HYDROGEOLOGY OF JIMMA AREA

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STUDIES

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ABSTRACT

The studied area is located 335 Km. southwest of Addis Ababa in the southwestern Ethiopian plateau. Over half of the map-area is underlain by thick basalt flows interlayered with tuffs and volcanoclastic sediments. The Jimma Volcanics, which is mainly composed of massive rhyolite in thick flows alternating with trachytes, tuffs, ignimbrites and subordinate basalts, underlain small area in the eastern and northeastern part of the basin.

Based on the hydrometeorologic data collected for the last 38 years an attempt has been made to calculate the hydrological parameters like precipitation, evapotranspiration, and runoff.

The annual mean rainfall in the basin is 1476.89 mm. The values of the annual potential evaportanspirtion and actual evapotranspiration are 837.51 mm and 822.29 mm respectively. The only runoff that leaves the studied area comes through Boye river and is 90.77 million cubic meter of water. The amount of water which is actually available to recharge the groundwater circulation within the hydrogeological basin is 51.14 million cubic meter.

The hydrogeological character of the outcropping lithotypes was discussed with particular reference to infiltration and their water bearing capacity.

The hydrogeology of the area varies in different parts of the basin. There is a great potential of groundwater in the valleys which is partly filled with alluvial sediments while a

less significant amount exist within the volcanic rocks forming the uplifted borders of the valleys.

Determination of the hydraulic parameters like transmissivity and permeability have been carried out. Due to the absence of observation well nearby a discharging wells it was impossible to calculate the coefficient of storage, a significant parameter which measures the volume of water the aquifer releases or take into storage. For basaltic aquifers a transmissivity value of 18.39 m^2/day and a permeability value of 3.31 x 10^{-4} cm/sec. have been calculated. A transmissivity value of 1.89 m^2 /day and a permeability value of 1.62 x 10^{-5} cm/sec. have been computed for both alluvial and rhyolitic aquifers.

Because of the lack of bore wells in the southwest, south, and southeast lower most part of the basin a thorough study of the actual variation of groundwater level was not possible. For the other part of the basin, appropriate groundwater level contour lines was constructed on the basis of the available static level data.

Proper chemical analysis of both the groundwaters and surfaces water carried out in the basin show low total dissolved solids. All of the samples have less than 1000 mg/l dissolved solids. The analysed samples also compared with the acceptable standard for human, agricultural, and industrial use.

1. INTRODUCTION

1.1. Objectives

Owing to the continuous increase in water demands, resulting from advances in agriculture and industry and the accelerating growth of global population, and the near exhaustion of surface waters, groundwater has become a major water source.

Present supply of water for Jimma town (i.e. the area under study) is obtained from a number of springs and wells. The rapid growth of population has tremendously raised the water demand of the town. However, the existing water supply, which has been used for a long time, is very insufficient to fulfil this dynamic demand prevailing in the town.

Eventhough the study area upto now has only small manufacturing and processing plants that require relatively small amounts of water, it has a good industrial prospect because of its location as the capital of the richest region in terms of agricultural cash crop production.To satisfy the water demands of these industries the proper development of groundwater has become increasingly important.

The lower part of the basin is suitable for large scale mechanized farming. The necessary water for irrigation will be provided either from the surface waters or groundwaters.

If the tourism industry continues to expand, undoubtedly Jimma will get its share of revenues as a transportation centre

and jumping off point for the wilderness. This will increase the commercials water requirements (commercial includes all the hotels, business and trade establishments).

All these domestic and non-domestic water requirements dictated the necessity to evaluate the groundwater potential in the basin, which is the main objective of this study.

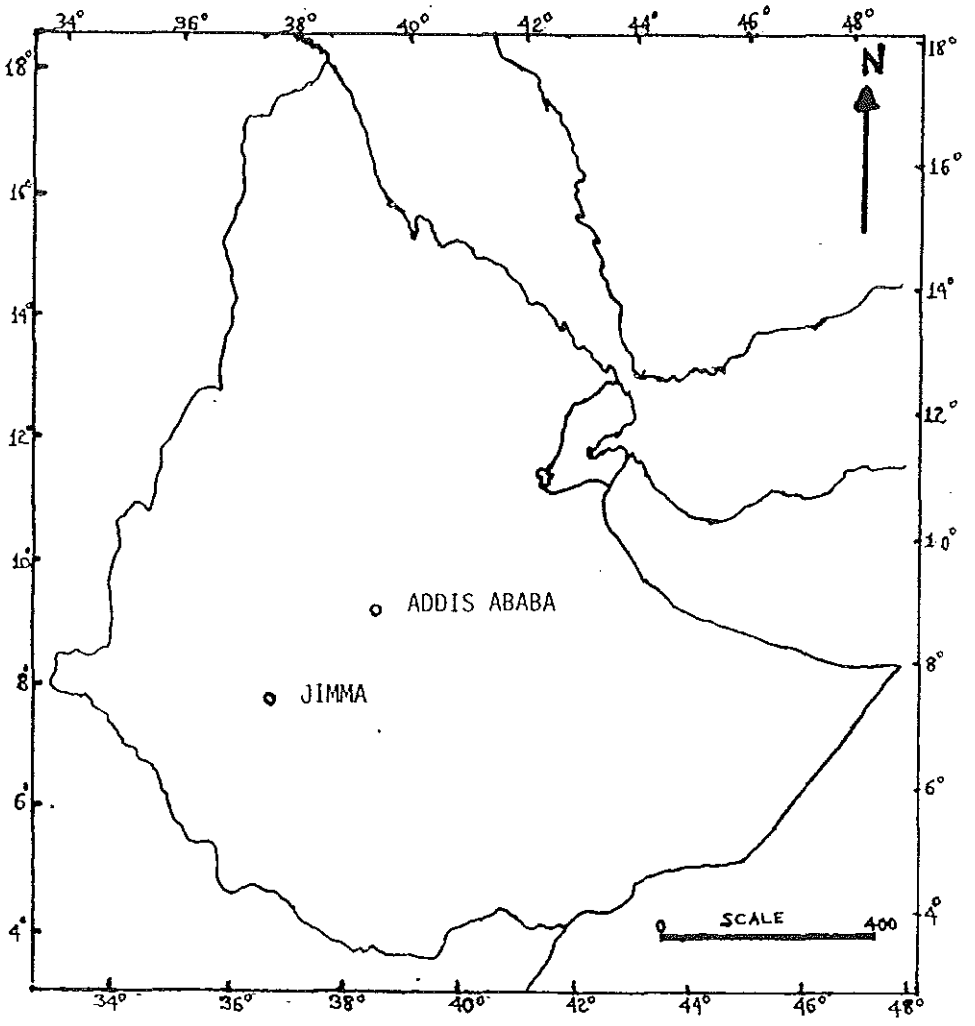
Specifically, the objectives of the study include:

1. To verify the occurrence of important groundwater reservoirs within unconfined and confined aquifers.
2. To establish physical parameters of aquifers, which define the hydraulic characteristics of a water-bearing formations.
3. To identify the general direction of groundwater movement.
4. To give a reasonable approximation of the water budget.
5. To check the quality of surface waters and groundwaters based on International Standard Quality requirement.
6. To suggest the water management of the area.

The results obtained could help for the development and planning of sufficient water supply services for Jimma and surrounding villages.

1.2. Location and Extent of the Area

The study area lies between 36^0 40' and 36^0 54'E and 7^0 36'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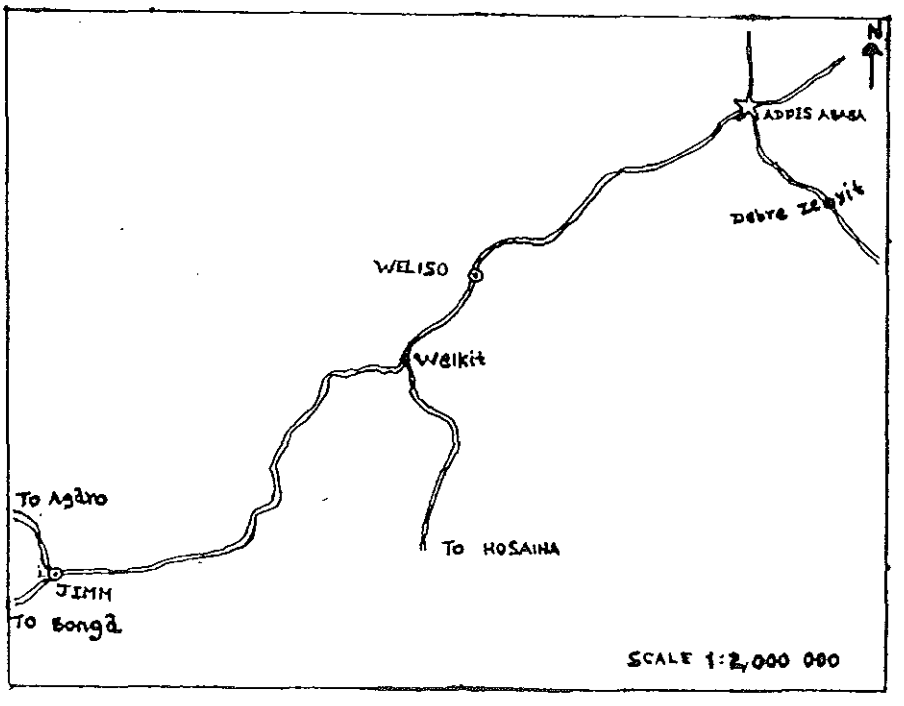
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Map 1

and 7^{0} 47' N, with road distance of 335km. southwest of Addis Ababa. The concerned area is situated on a low hill to the north of the wide alluvial plain of the river Gilgel Ghibe. The basin has a total area of 220.13 sq.km. with a general elevation of 1780 m above sea level.

In the east and northeast the basin is bounded by the Jiren hill range. Gentle slopping hills gradually developing into highlands surrounding the basin in the north and northwest. These highlands mark the boundary of the basin in these

geographic directions of the map-area. The west, southwest, south, and southeastern boundaries are delineated by the surface water divide.

1.3. Physiography and Drainage

The investigated area is located in the southwestern Ethiopia plateau in an area of moderate relief. According to Davidson, A., et al. (1976) the various landforms that has developed in this plateau is the result of the dissection of what was probably once a continuous northeast-rising plateau of sub-horizontal Tertiary volcanic rocks laying unconformably on crystalline basement.

The study area is characterized by a structural system of promontories separated by valleys that extend towards the north ending in a large plain in the south. The most important of these promontories is Hirmata, which has a maximum elevation of 1750m above sea level; parallel and on its side is Kochi and

further connected with the Jiren hill range. The Kochi highland and the Jiren hill have a maximum elevation of 1750m and 2080m above sea level respectively.

In the basin, broad valleys, which are cut into the volcanic rocks, are filled with alluvium which is mainly fine grained. Aerial photos of the area suggest that a fairly mature topography (developed on the volcanic rocks) is "flooded" or buried by deep alluvium. This type of topography would develop if the base level of the drainage system was raised. This could have happened as a result of recent volcanic activity or perhaps recent faulting. The general appearance of the large valleys indicates that deposition in the valleys has stopped and the streams are now down-cutting.

The remarkable topography mentioned above results in streams in the topographically high areas which have a fairly high gradient. These high gradient streams flow into rather sluggish, meandering streams in the main valleys. Most sediment removed from the hills by erosion is trapped in the broad valleys.

The Kochi valley is situated between the Jiren hill range and Kochi highland. It is drained by a small intermittent stream, called Kochi, that emanates east of the town and flows in the southwest direction. The bottom of this valley has an elevation of 1680m above sea level.

The Aweytu Valley, which is the central part of the studied area, is located between the Hirmata and the Kochi

highlands.

The lowest part of this valley has an elevation of 1710m above sea level. It is drained by Aweytu stream, which is perennial. This stream emanates north of the town and flows a long the middle of the valley in the south direction.

The Kitto valley, which is drained by the Kitto stream, is found on the right side of the Aweytu valley. Kitto stream, which is also perennial, emanates northwest of the town and flows through alluvial plain in southeast direction. The bottom of this valley has an elevation of 1710m above sea level.

All the streams are united and form Boye river in the lower part of the area. Boye river deviates to the east and after flowing a certain distance it finally leaves the basin in southeast direction and join the river Gilgel Ghibe, which is a right side affluent of the Omo River.

1.4. Previous Work

Published articles concerning the southwestern Ethiopian plateau are scarce, which means the southwestern Ethiopian plateau is less studied than the northern Ethiopian plateau. And even most of the published literature obtained for the basin are works of a general nature and specific publications have not been available concerning neither the geology nor the hydrogeology.

Studies pertaining to the Cenozoic rocks of the plateau including chronology, petrochemistry, petrogenesis and

nomenclature, carried out by Pagliani (1940), Mohr (1963, 1964), Zannettin et al. (1974, 1976, 1978), Lemoigne (1978), Merla et al. (1979), Levitte et al. (1974), and Kazmin (1975) are the most valuable.

Feasibility study for Jimma town water supply has been carried out by Water Supply and Sewerage Authority (1982). In this study the assessment of groundwater for the town water supply has not been worked out.

1.5. Methods and Materials

Hydrogeological map of the area were produced from data collected in two field trips. A topographical map of 1 : 50,000 scale was used as a base, with aerial photographs of the same scale as supplementary.

In this investigation, rock samples were taken from sites which are mostly suitable to provide complete geological information. Petrographic study of selected samples representing the outcropping formational units was undertaken.

Intensive hydrogeological work has been carried out by collecting hydrogeological and hydrological data of the basin. Hydrological data was obtained from different sources in Addis Ababa.

An attempt has been made to examine the seasonality of rainfall in the basin using the rainfall coefficient approach. Thornthwaite empirical method have been used for the determination of potential evaportanspiration. Actual evapotranspiration was computed using Thornthwaite methods

given in the original instruction manual by Thornthwaite and Mather (1957).

Field investigation was concentrated more on differentiating the rock units of groundwater significance and in collecting hydrogeological information, i.e locating of water points, collection of water samples, measurement of discharge of springs and wells.

From hydrogeological and hydrological informations the water balance of the basin has been computed by means of the following equation :

$$P - ET - Q - I = 0$$

Where the symbols, expressed as annual equivalent depths of water, represent precipitation (P), evapotranspiration (ET), river discharge from the basin (Q), and infiltration (I).

Pumping and recovery tests and lithological logs data for the wells in the area has been supplied by Regional EWWCA Office at Jimma. For the determination of hydrogeological parameters the Cooper-Jacob Method of Solution was employed.

Representative water samples were analyzed to examine the suitability of the waters (both groundwaters and surface waters) for such applications as drinking, industrial, and agricultural use. For the water samples, immediate field analyses has been conducted for temperature,pH, conductivity, colour, taste, appearance and odor. Thermometer, Digital pH meter and conductivity meter was employed during this field analysis.

As to the age, Lemoigne (1978) reports welded tuffs from the Omo gorge with silicified wood of probable lower Miocene age. Moreover, five radiometric dating range from 40 to 25 my. According to Merla et al. , (1979), the gross lithology and age strictly recall the Blue Nile Basalts. The attribution of this occurrence to the Omo Basalts is suggested by its stratigraphic position.

The Jimma Volcanics represent most of the effusives in Southwest Ethiopia with minor outcrops east of the Ethiopian rift. This unit is mainly composed of massive, white, pinkish and gray rhyolites in thick flows alternating with, tuffs and subordinate basalts (Merla et al., 1979).

The radiometric analyses give quite varied ages. Five samples collected in the Omo, Chencha and Yrga Alem areas have been dated 37 to 27 my. Moreover, two radiometric analyses on rhyolites from a faulted block of the Chencha escarpment (Lake Abaya) gave 11 and 13 my. According to Merla et al. (1979), they could represent the upper part of the Jimma Volcanites or, as suggested by Zannettin et al.(1978), they should be ascribed to an Upper Miocene local volcanism.

According to the geological map of Ethiopia and Somalia (Marla et al.,1979), the age of the Jimma Volcanics range from Oligocene to Miocene.

This unit rest directly on the basement or on the Omo Basalts. Both the Omo Basalts and the Jimma volcanics are frequently tilted and in the northern outcrops are unconformably

overlain by the Wollega Basalts.

The Wollega Basalts consists of predominant columnar basalt flows interbedded, particularly in the upper portion, with acidic tuffs and lose fluviolacustrine sediments (Merla et al., 1979).

Two samples of this unit were dated (K/Ar) 15 and 13 my. Near Chencha the Wollega Basalts have an age of 7 my (Zannettin et al., 1978). Lemoigne (1978) attributes to the Miocene (Lower Miocene ?) two silicified paleofloras found in tuffs near Ghion.

According to Zannettin et al. (1974) and Mohr (1968, 1971) the silicic varieties of the Oligocene - Miocene volcanic are concentrated in the belt adjacent to the plateau - Afar and plateau-rift border. From this belt, which occupies the central position in the volcanic area, the volume of silicic rocks gradually decreases to the west and east, so that they are scarce or absent on the southeastern plateau and on the western edge of the Ethiopian plateau. This silicic volcanism coincided with the geothermal high in the central part of the volcanic area, which is in the place where partial melting of the crust was most likely, Kazmin (1978). The Eocene - Lower Miocene area of pre-rift volcanism was related to mantle plume activity (Kazmin, 1976), and its development, according to Kazmin (1978), corresponded to the period of stability of the African plate in the Eocene.

The stratigraphic series and subdivisions of the Wollega

and Southwestern Ethiopian plateau volcanics has been set by Kazmin (1972) and Merla et al., (1979) as follows :

1. Omo Basalts ------- Oligocene - Miocene
2. Jimma Volcanics
3. Wollega Basalts ------ Miocene - pliocene
4. Basaltic flows and related
   spatter cones ------- Pleistocene-Recent
   (consist of younger volcanic of
   an alkaline olivine basalts)

The studied area is located in the Southwestern Ethiopian Plateau. The area is underlain by volcanic rocks of Tertiary Age. These volcanic rocks include the Early Tertiary age basaltic flows (Mohr, 1964) which underlain the Jimma Volcanics (Merla et al.,1964). Besides these volcanic rocks, which cover the topographically high areas, the broad valleys of the map-area are covered by recent alluvial sediments, which overlie the volcanics unit.

2.2. Local Geology

2.2.1. Introduction

The geology of the investigated area is constituted by the volcanic rocks and alluvial sediments. Over half of the map-area is underlain by basaltic flows, and the rest is by acidic flows, mainly rhyolite.

Successive investigation on the Jimma Volcanics by Levitte et al. (1974) have shown that the flood basalts with variable thickness underlain the acidic flows. According to Merla et

(Davidson et al., 1976), they underlie the Kochi and Hirmata highlands (Fig. 2.1), and also the north and northwestern part of the topographically high areas. They also underlie the alluvial sediments in the broad valleys of the central and western part of the map-area (Fig. 2.2 and Fig. 2.3).

Northwest of the map - area along the high way to Metu, thin exposures of this unit lies directly on basement.

The unit consists of five distinguishable basalt flows and is separated by at least two recognized horizons of tuff and Volcanoclastic sediment interbeds. The thickness of individual flows cannot be given for it varies from one part to another. However, the exposed thickness of the unit is in the range of 40 to 70 meters. There are no mappable lines of separation between the superimposed individual flows of the unit owing to the textural and compositional homogeneity.

The rock is typically dense and often show distinct hexagonal columnar jointing. Colour generally ranges from dark brown to black.

