THE UNIVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES

DEPARTMENT OF GEOGRAPHY

A CASE STUDY OF DRINKING WATER - AVAILABILITY AT KATETE MISSION, KATETE DISTRICT, ZAMBIA; A WATER BALANCE APPROACH

BY

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DEDICATION

THIS WORK IS DEDICATED TO MY MOTHER AND FATHER WHO ENCOURAGED ME TO FORGE AHEAD. MY WIFE WHOSE WORDS INSPIRED ME; MY CHILDREN WHO TOOK PRIDE AND UNDERSTOOD MY ABSENCE FROM HOME WHEN THEY NEEDED ME MOST; AND TO ALL THOSE WHO STRUGGLE DAILY TO SECURE A DROP OF WATER.

DECLARATION

I, NGOMA LEONARD .A. HEREBY DECLARE THAT THIS PROJECT WAS COMPOSED AND DESIGNED BY MYSELF AND THE WORK RECORDED IN THIS REPORT IS MY OWN; ALL CARTOGRAPHIC WORK AND DIAGRAMS WERE DESIGNED AND DRAWN BY ME AND WHERE RELEVANT THE SOURCES OF INFORMATION HAVE BEEN DULLY ACKNOWLEDGED. THIS WORK HAS NOT BEEN PREVIOUSLY SUBMITTED FOR ANY ACADEMIC AWARD.

Signed..............................

Date.....25/09/95.........

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"GOD BLESS YOU ALL"

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CHAPTER ONE

1.1.0. INTRODUCTION

Water is a vital resource which must be available to each and every individual in adequate quantities and good quality. Short of this people's lives and health will persistently be afflicted with water-related deaths and diseases.

There are a number of constraints, in both rural and urban areas, which make it difficult for people to meet their water consumption requirements. These include factors such as the water demand by far exceeding water availability due to falling output from the available sources as a result of prolonged droughts which may eventually lead to complete drying up of the sources, or because of the distances to be covered. Due to lack of appropriate technological know-how or total ignorance or a combination of the two man has often not channelled his efforts and resources to exploiting the vast quantities of water beneath the very ground on which he stands - ground water. Instead he chooses to walk the long distances to fetch his daily supply of water from the familiar surface sources.

1. 2.0. RESEARCH PROBLEM

Katete district, like many other districts in Zambia, has since 1990 been receiving inadequate rainfall with 1992 being a memorable year when the district experienced a severe drought. As a result most sources of water supply, both traditional and conventional sources (wells), have dried up. Thus, it is a matter of urgency that alternative sources of water are found and developed. In the absence of both meteoric and surface-water in the district the answer lies in ground water resources. But the catch to its exploitation is that information on ground water in the district is non-existent or at best very scanty. Hence, most wells in the district have dried up because they were sited without sufficient information about the local hydrology, geology, topography and ground-water flow. This research aims at inventorying the availability of ground water in the area as an alternative source of water supply.

1.3.0. OBJECTIVES OF THE RESEARCH

In the light of the above outlined water-supply status of Katete district, this research... was designed and undertaken to investigate:

(a) the existence of alternative sources of water supply in the area of study

(b) the potential availability and quantity of ground - water using the available meteorological, geological, topographical, geomorphological, and hydrological data of the district.

(c) the existing water consumption demands in the study area and to establish, through use of empirical hydrological equations, whether the available ground-water would adequately meet the consumption- demand among the consumers.

1.4.0. SCOPE OF THE RESEARCH

This research looks at problems of water-supply at Katete Mission/Secondary School and the possible exploitation of ground water from the delineated catchment area. Whereas its findings may not be beneficial to the whole district, it will serve as an inventory of the availability of an alternative source of water to the station and any other place within the vicinity of catchment area. In this research only basic meteorological data for the district is used. Hence, the findings will not be as accurate as expected had ample data been available.

1. 5.0 RATIONALE OF THE RESEARCH

The importance of water to the life and well being of man need not be over emphasised. Man simply has to have his water. Where the available water quantities fail to meet his demands, man has to think of alternative sources to supplement this demand. In the same vein, this research is meant to make an inventory of ground water as an alternative source of water to the study area. The existing water-supply-shortfall at Katete Mission is real and it is equally true for the entire Katete district. Hence, this research is meant to be beneficial to the people in the study area in particular and the district in general.

1.6.0. RESEARCH HYPOTHESES

1. The present demand for water at the station exceeds the available water supply.

2. The geologic and topographic properties of the Katete river Basin (catchment area) suggest an existence of a large quantity of ground water which can be developed into a sustainable source of water supply.

1.7.0. LIMITATIONS TO THE RESEARCH

A number of constraints came into play during both the design and execution phases of this research. The most pronounced being:

(i) the spatial vastness of Katete district. This made it difficult, in real terms impossible, to extend the research to the whole district. It would have required a large number of personnel and time.

(ii) None-availability of adequate geological data for the district even from the survey department main offices in Lusaka. This to some extent was true for meteorological data.

(iii) Finance and time. A research of this nature to cover the whole district is expensive in both time and money.

(iv) Chemical analysis of water samples from the area of study could not be done since they reached the laboratories at UNZA, Lusaka later than the testing demanded (ie expired).

(v) Transportation of rock samples from Katete to Lusaka, a distance of close to 500Km was equally a problem. This, only a few samples were transported for Laboratory analysis. However, due to lack of funds, the fees charged for the test could not be met.

1.8.0. DEFINITION OF TERMS

1. Traditional sources of water: refers to sources such as streams, rivers, lakes, dams shallow hand-dug water holes in dambos, river beds, etc.

2. Runoff coefficient - refers to that percentage of precipitation that appears as runoff.

3. Permeability coefficient - the rate of flow of water in cubic metres per day through a cross-section of one square metre under a unit hydraulic gradient.

4. Aquifer - Mass of rock material sufficiently permeable to conduct ground water and yield ecomonically significant quantities of water to wells and spring.

5. Specific yield - the ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of mass stated as a percentage.

6. Drainage basin - also called catchment area is a region or area bounded by drainage divided and occupied by a drainage system. Also called a hydrographic basin, watershed, river basin, etc.

7. Percolation - the slow laminar movement of water through small openings within a porous material.

CHAPTER TWO

REVIEW OF LITERATURE

2.1.0 INTRODUCTION

Water is a vital resource which must reach every individual, household, and the entire human community in sufficient quantities and usable form. Accessibility to this resource varies from one place to another and different methods for its abstraction exist. Whatever system of water supply is adopted in any given locality materially depends on the local hydrology, topography, geology and other climatological factors.

Problems of water-supply exhibit themselves in various forms some of which include consumption demand exceeding output from the source(s), low per capita consumption, women walking long distances to fetch water (hence devoting most of their time to this task), use of poor quality water, prevalence of deaths and diseases directly or indirectly linked to inadequate water supply, and many others.

Where such problems exist, development of alternative sources of water-supply or improvement to existing sources, becomes imperative. However, such options may not only prove to be difficult and expensive, but also call for ample knowledge and clear understanding of the existing potential of water availability from the sources to be developed.

2.2.0 SOURCES OF WATER SUPPLY

Water used by human beings is abstracted from various sources. the selection of sources of water-supply is greatly dependent on the bounty of nature. Twort (e tal), (1974), categories sources of water at man's disposal into three broad groups as follows:

TABLE 1: The three categories of types of water supply sources.

SURFACE WATER	GROUND WATER	WATER RECLAMATI ON
(i) River intake	(i) Springs	(i) Desalination
(ii)Reservoir for direct supply	(ii) Wells and boreholes	(ii) Re-use of treatment effects.
(iii) Reservior depending on indirect gravity or pumped inflow	(iii) Adits and gallaries	
(iv) River abstraction guaranteed by releases from upstream storage.	(iv) River abstractions guaranted by ground water regulation pumping	
(v) Tanks fed by collected rainfall	(v) River side collector wells	
	(vi) Artificial recharge	
	(vii) Storage in riverbed sand	

SOURCE: Twort A. C. e tal (1974, Water Supply; P28

Whether the supply is best taken from surface water or ground water aquifers is determined by the regional or local hydrological, geological or topographical endowment of the area.

Gecaga (1981) generally classified sources of water in rural areas into traditional and improved or modern conventional sources. Traditional sources are synonymous with natural sources such as rivers, streams, ponds, springs, lakes, water holes in dambos, etc. Improved conventional sources include all those technologically engineered sources such as deep wells, boreholes, etc. These two categories of water sources exist either singularly or in combination in different parts of Zambia. Whatever the source of water is adopted in a place, it is expected to provide quality water which is safe to consume and attractive to the users and must be in sufficient quantities.
Currently in Zambia, traditional sources are still the major suppliers of water to most rural households. Most of these sources have been adversely affected by droughts which have reduced their total output

to very low levels or have completely dried up. Wells and boreholes have, in some places, equally suffered the same fate. This has led people to abstract their supplie s of water from "unearthly" sources providing them with poor quality water.

2.3.0 PROBLEMS OF WATER SUPPLY IN ZAMBIA

A great disparity exists in the provision of water between the urban and rural areas in Zambia. Available data indicates that as high as 74% of the rural population in Zambia has no access to clean and safe drinking water (Times of Zambia, 26.10.93). Statistics from the Central Statistics Office (CSO), on the other hand, show that 90% of urban dwellers have access to piped, clean and safe drinking water (CSO, 1993).

Most wells and boreholes in rural areas have fallen into disuse on account of natural deterioration, vandalism and in some cases persistence of droughts. Rehabilitation of these structures is currently going on, but only at very slow pace. For instance, in Eastern Province between 1989 and 1992 only 35 new wells were constructed but 1,129 were rehabilitated. In most areas of the province, and Katete district in particular (especially in the Southern parts) even the rehabilitated wells have completely dried up.

A lot of effort and resources are being channelled, through both Non-Governmental Organisations (NGOs) and the Zambian Government, to water-improvement projects in both rural and urban areas.
For instance, Lutheran World Federation (LWF), an NGO) and the Department of Water Affairs are currently sinking new wells and rehabilitating old ones in Katete District. However, siting problems and underground water inventorying is an evident problem. In other parts of the country bilateral external support Agencies, NGOs, United Nations Agencies and Organisations, Development Banks, etc have financed water improvement projects and programmes.

2.4.0 WATER CONSUMPTION AND COMMUNITY HEALTH

While it is widely acknowledged that a relationship exists between water consumption and general community health, Morgan (1990 ,244) says, "improved (community) health can never directly result from the introduction of improved water supplies alone....., the road to health as far as water is concerned must take place in two stages. "Firstly, the water must be available closeby and in reasonable quantities, and secondly, the water that is available must be accompanied by hygienic practices by the individuals". Franceys (1990, 22) acknowledges that "to live a healthy life every individual needs water in sufficient quantity and potable quality .... the paradox of water is that "in plenty or in insufficiency (it) can cause diseases especially in areas where people congregate". While these assertions are true to some extent, experience has shown that usually quantity superseeds quality. It is better to have water of low quality in large amounts than to have water of very high quality but in very small amounts.

2.4.1 PER CAPITA WATER CONSUMPTION

Quantification of how much water constitutes what is generally referred to as a "sufficient amount" is usually difficult. Very few people take interest in Keenly knowing how much water they use individually, especially where the supply is unmetered. Thus as at now data on per capita water consumption in the rural parts of Zambia is either non-existent or at best very scanty and unreliable. Unfortunately, even in urban areas where meters may have been installed on the supply, computation of per capita water use is almost impossible because the meters are prone to vandalism, the supply may be intermittent and the tap may be communal. Twort e tal (1974) says it is difficult to measure water-consumption accurately because "standards of supply and maintenance vary widely, and to obtain accurate figures of consumption per capita may prove even more difficult - the population actually receiving a supply may not be accurately known in rural areas" (P1).

Per Capita consumption of water varies with distance between households and water sources, the depths from which water is drawn and people's attitudes towards water. In rural parts of Zambia it is not uncommon to find people using as slow as between 10 and 15 litres per person per day or even lower. In Botswana, according to a survey undertaken by Maikano and Nyberg (1981) most water supply improvement projects aim at providing 20 litres per person per day and 60 litres per ox per day. Similar projects in Malawi are designed to provide 27 litres per person per day (Robertson, 1981).

2.4.2 WATER AND DISEASES

The importance of water to human life is unquestionable. However, when badly handled water becomes home to many pathogenes so much so that it becomes the source of many diseases that cause illness and Wood (1979, 28) says "many of the diseases that cause illness and death to mankind are water related in one way or another". And according to the World Health Organization's estimates 80% of diseases prevalent in the rural areas of developing countries are caused by inadequate water supply and sanitation (Franceys, 1990).

