = 15.4*0.14*0.55 = 1.2
R_n = $R_{ns}-R_{nl}$ = 6-1.2 = 4.8
W = 0.75 (table 9)
W*R_n = 0.75*4.8 = 3.6
c = 1.05 (table 16)
ET_o = c[W*R_n + (1-W)f(u)(e_a-e_d)] = 1.05(3.6+1.32) = 5.7mm/day
Crop water requirement = 1.2*5.7 = 6.8mm/day.

MARCH 1990
T = 24.3, n=6.6, u=107.6 and RH=72.2% (table 2)
e_a = 30.4 (table 5)
e_d = e_a*RH = 30.4*0.722 = 21.9
e_a-e_d = 30.4-21.9 = 8.45
f(u) = 0.57 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-e_d) = 0.25*0.57*8.45 = 1.2
R_a = 15.6 (table 10)
N = 12.1 (table 11)
n/N = 6.6/12.1 = 0.55
R_s = (0.25 + 0.5n/N)R_a = (0.25+ 0.5*0.55)15.6 = 8.19
R_{ns} = (1-α)Rs = (1-0.25)8.19 = 6.14
f(T) = 15.4 (table 13)
f(e_d) = 0.13 (table 14)
f(n/N) = 0.60
R_{nl} = f(T)f(e_d)f(n/N) = 15.4*0.13*0.60 = 1.2
R_n = $R_{ns}-R_{nl}$= 6.14-1.2 = 4.94
W = 0.75 (table 9)
W*R_n = 0.75*4.94 = 3.71
c = 1.05 (table 16)
ET_o = c[W*R_n =(1-W)f(u)(e_a-e_d)] = 1.05(3.71 + 1.2) = 5.2mm/day
Crop water requirement = 1.2 * 5.2 = 6.2mm/day

Appendix-A (Cont.)

DECEMBER 1990

T = 24, n = 7.2, u=135 and RH=64.4% (table 3)

e_a = 29.8 (table 5)

$e_d = e_a*RH = 29.8*0.644 = 19.1$

$e_a-e_d = 29.8-19.1 = 10.73$

f(u) = 0.365 (table 7)

(1-W) = 0.27 (TABLE 8

$(1-W)f(u)(e_a-e_d) = 0.27*0.365*10.73 = 1.06$

R_a = 15.4 (table 10)

N = 12.4 (table 11)

n/N = 7.2/12.4 = 0.58

$R_s = R_a(0.25 + 0.5n/N) = 15.4(0.25+0.5*0.58) = 8.3$

$R_{ns} = (1-\alpha)R_s = (1-0.25)8.3 = 6.2$

f(T) = 15.4 (table 13)

$f(e_d)$ = 0.155 (table 14)

f(n/N) = 0.64 (table 15)

$R_{nl} = f(T)f(e_d)f(n/N) = 15.4*0.155*0.64 = 1.53$

$R_n = R_{ns}-R_{nl} = 6.20-1.53 = 4.67$

W = 0.73 (table 9)

$W*R_n = 0.73 * 4.67 = 3.41$

c = 1.01 (table 16)

$ET_0 = c[W*R_n + (1-W)f(u)(e_a-e_d)] = 1.01(3.41 + 1.06) =$ 4.5mm/day

Crop water requirement = 1.1 * 4.5 = 5.0mm/day.

JANUARY 1991

T = 24.1, n = 7.2, u= 119.4 and RH = 67.6% (table 3)

e_a = 29.8 (table 5)

$e_d = e_a*RH = 29.8*0.676 = 20.1$

$e_a-e_d = 29.8-20.1 = 9.7$

f(u) = 0.59 (table 7)

(1-W) = 0.25 (table 8)

$(1-W)f(u)(e_a-e_d) = 0.25*0.59*9.7 = 1.43$

R_a = 15.5 (table 10)

N = 12.3 (table 11)

n/N = 7.7/12.3 = 0.63

$R_s = (0.25 + 0.5n/N)R_a = (0.25 + 0.5*n/N)15.5 = 8.7$

$R_{ns} = (1-\alpha)R_s = (1-0.25)8.7 = 6.5$

f(T) = 15.4 (table 13)