In the top part the basalts are thoroughly weathered to dark brown, darkred, and red soils. The weathering product of the basalt can clearly be seen at some localities in succession from lateritic soil to unweathered fresh rock (Fig. 2.1). A nearby quarry to Saint Gabriel Springs, which are located close to the head of the Aweytu valley, shows that the valley is cut into slightly inclined flows of columnar basalt; a thick cover of red soil overlies the flows.

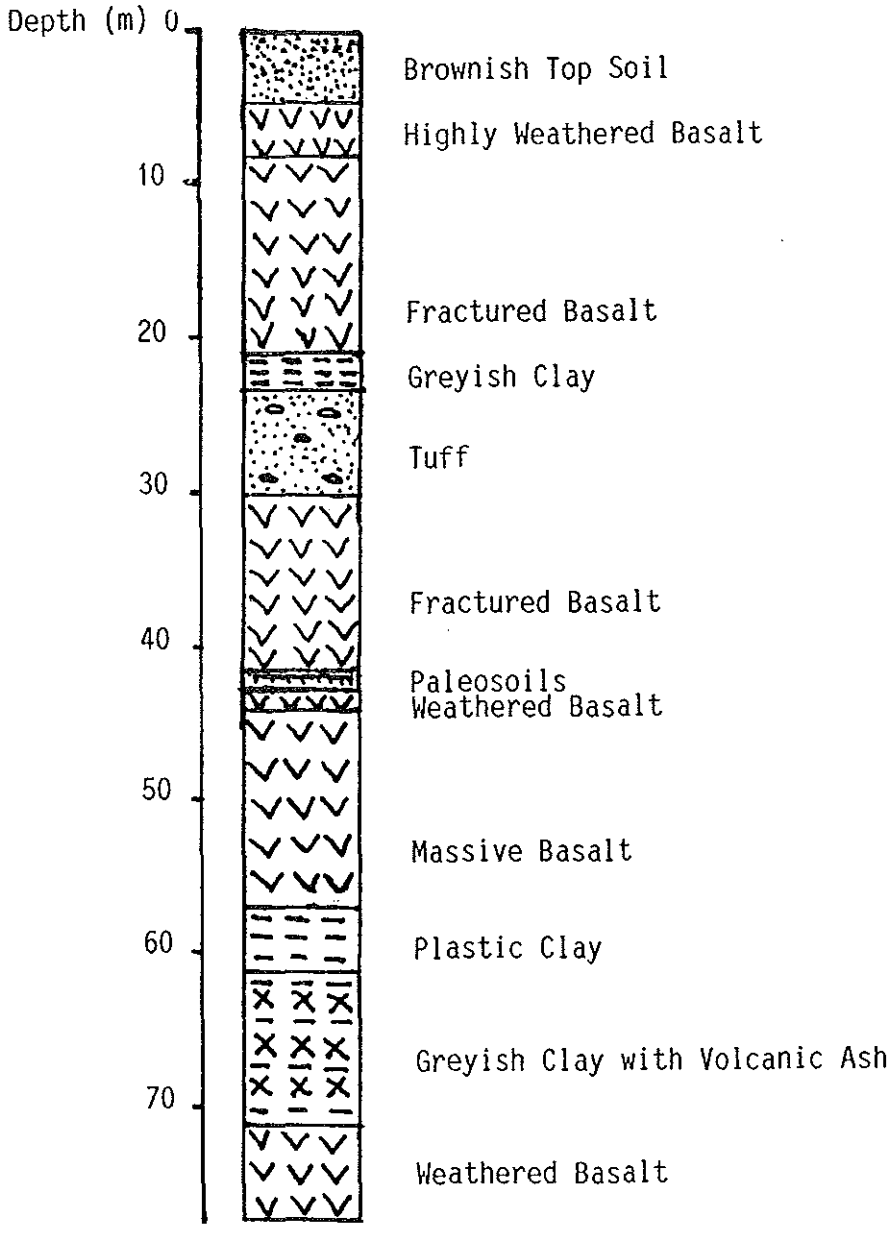

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Fig. 2.2 LITHOLOGICAL LOG FOR JIMMA STADIUM WELL

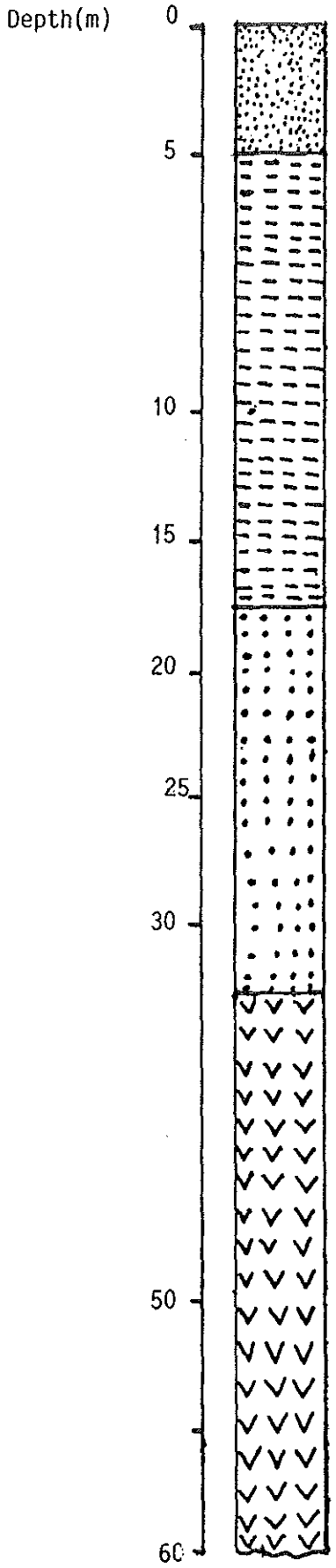

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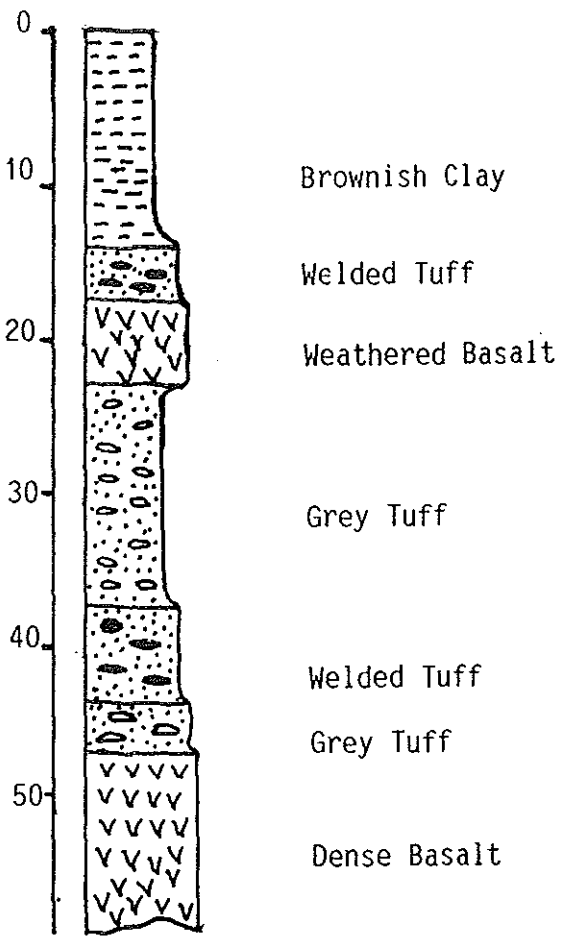
Fig. 2.3 LITHOLOGICAL LOG FOR KITTO WELL-WELL No.4



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The basalts are aphyric, with microphenocrysts of olivine and plagioclase feldspar. Subhedral grains of Plagioclase laths, olivine, and pyroxene together with iron oxide and volcanic glass constitute the ground mass.

The plagioclase in the ground mass vary from nonoriented to weakly aligned; compositionally they are predominantly within the labradorite range and rarely shows zoning.

Generally, the overall microscopic character is an aphanitic texture which may indicate a single period of rapid chilling and crystallization of the individual flows.

2.2.2.2. Rhyolite Flows

Acidic volcanic rocks are prevalent in the eastern and northeastern part of the map-area along the Jiren hill range. As shown in the Fig. 2.4 they also underlie the alluvial sediments in the Kochi Valley.

In the northeastern part of the basin, the Jiren hill range, thin basalt flows are interlayered with thick acidic flows, and the upper part of the basalt sequence interfingers with the lower part of the acidic sequence. In this part of the map - area the basaltic flows may be contemporaneous with the acidic flows. It is possible that the acidic succession can be emanated from fissures (Davidson et al., 1973).

In the studied area the acidic flows are represented by rhyolites. They are pinkish and gray, and almost every where contain 1 to 5 mm feldspar and quartz phenocrysts. In some rocks these are randomly oriented,and in others they show a

planar flow orientation. Porphyritic texture is common, in places with flow alignment, and the groundmass is usually finely crystalline rather than glassy.

Trachytes are much less prevalent than rhyolites, with which they are interlayered. They are highly porphyritic, but otherwise differ from the rhyolites only that they do not contain visible quartz, either as a phenocrysts or in the groundmass; alkali feldspar is the dominant or only phenocryst phase. Color generally ranges from light pink through violetgrey. Both porphyritic rhyolite and trachytes characteristically have very fine grained to aphanitic matrices.

Tuffs and ignimbrites made up mainly of acidic fragments are interlayered with the rhyolites.

2.2.2.3. Alluvial Sediments

Alluvial sediments cover the broad valleys of the map-area that underlain by volcanic rocks. Elsewhere bedrock is variably covered by earthy soils. The alluvium does not have the same thickness throughout the area in which they exposed.

Fine grained sediments are the dominant constituent of the sediments that cover the Kochi valley. The sediments grade laterally from reddish - brown, relatively coarse clastics near the highland and the mountains range bordering this valley, to black and gray sequences contain more clays toward the center of depression. As shown in the Fig. 2.4 clays are found interlayered with rhyolites. Here clays are a weathering

product of the rhyolites. Most of the rhyolites are partly or completely weathered to clay.

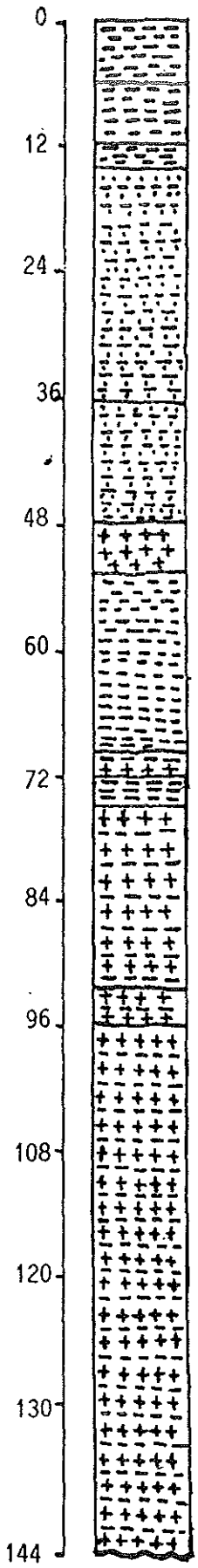
As observed from borehole log (Fig. 2.2) taken from Aweytu valley, the thickness of the alluvium reaches 38 m. Medium to coarse grained materials, mainly sand dominates the alluvium in the north of this valley. In the lower parts, fine grained materials are the major constituents of the sediments.

A meandering Kitto river and its associated floodplain also have coarse and fine grained deposits. The fine grained sediments covering the swampy area are transported by this river to be deposited where the topography is flat. The coarse sediments on the other hand left behind in the upper course of the river.

In some parts of Kochi and Kitto valleys alluvium are covered by grey tuffs, which has a thickness ranging from 25 to 30 cm and limited lateral extent.

The alluvial sediments in the map-area are generally very loose so that they can be easily eroded away.

Fig. 2.4 LITHOLOGICAL LOG FOR E.W.W.C.A. WELL



Black Yellow Clay

Grey Clay
Brown-Red Clay

Gray Sandy Clay

Grey Black Sandy Clay

Weathered Rhyolite

Grey Clay

Weathered Rhyolite with Grey Clay
Black Clay

Weathered Rhyolite with Grey Clay
to White Clay
Rhyolite with Yellow Clay

Weathered Rhyolites with Black Clay

Source: E.W.W.C.A Southwestern Region Office

V.S.= 1:600

3. SURFACE HYDROLOGY

Precipitation and the water that are discharged from the groundwater reservoirs are the source of surface water. Surface water and groundwater are intimately associated, and they are in a continuous process of exchange. Drainage from the groundwater body maintains stream flow during dry periods. In some arid regions the opposite process occurs, as runoff from desert washes may be the major source of groundwater recharge.

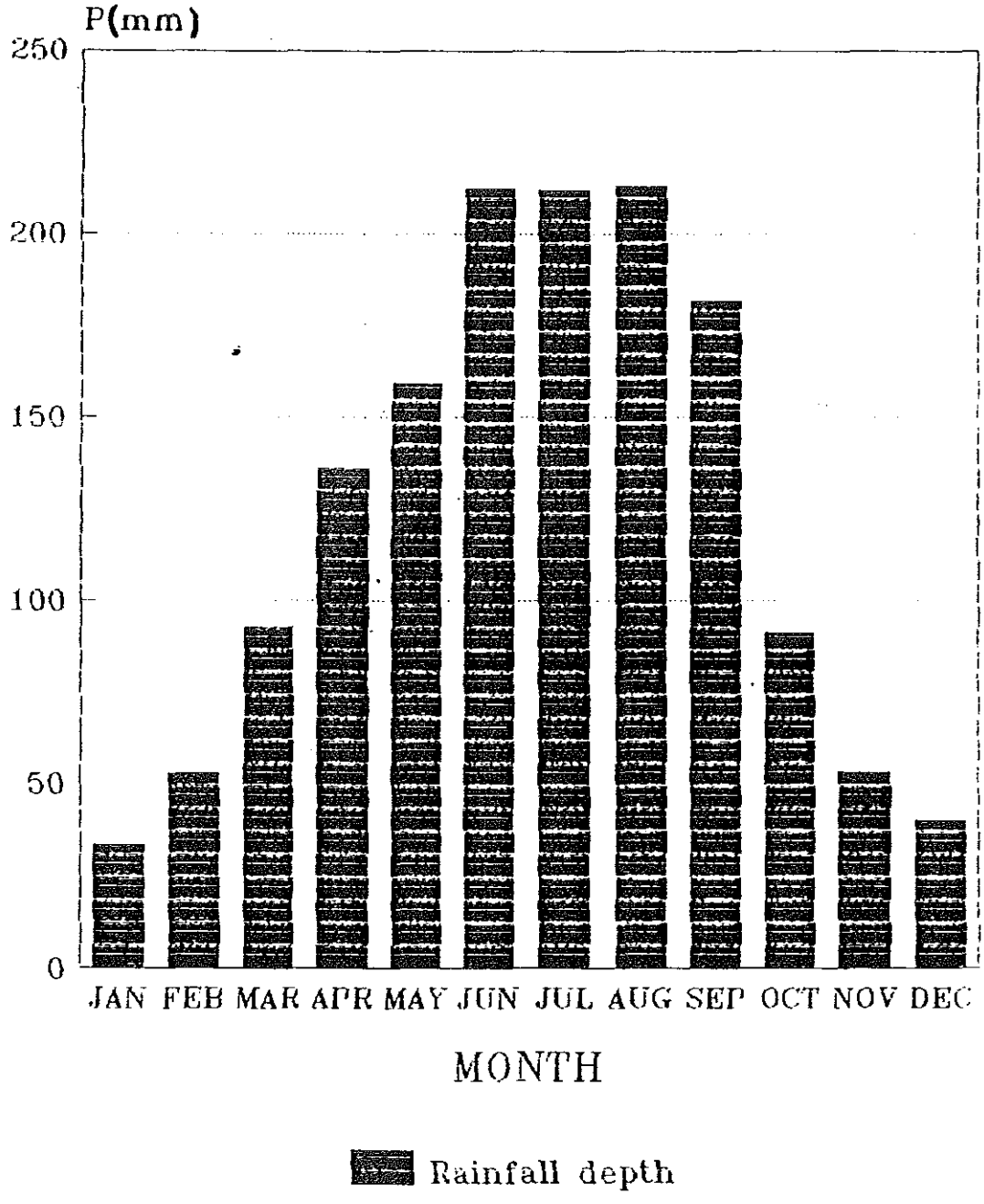
Discharge of groundwater occurs when water emerges from underground. Most natural discharge occurs as flow into surface water bodies, such as streams, lakes and oceans; flow to the surface appears as a spring. Pumpage from wells constitutes the major artificial discharge of groundwater.

Water is constantly evaporated from the earth and is precipitated back on the earth in the form of rain, snow etc. One part of this precipitation infiltrates into the ground, forming groundwater reservoir; second major part flows as runoff in the form of rivers; and the rest is lost in evaporation and transpiration.

The interaction between precipitation, infiltrated water, runoff, and groundwater is rather complex. It is affected by physiographic, geologic, meteorologic, and hydrologic factors as well as by human activities such as water use and pollution.

In the following sections the hydrology of the studied

Fig. 3.1 MEAN MONTHLY RAINFALL (mm)



of the altitude where the station are located, the computed mean annual rainfall value is considered as the minimum amount of rainfall depth for the whole area.

The seasonality of rainfall in the investigated area has been examined using the rainfall coefficient approach. The rainfall coefficient approach (R.C) is an approach where the year is divided into dry periods and rainy periods by using rainfall coefficient values obtained by dividing the mean monthly rainfall by one-twelfth of the annual mean (Daniel, 1977).

The rainfall coefficient of each month for the studied area have been calculated and tabulated as follows.

TABLE 3.1

Rainfall Coefficient at the Jimma Station

STA.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
JIM.	0.27	0.43	0.75	1.10	1.29	1.73	1.72	1.73	1.47	0.47	0.74	0.32

Based on these values, the year can be divided into dry and rainy periods. The classification is presented in Table 3.2 below.

TABLE 3.2

Dry and Rainy Periods

Designation	Rainfall coefficient	Months of the year
Dry months	less than .6	Nov, Dec. January & Feb.
Rainy months	0.6 and over	
- Small rains	0.6 to 0.9	Mar.& October
- Big rains	1.0 and over	
- Moderate concentration	1.0 to 1.9	April, May,Jun, July, Aug.,Sep.
- High concentration	2.0 to 2.9	-
- Very high concentration	3.0 & above	-

As it is depicted in the table 3.2, the rainy periods of the investigated area extends from March to October, a period when 87.84 percent of the total annual rainfall occurs. Whereas months from November to February are dry periods that are characterized by the occurrence of low amount of rainfall

(12.16 percent from the total annual rainfall). Compared to other parts the country, the investigated area has not experienced high concentration of rainfall, as a result the rainfall coefficient ranged from 0.2 to 1.9.

3.2. Evapotranspiration

Evapotranspiration is that portion of the precipitation which returns back to the atmosphere through evaporation from a free water surface, a bare soil or interception on a vegetal cover and other objects and transpiration from plants.

Since it reduces the amount of stream flow, lake storage, and groundwater available for direct human use in a given drainage basin, evaportanspiration is a "loss" from the water budget.

Distinction should be made between the evaporating potential or ability which depend on meteorological factors and the evaporating opportunity or availability which is governed by the adequacy of the moisture supply.

Potential evapotranspiration is the amount of water that would be removed from the land surface by evaporation and transpiration processes if sufficient water were available in the soil to meet the demand. Potential evapotranspiration is dependent on the evaporative capacity of the atmosphere. It is a theoretical calculation based on meteorological data.