Water-related diseases are for simplicity categorised as follows:

(a) Water-borne diseases - diseases carried in water which infect water consumers e.g. cholera, dysentry, typhoid, hepatitis, etc.

(b) Water-based diseases - diseases caused by organisms which spend part of their life cycle in an aquatic host e.g.schistosomiasis (bilharzia) cercaria, etc.

(c) Filth-borne or water-washed diseases - e.g. scabies, diarrhoea, trachoma, etc. Incidence of these diseases is reduced if ample water is made available for general hygiene.

(d) Water-associated diseases - diseases spread by insect vectors that breed in or near water bodies e.g. malaria, river blindness, sleeping sickness, etc.

Diseases in categories (a) and (b) can be drastically reduced by ensuring that the water supply system provides water that is free from infection. Hence the need to have a treatment system for water being supplied from whatever source(s) developed in a locality.

Comparatively, open surface-water sources are more prone to pathogenic infections than underground-water sources, providing other factors remain constant. However, people especially in rural areas tend to have an easy access to surface water than ground water, Brown etal (1972, 170) asserts to this by saying that "man is understandably most familiar with surface-water regime as this source is everywhere exposed to his direct observation. Water entering the ground passes out of direct contact with man's senses and immediately assumes an aura of mystery ..... consequently, he cannot appreciate the general conditions of occurrence of this potential resource .... and problems associated with its location and development".

2.5.0 GROUND-WATER, A POTENTIAL RESOURCE

Hydrologically, the occurrence of ground water is not merely a product of chance, but "the consequence of climatic, hydrologic, geologic, topographic, ecologic and soil-forming factors that together from an integrated dynamic system" (Brown e tal, 1972 2.1.p.1.) since most of these factors are measurable variables either through direct or indirect means ground-water development is rendered possible.

Exploitation of ground-water is but only at very low levels, especially so in rural parts of Zambia, because of the extraction expenses involved. To a large extent its exploitation is confined to a few deep wells and boreholes. That ground-water is a potential resource in places where surface-water alone fails to satisfy consumption demands is evidenced by the existence of ground-water even in hot, dry deserts with minimal annual precipitation. However, because of the expenses involved in ground-water abstraction planning and inventorying are essential to ascertain if the available quantity is economically exploitable. Ground-water inventorying should take into consideration all factors which influence availability of ground-water in an area both in terms of its quality and quantity

2.5.1 ENVIRONMENTAL FACTORS INFLUENCING THE OCCURRENCE OF GROUND-WATER

O'driscoll (1963) identifies five factors that affect the occurrence of ground-water in any place. These are:-

(i) Rainfall (precipitation),
(ii) topographic relief,
(iii) vegetative cover,
(iv) rock type, and
(v) structures developed in the rocks

Mc Ilroy (1963) adds evaporation to the above list while Brown e tal (1972) include the following climatic factor;

(i) Air temperature,
(ii) atmospheric pressure,
(iii) atmospheric humidity,
(iv) wind velocity

In looking at the extent to which these factors affect the occurrence of ground-water, it must always be borne in mind that "these factors are often mutually interdependent and although, one my be dominant in a particular locality, their effects usually overlap" (O'driscoll, 1963, 188)

A. PRECIPITATION

Precipitation in the form of rain has both direct and indirect influence on ground-water occurrence. Through infiltration or percolation, rain water will subsequently recharge ground-water reservoirs and cause a rise in ground-water levels. Indirectly, rainfall at a distant place through percolation and eventual slow underground flow may recharge the ground-water reservoir at another distant place.

Amounts of precipitation infiltrating to the ground-water body depend on many other factors including the intensity of the precipitation, morphological structure and vegetation cover.

Light but long-duration rainfall has a high infiltration potential than intense storms of short duration, other factors being held constant.

B. TOPOGRAPHIC RELIEF

The shape of the ground surface ie. the ruggedness of the relief of an area has a profound influence on ground-water recharge and discharge. Due to greater gradients, ruggedness of an area increases surface runoff, hence discouraging the recharge of ground-water (Brammer, 1973 Brown e tal, 1972). Conversely areas with gentle slopes or level encourage infiltration hence ground-water recharge.

Topography affects rainfall. Gibbs (1963, 189) says, "apart from its direct influence on rainfall topographic relief is important because hills shade water into stream courses, where it is concentrated and has maximum access to the rocks below".

C. VEGETATIVE COVER:

The importance of vegetation to ground-water is with respect to its ability to control surface runoff and losses by evapotranspiration. Where vegetation is thick more rain water is held in the soil, through which it moves slowly and has ample opportunity to percolate and become ground-water. Gibbs (1963) commenting on the loss of water through transpiration acknowledges that where vegetation is thick transpirational losses increase, but he argues that these losses rarely if ever, reach levels where downward percolation is completely inhibited.

D. GEOLOGICAL FORMATIONS

Ground-water occurs in many types of geologic formations which are broadly categorised into:

(a) Aquifers which are lithologic formations which contain sufficient permeable materials to yield large and significant quantities of water. Sands and gravels which are unconsolidated form good aquifers.

(b) Aquicludes are those lithologic formations which are saturated but rather impermeable, hence do not yield large quantities of water. Clay is a good example.

(c) Aquitards lithologic formations which are saturated but are poorly permeable and impede movement of ground-water. Aquitards may however, transmit appreciable amounts of water to or from adjacent aquifers (Todd, 1980), e. g. sandy clay

(d) Aquifuge is a relatively impermeable lithologic formation e.g. granite.

Many types of formations serve as aquifers. According to Todd (1980), the following formations provide good aquifers:

(i) Alluvial deposits which are chiefly sands and gravels which are unconsolidated.

(ii) Limestone

(iii) Volcanic rock, e.g. basalt

(iv) Sandstone and conglometrates, which are cemented forms of sand and gravel. The best sandstone aquifers yield water through their joints.

E. POROSITY AND PERMEABILITY

The ability of any geologic formation to yield, retain or transmit water depends on its porosity and permeability. These values vary with each formation. Given below is a tables indicating porosity expressed a s a percentage and coefficient of permeability in metres per day (m/day) of some common geologic formations

TABLE 2: POROSITY AND PERMEABILITY COEFFICIENTS OF SOME ROCK MATERIALS

ROCK TYPE	POROSITY (%)	COEFFICIENT OF PERMEABILITY (m/day)
Gravel	25 - 35	100 - 1000
Sand	30 - 40	5 - 40
Conglomerate	10 - 25	5 - 15
Loess	25 - 50	0.1
Sandstone	5 - 20	5 - 20
Fractures:		
Limestone with Primary permeability	20 - 35	around 25
Lime with Secondary permeability	>> 5	>> 25

Source: (Chow, 1959,Hydraulics of Ground water flow)

TABLE 3: RUNOFF COEFFICIENTS OF SOME SOILS

TYPE OF DRAINAGE AREA	RUNOFF COEFFICIENT
sandy soil, flat, 2%	0.05 - 0.10
sandy soil, average, 2 - 7%	0.10 - 0.15
sand soil, steep, 7%	0.15 - 0.20
heavy soil, flat 2%	0.13 - 0.17
heavy soil, average, 2 - 7%	0.18 - 0.22
heavy soil, steep, 7%	0.25 - 0.35

Source: (Chow, 1959)

F. EVAPORATION

Total evaporation which takes into account evaporation directly from the water-table, evaporation of precipitation referred to as evapotranspiration, has an influence over quantities and hydrochemical composition of ground-water. According to Brown etal (19720, the magnitute of evaporation is dependent on the following factors:

(i) Air temperature
(ii) Air humidity
(iii) Wind Velocity
(iv) Solar radiation
(v) Roughness and colour of land surface
(vi) Plant associations

2.6.0 WATER - BALANCE

Determination of water balance in a region is he most important objective of hydrologic studies (Bowen, 1980). In essence a water-balance statement is an application of the law of conservation of matter with respect to the hydrologic cycle. Stated simply, a water balance entails that in a specified period of time all the water entering a specified area must balance (or be equal to) that leaving it, i.e. water into an area is equal to water leaving it.

or **water in = water out**

The table below gives the different ways by which water may come in and go out of an area.

TABLE 4: GENERAL ITEMS OF WATER - BALANCE

ITEMS OF SUPPLY	ITEMS OF DISPOSAL
Precipitation on area	Evapotranspiration from area
Surface - water inflow	Surface - water outflow
Ground - water inflow	Ground - water outflow
Imported water for use or waste	Exported water for use or waste

Adopted from: Brown etal, 1972. 5.1 page 1

With respect to ground-water regime the hydrologic equation assumes a specialised form of balance that requires quantification of all items of inflow to and outflow from a ground-water - reservoir, as well as the changes in storage. Brown etal (1972), give a generalised form of ground-water balance equation:

TABLE 5: SIMPLE GROUND - WATER BALANCE ITEMS

ITEMS OF SUPPLY	ITEMS OF DISPOSAL
Precipitation infiltrating to the water table.	Evaporation from capillary fringe and in areas of shallow water table, and transpiration by phreatophytes.
Natural recharge from streams lakes and ponds.	Natural discharge by seepage and spring flow to streams, lakes and ponds.
Ground-water inflow.	Ground-water outflow.
Artificial recharge from irrigation, reservoirs, spreading operations and injection wells.	Artificial by pumping or flowing wells or drains.

(Source: adopted from Brown etal, (1972), 5.1, Page 2)

GROUND-WATER BALANCE

Total items of supply = total items of disposal

Of the items listed in the above table only a few are measurable, others can only be estimated.

This equation of hydrologic equilibrium has been variously stated to suit the variables under consideration.

(i) $I = O + S$

Where I is inflow, O is outflow and s is storage.

(ii) $P = O + E_T$

Where P is the precipitation, O is the total outflow, and E_T is evapotranspirative losses (Bowen, 1980, 172 - 173).

In most parts of Zambia, precipitation in the form of rainfall is the major source of the inflow component of the hydrologic equilibrium equation. This means that it is important to have data about the quantity of precipitation in a study area. Empirical formulas can be used to estimate availability of ground-water from the known parameters.

2.7.0 METHODS OF DETERMINING RECHARGE

Various methods have been used by Hydrologists, Geologists, Geographers, etc. to determine ground-water recharge. Meinzer (1963) outlines the following as being the most commonly used:

(a) Use of lysimeters

(b) the general inventory method which basically involves the determination (measurement) of the amount of precipitation on a drainage basin and deducting runoff and evaporation - losses; a method which gives fairly reliable results if the recharge is relatively large.

(c) the water-table method which involves observation of fluctuations of the water table and applying a factor for specific yield.

(d) Soil - moisture inventory method which involves making periodic determination of soil moisture at different depths.

(e) influent - seepage method which involves determining the decrease in flow of influent streams between gauging stations.

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3 1.0. INTRODUCTION:

The description of the study area being presented in this chapter is a product of the researcher's knowledge about the area, having spent 17 years of continuous stay in the area, and other documentary sources consulted for this purpose. Only those aspects of the area relevant to this research are described.

3 2.0. LOCATION

The study area for this research covers Katete Mission, inclusive Katete Secondary School, and the Katete river basin which forms the catchment area delineated in figures 1,3,4, and 7. Mbang'ombe Village is important and reference is constantly made to it because of its location in the vicinity of the catchment area, hence part of the research was done in this village.

Katete Mission Station is situated at the foot of the eastern range of Mphangwe Hills about 3km east of Katete Stores - the main business center of the District. It is approximately 8km from st. Francis General Hospital along the Great East Road towards Chipata. This Hospital is important not because of being the biggest in the district but more so because it is where rainfall reading for the district are taken which data was used in this study.

Mbang'ombe village is located 4km from Katete Mission and 7km from Katete Stores towards Chipata but 1.5km off the Great East Road to the west. Reference is constantly made to this village because of the existence of a borehole there which lies within the delineated catchment area. Data from this borehole records was extensively used in this study (see fig 1 and fig 2)

3.3.0. RELIEF AND DRAINAGE

The major relief features of the study area are the Katete river and the Mphangwe range of hills.

Katete river is the highest order drainage channel in the area. It has a total channel length of approximately 17.2km from the source to southern boundary of the catchment area (fig 1). The source of the river is at an altitude of about 1380m above sea level in the Eastern range of the Mphangwe Hills. Its southern exit of the catchment area is at about 1080m above sea level. Thus, the river has a channel fall of 300m in its passage through the catchment area. It is an influent river and only flows during the rain season for about three months (Dec - March).