$f(e_d)$ = 0.14 (table 14)

f(n/N) = 0.69 (table 15)

$R_{nl} = f(T)f(e_d)f(n/N) = 15.4*0.14*0.69 = 1.49$

$R_n = R_{ns}-R_{nl} = 6.5-1.49 = 5.01$

W = 0.75 (table 9)

$W*R_n = 0.75*5.01 = 3.76$

c = 1.05 (table 16)

$ET_0 = c[W*R_n + (1-W)f(u)(e_a-e_d)] = 1.05(3.76+1.43) =$ 5.4mm/day

Crop water requirement = 1.1 * 5.4 = 6.0mm/day.

Appendix-A (cont.)

FEBRUARY 1991
T = 24.4, n=6.2, u=117.6 and RH=64.3% (table 3)
e_a = 30.5 (table 5)
e_d = e_a*RH = 30.5*0.643 = 19.6
e_a-e_d = 30.5-19.6 = 10.9
f(u) = 0.59 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-e_d) = 0.25*0.59*10.9 = 1.61
R_a 15.8 (table 10)
N = 12.3 (table 11)
n/N = 6.2/12.3 = 0.5
R_s = (0.25+0.5n/N)R_a = (0.25+0.5*0.5)15.8 = 7.9
Rns = (1-α)R_s = (1-0.25)7.9 = 5.93
f(T) = 15.6 (table13)
f(e_d) = 0.14 (table 14)
f(n/N) = 0.55 (table 15)
R_{nl} = 15.6*0.14*0.55 = 1.2
R_n = 5.93 - 1.2 = 4.73
W = 0.75 (table 9)
W*R_n = 0.75*4.73 = 3.55
c = 1.05 (table 16)
ET_0 = 1.05(3.55 + 1.61) = 5.4mm/day
Crop water requirement = 1.2*5.4 = 6.5 mm/day.

MARCH 1991
T= 24.5, n=7.8, u=111.1 and RH=62.4% (table 3)
e_a = 30.8 (table 5)
e_d = e_a*RH = 30.8*0.624 = 19.2
e_a-e_d = 30.8-19.2 = 11.6
f(u) = 0.57 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-_{ed}) = 0.25*0.57*11.6 = 1.65
R_a = 15.6 (table 10)
N = 12.1 (table 11)
n/N = 7.8/12.1 = 0.64
R_s = (0.25 + 0.5n/N)R_a = (0.25+0.5*0.64)15.6 = 8.9
Rns = (1-α)R_s = (1-0.25)8.9 = 6.7
f(T) = 15.6 (table 13)
f(e_d) = 0.15 (table 14)
f(n/N) = 0.69 (table 15)
R_{nl} =15.6*0.15*0.69 = 1.6
R_n = 6.7-1.6 =5.1
W =0.75 (TABLE 9)
W*R_n = 0.75*5.1 = 3.83
c = 1.05 (table 16)
ET_0 = 1.05(3.83 + 1.65) = 5.8mm/day
Crop water requirement = 1.2*5.8 = 7.0 mm/day.

Appendix-A (Cont.)

DECEMBER 1991
T=24, n=6, u=128 and RH=64.3% (table 4)
e_a = 29.8 (table 5)
e_d = 29.8*0.643 = 19.2
e_a-e_d =29.8-19.2 = 10.64
f(u) = 0.35 (table 7)
(1-W) = 0.27 (table 8)
(1-W)f(u)(e_a-e_d) = 0.27*0.35*10.64 =1.0
R_a = 15.4 (table 10)
N = 12.4 (table 11)
n/N = 6/12.4 =0.5
R_s = 15.4(0.25 +0.5*0.5) = 7.6
f(T) = 15.4 (table 13)
f(e_d) = 0.15 (table 14)
f(n/N) = 0.55 (table 15)
R_{nl} = 15.4*0.15*0.55 = 1.27
R_n = 5.7-1.27 = 4.43
W = 0.73 (table 9)
W*R_n = 0.73*4.43 = 3.23
c = 1.01
ET_0 = 1.01(3.23 + 1) = 4.2mm/day
Crop water requirement = 1.1*4.2 = 4.6 mm/day.