Actual evapotranspiration is the proportion of potential evapotransiration that is actually evapotranspired under the existing soil moisture supply. It is dependent on the

unsaturated moisture storage properties of the soil. It is also affected by vegetative factors such as plant type and stage of growth.

Several methods of measuring evapotranspiration have been used. Some techniques indicates only potential evapotranspiration rates, while others measure actual evaportanspiration. Evaportanspiration may also be computed by empirical methods. The most common methods of calculating potential evapotranspiration are those of Blaney and Criddle (1950), Thornthwaite (1948), Penman (1948) and Van Bavel (1966). The first two of these are based on empirical correlations between evapotranspiration and climatic factors. The last two are energy - budget approaches that have better physical foundations but require more meteorological data.

Eventhough the Colorado Evaporation Pan method often gives erroneous results in the tropical climates it is still in use. Accordingly the monthly evaporation rate that was recorded from Class A pan for eighteen years (1969 - 86) at the Jimma Research station, the mean yearly evaporation rate for the investigated area was amounted to 1598.56 mm. This value, for this period, indicates a heavy loss of surface waters and implies that all the precipitation that fall and accumulated in small reservoirs during the wet months is returned back to the atmosphere in the subsequent dry months. This method over estimate the evaporation rate and therefore, the data can not be taken into consideration.

The best estimation of evapotranspiration is obtained from Thornthwaite method (Thornthwaite, C.W. and Mather J.R, 1957). This method uses air temperature as an index of the energy available for evapotranspiration and provides a figure for the consumptive use of a short closed vegetation with adequate water supply. The formula is expressed as:

$$E_t = 1.6\,[10T_n/J]^a \text{ ---------- } (3.1)$$

Where

E_t = Monthly gross potential evapotranspiration in centimeter per month.

T_n = Mean monthly temperature of the consecutive months of the year in ^0C.

n = 1, 2, 3.....12 is the number of the considered months

J = Annual heat index and it is given by

$$\sum_{n=1}^{12} j \quad \text{---- } (3.2)$$

j = is the monthly heat index and it is expressed as

$$j = (Tn/5)^{1.514} \quad \text{---------- } (3.3)$$

$$a = 0.49 + 0.0179J - 0.0000771J^2 + 0.000000675J^3 \text{ --}(3.4)$$

The computed gross potential evapotranspiration from Equation 3.1 is for a standardized month of thirty days and twelve hours between sunrise and sunset. It must be adjusted

for the number of days per month and the length of day (a function of latitude).

The mean annual temperature recorded at the Jimma station for the period 1952 - 1991 (excluding 1961 and 1962) was 18.9°C and the mean yearly maximum and minimum temperature was 27.2°C and 10.8°C respectively (Figure 3.2). The range of monthly average temperature is 3.1°C.

In the dry period the average monthly mean maximum and minimum temperature range from 27.3°C (in November) to 28.7°C (in February) and 6.6°C (in December) to 9.1°C (in February) respectively.During the rainy period the average monthly mean maximum temperature decreased from 31.9°C (in June) to 23.9°C (in July) and average monthly mean minimum temperature increased from 10.7°C (in March) to 13.2°C (in July). Fig. 3.3 shows rainfall and temperature in different months at Jimma station and it presents the relationship between the two elements of climate in the investigated area.

The actual evapotranspiration, for the studied area, has been evaluated through the calculation of the gross potential evapotranspiration using Thornthwaites formula by taking into account the available water capacity of soil, which in turn depend upon the texture of the soil and the rooting depth of

Fig. 3.2 TEMPERATURE (C) AT JIMMA STATION

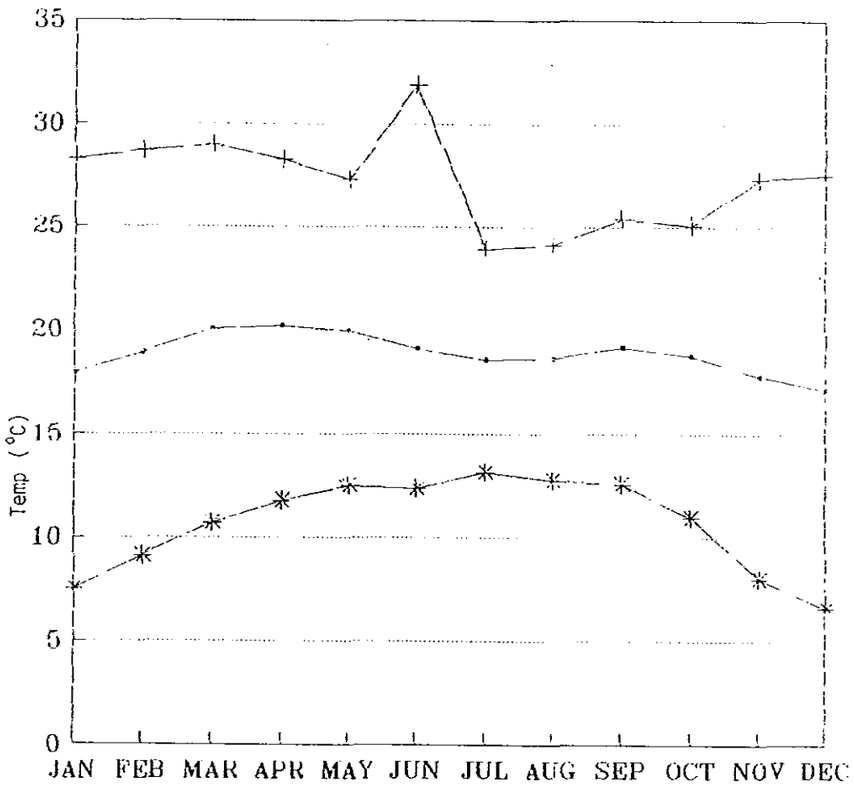
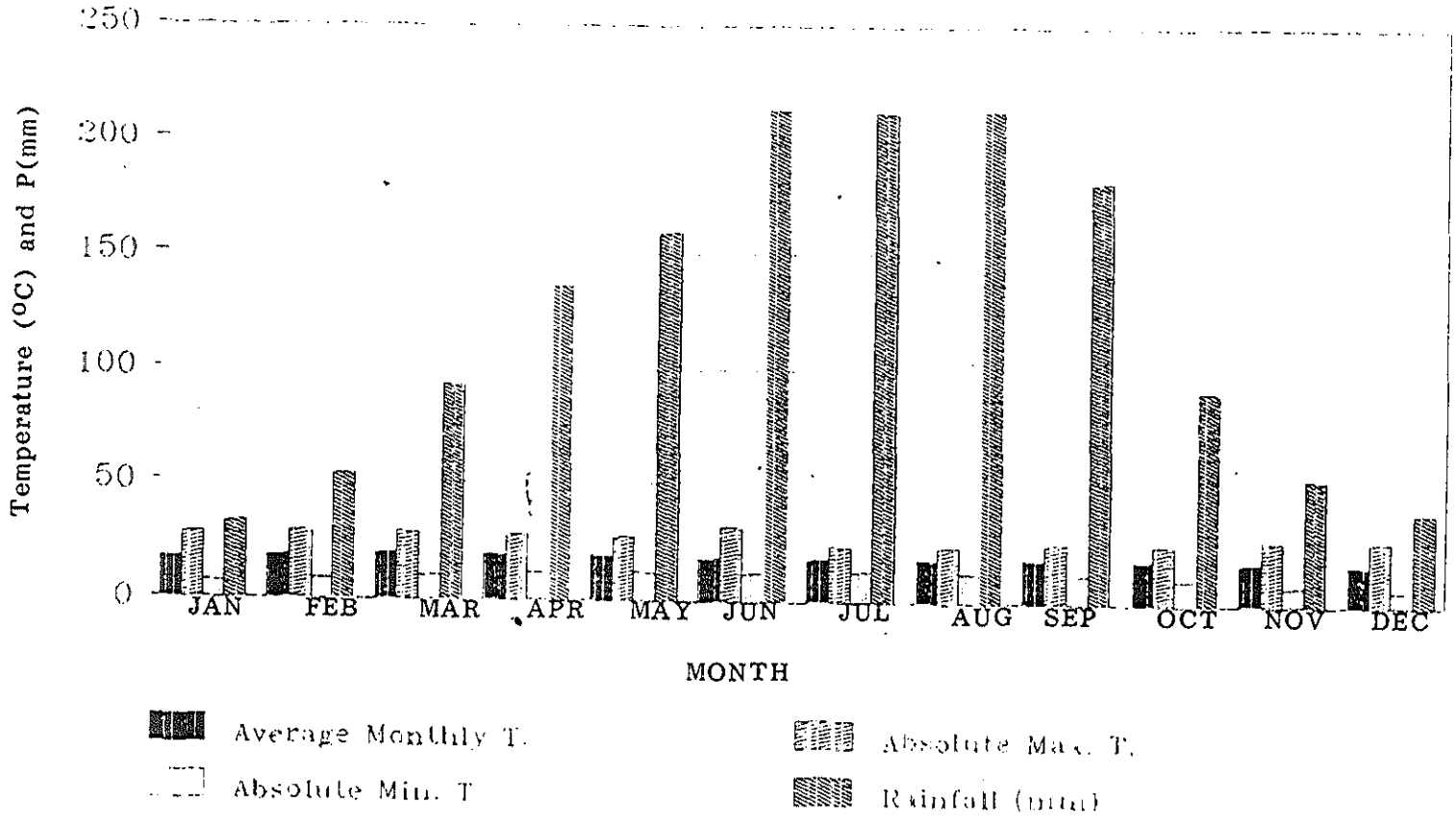


Fig. 3.3. RAINFALL AND TEMPERATURE RELATIONS AT JIMMA STATION



the vegetation, and appropriate latitude factor (Table 3.3).

In the investigated area the alluvial zones and the top ofthe highlands are mainly covered by clay soils. The available water capacity for this type of soil is 30 percent which means 300 mm of water per meter depth of soil (Thornthwaite, C.W., and Mather J.R, 1957). The studied area is largely covered with woody vegetation. The depth of root penetration under the brushy regenerating woodland is about 83.3 cm. (Average field estimation), indicating the root zone could hold (300 mm/m x 0.833 m) 250 mm of water at field capacity.

The procedure for calculating the actual evapotranspiration and other hydrologic parameters is given in Leopold,Luna B. and Dunne, T., 1978. The results are summarized in Fig. 3.4 and Table 3.3.

Figure 3.4 shows the main hydrologic characteristics of the basin. The graph indicates the seasonal pattern of :

- precipitation
- actual evapotranspiration
- potential evapotranspiration
- soil moisture deficit
- soil moisture utilization
- soil moisture recharge, and
- moisture or water surplus in the last thirty eight years.

Based on the above calculation the annual actual

evapotranspiration is equal to 822.29 mm. From the total annual precipitation of 1476.89 mm, the surplus is 654.60 mm, which is available for runoff and infiltration. The yearly amount of actual evapotranspiration and surplus in a basin is 55.68 and 44.32 percent of the annual precipitation, respectively.

3.3. Runoff

The investigated area is located in the upper part of the Ghibe-Omo River basin (Appendix 10) which drains into Lake Rudolf on the Ethiopian-Kenya Border.The nearest major tributary to the study area is the Gilgel Ghibe which flows through the wide alluvial plain in southeast direction south of the map-area.

The studied area is drained by two small streams, the Aweytu and the Kitto. Both the streams receive a supplementary feeding by small tributaries that flow down from the topographically high areas which have a fairly high gradients.

In the Kochi valley, runoff is carried by Kochi stream, which is intermittent, from the bordering steep, poorly drained Jirean hillside and genteel, moderately drained hill slope of the Kochi highland, and from the extensive valley bottom with poorly drained top soil.

Due to poorly drained nature of the top soil and its flat topography, the runoff from this valley is sluggish and this result a very small swampy area adjacent to this stream during the wet season and thus create an opportunity for infiltration to occur.

The discharge flowing in Aweytu river is the runoff from the central part of the studied area. The runoff occur from the bordering moderately drained, gentle concave hill slopes of the Hirmata and Kochi highlands, and from a narrow valley floor with moderately to well drained top soil. This valley become wider toward the south where the bordering hill slopes of the high lands are very gentle and finally become plain further toward the south. Because of the relatively well drained nature of the top soil of the valley floor, the water that flow from the hill slopes of the highlands is partly absorbed before reaching to the river as surface runoff.

The Hirmata hill slope also contribute to the runoff that occur through Kitto river from the Kitto valley. In the northwest and west, the bordering mountains range of this valley are characterized by a steep, moderately to highly drained hill slope. The extensive valley floor is covered by loose alluvial sediments that facilitates infiltration of surface water. Like the Kochi valley, this valley also has a small swampy area adjacent to the stream.

The discharge flowing in a Boye river is the runoff from the basin which is drained by its tributaries.

Since Boye river is a tributary of the Gilgel Ghibe river, in order to determine its runoff coefficient, due to the absence of gauging station, a computation of the runoff value, taking into consideration the Asendabo basin, has been carried out. The runoff coefficient is the least possible due to the

different morphological conditions of the two area. The vegetation and soil coverage and the geology of the two area is similar. Because of the lack of runoff data, therefore, the above assumption can help us to determine the runoff value for the area.

The mean annual runoff recorded at Asendabo station, at the outlet of the area, for the period 1972 - 1990 (excluding 1981, 1982 and 1987) was 1,198.82 million cubic meter of water. The annual mean rainfall in the Asendabo area is 1,156.94 mm within the area of 2,966 sq. km. The runoff coefficient in the Gilgel Ghibe river is

$$K = Q_A / (P_A \times A_A) \quad \text{------} \quad (3.5)$$

Where P_A = mean annual rainfall in Asendabo basin

A_A = surface area of Asendabo basin

Q_A = mean annual runoff in Asendabo basin

Hence, the runoff coefficient in the Asendabo basin is 0.349.

Since the basin is characterized by small streams which are the tributaries of the Boye river, by taking the mean annual precipitation (P_J) of the basin and the runoff coefficient of Boye river, the runoff from the basin can be calculated as follows.

The volume of runoff from the watershed of the studied area (Q) is given by

$$Q = (P_J \times A_b) K \quad \text{----------} \quad (3.6)$$

Where P_J = The mean annual precipitation at Jimma station = 1,476.89 mm

A_b = Area of the basin = 220.13 sq. km.

K = 0.349

Hence, Q becomes 113.46 X 10^6 m^3

Assuming 20 percent of infiltration from the river, the volume of the net runoff that leaves the studied area through Boye river will become 90.77 million cubic meter.

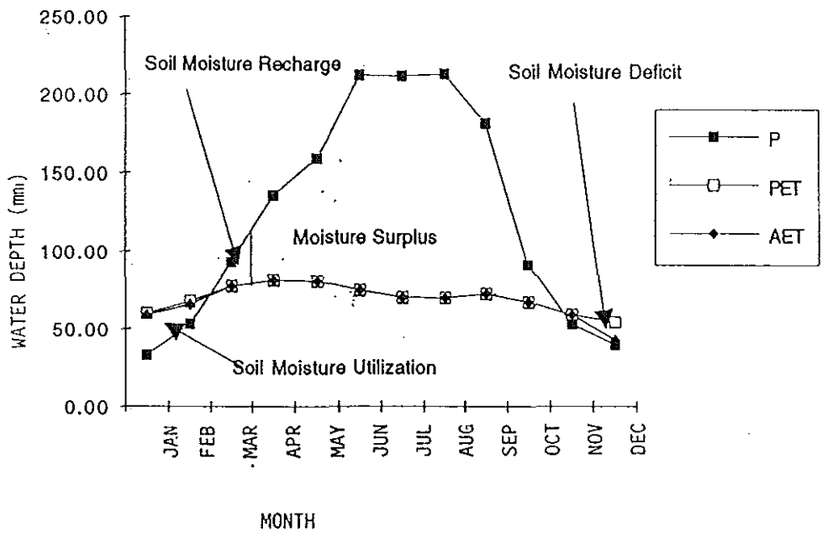
TABLE 3.3 AVERAGE MONTHLY WATER BALANCE

	J	F	M	A	M	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
T C	17 94	18.94	20 05	20 20	19 94	19.13	18 60	18 67	19 19	18.77	17.80	17.13	
J	6 92	7 51	8.19	8.28	8 12	7.63	7.31	7 35	7.66	7.41	6 84	6.45	89.67
GPET (mm)	62 37	69.37	77.57	78.72	76 74	70.75	66.95	67 45	71.18	68.16	61.42	56 97	
LCF 10 N	0.97	0.98	1.00	1.03	1 05	1.06	1.05	1 04	1.02	0.99	0.97	0 96	
CPET (mm)	60 50	67.98	77 57	81 08	80 58	75.00	70.30	70.15	72 60	67.48	59.58	54 69	837.51
P(mm)	33 37	53.07	92.84	135.78	159.07	212.33	211.78	212 87	181.38	91.31	53 27	39 82	1476.89
P-CPET(mm	-27.13	-14.91	15.27	54.70	78 49	137.33	141.48	142.72	108.78	23.83	-6.31	-14.87	639.38
APWL(mm)	-48.31	-63.22									-6.31	-21.18	
SM(mm)	215 00	202.00	217.27	250.00	250 00	250.00	250.00	250.00	250.00	250.00	244.00	241.00	
ΔSM(mm)	-26.00	-13.00	15.27	32.73	0.00	0.00	0.00	0.00	0.00	0.00	-6.00	-3.00	0.00
AET(mm)	59 37	66.07	77.57	81.08	80 58	75.00	70.30	70 15	72 60	67.48	59.27	42.82	822.29
D(mm)	1.13	1.91	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.31	11.87	15.22
S(mm)	0.00	0.00	0 00	21.97	78.49	137.33	141.48	142.72	108.78	23.83	0.00	0.00	654 60

T: Mean Monthly Temperature
J: Monthly Heat Index
GPET: Gross Potential Evapotranspiration
LCF: Latitude Correction Factor
CPET: Corrected potential Evapotranspiration
P: Mean Monthly Precipitation

APWL: Accumulated Potential Water Loss
SM: Soil Moisture
ΔSM: Change in Soil Moisture
AET: Actual Evapotranspiration
D: Soil Moisture Deficit
S: Soil Moisture Surplus

Fig. 3.4 MONTHLY AVERAGE WATER BALANCE



4. WATER BALANCE

The study of the water balance is the application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that, for any arbitrary volume and during any period of time, the difference between total input and output will be balanced by the change of water storage within the volume. In general, therefore, use of a water-balance technique implies measurements of both storages and fluxes (rates of flow) of water, though by appropriate selection of the volume and period of time for which the balance will be applied, some measurements may be eliminated (UNESCO, 1971).

The water balance equation for any natural area (such as a river basin) or water body indicates the relative values of inflow, outflow and change in water storage for the area or body. In general, the inflow part of the water balance equation comprises precipitation (p) as rainfall and snow actually received at the ground surface, and surface and subsurface water inflow into the basin or water body from outside (Q_{si} and Q_{ui}). The outflow part of the equation includes evaporation from the surface of the water body (E) and surface and subsurface outflow from the basin or water body (Q_{so} and Q_{uo}). When the inflow exceeds the outflow, the total water storage in the body (Δ s) increases; an inflow less than the outflow results in decreased storage. Consequently the water

balance for any water body and any time interval in its general form may be represented by the following equation:

$$P + Q_{si} + Q_{ux} - E - Q_{so} - Q_{up} - \Delta s = 0 \quad ----(4.1)$$

For application to a variety of water-balance computations equation (4.1) may be simplified or made more complex, depending on the available initial data, the purpose of the computation, the type of body (river basin or artificially separated administrative district, lake or reservoir, etc.), and the dimensions of the water body, its hydrographic and hydrologic features, the duration of the balance time interval, and the phase of the hydrological regime (flood, low flow) for which the water balance is computed.