The Mphangwe range of hills to the east of the Great East Road with the highest at 1633m above sea level and the isolated hills to the west and north form the drainage divide for the delineated catchment area in this study. The catchment area drops in altitude from 1160m to 1080m above sea level in a north - south direction. This gives it a basin relief of 80m over a mean distance of 12.2km (see figure 4)

3.4.0. CLIMATE

By definition the climate of a locality or region is a description of the characteristic conditions of the atmosphere for long periods of repeated observations. The climate of Katete is, like the rest of the country, a tropical climate with the following climatic regime:-

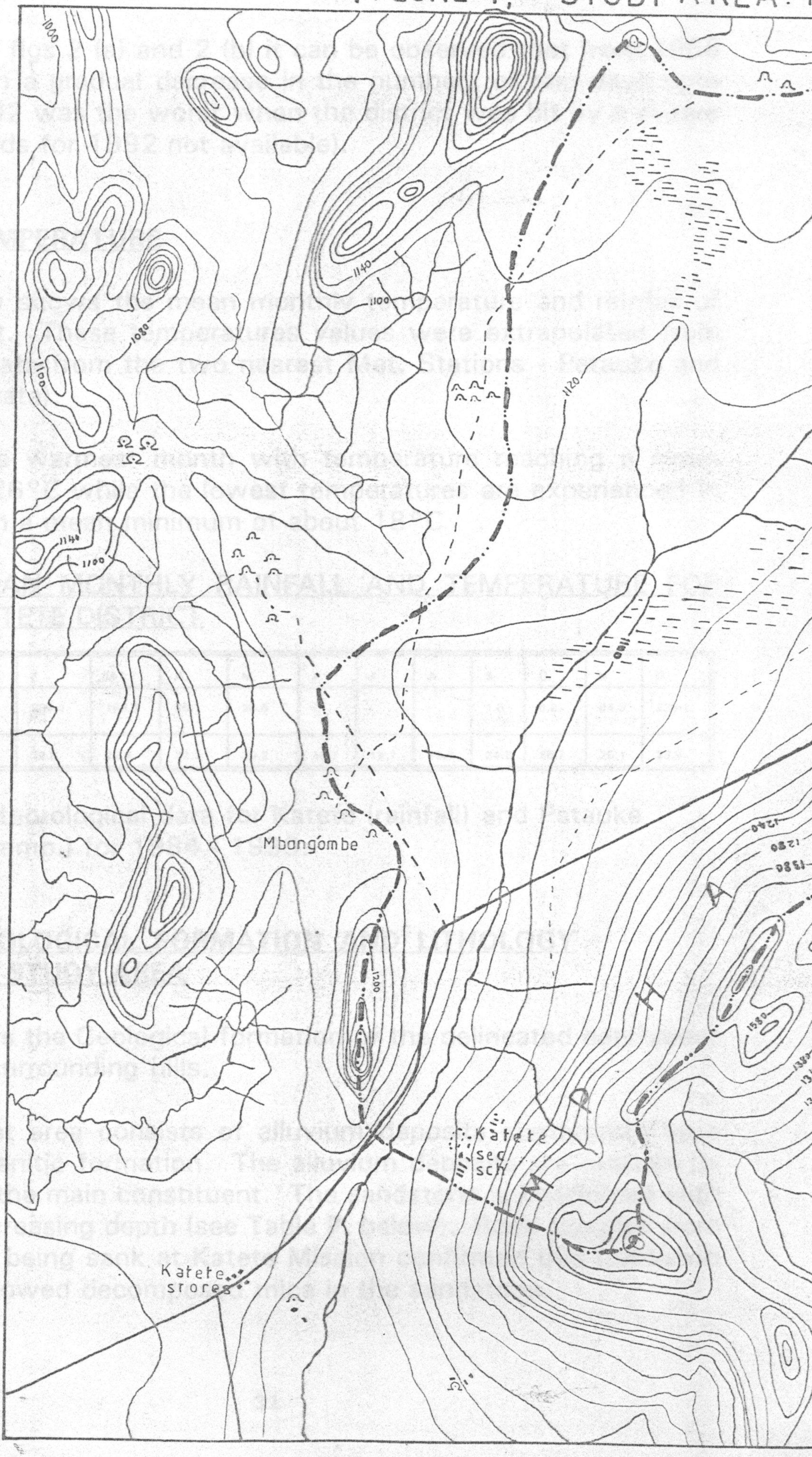
(i) a cold dry season - May to August
(ii) a hot, dry season - September to October
(iii) a hot wet season - November to April.

3.4.1. PRECIPITATION

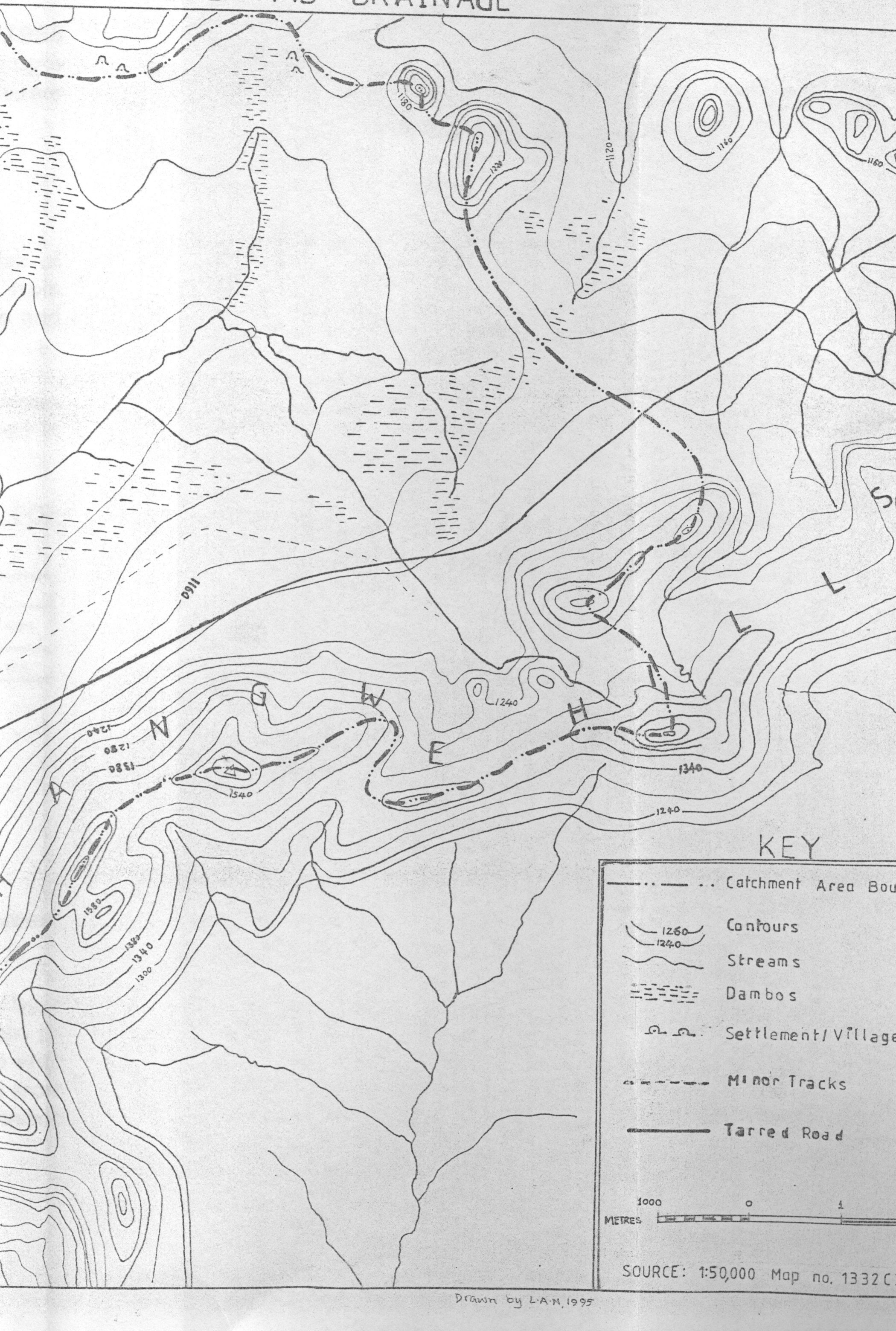
Katete has a mean annual precipitation of approximately 1081mm. Early rains start about late October. Over the years there has been a marked decrease in the amount of rainfall in the entire district.

Appendix 2 and figs 2(a) and 2(b) show the rainfall regime of the

FIGURE 1, STUDY AREA:



Y AREA: RELIEF AND DRAINAGE



Drawn by L.A.N. 1995

district. From figs 2 (a) and 2 (b) it can be observed that from 1986 there has been a gradual decrease in the number of rain days upto 1990 and 1992 was the worst when the district was hit by a severe drought (records for 1992 not available).

3.4.2. TEMPERATURE

Table 6 below shows the mean monthly temperature and rainfall of Katete District. These temperatures values were extrapolated from temperature data from the two nearest Met. Stations - Petauke and Msekera (Chipata).

October is the warmest month with temperature reaching a mean maximum of 26°C while the lowest temperatures are experienced in June/July with a mean minimum of about 18°C

Table 6: MEAN MONTHLY RAINFALL AND TEMPERATURE FOR KATETE DISTRICT

	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall (mm)	254.9	288.6	158.7	36.1	25.5	-	-	-	1.5	6.2	84.8	225.4
Temp.°C	23.1	22.8	22.9	22.3	20.2	18.7	18.7	19.9	24.2	25.7	25.1	23.8

SOURCE: Meteorological data for Katete (rainfall) and Petauke and Chipata (temp.) for 1984 - 1990.

3.5.0 GEOLOGICAL FORMATION AND LITHOLOGY OF STUDY AREA

Figure 3 shows the Geological formation of the delineated catchment area and the surrounding hills.

The catchment area consists of alluvium deposits surrounded by a gneiss-cum-granitic formation. The alluvium deposits are overlain by sandstone as the main constituent. The sandstone is intermixed with schist with increasing depth (see Table 7, below). Rock samples from the two wells being sank at Katete Mission confirmed this formation and further showed decomposed mica in the sandstone.