JANUARY 1992
T=25.2, n-8, u=126.6 and RH=55.8% (table 4)
e_a = 31.7 (table 5)
e_d = 31.7*0.558 = 17.7
e_a-ed = 31.7 - 17.7 = 14
f(u) = 0.35 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-e_d) = 0.25*0.35*14 = 1.22
R_a = 15.5 (table 10)
N = 12.3 (table 11)
n/N = 8/12.3 = 0.65
R_s = 15.5(0.25+0.5*0.65) = 1.22
R_a = 15.5 (table 10)
N = 12.3 (table 11)
n/N = 0.65
R_s = 15.5(0.25+0.5*0.65) = 8.92
Rns = (1-α)R_s =(1-0.25)8.92 = 6.7
f(T) = 15.7 (table 13)
f(e_d) = 0.15 (table 14)
f(n/N) = 0.69 (table 15)
R_{nl} =15.7*0.15*0.69 = 1.6
R_n = 5.8-1.6=4.2
W = 0.75 (table 9)
W*R_n = 0.75*4.2 = 3.15
c = 1.1 (table 16)
ET_0 = 1.1 (3.15 + 1.22) =4.81mm/day
Crop water requirement = 1.1*4.81 = 5.3 mm/day.

Appendix-A (cont.)

FEBRUARY 1992
T=24.1, n=6.4, u=118 and RH=66.8% (table 4)
e_a = 29.8
e_d = 29.8*0.668 = 19.9
e_a-e_d = 29.8-19.9 = 9.9
f(u) = 0.59 (table 7)
(1-W) = 0.27 (table 8)
(1-W)f(u)(e_a-e_d) = 0.27*0.59*9.9 = 1.58
R_a = 15.8 (table 10)
N = 12.3 (table 11)
n/N = 0.52
R_s = 15.8(0.25+0.5*0.52) = 8.1
R_{ns} = (1-α)Rs = (1-0.25)8.1 = 6.0
f(T) = 15.4 (table 13)
f(e_d) = 0.14 (table 14)
f(n/N) = 0.55 (table 15)
R_{nl} = 15.4*0.14*0.55 = 1.19
R_n = 6.0-1.19 = 4.8
W = 0.73 (table 9)
W*R_n = 0.73*4.8 = 3.5
c = 1.1
ET_0 = 1.1(3.51 + 1.58) = 5.6mm/day
Crop water requirement = 1.2*5.6 = 6.7 mm/day.

MARCH 1992
T=25.4, n=8.7, u=136.2 and RH=58.5% (table 4)
e_a = 31.7 (table 5)
e_d = 31.7*0.585 = 18.5
e_a-e_d = 31.7-18.5 = 13.2
f(u) = 0.62 (table 7)
(1-W) = 0.25 (table 8)
(1-W)f(u)(e_a-e_d) = 0.25*0.62*13.2 = 2.0
R_a = 15.6 (table 10)
N = 12.0 (table 11)
n/N = 0.73
R_s = 15.6(0.25+0.5*0.73) =9.6
R_{ns} = (1-α)R_s = (1-0.25)9.6 = 7.2
f(T) = 15.6 (table 13)
f(e_d) = 0.15 (table 14)
f(n/N) = 0.78 (table 15)
R_{nl} = 15.6*0.15*0.78 = 1.83
R_n = 7.2-1.83 = 5.4
W = 0.75 (table 9)
W*R_n = 0.75*5.4 = 4.0
c = 1.01
ET_0 = 1.01(4.0+2.0) = 6.0mm/day
Crop water requirement = 1.2*6.0 = 7.2 mm/day.

Appendix-B

Table 18 Monthly surface runoff from ephemeral streams.