On the other hand, depending on the specific problem, the terms of equation (4.1) may be subdivided. For example, in the compilation of water balances for short time intervals, the change in total water storage (Δ s) in a small river basin may be subdivided into changes of moisture storage in the soil (Δ M), in aquifers (Δ G), in lakes and reservoirs (Δs_l), in river channels (Δs_{ch}), in glaciers (Δs_{gl}) and in snow cover (Δs_{sn}). Thus in this case the water balance equation becomes;

$$P + Q_{si} + Q_{ux} - E - Q_{so} - Q_{up} - \Delta M - \Delta G - \Delta S_l - \Delta S_{ch} - \Delta S_{gl} - \Delta S_{sn} = 0 \quad ------ (4.2)$$

Where Q_{si} represents the net surface water diversion from other basins.

The main purpose of this computation is to make a quantitative evaluation of the amount of water that percolate into the ground to recharge the groundwater circulation occurring in the studied area.

Eventhough the studied area is characterized by balance regime the computation of the specific water balance are not made individually. In the investigated area, these land types cover less than 20% of the total basin area. For a given basin which are characterized by balance regime (grass, land, forest, irrigated or drained lands, swamps, glaciers, etc.), the computation of specific water balance for individual areas is made when these land types cover more than 20 - 30% of the total basin area (UNESCO, 1974).

Various assumptions have been made to derive the water balance equation for the studied area and these are summarized below :

1. Since the computation are made on annual basis, net change of soil moisture and groundwater storage are assumed to be zero.
2. Subsurface water exchange with neighbouring basins is assumed to be zero.
3. Assuming no artificial diversion from other basins.

Thus the water balance equation for the studied area is written as follows ;

$$P - ET - Q - I = 0 \qquad (4.3)$$

Where ET = Evapotranspiration

I = Infiltration

P = Precipitation

Q = River discharge from the basin

From the budget equation, Eqn. 4.3, the amount of water that percolate into the ground in a basin as a groundwater accretion has been calculated as follows.

A_s = Area of the basin = 220.13 sq.km.

P = 1476.89 mm

ET = 822.29 mm

Q = 515.42 mm

From Eqn. 4.3

$$I = P - ET - Q \qquad (4.4)$$

Therefore,

$$I = [\ (1476.89 - 822.29 - 515.42\ )]\ mm$$

$$= 139.18\ mm$$

In terms of water volume measured in cubic meter,

I expressed as :

$P = 325.11 \times 10^6\ m^3$

$ET = 181.01 \times 10^6\ m^3$

$Q = 113.46 \times 10^6\ m^3$

Therefore,

$$I = [\ 325.11 - (181.01 + 113.46)\ ] \times 10^6\ m^3$$

$$= 30.64 \times 10^6\ m^3$$

In the rainy period when flood occurs, seepage from the river occurs in the river bed to recharge the groundwater (Cooper and Rorabaugh, 1963), and this amount roughly evaluated as 20% of the total runoff (Tamiru, 1992). Therefore, the amount of water that infiltrate into the ground is given by

$I = 139.18\ mm + 0.2Q$

$= 242.26$ mm which is equivalent to $53.33 \times 10^6\ m^3$

Annual discharge for domestic and non-domestic uses in the basin is 2,185,444.8 cubic meter.Therefor,the net amount of water that percolate into the ground is given by

$In = I - 2,185,444.8$

$In = 51.14 \times 10^6\ m^3$

The water losses due to direct evaporation from the flowing water in the river beds are normally neglected, therefore, the annual amount of water percolating into the ground in a basin as infiltration is 15.73 percent of the yearly precipitation.

Based on the above calculation, therefore, it is possible to say that the total amount of water which is actually available to recharge the groundwater circulation within the hydrological basin is 51.14 million cubic meter.

5. HYDROGEOLOGY

The modes of groundwater occurrence are affected by the geologic development and properties, delineation, and boundary conditions of the unconsolidated sediments and rocks through which the water percolates. They depend also on ongoing activities and climatic and environmental conditions.

In groundwater studies, the rock structure of a formation is more important than its texture. The presence of small holes or vesicles throughout a formation, such as those in pumice and some basalts, increase the permeability of these rocks. Open or closed rock fissures, in the form of joints and fractures, are important features in groundwater hydrology. The rock may be practically impervious. The presence of these deficient structures (vesicles, vugs, joints, and fractures) gives a rock formation a higher water - yielding capacity. The degree of permeability of unconsolidated sediments determine their ability to store and to transmit water through them.

In this chapter the hydrogeological character of the outcropping rocks and unconsolidated sediments are discussed with a particular reference to their infiltration and water-yielding capacity.

On the basis of their hydrogeological character the rocks and unconsolidated sediments that constitute the geology of the studied area are classified into two groups: Volcanics and alluvial sediments.

5.1. Volcanic Rocks

This group consists of varying volcanic rock types with differing hydraulic conductivity, such as trachyte, rhyolite, basalt and pyroclastic rocks.

The general occurrence and character of the acidic volcanic rocks, which are predominantly rhyolites with minor outcrops of trachytes, indicates that the primary porosity and permeability of these rocks are relatively small. Joints and fissures where present is barely sufficient and far apart to each other. Because of the insufficiency of these structures and their low degree of interconnectivity, the permeability and yield of these rocks are extremely small; and are considered as poor aquifers.

Lithological log of borehole (Fig. 2.4) and exposure in quarries shows that the rhyolite and trachyte rocks are weathered, which causes a reduction of the size of fractures and other openings and results a progressive decreasing of permeability of these rock bodies.

The topography of the area in which the acidic volcanic rocks outcrop has also a contribution to their low degree of water productivity. These rocks are well represented in the northeast and eastern part of the studied area, in the Jiren hill range, which has a higher elevation. The scarce vegetation cover and steep hill slope nature of this hill range highly facilitates the runoff and consequently the infiltration

is lowered.

The tuff that are found interlayered with basaltic flows in the north and northwestern part of the studied area, both in the highlands (Fig. 2.1) and valleys (Fig. 2.3), are welded so that they can be considered as impervious units. Whereas the ignimbrites and tuffs that are found interlayered with the acidic volcanic rocks in the east and northeastern part of the studied area where intersected by local vertical joints and fractures act as an aquitard.

Conditions for groundwater recharge in the uplands, north, northwest and central part of the studied area, which are characterized by a relatively lower elevation than that of the Jiren hill range, seem to be favorable. Exposures in road cuts, quarries, and boreholes shows that the basalts are quite deeply weathered and that the weathered layer at the surface is fairly permeable. Numerous springs, none of which have very large discharge, along with records of a few rock wells, show that the basaltic rocks are good aquifers. In addition to the secondary permeability, the basaltic rocks have primary features that cause permeability within them. Davis (1969) notes that these features are related to the history of the rocks. The water moves through fractures in basalt and also in permeable zones along the horizontal contacts between lava flows. Such permeable interflow zones are created when molten lava flows over a surface where there was sufficient moisture to generate steam.

In the central part of the studied area, in the Kochi and Hirmata highlands, basalts are overlain by a thick brownish red soil. Since these highlands are covered by vegetation, the infiltration capacity of the soils will be high and consequently the degree of water productivity of the underlying basaltic aquifers are increased.

In the investigated area, the degree of water productivity of the basaltic aquifers, however, is limited by two main factors. These are :

1. Due to its location in the topographically high area, it act as a source of replenishment for the aquifers that occur down in the topographically lower areas. Wells drilled in this rock also obtain water but have limited capacity.

2. Due to the relatively large volumes of groundwater discharge as a major springs with sustained base flows. Because of the great thickness of the basaltic flows groundwater is most readily available in valley bottom; however, in the highlands, deep wells are required to extract sufficient yields of groundwater.

Due to the effect of these factors in its water-yielding capacity, the basaltic aquifers have a relatively less degree of productivity than the alluvial sediments which constitute the relatively high productive aquifers of the studied area.

5.2. Alluvial Sediments

The alluvial sediments occur filling partly the broad valleys of the studied area which serve as the storage volumes

for water flowing from near by highlands and mountains. The alluvial fill function as a productive aquifer and creates the opportunity for development of relatively high-yielding wells. The alluvial sediments are conspicuously absent in the volcanic cover of the topographically high areas.

The thickness of the alluvial sediments beneath the ground surface varies from 20 m in the upper part to more than 200 m in the deeper part of these valleys.

In the valleys, because of the shifting position of stream channels and the ever-changing depositional velocities, the alluvial sediments have characteristic texture variability that causes much heterogeneity in the distribution of hydraulic properties. In the north, northeast and northwest toward the mountain front, the alluvial sediments are dominated by subangular to subrounded coarse grained particles. Fine grained particles, mainly clay and silt with minor amount of sand, are predominant in the central and lower part of these valleys (Fig. 5.1, Fig. 5.2 and Fig. 5.3).

The degree of water productivity of a water-bearing formation depends on the degree of natural water recharge, its physical and chemical properties, climatic conditions, the characteristics of its geometric and hydrologic boundaries, vegetation, and human activities. In the investigated area because of the relatively high degree of permeability of the volcanic rocks and the alluvial sediments and because of groundwater drainage from the bordering mountains and highlands

wells of relatively high average yield occurs in the valleys.

On the basis of topography, variations in hydraulic properties of volcanic rocks and alluvial sediments, and their location three sub - basins have been established within the area under study. These are the Kochi, the Aweytu, and the Kitto Sub - Basins (Map 2). Each of these sub - basin will be discussed separately in the following sections. This will describe briefly about the main types of formations associated with groundwater occurrence and their yielding capacities of the main hydrogeological basin.

1. Kochi SUB - BASIN

The Kochi sub - basin is located in the eastern part of the studied area. It has an area of about 25 sq.Km. 11 sq.Kms. of the total area of this sub-basin is covered by alluvial sediments while the rest 14 sq.Kms. is covered by volcanic rocks.

This sub-basin is formed principally by volcanic rocks interbedded with or overlain by alluvial sediments. For the sediments, the grain size analysis have been carried out from a pit sample of 3 m depth from the central part of this sub - basin with the assumption that this part would represent the whole alluvial sediments in this sub - basin. Results are plotted on a particle- size distribution graph shown in Fig. 5.1. From this figure 65% is clay, 20% is silt, and the remaining 15% is sand. This result is confirmed by the occurrence of clay with a thickness of 15 m below the ground

surface in the lower part of this sub - basin (Fig. 2.4). The predominant occurrence of this fine grained sediments, which has low value of hydraulic conductivity, suggests low rate of deep percolation of rainfall in this sub - basin. The Kochi sub - basin is constituted by unconfined, semi- confined and confined aquifers. The alluvial sediments and weathered and fractured volcanic rocks are the principal aquifers of this sub-basin. As shown in Fig. 2.4, weathered rhyolite are found interlayered and mixed with clay units, derived from weathering so that groundwater occur within a multilayer aquifers under semiconfined or confined conditions, where the clay units play an important role as leaky aquitards.

It is exploited by a number of wells whose yields range from 1 l/s., in the southern part, to 6.3 l/s., in the northeastern part of it. The well productivity increases toward the highland and the mountain front where the alluvium is coarse and permeable and the underlain bed rock is more intensely fractured.

The multilayer aquifers are recharged by the runoff coming from the Jiren hill range and the Kochi highland and by the direct deep infiltration of rainy water where the poorly drained top sediment is absent or affected by evident shrinkage cracks.

As a whole the upper part of this sub - basin is a source of replenishment for the aquifers that occur down in the lower most part of it.

2. AWEYTU SUB - BASIN

The Aweytu sub - basin is located in the central part of the studied area. It is situated between the Hirmata and Kochi highlands. It has an area of about 81 sq. Km. The basalts in this area comprise 75 sq. Kms. while the sediments cover 6 sq. Km.

This sub - basin is also a recharging area for the aquifers that occur down in the southeastern part of the studied area.

In this sub-basin the alluvial sediments is underlain by highly weathered and fractured basalts. Sample of sediments have been taken from this sub-basin, near the centre of the town, from a pit of 3 m depth for grain size analysis which could give a clue to the porosity of the sediments. The sample is taken with the assumption that it would represents the whole alluvial sediments in this sub-basin. Results are plotted on a particle-size distribution graph shown in Fig. 5.2. As it was depicted in the figure 77 percent of the sediments are clay and silt and 23 percent is sand. Here, with a small amount of percentage difference, again fine grained particles are predominant. However, as it was shown from the lighological log of Jimma stadium well (Fig. 2.2), this sub-basin is characterized by a moderately drained top soils which has a relatively high infiltration capacity. This is may be due to the relatively dense vegetation cover of the area. The presence of a vegetative cover over a soil provides a layer of decaying

organic matter which promotes the activity of burrowing insects and animals which, in turn, produces permeable soils structure.

The Aweytu sub-basin consists of unconfined, semiconfined and confined aquifers. Aquifers are alluvial sediments and weathered and fractured basalts with low to moderate yields. They are recharged by the runoff coming from the two highlands and mountains in the north and northwest, by direct deep infiltration of rainfall, and by the Aweytu river.

In this sub-basin there are 5 boreholes and of these 4 are located on the basaltic aquifer and the remaining one is located on the alluvial and basaltic aquifers. Wells yield range from 1.5 l/s., in the highlands, to 4.5 l/s., in the valley.

3. KITTO SUB - BASIN

The Kitto sub - basin is located west of the Aweytu sub basin. It includes the northwestern, western, and southwestern part of the studied area. It has an area of about 114 sq. Km. The alluvial sediments cover an area of 26 sq. Kms.,which is equivalent to 60.47 percent of the total area covered by the sediments in the basin. 88 sq. Kms. of this sub-basins covered by basaltic rocks.

Log information from the wells, Fig. 2.3 and exposure in quarries indicates that this sub-basin is underlain by basaltic flows.

With the assumption that the sediments near the airport would represent the whole alluvial sediments in this sub-basin,

grain size analysis have been carried out from a pit sample of 3 m depth. Results are plotted on a particle-size distribution graph shown in Fig. 5.3. From the figure 58 percent is clay, 26 percent is silt, and 16 percent is sand. However, these fine grained sediments, which are predominant, are moderately permeable. The Kitto sub-basin is largely covered with vegetation as compared to the other two sub-basins. In the highlands and valley toward the northwest and western part of this area, coffee plants are grown under the shade of different species of tropical trees. Apart from coffee many crops such as maize (Zea mays), banana (Musa spp.), citrus (Citrus spp.) etc. are also grown in this part of the area. The presence of this vegetation cover help in increasing the infiltration capacity of the sediments. This is confirmed by the yields of the wells at Kitto well field. The Kitto well field consist of five drilled wells located in the valley near the airport. According to the report of WSSA of Jimma, the alluvial aquifer in this well field is productive and is capable of supplying much more water than is being withdrawn at the present time.

In this sub-basin, in addition to the Kitto well field, there is also one drilled well which is located in the Agricultural Research office. In the Kitto well field, all the wells are close to a swampy area along a meandering Kitto river. They each have a subsurface pump chamber which is reported to get flooded during high water in the rainy season. These wells produce large quantities of water for the community

water system of Jimma, as infiltration from the river augments groundwater supplies.

This sub-basin consist of unconfined, semiconfined, and confined aquifers. The Agricultural Research Office and 4 wells from the Kitto well field are the presently functioning wells tapping water from the alluvial and basaltic aquifers. Wells yield from these aquifers range from 4 - 8 l/s. The aquifers are recharged by the runoff from the bordering mountains, in the northwest and western part, and highland (Hirmata), in the eastern part, by downward percolation of water from precipitation and from Kitto stream. This sub-basin is also a recharging area for the aquifers that occur down in the southeastern part of the studied area.

As it is shown in the groundwater flow net in Map 2 the whole Kitto and Aweytu sub-basins and the upper part of the Kochi sub-basin converge toward the aquifers that are located adjacent to the Boye river in the southeastern part of the studied area. The flow lines in the Map 2 deliver groundwater from recharge areas to discharge areas. The areas adjacent to the Boye river is the medium through which the discharge of the whole hydrogeological basin takes place. Here the alluvial sediments have relatively large lateral extent and thickness. Up to now, however, no well is drilled in this area, because of this a through study of the types and groundwater potential of the aquifers was not possible.

Eventhough the aquifers in the studied area are exploited

by a number of wells both in the valleys and highlands, the actual groundwater productivity of these acquifers has not yet been determined.