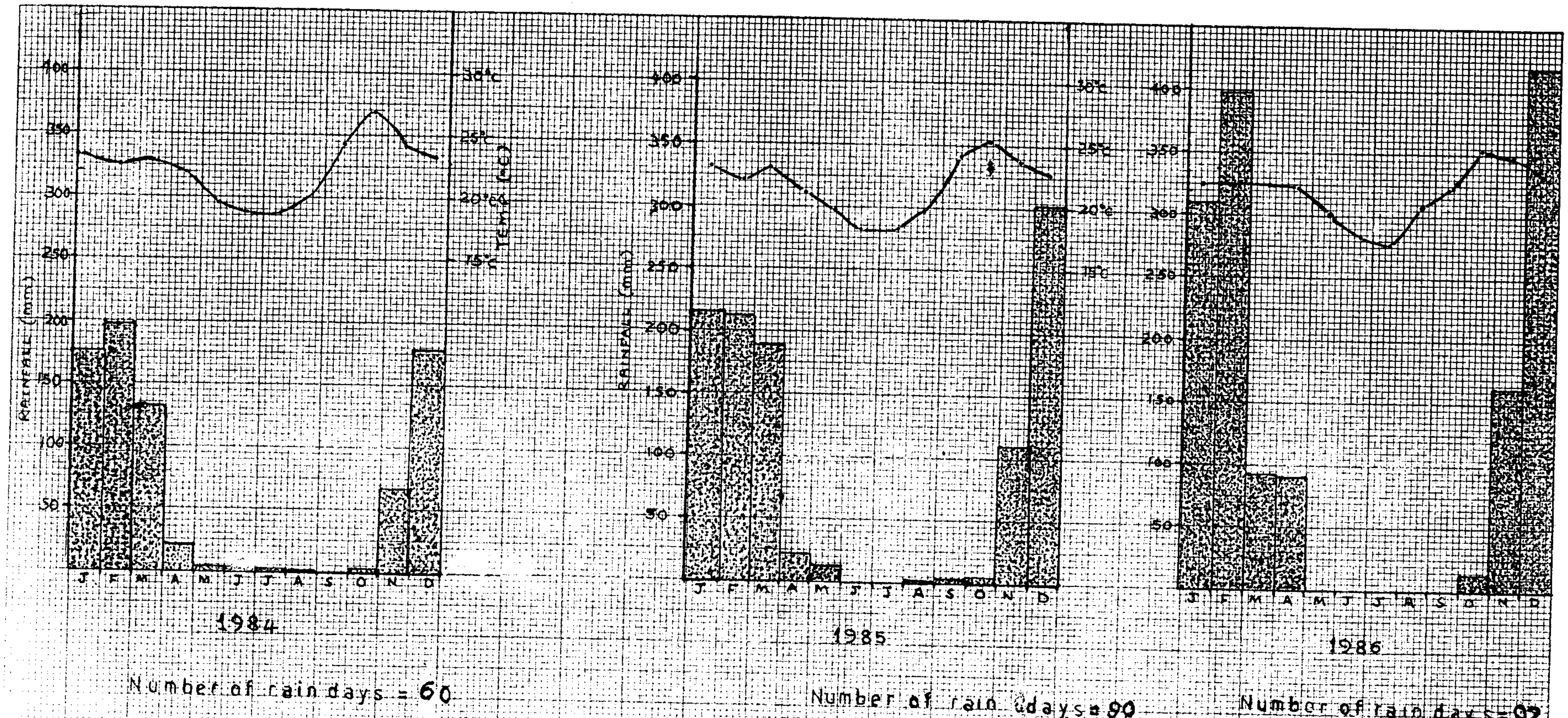


FIGURE 2 (a) RAINFALL AND TEMPERATURE GRAPHS FOR KATETE DISTRICT 1984 – 1986

Source: Meteorological data, MET DEPT, LUSAKA

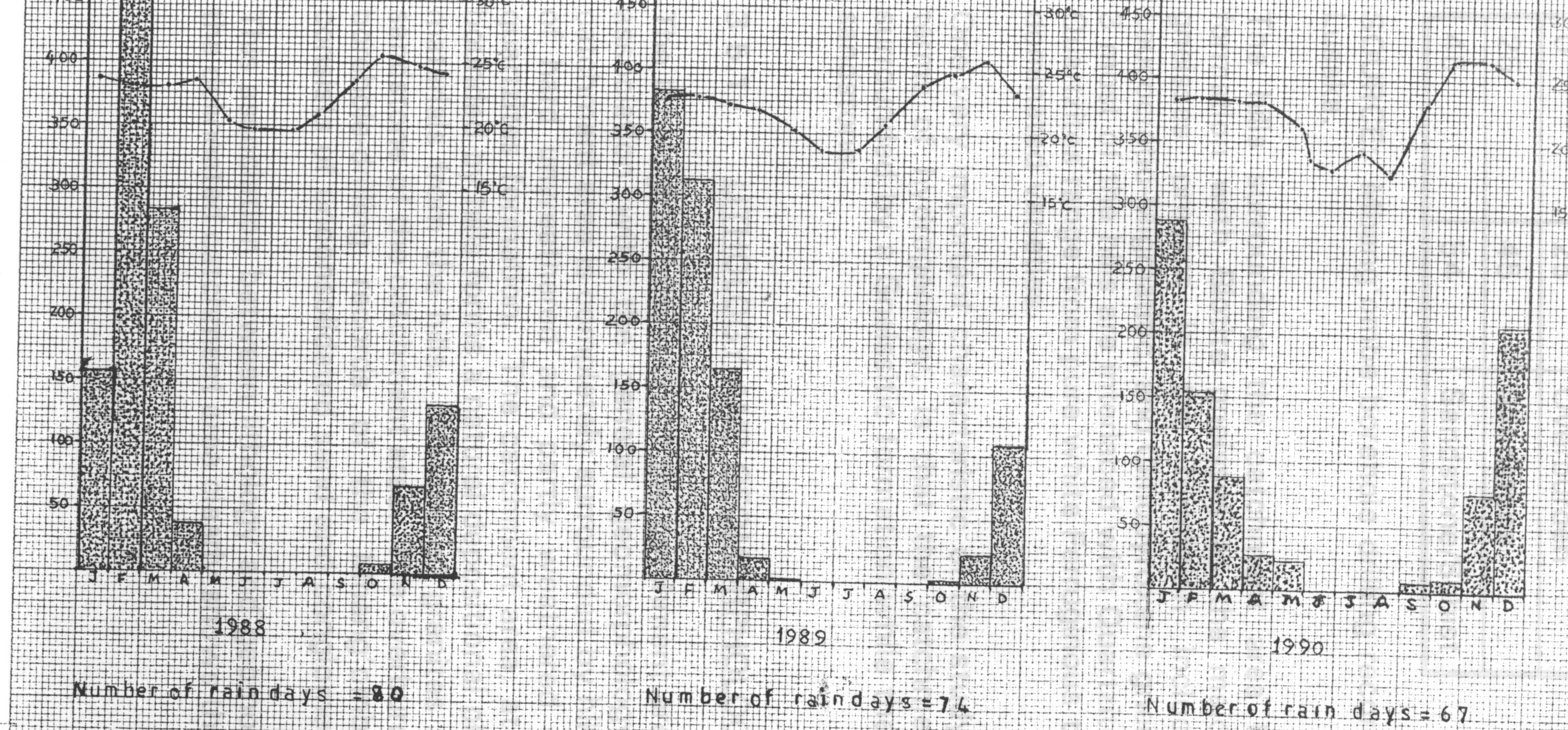


FIGURE 2(b) RAINFALL AND TEMPERATURE GRAPHS FOR KATETE DISTRICT FOR 1988, 1989, and 1990

SOURCE: Meteorological data MET. DEPT. LUSAKA

Table 7: <u>FORMATION FROM BOREHOLE DRILLING RECORDS</u>

FROM (m)	TO (m)	FROMATION BORED
0	25	Overburden
25	45	Sandstone
45	54	Sandstone/Schist

SOURCE: Mbang'ombe borehole drilling records. By Foradex Drilling Lusaka.

The hills surrounding the catchment area have a granitic-gneiss formation with Biotite gneisses as the major constituent. Other gneisses present in the formation include Hornblende-biotite, Leucocratic-Migmatitic, and Clinopyroxene gneisses. As shown on Fig 3 most of the hills are interlaced with Quartzites in many parts. These Quartzites range from pure white Ferruginous to Epidote and Fuchsite dominated varieties.

One very important characteristic of the study area, especially so in terms of hydrogeology, is that the catchment area is completely surrounded by a Gneissitic formation while the area itself consists of sandstone.

3 5.1 <u>LITHOLOGY AND GEOMORPHOLOGY</u>

The lithological formation of the catchment area reveals a very close association with the general geomorphology of the area. The catchment area is completely surrounded by hills which are composed of hard unweathered and partly weathered gneisses, granitic and quartzites formation. The catchment area, at a lower elevation and bounded by hills forms a natural depositional plain for weathered rock materials from the hills. Weathered granites and gneisses form the sandstone of the catchment area. The overburden, as revealed by the borehole-drilling records of the Mbang'ombe borehole, basically consists of unconsolidated sand and conglomerates.

This association between lithology and geomorphology, especially in the delineated catchment area clearly shows that materials weathered

FIGURE 3 Geological Formation of Catchment Area an

t Area and surrounding hills

Drawn

on the hills and slopes get deposited on this area.

3.6.0 THE CATCHMENT AREA

In terms of areal extent the catchment area covers an area of 65.5 square kilometre. As shown in fig.4, the northern end is at a higher altitude of about 1160 m than the southern end at 1080 m above sea level giving it a basin fall of 100 m over a distance of approximately 12.2 Km. This means that the basin is relatively flat with a gradient of 0.01 or 1%. Katete river and its tributaries constitute the main drainage channel.

The area is very sparsely populated. Land use activities in the area are mainly deforestation and agriculture. In terms of water abstraction, the borehole at Mbang'ombe village is the major facility.

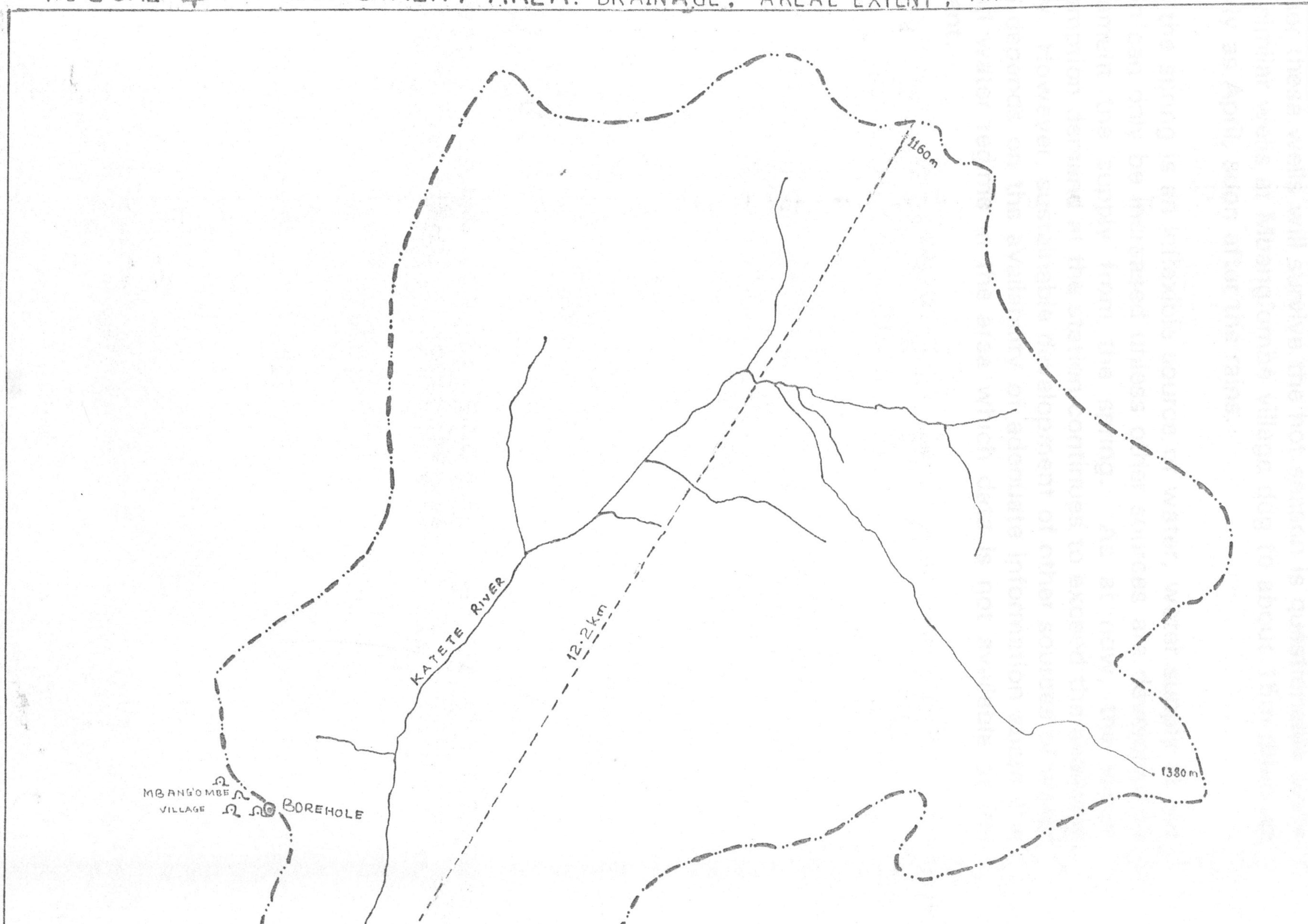
As discussed under relief and drainage (3.3.0) the whole of the catchment area is sandstone in formation.