	1969-1970							1970-1971						
	N	D	J	F	M	A	M	N	D	J	F	M	A	M
Manonga River at Kagela														
discharge in 10^6 m^3	–	–	0.84	1.67	–	–	1.67	–	7.53	0.93	5.31	0.37	5.57	2.39
run off in mm (ca 140 km^2)	–	–	6	12	–	–	12	–	55	7	38	3	40	17
rainfall in mm	137	75	90	120	211	217	19	104	178	99	160	50	216	23
Mhala River at Lubaga														
discharge in 10^6 m^3														
run off in mm (ca 250 km^2)														
rainfall in mm														
Mwadugolinda River at Uduhe														
discharge in 10^6 m^3														
run off in mm (ca 55 km^2)														
rainfall in mm														
Negazi River at Bridge														
discharge in 10^6 m^3														
run off in mm (ca 90 km^2)														
rainfall in mm														
Ningwa River at Chibe														
discharge in 10^6 m^3	–	1.64	–	4.75	14.14	2.55	0	–	1.94	0.93	1.76	0	13.87	0.10
run off in mm (ca 140 km^2)	–	12	–	34	101	18	0	–	14	7	13	0	99	1
run off in mm (ca 200 km^2)	–	8	–	24	71	13	0	–	10	5	9	0	69	1
rainfall in mm	111	85	139	125	235	151	18	91	177	94	122	58	250	22
Nyamuli River at Bugarama														
discharge in 10^6 m^3														
run off in mm (ca 110 km^2)														
rainfall in mm														
Tungu River at Lubaga														
discharge in 10^6 m^3														
run off in mm (ca 1170 km^2)														
rainfall in mm														

	1971-1972							1972-1973						
	N	D	J	F	M	A	M	N	D	J	F	M	A	M
Manonga River at Kagela														
discharge in 10^6 m^3	–	–	1.39	1.15	0.57	0	–	–	–	5.44	0.50	0.53	2.75	0
run off in mm (ca 140 km^2)	–	–	10	5	5	0	–	–	–	39	4	4	20	0
rainfall in mm	113	151	134	113	73	71	53	195	129	145	35	150	145	22
Mhala River at Lubaga														
discharge in 10^6 m^3						0.55	1.15	–	6.34	3.54	1.31	3.12	2.31	0
run off in mm (ca 250 km^2)						2	5	–	25	34	7	13	12	0
rainfall in mm					156	90	55	197	140	173	97	77	131	17
Mwadugolinda River at Uduhe														
discharge in 10^6 m^3								–	–	2.39	–	0.45	0.22	0
run off in mm (ca 55 km^2)								–	–	43	–	3	4	0
rainfall in mm								181	147	134	67	72	137	23
Negazi River at Bridge														
discharge in 10^6 m^3								–	2.10	1.77	0.48	0.60	1.44	0.57
run off in mm (ca 90 km^2)								–	22	20	5	7	16	6
rainfall in mm								181	148	134	50	75	147	15
Ningwa River at Chibe														
discharge in 10^6 m^3	1.51	4.00	1.37	5.20	0.65	0.43	0.96	4.48	5.08	5.31	1.14	0.54	3.15	0
run off in mm (ca 140 km^2)	11	29	13	37	5	5	7	32	36	38	8	4	22	0
run off in mm (ca 200 km^2)	8	20	9	25	3	2	5	22	25	27	6	3	16	0
rainfall in mm	110	146	125	131	111	47	51	168	116	153	91	94	139	15
Nyamuli River at Bugarama														
discharge in 10^6 m^3								–	5.14	4.12	3.68	0.52	0.09	0
run off in mm (ca 110 km^2)								–	47	37	33	5	1	0
rainfall in mm								173	150	167	97	91	59	25
Tungu River at Lubaga														
discharge in 10^6 m^3					–	13.92	5.87	–	–	–	7.79	2.93	–	0
run off in mm (ca 1170 km^2)					–	12	5	–	–	–	7	3	–	0
rainfall in mm					156	90	55	187	140	178	37	77	101	22

	1967-1968							1968-1969						
	N	D	J	F	M	A	M	N	D	J	F	M	A	M
Ningwa River at Chibe														
discharge in 10^6 m^3	–	6.98	1.60	3.52	18.38	18.82	3.76	0	1.41	4.41	–	0	0.65	0.12
run off in mm (ca 140 km^2)	–	50	11	25	131	130	27	0	10	31	–	0	5	1
run off in mm (ca 200 km^2)	–	35	8	18	92	92	19	0	7	22	–	0	3	1
rainfall in mm	154	164	97	222	193	254	20	50	168	123	94	65	80	41