Fig. 5.1 GRAIN SIZE DISTRIBUTION OF THE SEDIMENTS IN KOCHI SUB-BASIN

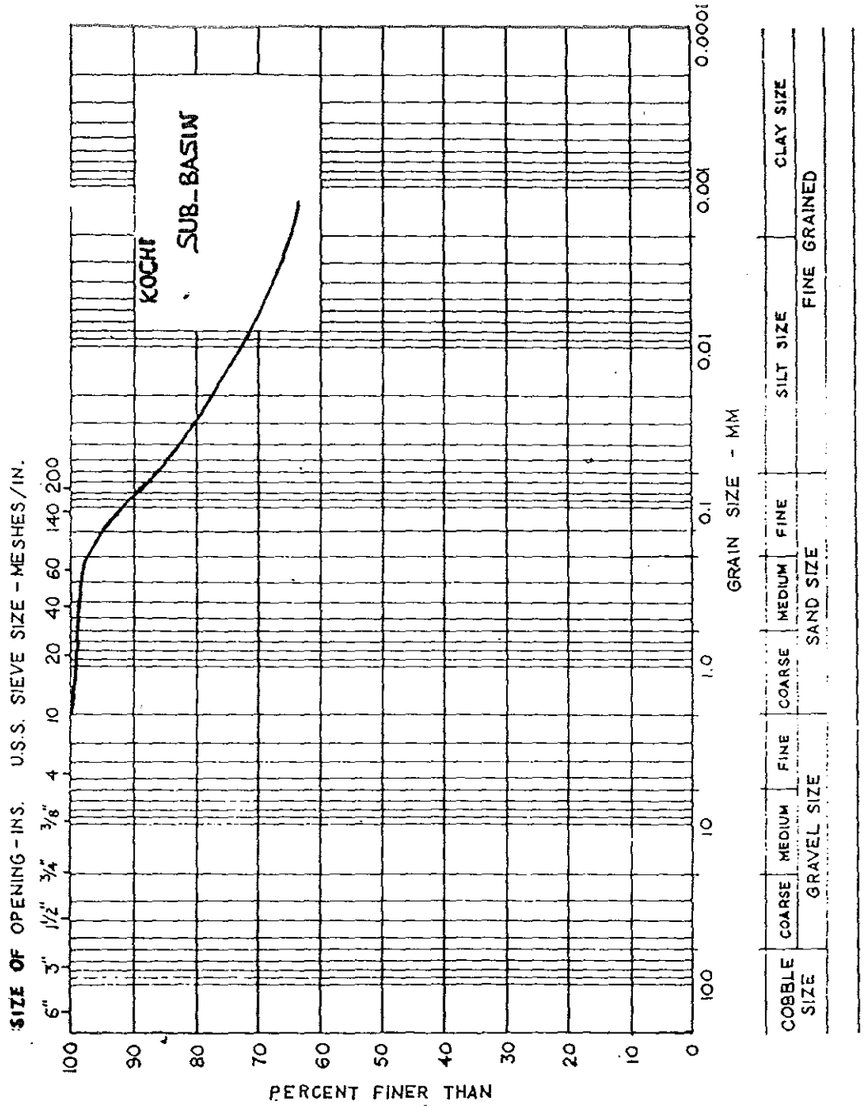
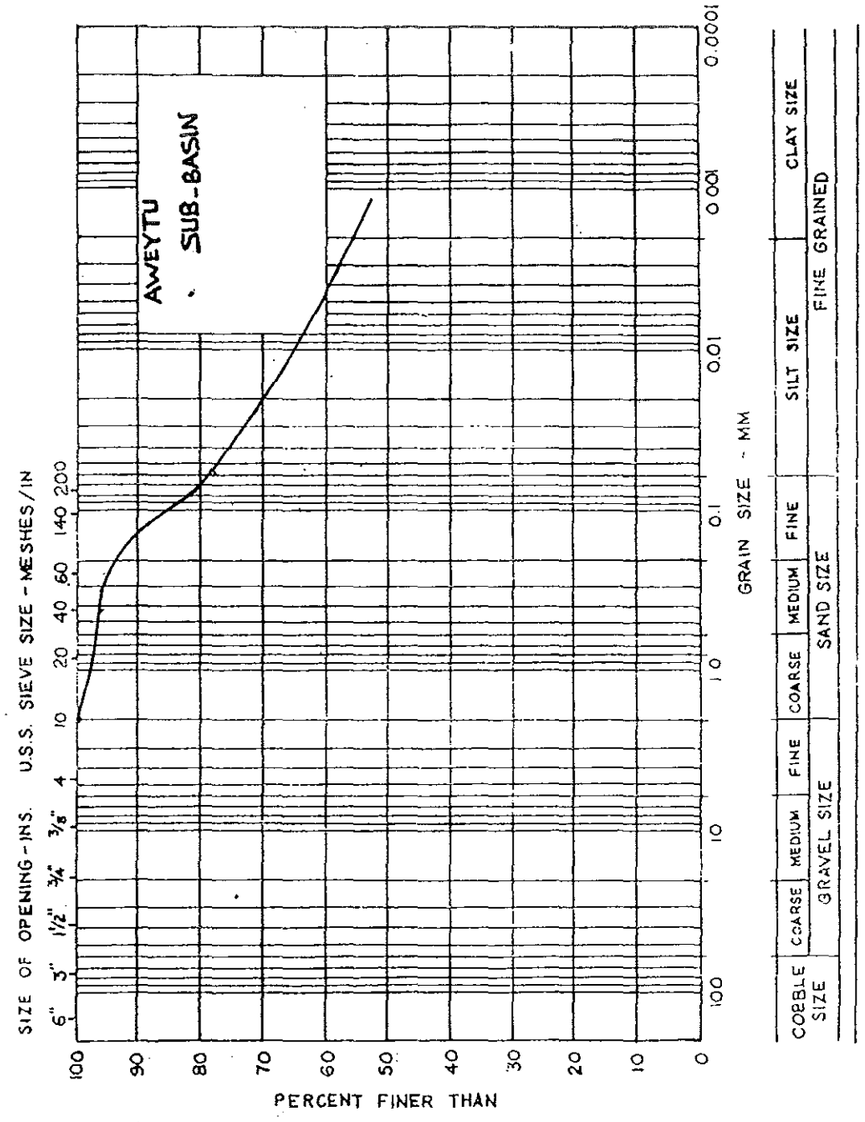


Fig. 5.2 GRAIN SIZE DISTRIBUTION OF THE SEDIMENTS IN AWEYTU SUB-BASIN



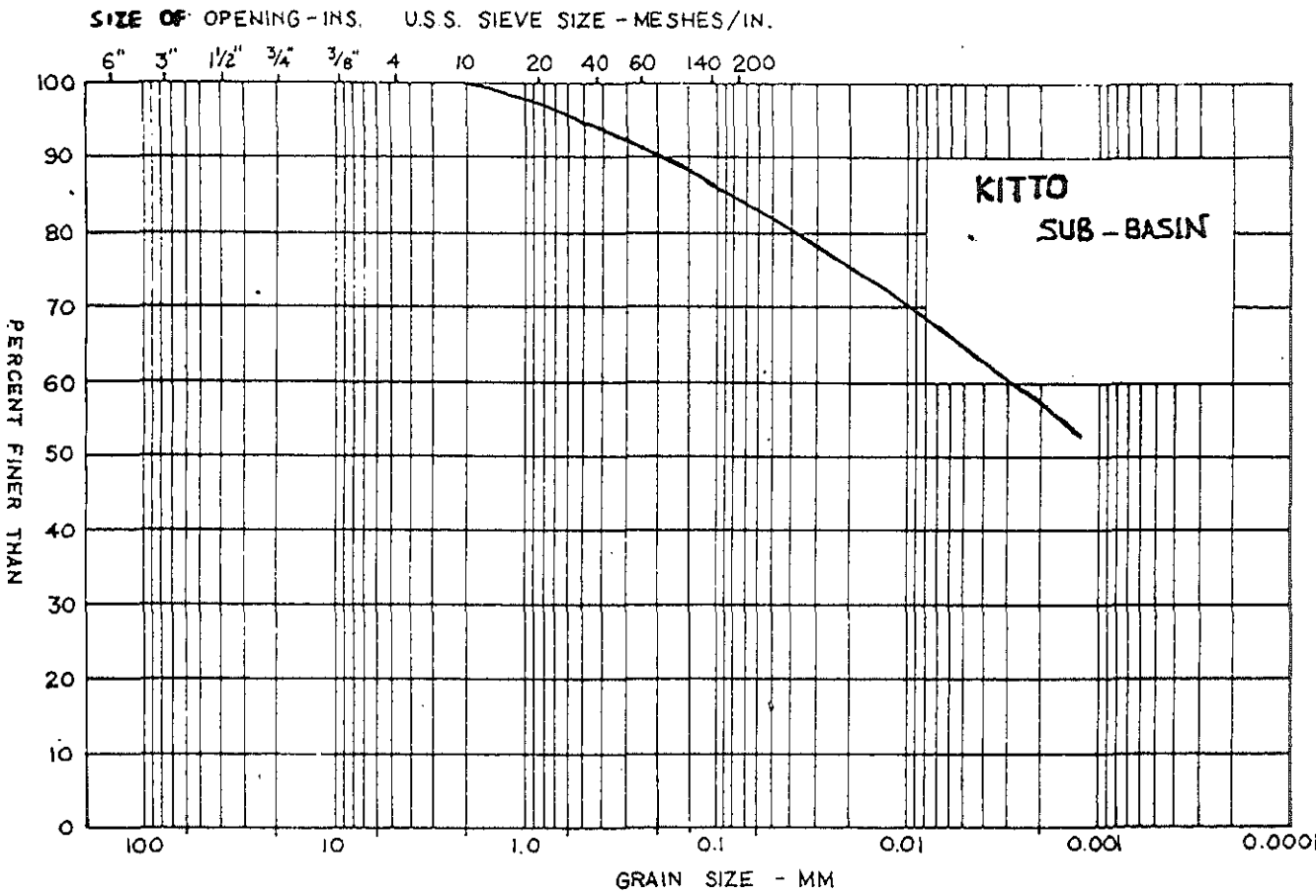


Fig. 5.3 GRAIN SIZE DISTRIBUTION OF THE SEDIMENTS IN KITTO SUB-BASIN

6. HYDRODYNAMICAL INVESTIGATION OF AQUIFERS AND WELLS

6.1. General

In designing capture and dewatering systems of groundwater, besides schematizing the natural hydrogeological conditions, it is important to know the hydrogeological parameters. Their determination constitutes one of the principal problems of hydrogeology, due to the various degrees of accuracy of the methods employed and of the expense of field test. Determination of hydrogeological parameters can be made by several laboratory or field techniques. Methods based on well-pumping tests generally give the most reliable results for field measurement.

The hydrodynamic investigation of the aquifers by pumping, frequently followed by the recovery of the water level in the experimental well constitutes an investigation technique indispensable to any kind of hydrogeological research. This method uses empirical relations based directly on the experimental data. By pumping test of wells, hydrogeological parameters characterizing the aquifer proper in areas can be determined; furthermore, with these aquifer characteristics known, future declines in groundwater levels associated with pumpage can be calculated.

Hydrogeological parameters are divided into two groups: The first group includes the parameters characterizing the experimental drilling and its adjacent area, namely the rate of

discharge Q and the drawdown s which permit us to draw the indication diagram Q = f(s), the well loss and the seepage resistance of the well.

The second group includes the parameters characterizing the aquifer proper in areas more or less remote from the experimental well, to wit the hydraulic conductivity K, the transmissivity T, the storage coefficient S, the hydraulic diffusivity and the capillary rise. Naturally to the second group could be added the aquifer thickness, the position of the piezometric surface or of the water table as well as other geometrical characteristics of the aquifer (scattering area, slope, shape of its boundaries in the horizontal and in the vertical sections); but these parameters do not involve particular experimental works since they are determined by hydrostatic methods.

The transmissivity and storage coefficients are especially important because they define the hydraulic characteristics of a water-bearing formation. The coefficient of transmissivity indicates how much water will move through the formation, and the coefficient of storage indicates how much can be removed by pumping or draining. If these two coefficients can be determined for a particular aquifer, predictions of great significance can usually be made. Some of these are :

1. Drawdown in the aquifer at various distances from a pumped well.
2. Drawdown in a well at any time after pumping

starts.

3. How multiple wells in a small area will affect one another.
4. Efficiency of the intake portion of the well.
5. Drawdown in the aquifer at various pumping rates.

The certainty degree of the tested aquifer parameter depends on the importance that the design and the accomplishment of the hydrodynamic test granted to the features of the hydrogeological conditions as well as to theoretical achievements in this field(Gheorghe,A., 1978).

6.1.1. Well Flow Equations

Well flow equations have been developed for steady and unsteady flows, for various types of aquifers, and for several special boundary conditions. For practical application most solution have been reduced to convenient graphic or mathematical form. There are two types of well flow equations, equilibrium well equations and nonequilibrium well equations.

6.1.1.1. Equilibrium Well Equations

Well flow equations for equilibrium conditions were derived by various investigators (Slichter, 1899; Turneaure and Russell, 1901, Thiem, 1906). These equations relating well discharge to drawdown assumed two-dimensional radial flow

toward a well (the vertical component of flow is ignored). There are two basic equations : one for unconfined conditions and the other for confined conditions. For both equations, all dynamic conditions in the well and ground are assumed to be in equilibrium; that is the discharge is constant, the drawdown and radius of influence have stabilized, and water enters the well in equal volumes from all directions. Both assume horizontal flow every where in the aquifer with recharge occurring at the periphery of the cone of depression.

Confined Aquifer

The equation for a well operating under confined condition is:

$$Q = \frac{2.73\ kb\ (H-h)}{\log R/r} \quad \text{-----} \quad (6.1)$$

Where

Q = Well yield or pumping rate, in m^3/day

K = hydraulic conductivity of the water - bearing formation, in $m^3/day/m^2$ (m/day).

b = aquifer thickness in m.

H = static head measured from bottom of aquifer, in m.

h = depth of water in the well while pumping, in m.

R = radius of the cone of depression, in m

r = radius of the well in m.

Equation (6.1) is often called the equilibrium or Thiem, equation.

Unconfined Aquifer

The equation for the well yield of an unconfined aquifer is:

$$Q = 1.366 \frac{K(H^2 - h^2)}{\log R/r} \quad \text{--------} \quad (6.2)$$

All the terms are as defined for equation (6.1).

Derivations of the foregoing equations are based on the following simplifying assumptions:

1. The water-bearing materials have a uniform hydraulic conductivity within the radius of influence of the well.
2. The aquifer is not stratified
3. For an unconfined aquifer, the saturated thickness is constant before pumping starts; for a confined aquifer, the aquifer thickness is constant.
4. The pumping well is 100 percent efficient, that is the drawdown levels inside and just outside the well bore are at the same elevation.
5. The intake portion of the well penetrates the entire aquifer.
6. The water table or potentiometric surface has no slope.
7. Laminar flow exists throughout the aquifer and within the radius of influence of the well.
8. The cone of depression has reached equilibrium so that

both drawdown and radius of influence of the well do not change with continued pumping at a given rate.

Equations 6.1 and 6.2 can be modified to calculate hydraulic conductivity if Q, H, and R are determined from a pumping test, and b is known from the driller's log. For a confined aquifer, the equation for calculating K is:

$$K = \frac{Q \log r_2/r_1}{2.73b(h_2-h_1)} \qquad \text{------(6.3)}$$

Where

r_1 = distance to the nearest observation well, in m.

r_2 = distance to the farthest observation well, in m.

h_2 = head, in m, at the farthest observation well, measured from the bottom of the aquifer.

h_1 = head, in m, at the nearest observation well, measured from the bottom of the aquifer.

b = thickness of the aquifer, in m.

All other terms are as defined in Equation 6.1

The transmissivity is given by

$$T = Kb = \frac{Q \log r_2/r_1}{2.73 (h_2 - h_1)} \qquad \text{-------} \quad (6.4)$$

From a practical stand point, the drawdowns, rather than the head h, is measured so that Eq. 6.4 can be written

$$T = \frac{Q \log r_2/r_1}{2.73 (s_1 - s_2)} \qquad \text{--------} \quad (6.5)$$

Where :

s_1 = drawdown, in m at the nearest observation well.

s_2 = drawdown, in m at the farthest observation well.

For unconfined conditions, the equation for determining the hydraulic conductivity is

$$K = \frac{Q \log r_2/r_1}{1.366(h^2_{\ 2} - h^2_{\ 1})} \qquad \text{---} \quad (6.6)$$

Where

all terms except the following are the same as for Eqn. 6.3

h_2 = saturated thickness, in m, at the farthest observation well.

h_1 = saturated thickness, in m, at the nearest observation well.

This equation fails to describe accurately the drawdown curve near the well because the large vertical flow components contradict the Dupuit assumptions; however, estimates of K for given heads are good. In practice, drawdowns should be small

in relation to the saturated thickness of the unconfined aquifer.

The transmissivity can be approximated from Eq. 6.6

$$T = K \frac{h_1 + h_2}{2} \quad \text{---------} \quad (6.7)$$

Where drawdowns are appreciable, h_1 and h_2 in Eq. 6.6 can be replaced by $(h_0 - s_1)$ and $(h_0 - s_2)$, respectively. Then the transmissivity for the full thickness becomes.

$$T = Kh_o = \frac{Q \ln(\frac{r_2}{r_1})}{2\pi[(s_1 - \frac{s_1^2}{2h_o}) - (s_2 - \frac{s_2^2}{2h_o})]} \quad (6.8)$$

Where h_0 is the saturated thickness, in m, at the pumped well before pumping was started, while s_1 and s_2 are as defined in Eq. 6.5. All other terms are as defined in Eq. 6.6.

6.1.1.2. Nonequilibrium Well Equations

The applicable differential equation in plane Polar Coordinates is

$$\delta^2 h/\delta r^2 + 1/r \; \delta h/\delta r = S/T \; \delta h/\delta t \quad \text{------} \quad (6.9)$$

Where h is head, r is radial distance from the pumped well, S is the storage coefficient, T is transmissivity, and t is the time since beginning of pumping. Theis obtained a solution for Eq. 6.9 based on the analogy between groundwater flow and heat condition. By assuming that the well is replaced by a mathematical sink of constant strength and imposing the boundary conditions $h = h_0$ for $t = 0$ and $h \longrightarrow h_0$ as $r \longrightarrow \infty$ for $t \geq 0$, the solution

$$s = Q/4\pi T \int_u^{\infty} e^{-u} \, du/u \qquad (6.10)$$

is obtained, where s is drawdown, Q is the constant well discharge, and :

$$u = r^2 S/4Tt \quad \text{----------} \qquad (6.11)$$

Equation 6.10 is known as the nonequilibrium, or Theis, equation. The integral is a function of the lower limit u and is known as an exponential integral. It can be expanded as a convergent series so that Eq. 6.10 becomes

$$S = Q/4\pi T \, [-0.5772 - \ln u + u - u^2/2.2! + u^3/3.3! - u^4/4.4! + \ldots] \quad \ldots (6.12)$$

The nonequilibrium equation permits determination of the formation constants S and T by means of pumping tests of wells.

The equation is widely applied in practice and is preferred over the equilibrium equation because :(1) a value of S can be determined, (2) only one observation well is required, (3) a shorter period of pumping is generally necessary, and (4) no assumption of steady state flow conditions is required.

The assumption inherent in Eq. 6.10 should be emphasized because they are often overlooked in applying the nonequilibrium equation and thereby can lead to erroneous results. The assumptions include :

1. The aquifer is homogeneous, isotropic, of uniform thickness, and of infinite areal extent.
2. Before pumping, the piezometric surface is horizontal.
3. The well is pumped at a constant discharge rate.
4. The pumped well penetrates the entire aquifer, and flow is every where horizontal within the aquifer to the well.
5. The well diameter is infinitesimal so that storage within the well can be neglected.
6. Water removed from storage is discharged instantaneously with decline of head.

Seldom, if ever, are these assumptions strictly satisfied, but recognition of them can create an awareness of the approximations involved for employing the nonequilibrium equation under field conditions. Average values of S and T can

be obtained in the vicinity of a pumped well by measuring in one or more observation wells the change in drawdown with time under the influence of a constant pumping rate. Because of the mathematical difficulties encountered in applying Eq. 6.10 or, its equivalent Eq. 6.12 several investigators have developed simpler approximate solutions that can be readily applied for field purposes. Three methods, by Theis, Cooper and Jacob, and Chow, are described in the following sections.

Theis Method of Solution. Eq. 6.10 may be simplified to :

$$s = (Q/4\pi T)\, W(u) \quad \text{----------} \quad (6.13)$$

Where

s = drawdown, in m, at any point in the vicinity of a well discharging at a constant rate

Q = pumping rate, in m^3/ day

T = coefficient of transmissivity of the aquifer, in m^2/day.

W(u)= Well function and represents an exponential integral.

Rewriting Eq. 6.11 as

$$r^2/t = (4T/S)u \quad \text{----------} \quad (6.14)$$

It can be seen that the relation between W(u) and u must be similar to that between s and r^2/t because the terms in parentheses in the two equations are constants. Given this

similarity, to obtain the formation constants from pumping test data, Theis suggested an approximate solution based on a graphical method of superposition.

A plot on logarithmic paper of W(u) versus u known as a "type curve," is prepared. Appendix 6 gives values of W(u) for a wide range of u. Values of drawdowns are plotted against values of r^2/t on logarithmic paper of the same size as for the type curve. The observed data curve is superimposed on the type curve, keeping the coordinate axes of the two curves are parallel, and adjusted until a position is found by trial whereby most of the plotted points of the observed data fall on a segment of the type curve. An arbitrary point is selected on the coincident segment, and the coordinates of this matching point are recorded. With values of W(u), u, s, and r^2/t thus determined, S and T can be obtained from Eqn. 6.13 and 6.14.