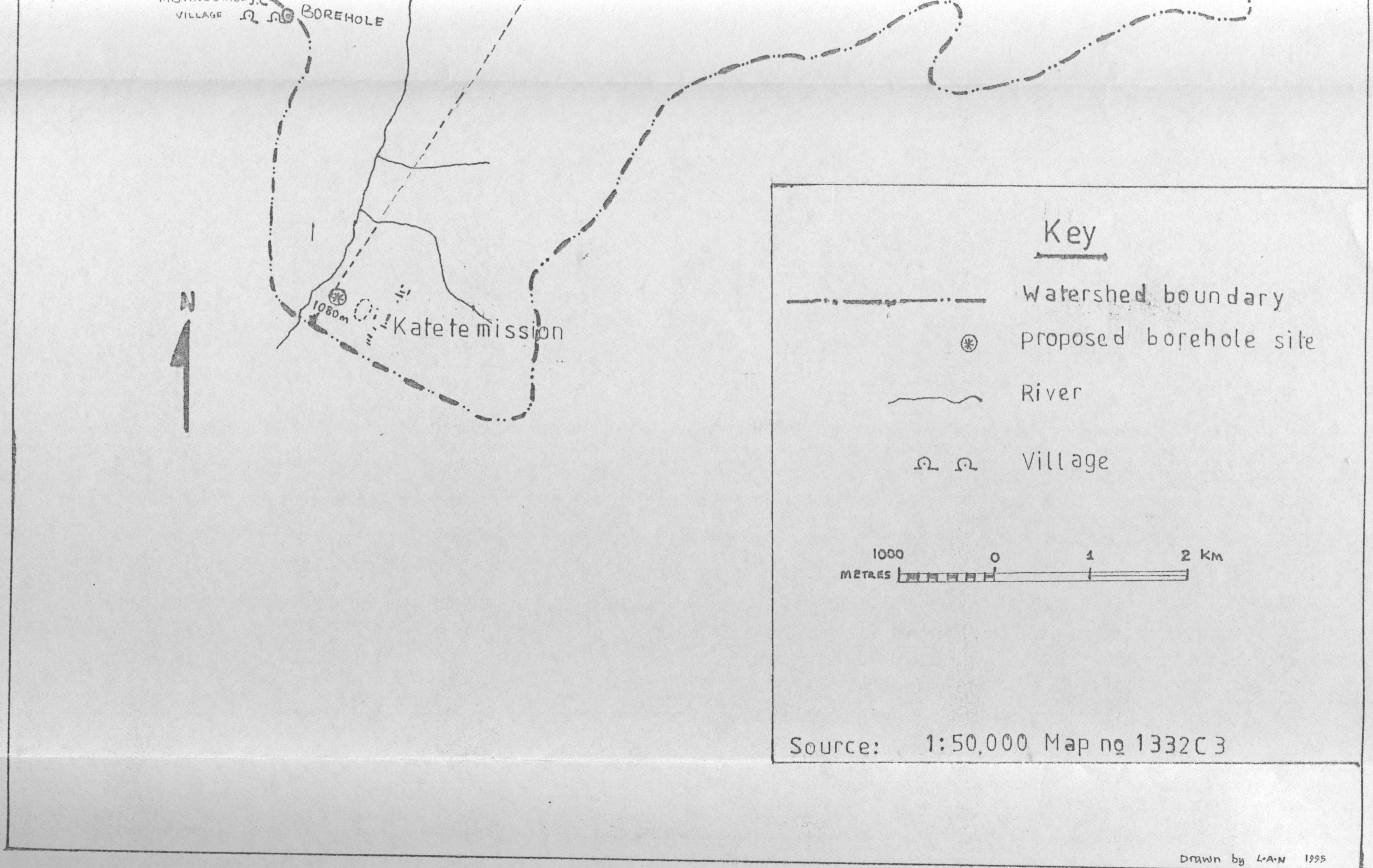
3 7.0 SOURCES OF WATER SUPPLY AT KATETE MISSION STATION

Water supply at Katete station comes from the spring at Mphangwe hills. This spring is at an altitude of approximately 1260m above sea level while the station is at about 1100m. The entire water supply system is thus fully gravity driven. No mechanical pumping is done at any point. Fig.5 shows the layout of this system.

The spring has been and still remains the only source of water to the station since the early 1950s when the station was founded. Since then, the spring has faithfully performed its function of supplying water. However, its output has been on the decline since the late 1980s. The drought of the 1990s has further worsened the situation so much so that water at the station fails to meet the consumption demand. Apart from the fall in the spring output, the entire water articulation system suffers from natural wear and tear resulting in leakages and a fall in the pressure with which the water flows in the pipes.

FIGURE 4 CATCHMENT AREA: DRAINAGE, AREAL EXTENT, AND ELEVATION





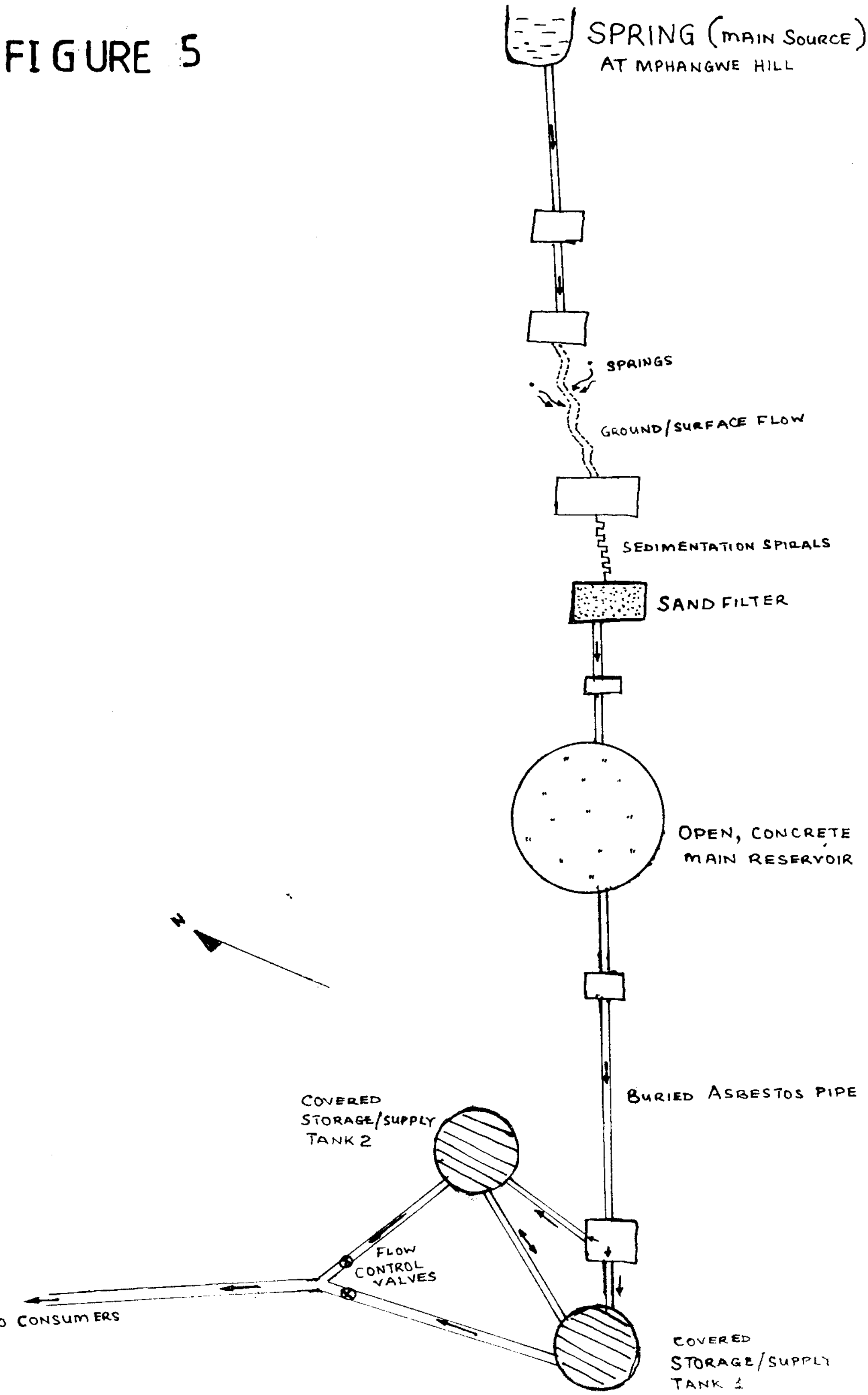
VILLAGE
BOREHOLE
N
1080m
Katete mission
Key
Watershed boundary
proposed borehole site
River
Village
1000
METRES
0
1
2 KM
Source: 1:50,000 Map no 1332C3
Drawn by L.A.N 1995

Currently, two wells are being sank at the station. In both wells, which are hand dug, water was first struck at 12m depths. As to whether these wells will survive the hot season is questionable since three similar wells at Mbang'ombe village dug to about 15m dried up as early as April, soon after the rains.

Since the spring is an inflexible source of water, water supply at the station can only be increased unless other sources are developed to supplement the supply from the spring. As at now, the water consumption demand at the station continues to exceed the available supply. However, sustainable development of other sources of water much depends on the availability of adequate information about the ground water regime in the area which data is not available at the moment.

KATETE MISSION / SECONDARY SCHOOL.

FIGURE 5



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CHAPTER FOUR

RESEARCH METHODOLOGY

4.1.0. INTRODUCTION

Methods employed in data collection constitute an important procedural component of any research. In this chapter, methods of data collection used in this study are presented in a brief but vitally detailed manner. For the sake of academic clarity the methods herein presented are broadly categorised into secondary and primary data.

4.2.0. SECONDARY DATA:

The following documentary sources yielded the required secondary information for this study and constitutes the bulk of the data:-

(i) Topographic maps
(ii) Geological map
(iii) Meteorological data
(iv) Library Literature

4.2.1. TOPOGRAPHIC MAPS

Two 1:50 000 topo maps, degree sheet numbers 1332C3 and 1432A1 of 1979 and 1969 editions, respectively, were used. The 1332C3 topographic map was purchased from the Survey Dept. map sales depot at Mulungushi House, Lusaka. The 1432A1 map was provided, for the sake of this research, by katete District Council, land use Department, Katete.

The two maps were used side by side to work out the following aspects with respect to the area of study:

(a) Location
(b) Relief and Drainage
(c) Delineation and areal extent of the catchment area.
(d) Longitudinal and total channel length of Katete river the only first order drainage channel in the catchment area.

4.2.2. GEOLOGICAL MAP.

A 1:100 000 geological map degree sheet 1332C1 (SW quarter) which covers the Mtetezi River Basin was purchased from the Geological Survey Department, Lusaka.

This map only covers the northern part of the study area. The actual geological map which covers the entire study area, a 1:250 000. sheet no. SD-36-10, 1984 edition was not available at both the Geological Survey Dept. and the cartographic office of the University of Zambia. However, the geological formation of the northern part of the study area was worked out using map 1332C1 , hence fig 3 in this report.

Since the area of study is surrounded by the same hills, it was assumed in this study that the same geological formation continues to the rest of the southern parts.

To prepare figure 3 in this report, the geological Map 1332C1 which is at a scale of 1:100 00 was blown to twice its scale ie 1:50 000 and superimposed on to the 1:50 000 topographic map no. 1332C3. The two maps only made a mean fit which was good enough to know the formation of the hills and the catchment area.

4.2.3. METEOROLOGICAL DATA.

RAINFALL: Mean monthly rainfall readings for Katete District were obtained from Meteorological Department Hq, Lusaka. The records were compiled at St. Francis General Hospital for the years 1983 to 1990. The station does not take temperature readings.

TEMPERATURE: Due to the absence of temperature records for Katete District, minimum and maximum mean monthly temperature records for Petauke and Msekera (Chipata) Met. stations were obtained from the Meteorological Dept; Lusaka. Katete lies approximately midway between the two stations, hence these readings were used to extrapolate the mean annual monthly temperatures for Katete (see appendix 2 and table 6).

The mean annual monthly temperature and rainfall values presented in table 6 were then used to compute:-

(a) mean annual temperature
(b) mean annual rainfall
(c) potential evaporation (Epot)
(d) actual evaporation (Ea),
(e) draw the rainfall - temperature graphs fig 2(a) and 2(b) with respect to the district.

Not all the years in the period 1983 - 1993 were used due to a number of gaps in this data, especially temperature. For this research data for the year 1984, 1985, 1986, 1988, 1989, and 1990 were used because they have continuous data for both rainfall and temperature.

4.2.4. BOREHOLE DRILLING LOG.

A copy of drilling records of the borehole at Mbang'ombe village was obtained from the Department of water affairs at Katete Boma offices. This revealed the geological formation up to a depth of 54m.

4.2.5. LIBRARY LITERATURE:

Libralies at the University of Zambia and Katete Secondary school were extensively exploited in terms of text books and other materials for review of literature relevant to the study undertaken in this research.

4.3.0. PRIMARY DATA

The following approaches were employed to gather the relevant primary information for this research:

(a) field surveys
(b) scheduled and unscheduled interviews
(c) collection of water and rock samples

4.3.1. FIELD SURVEYS

Field surveys were conducted to determine:-

(a) the total population in the study area.

(b) water output of the spring (the only source of water at Katete Mission/Secondary school)

(c) water consumption

4.3.2. COLLECTION OF SAMPLES

Water samples from the spring were collected as well as rock samples from the two wells being sank at Katete Secondary School for chemical analysis.

CHAPTER FIVE

PRESENTATION OF RESEARCH FINDINGS AND DISCUSSION

5.1.0. INTRODUCTION

This chapter presents the main findings of this study. A number of assumptions have been made where relevant.

5.2.0. POPULATION

A population survey carried out at Katete Mission / Secondary School yielded the following categorisation of the total population.