Cooper - Jacobo Method of Solution. It was noted by Cooper and Jacob (1946) that for small values of r and large values of t, u is small, so that the series terms in Eq. 6.12 become negligible after the first two terms. As result, the drawdown can be expressed by the asymptote

$$s = Q/4\pi T\ (-0.5772 - \ln r^2S/4Tt) \quad \text{------ (6.15)}$$

Rewriting and changing to decimal logarithms,

this reduces to

$$s = 0.183Q/T\ (\log 2.25Tt/r^2S) \quad \text{----(6.16)}$$

By using these simplified relationships based on Equation 6.16, it is possible to derive information on the hydraulic characteristics of aquifer by plotting drawdown and time data taken during a pumping test. The data are plotted on semilogarithmic paper. A plot of drawdown s versus the logarithm of t forms a straight line. Projecting this line to $s = 0$, where $t = t_0$

$$0 = 0.183Q/T \log(2.25Tt/ r^2S) \text{ ---- } (6.17)$$

and it follows that

$$2.25Tt_0/ r^2 S = 1 \text{ ----- } (6.18)$$

Resulting in

$$S = 2.25T_0/ r^2 \text{ --- } (6.19)$$

A value for T can be obtained by noting that if $t/t_0 = 10$, then $\log t/t_0 = 1$; therefore, replacing s by Δs , where Δs is the drawdown difference per log cycle of t, Equation 6.16 becomes

$$T = 0.183 Q/\Delta s \text{ ------- } (6.20)$$

Thus, the procedure is first to solve for T with Eq. 6.20 and then to solve for S with Eq. 6.19. The straight line approximation for this method should be restricted to small values of u ($u<0.01$) to avoid large errors.

Chow Method of Solution. Chow developed a method of

solution with the advantages of avoiding curve fitting and being unrestricted in its application. Again, measurements of drawdown in an observation well near a pumped well are made. The observational data are plotted on semilogarithimic paper in the same manner as for the Cooper - Jacob method. On the plotted curve, choose an arbitrary point and note the coordinates, t and s. Next, draw a tangent to the curve at chosen point and determine the drawdown difference Δs, in feet, per log cycle of time. Then F (u) can be computed from Eqn. 6.21 which is given below.

$$F(u) = s/\Delta s \qquad \text{----------} \quad (6.21)$$

The corresponding values of W(u) and u are determined from the figure which is given in the Appendix 11. Finally, the formation constants T and S can be computed using Eqn. 6.13 and Eqn. 6.14 respectively.

The above solution methods for the nonequililbrium equation applied to pumping tests in confined aquifers, but the solution methods can be applied also to unconfined aquifers providing that the basic assumptions are satisfied (i.e. drawdown is small compared to the total saturated thickness).

Recovery Test When pumping is stopped, well and aquifer water levels is recovered so as to reach the initial piezometric level. The rate of recovery provides a means for calculating the coefficients of transmissivity and storage.

The time- recovery record, therefore, is an important part of an aquifer test.

The water-level recovery data from an observation well will indicate the hydraulic characteristics of the aquifer if the well is located close enough to the pumped well so that the drawdown changes significantly during the pumping test. If no observation well is available, the water-level recovery data from the pumped well can be used for limited calculations of aquifer capability. Recovery data can be analysed only when the test pumping is done at a constant rate.

The recovery curve, which is a plot of change in water level with time during recovery period, is difficult to portray by mathematical analysis. It can be simplified for analysis, however, in either of two ways : Theis (1935) corollary to the nonequilibrium equation, or Jacob's (1946b) modification of the nonequilibrium equation. It has been shown that the time-drawdonw curve for the pumping period becomes a straight line on a semilogarithmic diagram. The same simplification can be used for the time-recovery plot, where the horizontal scale represents the logarithm of time during the recovery period and the vertical scale represents water-level recovery.

If a well is pumped for a known period of time and then shut down, the drawdown thereafter will be identically the same as if the discharge had been continued and a hypothetical recharge well with the same flow were superposed on the discharging well at the instant the discharge is shut down.

From this principle Theis showed that the residual drawdown s' can be given as

$$s' \quad Q/4\pi T \ [W(u) \ - W(u')] \ ---- \ (6.22)$$

Where

$$u = r^2S/4Tt \text{ and } u' = r^2S/4Tt' \ ----- \ (6.23)$$

and time since pump started and time since pump stopped are represented by t and t' respectively. The rest symbols represent the same terms as in Equation 6.13 and 6.14.

For r small and t' large (Jacob Method), the well functions can be approximated by the first two terms of Eq. 6.12 so that Eq. 6.22 can be written as

$$s' = (2.30Q/4\pi T) \ \log t/t' \ ---------- \ (6.24)$$

Thus a plot of residual drawdown s' versus the logarithm of t/t' forms a straight line. The slope of the line equals $2.30Q/4\pi T$ so that for $\Delta s'$, the residual drawdown per log cycle of t/t' the, transmissivity becomes

$$T = 2.30Q/4\pi\Delta s' \ ----- \ (6.25)$$

The transmissivity of the aquifer from the time-recovery data can be calculated from the following equation

$$T = 2.30Q/4\pi(s-s') \text{ ----- } (6.26)$$

Where $s-s'$ = change in water level recovery

If measurements are made in at least one observation well during the recovery period, the storage coefficient can be calculated from portions of these data. The data must be plotted as a time-recovery plot. The residual drawdown plot can not be used for determining the storage coefficient, eventhough the plot is valid for calculating the transmissivity.

Although most aquifers do not conform to all the theoretical conditions assumed by Theis and Jacob, results from the application of these equations and their graphic relationships have been quite satisfactory.

6.2. Wells and Springs in the Studied Area

The investigated area is now supplied largely with groundwater, from a number of springs and wells. These source are not integrated into a common distribution system. An inventory of the boreholes and springs that was carried out in the area are given in Table 6.1 and Table 6.2 respectively, and their location are shown in Map 2. As it was shown in the map the boreholes are concentrated in the town.

Dug Wells

In the studied area small amount of groundwater is extracted using dug wells. The diameter of these dug wells

vary from 1 - 2.5 m. and they are generally less than 20 m in depth. They have concrete and dry brick or stone lining and are abundant in Jimma town. With the exception of a few dug wells which are fitted with surface pump that can discharge less than 1.5 l/s., all are equipped with pulley.

The yield of these wells is limited, because they are excavated only to a limited depth in weathered and fractured volcanic material which is the upper shallow aquifer in the area.

The depth of static water level varies from 9 - 13 m. The wells are rich in water during the rainy season and the water table become shallow while during dry season the majority of them will dry up.

Boreholes

Twenty five bore wells are found in the studied area, and are mainly used for the supply of drinking water to the Jimma town. Out of these, three wells was abandoned and the rest are functional. All the wells are well equipped with steel casings and electrical submersible pump.

These wells are bored or drilled deep into the ground, intercepting one or more water bearing stratum. The depth of the wells vary from 70-144 m.In the highlands such wells are located in the unconfined and confined aquifers which is made of basaltic material that has been affected by different degree of weathering and possess different permeability value. While

in the valleys, both the alluvial sediments and the volcanic rocks are the main aquifers of the wells. The diameter of these wells also vary from 9" - 12".

Those wells that are located in the highlands have a low capacity, their yields vary from 1.5 l/s. to 6.3 l/s.; while those in the valleys have a moderate capacity, 1.5-8.5 l/s.

Pumping and recovery tests and lithological log data are available only for very few wells.

Springs

Several small springs, whose discharges range from 8 - 0.2 l/s. and most of them are contact types, are found in the investigated area. However, only three are perennial, and are used for various purpose in the domestic consumption. These are the Saint Gabriel, Jiren, and Lagahar springs.

The Saint Gabriel Springs are located 3 km. north of Jimma close to the head of Aweytu valley. The main spring was developed in the late 1930's by the driving of two short adits probably into the weathered basaltic rock. The installation is protected by concrete structures which formerly led the water to concrete setting tanks; these tanks are no longer use. There is also an open spring area about 325 m. away; it is completed with

an open concrete flume to convey water to the main spring area. A 0.076 m (3") diameter steel pipe conveys the water from the springs by gravity to an old pumping station on Agaro road at

the edge of Jimma. The total flow of the springs at the time of field investigation was 8 l/s. The flow at the Agro road pumping station is much less than this, possibly because the pipeline is partly clogged with sand, silt and other debris. From two concrete reservoirs at the pumping station, water is pumped by a single centrifugal pump into the system. Each of the two reservoirs at the pumping station holds about 100 cubic meter.

The Jiren springs, which are found in the eastern part of the studied area, are at a higher elevation than the Saint Gabriel springs; they produce less water 0.5 l/s. and they do not feed the main Jimma water system. They also issue from basaltic flows. They have been improved by concrete walls and covers. The water is conveyed by small diameter steel pipes to the facilities being served, namely the Hospital and the Prison with minor amounts going for domestic use.

Lagahar springs, which was probably originally developed along with Saint Gabriel and Jiren Springs, was renovated in 1981 by WSSA for the community of Jimma. It is located in the lower part of the Aweytu valley and consists of a group of small springs all piped by gravity to a new 50 cubic meter concrete

tank. From here the water is pumped into the distribution system which serves a portion of the down town area. These springs are all located in a small area which is fenced to keep out livestock. The yield of the springs was 1.5 l/s. at the

time of field investigation.

6.3. Hydraulic Analysis

The groundwater potential in the western and northwestern part of the studied area is relatively high both from the alluvial sediments and the volcanic rocks. Out of the six wells that are found in this part of the area, according to the report of WSSA of Jimma, only the performance of well-3 (in the Kitto Well field) has been checked by pumping test. However, pump test data was not obtained, and quantitative estimates of well performance has not been made by the author. This report declare that pumping at 8.5 l/s. caused 12.57 m drawdown after about 1000 minutes of pumping. Analysis of this pumping test, according to this report, revealed the following:

- The well behaves like a well constructed in a granular aquifer.
- The transmissivity is about 125 m^2 /day.
- The well is fairly efficient with a specific capacity of 0.675 l/s/m of drawdown after 24 hours of pumping at 8.5 l/s.
- Assuming that the well is 82 m. deep and that the total available drawdown is about 70 m., the capacity of the well using 70 percent of the total available drawdown may be about 30 l/s.
- A more efficient well in this aquifer might have a capacity as high as 40 l/s.

In general the pump test shows that the aquifer at Kitto well field (Kitto sub basin) is highly productive and, if extensive in area, is capable of supplying several properly constructed wells each with a capacity of 30 to 50 l/s.

For the wells in the central part of the basin (Aweytu sub- basin), pumping test and recovery test data are available only for one well (Jimma Agricultural Collage Borehole). By using these data, the aquifer characteristics in the central part of the basin will be discussed as follows.

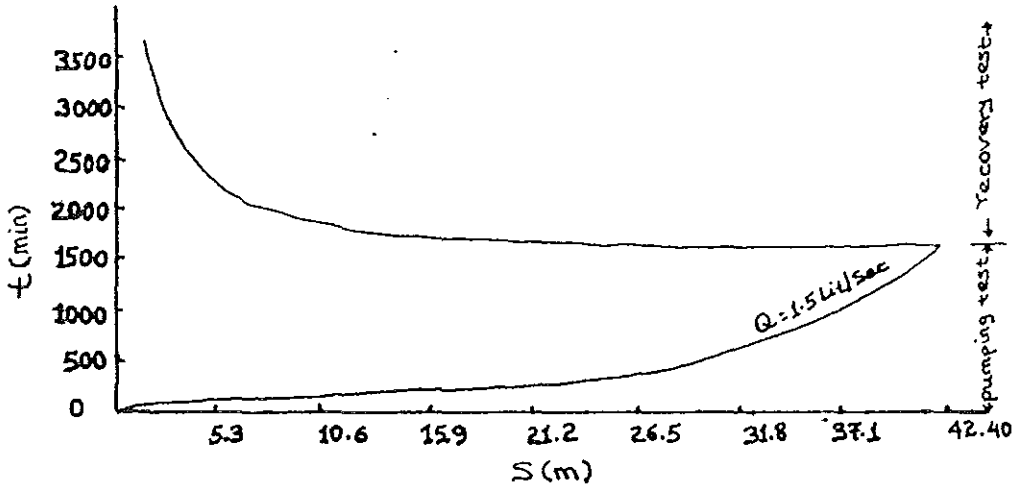
The Jimma Agricultural Collage borehole is drilled on the basaltic rocks in the Hirmata highlands at an elevation of about 1750 m.

Continuous pumping test for this borehole was carried out with average discharge of 1.5 l/s. After pumping for 24 hours a volume of 129.60 m^3 of water was pumped out and a maximum drawdown of 42.40 m was measured.

Drawdown - recovery data (Appendix 7A and 7B) from the pumped well has been plotted on a graph (Fig. 6.1). As it is depicted in the plot the recovery is slow. Because of shortage of water, at the end of recovery test, the water level did not reach the original static water level. This is attributed to phreatic nature of the aquifer and shortage of potential recharge.

Since no observation well was available to measure the

Fig. 6.1 DROWDOWN-RECCVEFY CURVE FOR JIMMA AGRICULTURAL COLLAGE WELL



drawdown further away from the discharge well. Theis equation has not been applied to calculate the storage coefficient. However, applying Jacob Non-Equilibrium formula the parameters transmissivity and permeability have been calculated.

The time - recovery plot for the pumped well is more accurate than its time-drawdown plot because the residual - drawdown measurements are more accurate. During the recovery period, water-level measurements can be made without being affected by pump vibrations and momentary variations in the pumping rate.Because of these, the recovery data from the pumped well usually provide the best basis for calculating the transmissivity of the aquifer.

Using Eqn. 6.20 and the time-recovery data (Appendix 7B) from the pumped well, shown in Fig. 6.2, the transmissivity of the aquifer has been calculated as follows.Recall that the Jacob's modification of the more general
Theis equation, Eqn. 6.20 is :

$$T = 0.183\ Q/\Delta s$$

Where $\Delta s = 1.29$ m

$Q = 1.5$ l/s. $= 129.6\ m^3$ /day

Thus

$$T = \frac{0.183 \times 129.6\ m^3/day}{1.29\ m}$$

$$= 18.39\ m^2\ /day$$

The relation between the permeability and transmissivity is simple, and is given by

$$T = Kd \quad \text{---- (6.27)}$$

where K = Permeability

d = Saturated aquifer thickness

from Eqn. 6.27, we have

$$K = T/d \quad \text{-------} \quad (6.28)$$

Where d = 64.19 m

Hence, $K = \frac{18.39\ m^2/day}{64.19\ m}$

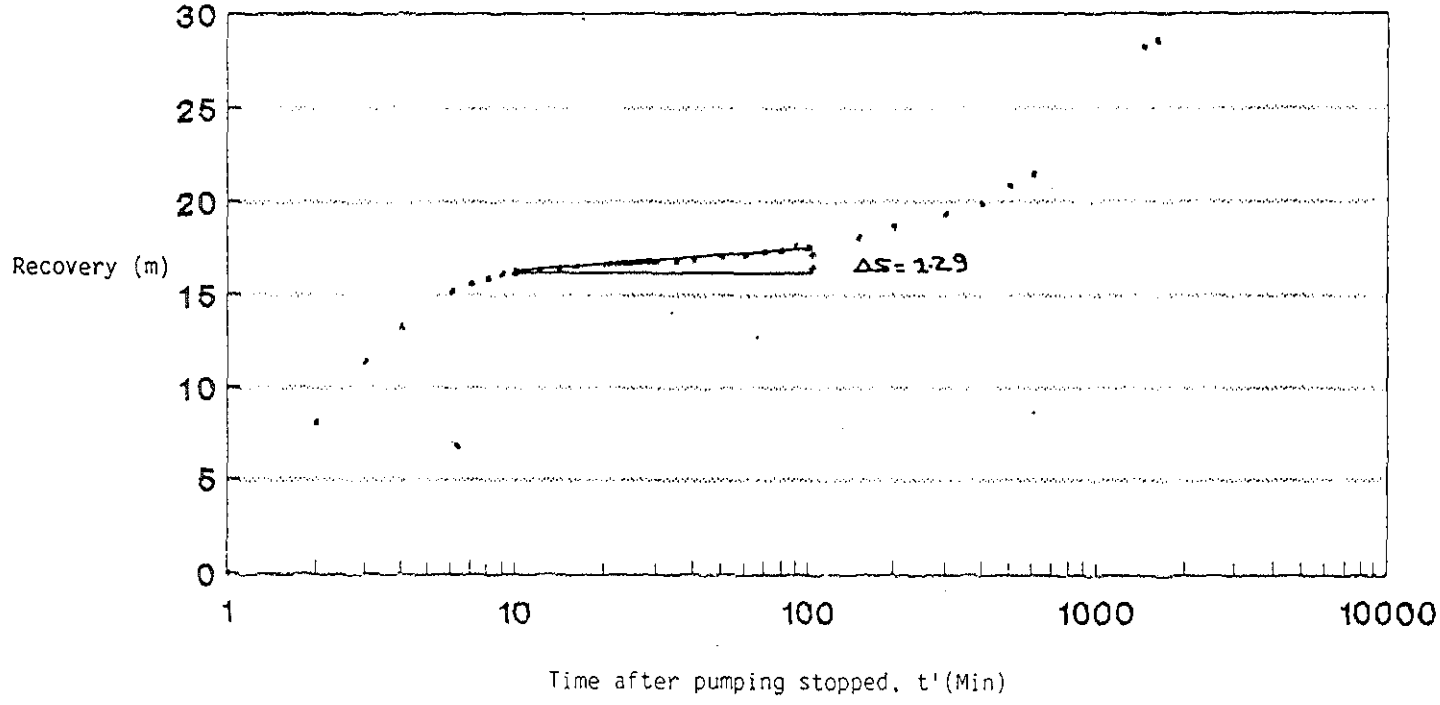
$= 0.286$ m/day which is equivalent to 3.31×10^{-4} cm/sec.

Based on the above results the basalt aquifer in the central part of the basin has a transmissivity of 18.39 m^2 /day and a permeability of 3.31×10^{-4} cm/sec.

According to Johnson (1966), an aquifer that has a transmissivity of less than 12.4 m^2/day, it can supply only enough water for domestic wells or other low-yield uses. When the transmissivity is 124 m^2/day or more, well yields can be adequate for industrial, municipal, or irrigation purposes. The transmissivity value obtained in the aquifer for the central part of the basin can therefore be recommended for municipal uses where water consumption is not high and other alternative source of water is not at hand.

More than half of the total wells are found in the eastern and northeastern part of the basin (Kochi sub-basin). It is from both the alluvial and volcanic aquifers that most of the groundwater is tapped from these wells. Pump test and recovery

Fig. 6.2 TIME-RECOVERY PLOT FOR JIMMA AGRICULTURAL COLLAGE WELL



test data was obtained only for one well (Jimma Staff Residential Borehole), for the rest pumping test, recovery test and lithological log data are not available. Using this data the aquifer characteristics in this part of the area will be discussed as follows.

The Jimma Staff Residential borehole is located in the lower part of the Kochi sub basin at an elevation of 1710 m. Both the sandy sediments and weathered rhyolite are the main aquifers of the borehole.

The pumping test and recovery test data (Appendix 8A and 8B) plotted on Fig. 6.3 shows that the recovery is very fast. This was happened because due to its location some recharge water reached the aquifers during the pumping period and results a full recovery to original static level during a relatively short recovery period.

Drawdown-recovery data was conducted on the pumped well and no observation wells were available during the test and thus the coefficient of storage has not been calculated. Based on the pumping test data (Appendix 8A) a graphical solution by Jacob's method (Fig. 6.4) for transmissivity has been carried out using Eqn. 6.20.

Thus

$$T = \frac{0.183 \times 86.4 \text{ m}^3}{8.38 \text{ m}} \text{ /day}$$

$$= 1.89 \text{ m}^2 \text{ /day}$$

Where $Q = 1$ lit./sec. $= 86.4\ m^3$ /day

$\Delta s = 8.38$ m

and the permeability (k) from Eqn. 6.28 gives

$$K = \frac{1.89\ m^2/day}{130.62\ m}$$

$$= 0.014\ m/day$$

Which is equivalent to 1.62×10^{-5} cm/sec.