Table:8 POPULATION OF STUDY AREA

CATEGORY	POPULATION
Workers (Teachers and others	588
Pupils: Boarders	1162
Pupils: Day Scholars	200
Pupils: Primary School	450
Total	2,400

In the case of the workers ie. teachers, general workers and others resident at the station, the survey showed that the average number of persons per household was 6. A total of 99 Households were found to be resident at the station.

5.2.1. WATER USE AT THE STATION

Because of the intermittent supply of water at the station, water is mainly used for domestic purposes limited to bathing, washing, cooking and drinking, and sanitation (flush-toilets). Only about five households had small backyard vegetable gardens which visibly showed signs of inadequate watering.

5.2.2. PER CAPITA WATER CONSUMPTION

Most of the residents, through both scheduled and unscheduled interviews, found it rather difficult to state how much water they used per person per day. Due to the critical water shortage at the station, most of them estimated their per capital water consumption to have been as low as between 10 and 15 litres per day. This excluded the water used to work the water-borne toilets whose flushing rate was estimated at 3 times per person per day.

Total water consumption was estimated through computations shown in stages below.

A. WATER BORNE TOILETS:

The following data was obtained through field survey conducted with respect to the use of water in flush-toilets.

(i) Only 36 households (of the 98) possessed water-borne toilets with a population of 216 persons plus the 1162 boarding pupils.

(ii) The average cistern capacity of the toilets is 12.5 litres.

ASSUMPTION 1

From the survey conducted, an assumption that each person flushed the toilet at least 3 times per day was adopted and used in the computations

Therefore, volume of water used = 1.378 x 12.5 x 3

= 51675 litres/days

ASSUMPTION 2

Day-pupils at least flush toilets once per day each. Only secondary school pupils have access to this facility. Primary School pupils use their pit-latrines, hence are excluded from the computations.

Number of day-pupils = 200

Therefore, volume of water used = 200 x 12.5

= 2 500 litres/day

Total volume of water used = 51675 + 2500

= 54,175 litres/day

B. DOMESTIC USE OF WATER

In the computation of water consumption in domestic chores only the resident population is considered ie. workers and pupils in the boarding.

Thus, population considered = 1162 + 588

= 1750

Day-pupils are excluded in this computation because they use very little water. It has also been assumed that the 15 litres per person per day, as the upper limit of the given range of 10 - 15 litres per person per day, be used in this computation.

Therefore, Volume of water used = 1750 x 15

= 26,250l/day

Total volume of water used at the station

V = 54,175 + 26,250

= 80,425 litres/day

Considering that people at the station only gave a crude estimate of their per-capita water consumption based on the current water scenario at the station and that they declared that their actual demand for water is not met, this calculated daily water consumption calculated above is assumed for the purpose of this research, to represent the lower limit of the potential actual water consumption at the station.

5.3.0. WATER DISCHARGE BY THE SPRING

Tables 9 and 10 below show the flow rate of water at two points - the source and the main reservoir. There is more water entering the main reservoir than that which leaves the source. This is attributable to the existence of other springs in the main spring - flow channel as indicated in fig 5. Thus, measurement of the flow rate into the main reservoir is materially more important than measurements at the source because it is the water from the main reservoir which is made available to the consumers.

Table 9: FLOW RATE OF WATER AT SOURCE OF THE SPRING

OBSERVATIO NS	VOLUME OF WATER COLLECTED (L)	TIME (SEC)	FLOW RATE (L/S)
1st	10 Litres	120	10/120 = 0.083
2nd	10 Litres	123	10/123 = 0.081
3rd	10 litres	123	10/123 = 0.083
4th	10 Litres	123.5	10/123 = 0.083
5th	10 Litres	123	10/123 = 0.083
6th	5 Litres	59	5/59 = 0.085
7th	5 Litres	60	5/60 = 0.083
8th	5 Litres	58	5/58 = 0.086
9th	5 Litres	60	5/60 = 0.083
10th	5 Litres	59	5/59 = 0.085

From these measurements the mean discharge rate was found to be 0.083 litres/sec. This is equivalent to a flow of 7,177.6 l/day or 7.2m^3 /day

Table 10: WATER FLOW RATE INTO MAIN RESERVOIR

OBSERVATIONS	VOLUME OF WATER COLLECTED (L)	TIME	RATE
1st	10	10s	1 l/s
2nd	10	9.5s	.95 l/s
3rd	10	11s	1.1 l/s
4th	10	10s	1 l/s
5th	10	10s	1 l/s

Mean flow rate of water into main reservoir

= 1.01 litres/sec

= 87,264 litres/day

ASSUMPTION:

Not all the 87,264 litres is available in total. The physical design of the main reservoir ie. the top is not covered, and leakages in the whole reticulation means an appreciable quantity of water is lost. It is estimated that about 10% of the calculated amount is lost through evaporation and leakages. In real terms this loss is expected to be higher than the estimated 10%

Thus, total available water = 87,264 less 10%

= 78,538 litres/day

Compared to the daily water demand of 80,425 litres/day this output is exceeded by the mean demand, hence the supply can not be on throughout the day. In the dry season the output is bound to get even less due to increased evaporation and increased drinking water demand.

The spring which is the source of this water is inflexible to human manipulation to increase its total output. However, the delineated catchment area (fig 1) offers the only alternative potential source of water to supplement the existing water supply.

5.4.0 TOPOGRAPHIC RELIEF, GEOLOGIC FORMATION, AND GROUND-WATER POTENTIAL OF CATCHMENT AREA

The topographic relief and geologic formation of the catchment area and the surrounding hills and the low gradient of flow of Katete river suggests a great opportunity for precipitation to infiltrate and percolate to the ground-water reservoir.

Topographically, the catchment basin drops in altitude form 1180m to 1080m above sea level giving it a basinfall of 100m over a distance of 12.2 Km in a north-south direction (fig. 4). Thus, the basin generally is flat with a mean gradient of 0.01 or 1%.

The river channel drops in altitude from approximately 1380m at the source to 1080m above sea level at the southern exit of the catchment area. This gives it a main channel fall of 300m over a total channel length of 17.2 Km rendering it a gradient of about 0.02 or 2% (see fig.6). The low flow gradient of the river suggests that quite an appreciable quantity of water is afforded the chance to percolate and become ground-water.

Another aspect of the catchment area which encourages infiltration and eventual percolation of precipitation is its geologic formation. The entire area is surrounded by a gneiss/granite formation which is quite impervious. The area itself contains a formation which is basically alluvial and colluvial depositional materials overlaying the sandstone which is unconsolidated in the upper layers but gets consolidated with increasing sandstone, because of its porosity and permeability forms a good aquifer.

Hydrogeological data from the Mbang'ombe borehole drilling records presented in Table 11 below, shows that ground water in the catchment area is within a reasonably extractable depth - and the yield, as witnessed by the pumping test, is quite large.

Table 11 HYDROGEOLOGICAL DATA FROM BOREHOLE DRILLING RECORDS

Depth (m) from	Depth (m) to	Geologic Formation	Water first struck (m)	Pumping test yield: Yield (l/s)-6hr.

0 25 45	25 Sandstone Sandstone/ schist	Overburden	9m	0.8 l/s

SOURCE: Dept. of water Affairs, Katete, Mbang'ombe borehole drilling records)

From the above discussed hydrogeological properties inherent in the catchment area, it can reasonably be stated that the area has a great potential for existence of large quantities of ground -water.

ESTIMATION OF TOTAL EVAPORATION FROM THE CATCHMENT AREA

Empirical formulas of Longbein's and Turc's are used in the calculation of potential evaporation and actual evaporation, respectively. Rainfall and temperature data, which are mean annual rainfall and temperature of Katete District are used. These are 1081mm and 22.3°Crespectively.

A. POTENTIAL EVAPORATION

FORMULA: $E_p = 325 + 21T_y + 0.9\,(T_y)^2$

where Ep is potential evaporation, T_y is the mean annual temperature which for the study area is 22.3°C.

$$\begin{aligned} \text{Therefore, } Ep &= 325 + (21 \times 22.3) + 0.9 \times (22.3)^2 \\ &= 325 + 468.3 + 447.6 \\ &= \underline{1240.9\text{mm/year}} \end{aligned}$$

B. ACTUAL EVAPORATION

$$E_a = \frac{P_y}{\sqrt{0.9 + \frac{(P_y)^2}{(E_p)^2}}}$$

where Ea is actual evaporation, P_y is total annual precipitation which in the study area is 1081mm; and E_p is potential evaporation.

$$E_a = \frac{1081}{\sqrt{0.9 + \frac{1081^2}{1240.9^2}}}$$

$$= 833 \text{mm/yr}$$

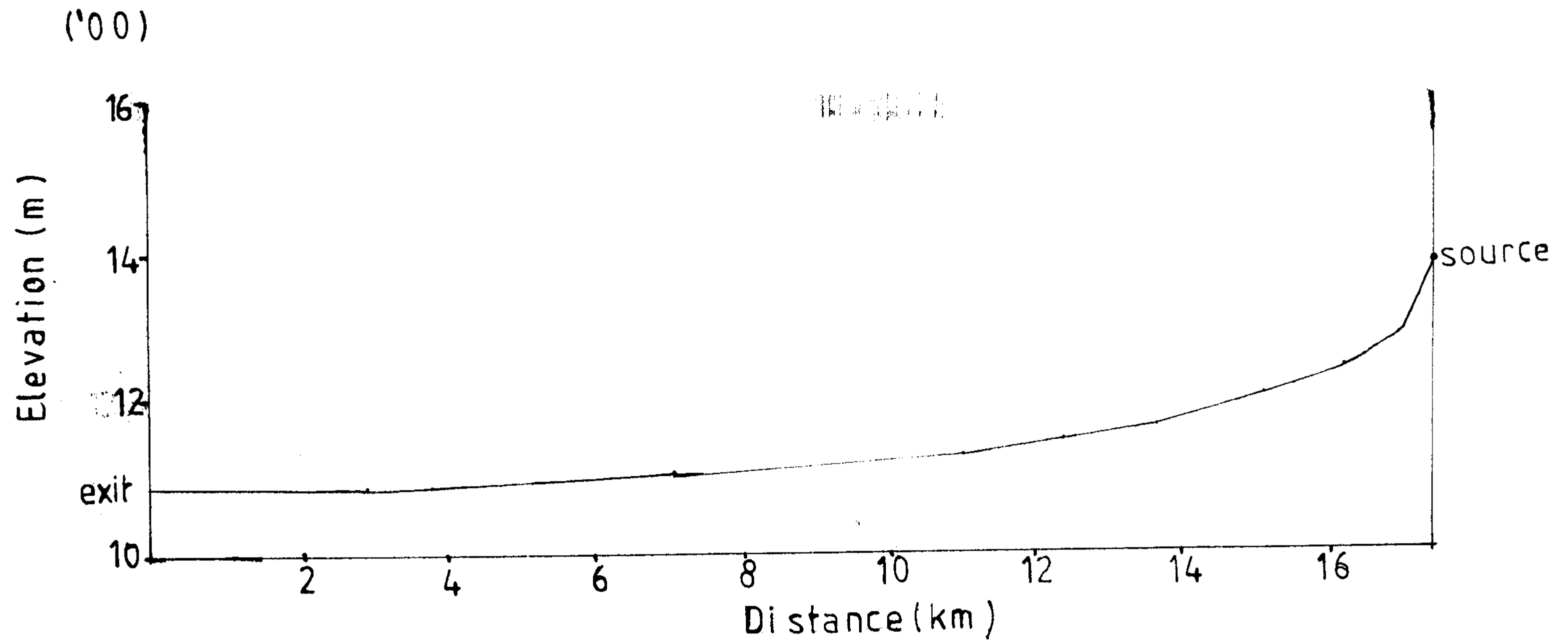
This value of actual evaporation (838mm/yr) is presumed to be far much greater than what actually occurs in the area of study. This assumption is premised on the reasoning that the empirical formulas used in its computation are best suited to climatic conditions, as obtain in Europe, where at no time is there lack of sufficient water to be evaporated from both the ground soil and vegetation.

5.4.2. ESTIMATION OF CHANNEL DISCHARGE (RUNOFF)

Katete river, the only drainage channel in the catchment area flows for about 3 months (Jan - March) and is influent. No discharge hydrographs exist. Hydrogeological properties of the catchment area and the channel are used to estimate discharge.

In section 5. 4.0., it was established that both the geologic-formation and topographic relief gradients of the river channel (2%) and the catchment area (1%) offer a greater opportunity for infiltration and eventual percolation of water. It is assumed that in real terms, the gradient of the catchment area ranges between 2 - 7%. Table 3 shows that the runoff coefficient of sandy soil with this range of gradient ranges between 0.10 and 0.15 or 10 - 15%. The upper unit of 15% is adopted in this estimation of runoff or discharge.