Where $d = 130.62$ m

The aquifers in this part of the area has thus a transmissivity of 1.89 m^2/day and a permeability of 0.014 m/day, i.e. 1.62×10^{-5} cm/sec. The transmissivity value of the aquifers could supply enough water for domestic wells or other low-yield uses.

Fig. 6.3 DROWDOWN-RECOVERY CURVE OF E.W.W.C.A WELL

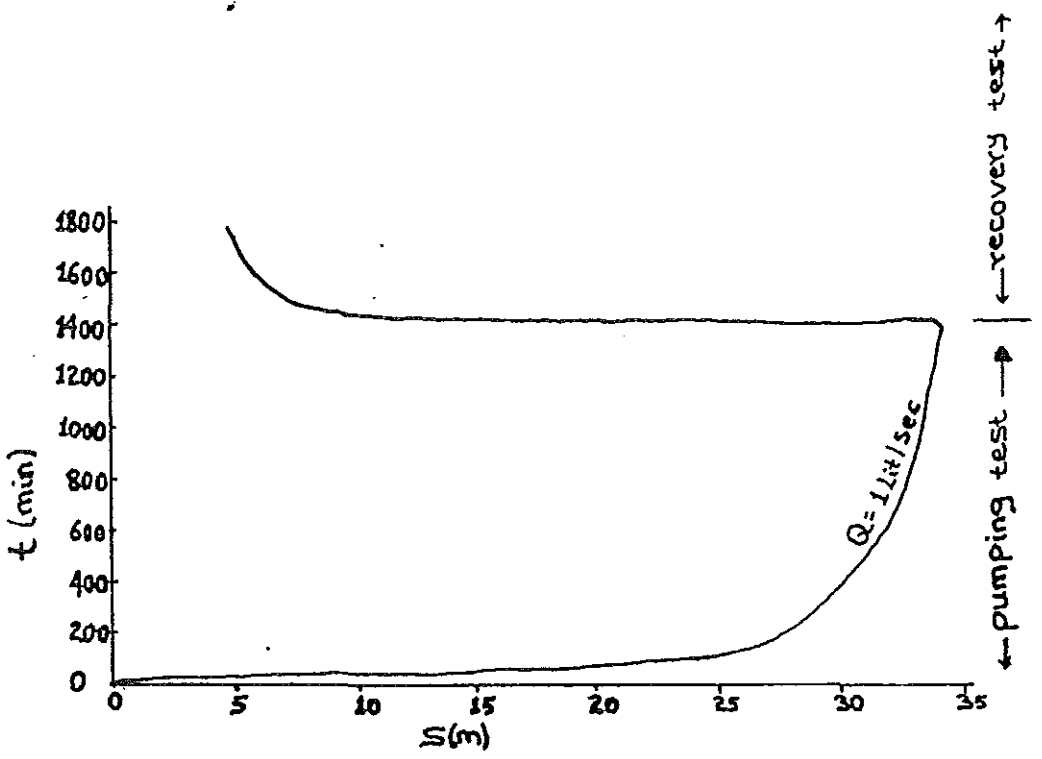
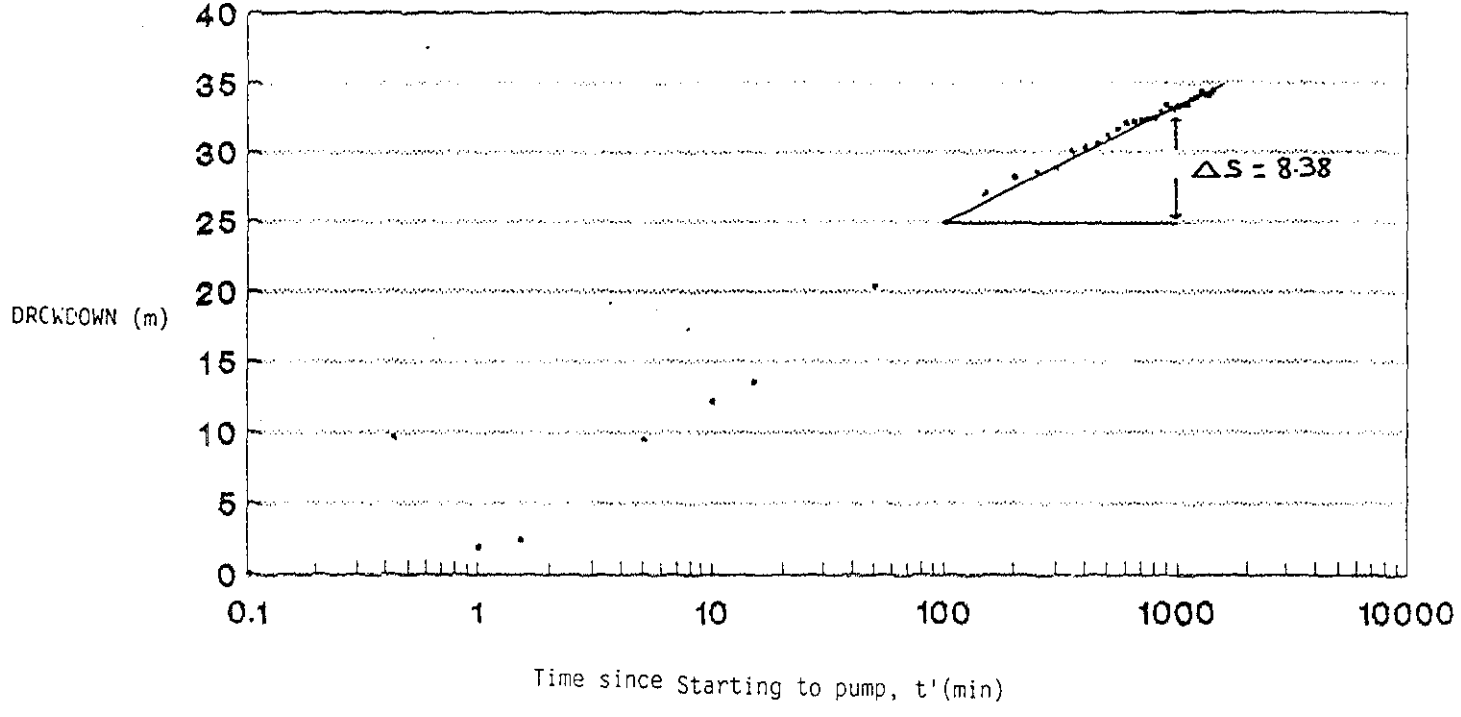


Fig. 6.4 TIME-DROWDOWN PLOT FOR E.W.W.C.A WELL



Based on the available data the potential of the aquifers in the three sub-basins are summarized and is given in Table 6.3 below.

Table 6.3

Values of Transmissivity, T and Permeability, k for Three Wells

Name of the Borehole	Location and Name of the Sub-Basin	Transmissivity T, (m^2/day)	Permeability, K (cm/sec)
Kitto Well number 3	Valley - Kitto	125	-
Jimma Agricultural Collage	highland - Aweytu	18.39	3.31×10^{-4}
Jimma Staff Residential	valley - Kochi	1.89	1.62×10^{-5}

TABLE 6.1 Borehole Inventory Jimma

Map reference Number	Location and Owner	Map reference	Elevation a.s.l (m)	Date constructed (G.C	Total deepth (m)	Pump Pos. (m)	Static water level (m)	Dynamic level (m)	Type of pump	Yield (lit/sec.	Water use
1	Kitto - Community	1:25000	1710	1971	60	-	-	-	Sub.	6.7	Domestic
2	Kitto - Community	"	"	"	55	46	-	-	"	2.5	"
3	Kitto - Community	"	"	"	82	62	-	12.57	"	8.5	"
4	Kitto - Community	"	"	1986	58	-	23.36	-	"	4.5	"
5	Kitto - Community	"	"	-	72	-	22.80	-	"	-	"
6	Kule Ber commu.	"	1700	1976	80	-	12.94	-	-	4.0	"
7	Near Plywood mill mill community	"	1715	1977	71	62	17.16	59.15	Sub.	2.5	"
8	Jimma Hotel	"	1730	-	75	-	10.5	-	"	2.5	Non - domestic
9	Aid Bank	"	1718	-	-	-	-	-	-	-	"
10	Commercial Bank	"	1715	1976	-	-	-	-	-	1	"
11	Gondrand	"	1740	-	-	-	-	-	-	-	domestic
12	Ethiopian Road Authority	"	1740	-	-	-	-	-	-	-	Non - domestic
1	Fog-o station	"	1740	-	70	62	12.76	-	Sub.	1	domestic

TABLE 6.1 (Continued)

Map reference Number	Location and Owner	Map reference	Elevation a.s.l (m)	Date constructed (G.C)	Total depth (m)	Pump Pos. (m)	Static water level (m)	Dynamic level (m)	Type of pump	Yield (lit / sec.)	Water use
14	Jimma staff residential E.W.W.C.A	1:25000	1710	1988	144	102	13.38	47.80	Sub.	1	Domes
15	Rural Projects Agency	"	1730	1977	50	-	18.26	-	-	1.5	Non-domes
16	R.P.A.-Health assistant Train.	"	1776	1977	51	-	13.21	-	-	0.4	For Ho ital
17	Agricultural Research station	"	1725	1970	-	-	-	-	Sub.	2	Domest Planta
18	Jimma Agricultural Collage	"	1750	1988	77	75.50	12.81	42.40	"	1.5	For th Collag
19	Jimma Hospital (Chinese)	"	1768	1974	97	-	6.63	15.96	-	6.3	For Ho ital
20	Jimma Hospital (American)	"	1775	-	-	-	-	-	-	-	For Ho ital
21	Teacher Training Institute	"	1794	1971	105	-	10.06	-	-	1	For th Instit
22	AADUEELPA Community	"	1720	1982	134	-	6.86	-	Sub.	2.3	Domest
23	AADU Jiren Community	"	1780	1982	112	-	13.62	-	"	1.7	Domes
[illegible]	Stadium - Community	"	1735		60	56.30	[illegible]	12.24	"	1.5	"
[illegible]	South Western Command	"	1713	-	[illegible]	80	[illegible]	18.25	"	3.5	Non domest

TABLE 6.2 Spring Inventory Jimma

Map refe-rence Numver	Location and Owner	Map refe-rence	Elevat-ion a.s.l (m)	Tempret-ure (C)	Mode of emerge-nce	Rock Type	Perenn-ial or Inter.	Flow Q/s) lit./ sec.	Method of measurm	Kind of dev't	Water use
1	Saint Gabriel springs-Community	1:25,000	1710	21	Contact	Basa-	Peren-	8	Observ-	Concr-	Domestic
2	Jiren Springs-Community	"	1850	23	"	"	"	0.5	"	"	Domestic Hospital Prison
3	Lagahar Springs -Community	"	1710	20	Depres-sion	Allv. Sedem	"	1.5	"	"	Domestic
4	Shoa-Berr-Kebele	"	1730	21	-	-	Interm.	-	-	-	"
5	Caba - Spring	"	1710	21	Contact	Basa-lt	Interm.	0.2	Observ-ation	-	"
6	Samucha Spring	"	1775	23	"	"	Interm.	0.8	"	-	"
7	Mendera Spring	"	1850	20	"	"	Perenni	3.4	"	Concr-ete	Domestic

7. WATER QUALITY

7.1. Sampling and Analysis

In the studied area quality analysis for both groundwaters and surface waters has been conducted and the data are given in Appendix 9A and 9B. A representative samples were taken from river, springs, dug well and bore wells. In December 1993 and March 1994, one liter of water was collected within plastic bottles and the analysis was carried out (privately) in the respective months.

To avoid nonrepresentative samples, from which well samples were taken after it has been pumped for some time in the morning. With each sample a record have been made on wells location, size of casing, date, and operating conditions of the wells immediately prior to the sampling. Due to the absence of deep meter depth of samples and static level measurement have not been carried out. Samples from a river were taken at different sites.

Due to the lack of portable laboratory kits and shortness of the time needed between the collection of the samples and their analysis, biologic test has not been carried out.

For all the samples determinations of temperature, pH, odour, color (true), taste, electrical conductance, and appearance have been carried out in the field. The instruments used in the field are Thermometer, Digital pH meter, and Conductivity meter.

7.2. Hydrogeochemistry

The chemistry of the water in the basin has been treated based on the respective aquifers the samples come from, temperature of the water during sampling and mode of occurrence of the surface water.

In the hydrochemical investigation of the basin aquifers, chemical analysis of four wells, three springs, and one river were conducted. Of the four wells, two are in the alluvial and basaltic aquifers, one in the alluvial and rhyolite aquifers, and one in the basaltic aquifer. Two of the springs discharge from basalt and one from alluvial. For the surface water, samples were taken from Aweytu river at two different sites and have been treated separately.

The chemical quality test has been plotted on a piper diagrams (Fig. 7.1A & 7.1B). These diagrams conveniently reveals similarities and differences among the various water samples because those with similar qualities will tends to cluster together. The results indicate the surface water and the spring water form basalts are strictly magnesium - calcium bicarbonate type. The lagahar springs that issue from the alluvial sediment is magnesium - calcium chloride type. The rest of the water are alkaline bicarbonate type. The bicarbonate concentration in igneous rocks could be accounted for the dissociation of water under the presence of carbon dioxide, but Cl^- and So_4^{2-} are not significant constituents in igneous rocks and there is no tendency toward the development

of Cl^- and SO_4^{2-} facies as groundwater moves along flow paths in these rocks. The Cl^- occurrence in lagahar springs water up to 64 % is unusual. The location of this spring is very unfortunate which is in a short distance down slope from very congested area of houses and stores. Its high concentration may indicate sources of past or present pollution. The sewage may furnish a large amount of this soluble constituent. The anion SO_4^{2-} occurs in only minor or trace concentration. Its occurrence normally be attributed to atmospheric sources. to the decomposition of organic matter in soil, and to the trace impurities in rocks and minerals. K^+ is generally the least abundant of the cations.

With the exception of the lagahar springs, HCO_3^- is the dominant anion and SiO_2, with the exception of Na^+, is present in major concentrations relative to the cations. Although mafic rocks contain little or no quartz and are lower in total silica than felsic rocks, the chemical instability of the minerals accounts for relatively high content of SiO_2 in associated water.

As value of pH 7.0 is neutral, pH ranging from 5.2 to 8.4 was recorded in the studied area with the high values generally corresponding to the groundwater. This indicates that the groundwater in the area is slightly alkaline. The Aweytu river sampled at two different sites i.e. north of the town which is above EELPA and near the center of the town showed pH values of 7.3 and 6.3 respectively. Most natural water have a range of

pH between 6 and 8.5 (Hem, 1970). When pH values are greater than 8.5, water has usually come in contact with sodium carbonate; when pH values are below 4, water contains free acids. Moderately low values of pH indicate water that contains small amounts of mineral acids from sulfide sources or contains organic acids.

The solubility of silica with respect to pH values of all the samples in the basin has been plotted in Fig. 7.2. As it is presented in the figure, the concentration of silica, in solution for the majority of the samples lies between pH values of 6 and 8.5. The pH of the environment is especially significant for transportation of silica and its ultimate redeposition. At pH value less than 4 silica is only slightly soluble. For pH values ranging from 5 to 9 the solubility of silica increases considerably, and it would present in solution significantly (Mason, 1966).

The total dissolved solids (TDS) for the samples in the basin range from 113.38 to 795.93 ppm. Higher concentrations of dissolved constituents were found in groundwater than in surface water. This is may be due to the greater exposure of the groundwater to soluble materials in geologic strata. Generally, this TDS value indicates that there is low water-rock interaction in the area. The type and concentration of salts depend on the content of solute in the initial rain, the extent of reaction with rock and soil, loss of constituents by precipitation or absorption, and loss of water because of

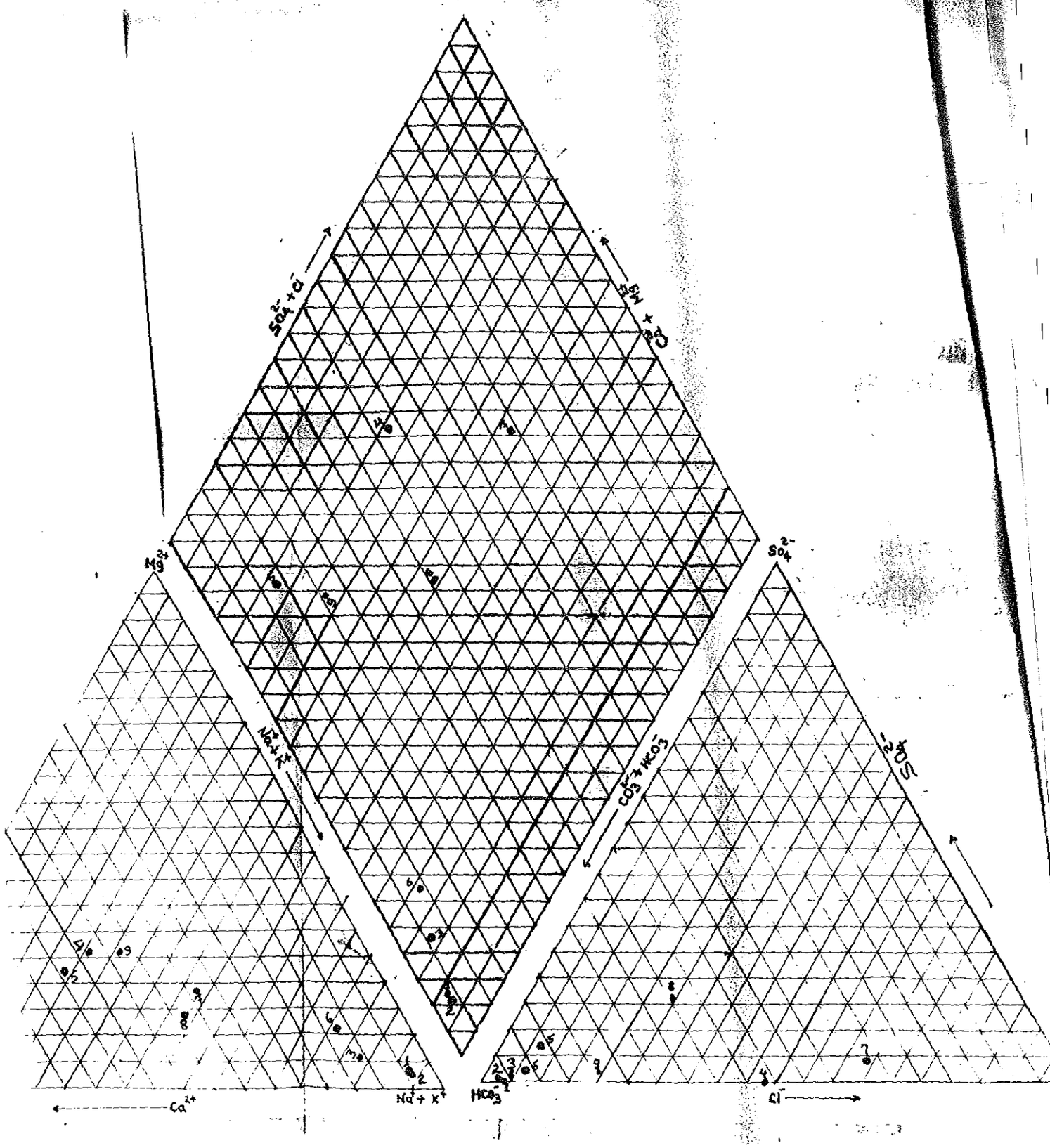


Fig. 7.1A. TRILINEAR DIAGRAM SHOWING THE DISTRIBUTION OF WATER TYPES IN THE BASIN

10, 20 } Waters from Alluvial and Basaltic Aquifers
30 Water from Alluvial and Rhyolitic Aquifers
40, 50 } Spring Waters that Issue from Basalt
60 Dug Well Water from Basaltic Aquifer
70 Spring Water that Issue from Alluvium
80, 90 } River Waters

evaporation, transpiration or reaction with mineral.