FIGURE 6 : LONGITUDINAL PROFILE OF KATETE RIVER FROM SOURCE TO SOUTH END OF CATCHMENT AREA.



Source 1:50000 Map no. 1332C3

This means that of the total precipitation falling on the catchment area, it is assumed that 15% of that will be discharged as channel runoff. Hence its computation below:

Annual precipitation = 1081mm = 1.081m
Area of catchment area = 65.5Km^2 = 65.5 x 10^6 m^2
Therefore, discharge = 15% of total precipitation
= 15/100 x (1.081 x 65.5 x10^6)
Q = <u>10.62 x 10^6 m^3/yr</u>

This figure is greater than what is expected. The percentage of the total precipitation could be anything between 10 and 15%. The 15% used is the upper limit.

5.5.0. ESTIMATION OF GROUND-WATER STORAGE BY WATER BALANCE METHOD

The water balance method and stream hydrograph analysis are indirect methods for determination of how much ground water is contained in an area or drainage basin (Omdrinbola, 1984). Meinzer (1963) calls this method the general inventory method; it involves "determining the amount of precipitation on a drainage basin and deducting the runoff and evaporation losses" (P.405).

From the computations done above the following data has been made available which is used in this study to estimate ground-water quantity in the catchment area.

DATA:

area of watershed ,A, = 65.5 Km^2
Precipitation P, = 1081 mm
Actual Evaporation,Ea, = 838 mm/yr
Stream channel discharge (or runoff) ,Q, = 15% of P (assumption)

Ground-water,Gw = ?

WATER-BALANCE

Stated in its simplest form, a water balance or water budget statement of basin says; water entering an area is equal to the water leaving the area. In other words, water inflow is equal to water-outflow from any area.

The above data can thus be categorised into items of water inflow and water outflow.

Water balance equation:

$$\text{Water inflow} = \text{Water outflow}$$
$$P = E_a + Q + Gw$$
from which, $Gw = P - E_a - Q$
$$= (P \times A) - (Ea \times A) - Q$$

where A is the area in m^2 of the catchment area.

Therefore, $Gw = (1.081 \times 65.5 \times 10^6) - 0.838 \times 65.5 \times 10^6) - 15/100\ (1.081 \times 65.5 \times 10^6)$
$= (70.81 \times 10^6) - (54.89 \times 10^6 - (10.62 \times 10^6$
$= (70.81 - 54.89 - 10.62) \times 10^6$
$\underline{= 5.3 \times 10^6\ m^3/yr}$

In the Researcher's view, this value of ground water storage, Gw, is smaller than the actual one with respect to catchment area. The values of Ea and Q used in the above computation are bigger than their actual values (see 5. 4.1 and 5. 4.2 for explanation). If these Ea and Q values were to be reduced to their actual values with respect to the climatic conditions of the catchment area, the net effect would be an increase in the final value of Gw.

A ground water storage value of $5.3 \times 10^6\ m^3/yr$ is quite enormous. The argument which arises immediately is whether the storativity of the sandstone aquifer in the catchment area is capable of holding this amount. The simple computation below is used to check this:-

ASSUMPTION

In this computation an aquifer depth of 50m is used since the

Mbang'ombe borehole is 54m. In reality the depth of this aquifer should be more than this depth considering that the Mbang'ombe borehole did not reach the baserock. Thus, the estimated 50m depth used here is purely for the purpose of easy computation.

The specific yield value of 7.1% was adopted from work done on a similar alluvial deposit in sacramento valley in California (Todd.1959).

Thus, Aquifer area (A) $= 65.5 \times 10^6 \ m^2$
Aquifer depth (D) $= 50m$
Specific yield of aquifer (Sy) $= 7.1\% = 0.071$

Therefore maximum potential storativity, Vwd, of aquifer is:

$$\begin{aligned} Vwd &= A \times d \times (Sy/100) \\ &= 65.5 \times 10^6 \times 50 \times 0.071 \\ &= \underline{232.53 \times 10^6 \ m^3} \end{aligned}$$

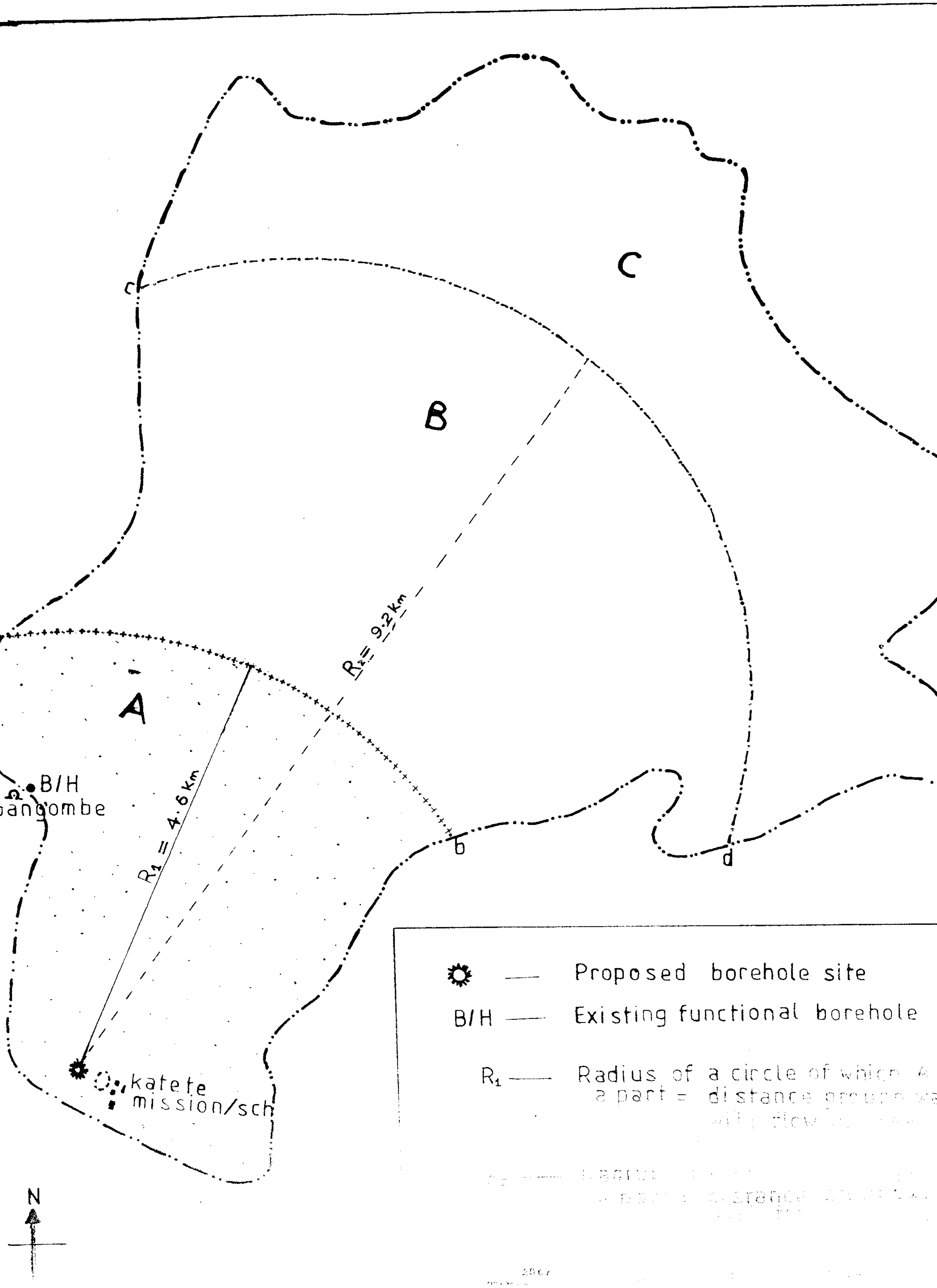
Since the ground water recharge is only $5.3 \times 10^6 \ m^3/yr$, the above computation shows that this recharge is much smaller than the potential storativity of the aquifer, hence it is all safely held in the aquifer without being released as runoff or channel discharge.

5.5.1. HYPOTHETICAL GROUND WATER FLOW AND WATER ABSTRACTION FROM THE CATCHMENT AREA

Fig. 7 shows a hypothetical situation where the catchment area is divided into zones A,B, and C. These zones are parts of concentric circles with the proposed borehole site as their centre. Assuming that the sandstone in this area has a permeability coefficient of 12.5m/day (mid point value of the range of permeability coefficient of sandstone; (see Table 2), then, in 365 days (1 yr) water will move a distance of 4.6 km through the aquifer. Thus R1 represents the radius of a circle, of which zone A is a part, from which ground water will be available to the borehole in this 1 year period while the water in zone B and C remains in storage.

Based on such an assumption, then the aquifer will, with respect to water abstraction, behave as a source of water to the borehole and a reservoir. In the first year only water form zone A will travel through the 4.6 km and be available for abstraction at the proposed borehole.

FIGURE 7 HYPOTHETICAL GROUND WATER FLOW AND WATER - ABSTRACTION FROM THE CATCHMENT AREA



That this amount of water from zone A will be more than adequate can be shown as follows:-

Area of zone is roughly 1/4 of the total catchment area.

Hence, a 1/4 of the ground water in the catchment area will be available for abstraction in the first year from zone A

$= 1/4 \times 5.3 \times 10^6$
$= 1.325 \times 10^6 \ m^3/yr$
$= \underline{3.63 \times 10^3 \ m^3/day}$

compared to the water demand at the station of only 80.43 m^3/day, then it means there will be plenty of water. Infact the water from zone A is 45 times greater than the current actual water use at the station.

Hypothetically, should there be a total drought in the subsequent year, then water from zone B will have covered the distance R2, radius of a circle of which zone B is a part, and will be available for abstraction at the borehole without any noticeable fall in out put. Zone B is roughly half the total area of drainage basin. Should the drought stretch into the third year, the borehole will still be able to supply water from zone C. Thus, in theory the borehole will be able to provide an even supply of water despite seasonal changes in precipitation.

5.5.2. CATCHMENT AREA AS A POTENTIAL SOURCE OF WATER SUPPLY

That the delineated catchment area possesses a vast potential for development into a sustainable source of water supply lies in the enormous quantity of ground-water stored in its aquifer. Considering the population of Katete Mission and settlements in the vicinity of this catchment area, the estimated ground-water in the area (5.3×10^6 m^3/yr) when sustainably exploited can adequately meet the water consumption demand. For instance, the estimated water demand at Katete Mission of 0.0294×10^6 m^3/yr is only a very small fraction of the available ground-water (1/180th). Thus, even if the demand increased a hundred times the current level there would still be plenty water left unused.

Accessibility and extractibility of this ground water is rendered possible because of the topographic, geologic and hydrologic properties of the catchment area. The basin fall, at a gradient of 2%, means that the aquifer is more or less dipped at such an angle that ground water flows from north to south i.e. towards the proposed borehole. The geologic formation - alluvial sandstone is permeable with a coefficient of between 5 - 20m/day. The funnel-effect also ensures that water flows towards the borehole site. In terms of bacteriological contamination. Hence water from this area would require minimal treatment and purification.

It should be emphasised that the potentiality of this drainage basin as a source of water supply lies in the abundance of ground water at an economical depth of less than 100m.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1.0. INTRODUCTION:

From this research study a number of conclusions have been drawn highlighting the main areas of concern. Recommendation pertaining to how the areas of concern can be addressed are presented in this chapter.

6.2.0. CONCLUSION:

(i) Water consumption demand exceeds the available water supply at Katete Mission station. This can be attributed to the low output (discharge) of the spring which is the only source of water at the station. Over the years an inverse relation has developed between the pupolation size at the station and the water discharge of the spring. While population at the station has been on the increase over the years, the spring output has been decreasing as a natural response to the decrease in the precipitation and recent droughts in the area. Leakages from the reticulation system and evaporation losses, though minor, also contribute to the inadequacy of water supplied to the station. However, even if those losses were fully controlled the supply would still be inadequate.

(ii) The spring is materially inflexible to human manipulation to increase its discharge. This depends on the bounty of nature. Therefore, water supply increase at the station can only be achieved by developing an alternative supply of water to supplement the one from the spring. Since there are no surface water sources in the vicinity of the station, development of ground water resources is the only handy alternative.

(iii) The estimated groundwater storage in the area, and in the catchment area in particular is enormous. This is evidenced from the large annual ground water recharge of $5.3*10^6$ m^3/yr in the catchment area. From the hypothetical computation it worked out that a borehole at the proposed site would have a potential yield of about 3600m^3/day which is nearly 45 times the current water demand.

(iv) Because of the large reservior of ground water, as estimated through this research, several boreholes can be sank in the catchtment area to serve not only Katete Mission but also the nearby settlements, villages and farms.

(v) As evidenced by the borehole at Mbang'ombe village, which is only 54m deep and supplies water to the residents throughout the year, the water in the catchment area is at readily accessible depth, hence is readily extractable and may require no purification because the rate of flow in the sandstone aquifer of between 5 - 20m per day allows the ground water to get filtered through the sandstone material. Thus, from an economic point of view only construction cost may be considered.

(vi) From observations of the well behavior in the area, hand dug wells are not ideal. Their drying up soon after the rains means that the water table is deeper than the average 15m depth of most of these wells. Alternatively such wells need to be much deeper than they are.

6.3.0. RECOMMENDATIONS

(i) From the findings of this research it is highly recommended that ground-water in the catchment area is plenty and a sustainable supply of water can be developed to meet the water consumption demand at the station. A borehole at or closer to the proposed site would yield enough water for the station.

(ii) The sustainability of the water supply developed from the area will depend much on land use activities in the catchment area. Therefore, it is highly recommended that deforestation and other land uses such as agriculture in this area be heavily monitored and controlled to encourage infiltration and percolation of whatever precipitation may fall on this area.

(iii) It is also recommended that boreholes of depths equal or greater than 54m are ideal in the area. However, to determine the most economical and productive depths there is need for a systematic ground water inventory to be carried out in the area.

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APPENDIX 1.

SCHEDULED INTERVIEW SHEET ON WATER SUPPLY AT KATETE MISSION

1. Do you get an adequate supply of water? Yes/No

2. List down the different ways to which water is put to use in your home

3. What type of toilet do you have? Waterborne / pit latrine

4. How many people are there in your house?..............................
....

5. How much water does each person use per day approximately?...liters/day

6. On the average how many times does each person flush the toilet if it is water-borne?....................times.

Thank you.

RAINFALL SUMMARY

APPENDIX 2

1989 / 1990

Station: KATETE HOSPITAL No. 1399 14° 08' S 31° 55' E

Observer: Copied by: E. M. M. [illegible]

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	
1						3.5	9.0	16.0					
2						9.5	22.5	2.0		4.5			
3							39.0						
4						0.5	6.5	5.0					
5							12.0	4.0			21.0		
6							16.0						
7							14.5						
8			2.0			38.5		2.5					
9								19.0					
10						9.5		5.0					
11			3.5			1.0							
12					TR	12.0		16.0					
13							35.5	8.0					
14					9.0	34.5	1.5	30.5					
15													
16					24.5		7.0	1.5					
17					37.0			2.5	3.5				
18							17.0	28.0					
19					TR		17.5		29.5				
20							17.0		6.5				
21					2.0			2.5	11.0				
22									5.0				
23								8.0					
24							18.0	3.5		1.0	1.0		
25				8.0	TR		8.0						
26					TR	4.0	1.0						
27						16.0	33.9			20.5			
28					1.5	16.0			28.0				
29					2.5		12.5						
30									3.5				
31						65.5			2.5				
AL	NIL	NIL	5.5	8.0	76.5	208.5	288.4	154.0	89.5	26.0	22.0	NIL	87[illegible]
≥ 1mm			2	1	6	11	18	16	8	3	2		1

RAINFALL SUMMARY

1989 (1989)

1988 / 1989

Station: KATETE HOSPITAL No. 1899 14° 08' S 31° 55' E

Observer: Copied by: L. M. M. PHIRI

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1								25.0	27.5	5.5		
2						20.5		21.5	14.0	10.5		
3						0.5	10.0	21.0				
4							1.0	43.0	1.0			
5						13.5		6.5	1.5			
6						2.5		11.0	4.0			
7					0.6	1.5			5.5			
8						0.5	15.5	19.0	4.0			
9					16.0				6.0			
10							19.0					
11							1.0					
12				1.0			27.5					
13				0.5			42.0					
14							37.0	30.0				
15						5.0	27.0	15.5				
16						3.0	24.5	7.5				
17							21.0	13.5		0.5		
18							7.0	1.5				
19									2.5		1.0	
20						12.5		27.0				
21						12.0	17.0	1.5				
22						2.5			1.5			
23							7.0	13.5	40.0			
24							14.0	2.5	1.5			
25							8.0	2.0	55.5			
26						21.0	42.0	29.0				
27					2.5		23.0	15.0				
28							2.0	7.5				
29					3.5				0.5			
30					1.0	1.5	36.0			0.5		
31						12.0	1.0					
TOTAL	NIL	NIL	NIL	1.5	23.6	108.5	382.5	313.0	165.0	17.0	1.0	NIL
No. of Days of RAIN				1	4	12	21	20	13	[illegible]		
No. of Days of T												
No. of Days of HAIL												
Heavy falls												

RAINFALL SUMMARY

P/Bag 11, KATETE.

1987 / 1988

Station KATETE HOSPITAL No. 1399 14° 08′ S 31° 55′ E

Observer .... Copied by L. M. M. PHIRI

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	Ju
1				4.0		13.0						
2				0.5		3.5				5.5		
3				1.0		15.0						
4						1.0			22.5			
5						6.0	4.0		20.0			
6								17.5				
7					TR	24.0	1.0	62.0				
8						9.5	0.5	126.0		8.0		
9						1.0		30.5	18.5	8.5		
10							1.5	26.0	11.5			
11						4.0	0.5	1.0	11.0			
12							12.0	3.5				
13						0.5	6.5	9.5	6.0			
14						4.0	0.5	18.5	11.5			
15				1.0		0.5		10.0	23.5			
16							1.0	12.5				
17						4.0	22.5	4.0	3.5			
18								22.5	45.0	15.0		
19							2.0	6.0	54.0			
20						3.5	7.0					
21					6.5		24.0	16.0	45.0			
22					1.5		0.5	2.0				
23					2.0	2.5	1.0	11.0				
24												
25						0.5	17.5	45.0	10.5			
26							27.0					
27							17.5	1.5				
28					32.5	9.0	5.0	4.0				
29					3.5	25.0	6.0	27.0				
30					23.0		1.0					
31						6.0						
TOTAL	NIL	NIL	NIL	6.5	69.0	132.5	158.5	456.0	282.5	37.0	NIL	[illegible]
No. of Days of RAIN (≥1mm)				3	6	16	17	21	[illegible]			
No. of Days of T												
No. of Days of HAIL												

MOZ. 31
★

RAINFALL SUMMARY

1986 / 1987

Station KATETE HOSPITAL No. 1399 14 08 S 31 55 E

Observer .... Copied by L. M. M. PHIRI

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1					1.0	1.0	2.0	1.5				
2					26.5	6.5		7.5	12.0			
3							15.0		12.0			
4							1.0	13.0				
5						5.5	0.5	31.5			0.5	
6						12.0					0.5	
7						1.0						
8						27.0						
9					1.0	9.0				2.0		
10				13.0		20.0	3.0		1.5			
11				5.5		30.5	8.0	0.5				
12				15.0		7.5	1.0					1.0
13							1.0	7.0				
14				1.0			2.5	12.5	26.0			
15				1.0	0.5		51.0					
16							12.0					
17						1.0	50.5			2.5		
18							4.5					
19												
20							17.5					
21					1.0		5.5					2.0
22				2.0			7.5	3.0				
23					6.5		24.5	1.0				
24				0.8				7.0				
25								1.5				
26						4.5	2.0	13.5	5.0			
27						0.5	9.0					
28							0.5					
29					0.5	10.5	2.0		7.0			
30						5.5						
31												
TOTAL	NIL	NIL	NIL	38.3	37.0	142.0	220.5	99.5	63.5	4.5	1.0	3.0
No. of Days of RAIN	≥ 1mm			6	5	14	19	11	6			
No. of Days of T												
HAIL												
Heavy falls												

MOZ. 3 ★

RAINFALL SUMMARY

Station KATETE HOSPITAL No. 1399 1985/86

Observer .... 14 08 S 31 55 E

Copied by L. M. M. PHIRI

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1								7.0	10.0	8.5		
2						1.0	23.5	2.5	5.5			
3							0.5		5.5			
4						23.0			8.0	2.0		
5						6.0	21.0	30.5	12.0			
6					17.0	74.0	27.0	1.5	4.0			
7					19.0	57.0		24.5	1.0			
8					14.0	3.0		4.0	20.0			
9					0.5	21.0		26.0	17.0			
10					82.0			1.5	2.5	1.5		
11					4.0		12.5	7.5				
12						7.0	42.0	10.5				
13							3.5					
14						11.0	6.0					
15												
16						10.0				2.0		
17						4.0	1.5	0.5		1.0		
18					2.5	42.0	13.0	1.0	0.5	36.5		
19				2.5		46.0	5.5			4.5		
20						2.5	56.5			23.5		
21					0.5	1.5	31.5	45.0		14.0		
22					18.0	8.5	4.0					
23					4.5	9.0	5.5					
24							6.5					
25					1.0		6.0	13.5	5.5			
26				2.0		7.0	20.0	10.0				
27						23.0	8.5					
28						28.0						
29				6.0		30.0	1.5					
30				2.0		9.5	5.0					
31				1.5			9.5		3.0			
TOTAL	NIL	NIL	NIL	14.0	163.0	424.0	310.5	398.5	94.5	93.5	NIL	NIL
				5	9	22	21	14	12	9		

149[illegible]

RAINFALL SUMMARY

1984, 85

Station KATETE HOSPITAL No. 1399 14° 08′ S 31° 55′ E

Observer Copied by L. M. M. PHIRI

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1								14·5	3·0			
2		1·5					3·0	1·5	1·5	0·5		
3						14·0		55·5		0·5		
4								12·5	1·5	10·5		
5						0·5		17·0		3·5		
6							0·5	22·5	50·0	5·5		
7						5·0		7·0	1·5			
8					2·0	36·0	11·0	0·5	1·0	1·0		
9					1·0	0·5	2·0		1·5			
10					5·0	62·0	55·0	15·5	3·0			
11					66·0	5·5	6·5	20·5				
12					6·5	2·0	1·0	16·5				
13					1·0	36·5	0·5	17·0		0·5		
14						1·0		10·5	1·5		12·7	
15						11·0			1·0			
16				1·5		3·5	4·0					
17						34·0			5·5			
18					0·5	0·5			14·5			
19						4·0	31·0		13·0			
20					3·0	10·5			12·5			
21					12·0	18·0	2·0		1·5			
22			3·5			2·0	34·0		37·5			
23					1·0		1·5		1·5			
24				3·0	1·5		30·0		12·5			
25							5·5	1·5	8·0			
26							11·0		12·5			
27					11·0	15·0	5·0		3·5			
28						2·0	10·0					
29						22·5	1·5					
30						16·0						
31												
TOTAL	NIL	1·5	3·5	4·5	110·5	302·0	215·0	212·5	188·0	22·0	12·7	NIL
No. of Days of Rain	≥1mm	1	1	2	11	19	17	13	21	4		
No. of Days of T[hunder]												
No. of Days of Hail												
[H]eavy [F]alls												

RAINFALL SUMMARY

1983 / 84

Station: KATETE HOSPITAL No. 1399   14° 08' S   31° 55' E

Observer: ....   Copied by: L. M. M. PHIRI

Day	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1							1.0					
2					2.5	1.5	97.5		14.0	1.5		
3						26.0	4.5	3.0	1.5	1.0		
4									20.5			
5								42.5	2.5			
6						24.5		35.0	15.0			
7		1.5			0.5		7.5		0.5			
8							19.0					
9						9.0	6.0	9.5	0.5			
10									0.5			
11						48.5	6.0					
12												
13												
14					0.8		1.0					
15				2.5			19.5		11.0			
16						4.0	0.5		14.0			
17												
18	2.5					2.0						
19						21.0			1.5			
20						2.5		22.5	10.0		3.0	
21								2.0	5.5			
22					4.5			19.0				
23		0.5			4.5	9.5						
24						0.5		5.0				
25						12.0		59.0				
26						5.5						
27					1.0	10.5			7.5			
28									10.5	18.5		
29					21.0		0.5		7.5			
30					31.5		11.5		1.5			
31									8.5			
TOTAL	2.5	2.0	NIL	2.5	66.3	177.0	174.5	197.5	132.5	21.0	3.0	NIL
No. of Days of Rain ≥1mm	1	1		1	6	13	10	9	15	3	1	
No. of Days of Thunder												
No. of Hail												
Heavy falls												

GT 778 8