A range of temperature values between 20 and 24°C was recorded for both groundwater and surface water. The maximum value that was recorded for the surface water samples is 24°C and the minimum value recorded for the groundwater samples is 20°C. In the investigated area the temperature of groundwater remains more or less constant. It has been found that the temperature of groundwater at depths between 10 and 20 m is almost constant and normally exceeds the mean annual air temperature by 1.0 to 1.5°C(Collins, 1925). The more or less stationary temperature of groundwater is an advantage in the use of groundwater in industry, as a water supply, and in such other applications as heat-pump temperature control in buildings for cooling in summer and heating in winter (Gass and Lehr, 1977).

7.2.1. Water Quality Criteria for Domestic use

The chemical analysis of the water samples in the studied area have been compared with the international standard values set by World Health Organization (1963 & 1984) and by water quality criteria California (1952). The chemical constituents of most of the water fall within the standard limits except for some ions as fluoride (F^-) nitrate as (No_3^-), bicarbonate (HCo_3^-), and iron (Fe^{+3}).

The fluoride level in the springs and boreholes is between 2 and 3 mg/l. One of the abandoned borehole in the area has 15

mg/l. The concentration is too high for potable supply. The World Health Organization recommends an upper limit of 1.5 mg/l. However, its local application must take into account climatic conditions and higher levels of water intake. At levels above 1.5 mg/l, mottling of teeth has been reported very occasionally, and at 3.0 - 6.0 mg/l skeletal fluorosis may be observed; when a concentration of 10 mg/l is exceeded, crippling fluorosis can ensue (World Health Organization. 1984).

Content of nitrate up to 145.3 mg/l has been observed in the lagahar springs. The maximum allowable concentration of 10 mg of nitrate- N per liter is recommended by WHO. The high concentration is mostly attributed to the open pit latrines as there is no proper sewerage systems in the towns. Nitrate is toxic when present in excessive amounts in drinking water, and in some cases causes methaemoglobinaemia in bottle - fed infants; for older age groups, this problem does not arise, but there is possibility that certain forms of cancer might be associated with very high nitrate concentrations.

High concentrations of bicarbonate were observed in most of the analyzed water samples as compared to the maximum allowable limit of 150 mg/l, which is specified by WHO. The consumption of this ion over a concentration of 500 mg/l will cause gastro-intestinal irritation (Hart, 1974). Here the presence of bicarbonate may be related to the bubbling of volcanic gas and decay of humus. Dissolved volcanic and under

ground biogenic carbon dioxide (Co_2), produces carbonic acid, which leads to much more rapid carbonation than might be suspected from the small amount of carbon dioxide in the atmosphere.

In the chemical analysis of water, high concentration of total iron has been observed. As it was shown in the Appendix Table 9A and Table 9B values above the standard specification 0.3 mg/l (WHO, 1984) was recorded. This is probably caused by the suspended silt content and can be corrected by normal water treatment processes. Although iron is an essential element in human nutrition, drinking water is not considered to be an important source. At levels of about 0.3 mg/l, iron stains laundry and plumbing fixtures and causes an undesirable taste in beverages. The precipitation of excess iron gives an objectionable reddish -brown color to the water. Increases in the concentration of iron in water during distribution may be due to either corrosion of iron pipe work or disturbance of existing deposits. The presence of iron at concentration greater than 0.1 mg/l may lead to deposits in pipes, and in the presence of aluminum may lead to dirty - water problems. At levels higher than 0.3 mg/l there may be increased maintenance costs and complaints about taste (WHO, 1984).

A general standard limit set by World Health Organization (1963 and 1984) and Water Quality criteria California (1952) is given in Table 7.1 below. Data obtained from Guidelines for Drinking water quality (World Health Organization, 1984) and

from Ethiopian Water Resources Authority (EWRA) Technical Report (1977).

Table 7.1 International Standards of Chemical Analysis of Water for Domestic Use

Constituent or Characteristic	Unit	Maximum Acceptable	Maximum Allowance
Color	True Color Units (TCU)	-	15[I]
Taste and Odour	-	In offensive to most consumers	-
Turbidity	Nephelometric turbidity unit (NTU)	5[I]	25[II]
pH	-	6.5 - 8.5[I]	9.2[II]
Floating solids	-	Absent	
Suspended Solids	-	Absent	
Solids - total dissolved	mg/l	1000[I]	1500[II]

(continued)

Hardness	mg/l (as $Caco_3$)	-	500^{I}
Carbonate alkalinity	mg/l (as $CaCo_3$)	-	120^{III}
Bicarbonate alkalinity	mg/l (as $CaCo_3$)	-	150^{III}
Ammonium (NH_4^+)	mg/l	-	0.5^{III}
Sodium (Na^+)	mg/l	115^{III}	200^{I}
Potassium (K^+)	mg/l	-	2000^{III}
Calcium (Ca^{+2})	mg/l	75^{II}	200^{II}
Magnesium (Mg^{+2})	mg/l	50^{II}	150^{II}
Total iron (Fe)	mg/l	0.3^{I}	1.00^{II}
Manganese (Mn^{+2})	mg/l	0.1^{I}	0.5_{II}
Zinc (Zn^{+2})	mg/l	5^{I}	15^{II}
Chloride (cl^-)	mg/l	200^{II}	250^{I}
Fluoride (F^-)	mg/l	-	1.5^{I}
Nitrite (No_2^-)	mg/l	-	2^{III}

(continued)

Nitrate (No_3^-)	mg/l	-	10^{I}
Bicarbonate (HCO_3^-)	mg/l	-	150^{III}
Carbonate (Co_3^{-2})	mg/l	-	20^{III}
Sulfate (SO_4^{-2})	mg/l	-	400^{I}
Total silica (Sio_2)	mg/l	40^{III}	50^{III}

X = WHO (1984)

XX = WHO (1963)

XXX = Water Quality Criteria - California (1952)

7.2.2. Water Quality Criteria for Agriculture

Water quality for agricultural purposes is determined on the basis of the effects of the water on the quality and yield of the crops, as well as the effects on drainage efficiency and characteristic changes in the soil (Richards, 1954; Wilcox, 1955). Therefore, the quality of chemical composition of water is a major factor to be taken into account when considering a development in the field of agriculture.

Analysis of the chemical composition of both the groundwater and surface water has been carried out so as to be able to analyse the effect for agricultural purpose. The

quality of the water is determined by the total salt and ionic contents. Eventhough it plays a major role in plant growth, trace elements analysis was not possible to conduct.

Salts may harm plant growth physically by limiting the uptake of water through modification of osmotic processes, or chemically by metabolic reactions such as those caused by toxic constituents. Effects of salts on soils, causing changes in soil structure, permeability, and aeration, indirectly affect plant growth. Specific limits of permissible salt concentrations for irrigation water cannot be stated because of the wide variations in salinity tolerance among different plants; however, field-plot studies of crops grown on soils that are artificially adjusted to various salinity levels provide valuable information relating to salt tolerance.

Sodium concentration is important in classifying an irrigation water because sodium reacts with soil to reduce its permeability. The Salinity Laboratory of the U.S Department of Agriculture (1954) recommends the Sodium Absorption Ratio (SAR) because of its direct relation to the absorption of sodium by soil, and has been used to classify the water in the area under study. It is defined by

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}} \qquad \text{-------} \qquad (7.1)$$

where the concentrations of the constituents are expressed in milliequivalent per liter.

A low SAR, which range from 2 to 7, indicates little danger created by sodium ion ; medium hazards are between 7 and 18, and high hazards between 11 and 26 (Fetter, 1986).

In the investigated area, as it was shown in the Table 7.3, the SAR values of all the water range from 0.37 to 15.30. Only the water from two boreholes have a value greater than 10, all the rest have a value below 7. Based on this fact, the sodium concentrations in the water doesn't create a problem for plant growth in the studied area. As to the trace element analysis, future works have become necessary to set the criteria.

Another classification of suitability of water for irrigation with respect to electrical conductivity and soluble-sodium percentage has been established by Wilcox (1955). The soluble - sodium percentage (also known as sodium percentage and percent sodium) is defined by :

$$\%Na = (Na + K)100/Ca+MG+Na+K \qquad (7.2)$$

where all ionic concentrations are expressed in milliequivalent per liter. The electrical conductivity results have been calculated from the total dissolved solids of the samples by conversion where:

$$1 \text{ meq/l of cations} = 100EC \times 10^{6} \text{ and}$$

$$1 \text{ mg/l} = 1.56EC \times 10^{6}$$

The EC denotes electrical conductivity for most water with

EC ranging between 100 and 5000 microsiemens per centimeter(μs/cm) at 25°C (Todd, 1959).

Based on the above fact, the chemically analyzed water samples were taken to calculate the sodium percentage and the EC applying:

$$1 \text{ meq/l of cations} = 100EC \times 10^{6}$$

Calculated values of sodium absorption ratio (SAR), sodium percentage, and electrical conductivity for analyzed samples are given in Table 7.3.

By plotting the two parameters in Wilcox's diagram (Fig. 7.3), the analyzed samples has been classified into different water classes. As will be noted from the figure most of the water in the studied area are good to permissible except for the boreholes and dug well waters which are in the doubtful to unsuitable region. The basis for classification is expressed by the following table, after Willcox (1955).

Table 7.2. Quality Classification of Water for Irrigation (after Wilcox)

Water Class	Percent Sodium	EC $x10^{6}$ at 25°C
Excellent	< 20	<250
Good	20 - 40	250 - 750
Permissible	40 - 60	750 - 2000
Doubtful	60 - 80	2000 - 3000
Unsuitable	>80	>3000

Table 7.3 Computed Values of Sodium Adsorption Ratio (SAR), Sodium percentage, and Electrical Conductivity for Analyzed Samples.

Location & Names of the Boreholes, Springs, Dug well, and River	SAR	% Na	EC x 10^3 at 25°C
Kitto Borehole	12.72	92.93	708
AADU EELPA borehole	15.30	93.48	964
AADU Jiren borehole	5.97	83.48	472
Saint Gabriel Spring	0.37	25.23	110
Jiren Spring	0.39	23.53	155
Hirmata dug well	4.07	76.56	389.3
Lagahar spring	2.24	47.18	622.2
Aweytu River (near to the center of the town)	1	48.18	142
Aweytu river (above EELPA)	0.40	31.18	103

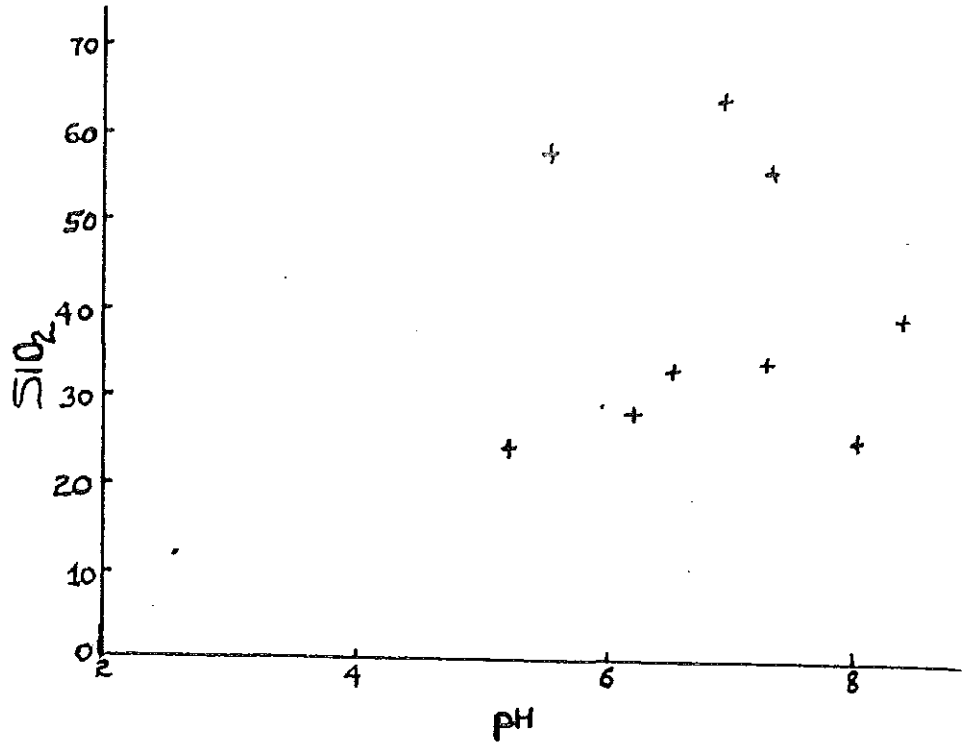


Fig. 7.2 SOLUBILITY OF SILICA WITH RESPECT TO pH

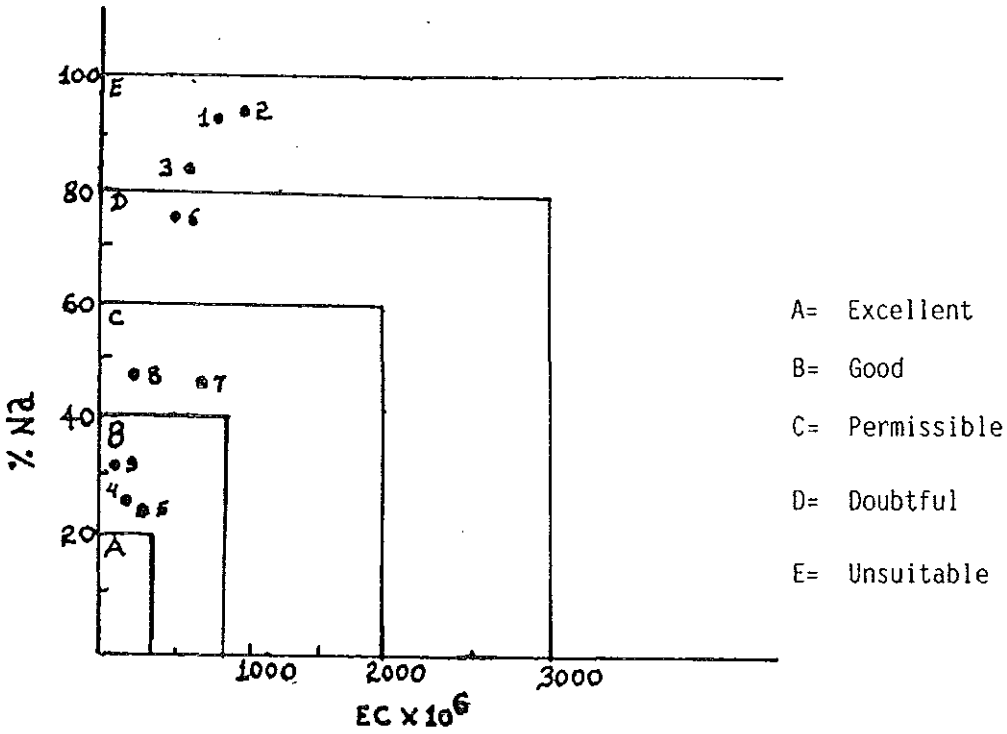


Fig. 7.3 CLASSIFICATION OF WATER FOR IRRIGATION
(After Wilcox)

7.2.3. Water Quality Criteria for Industry

Industries should be required to develop and operate their own system if they have a heavy water demand. There are several reasons for this, the main one being that when the demand is supplied by the community it will often place a heavy financial burden on the local residents. Also industries very often have their own special requirements for water supply which are not necessarily compatible with the community supply system.

Water-quality standards for industrial use depend on the function of the industry. Thus, makeup water for high-pressure boilers must meet extremely exacting criteria where as water of as low a quality as seawater can be satisfactorily employed for cooling of condensers. Even within each industry, criteria can not be established; instead, only recommended limiting values or ranges can be stated. Salinity, hardness, and silica are three parameters that usually are important for industrial water (Todd, 1923).

Up to now no industry of major importance existed in the studied area except for the small manufacturing and processing plants that require relatively small amounts of water. These industries provide their own water requirement from boreholes.

Jimma is the largest coffee trading center in Ethiopia. It is the capital of the richest region in terms of agricultural cash crop production. With this in mind, water quality assessment for use in fruit and vegetable processing

and paper and textile plants has been considered. Water quality requirements at point of use for fruit and vegetable processing and paper and textile plants are given in Table 7.4 (National Academy of sciences and National Academy of Engineers, 1972).

Table 7.4 Quality Requirements of Water at Point of Use for Fruit and Vegetable Processing, Paper Manufacturing, and Textile Plants[1].

Constituent or Characteristic	Fruits and Vegetables	Paper	Textile
Acidity ($H_2 So_4$)	0	-	-
Alkalinity ($CaCo_3$)	250	75 - 150	50 - 200
Aluminum oxide (Al_2O_3)	-	-	8
Calcium (Ca)	100	-	-
Calcium hardness ($CaCo_3$)	-	0 - 50	-
Carbon dioxide (Co_2)	-	10	-
Chloride (Cl)	250	0-200	100
Chlorine (Cl)	+	0 - 2	-
Color, Units	5	5 - 100	0 - 5
Copper	-	-	0.01 - 5

(continued)

Fluoride (F)	1++	-	-
Hardness ($CaCo_3$)	250	100 - 200	0 - 50
Iron (Fe)	0.2	0.1 - 1	0 - 0.3
Magnesium hardness ($Mg\ Co_3$)	-	0 - 50	-
Manganese (Mn)	0.2	0.03 - 0.5	0.01 - 0.05
Nitrate (No_3)	10++	-	-
Nitrite (No_2)	0	-	-
Organic (Carbon tetra-chloride extractables)	0.2	-	-
Organic growths	-	0	-
pH, units	6.5 - 8.5	-	-
Silica (Sio_2)	50	20 -100	25
Sulfate (So_4)	250	-	100
Suspended solids	10	10 -100	0 - 5
Total dissolved solids	500	200-500	100-200
Turbidity, units	-	-	0.3 -5

x - Numbers indicate miligrams per liter (mg/l) that normally should not be exceeded.

+ - Process water is chlorinated to prescribed

levels. Unchlorinated water is used for canning syrups.

++ - Low values should be used for baby food.

SOURCE: Derived from National Academy of Sciences and National Academy of Engineering, Water Quality Criteria 1972, Washington, 1972.

As will be noted from Appendix 9A and 9B the above parameters are not within the standard limitations for fruit and vegetable processing and textile plants, whereas for paper manufacturing most of them are within the standard limitation. Due to these facts before constructing the above types of industries precautions should be taken. For the use of water in industry in the studied area further water quality investigation are necessary.

8. CONCLUSIONS AND RECOMMENDATIONS

The studied area is underlain by Tertiary volcanic rocks. In the valleys the bedrock is overlain by alluvial sediments. Elsewhere bedrock is variably covered by earthy soils. The outcropping formational units are thick basalt flows, which are separated by tuffs and volcanoclastic sediments, followed by Jimma volcanics, which is manly composed of massive rhyolites in thick flows alternating with trachytes, tuffs, ignimbrites, and subordinate basalts. The relations among these formational units are examined on the basis of their lithostratigraphic character.

On the basis of topography, variation in hydraulic properties of volcanic rocks and alluvial sediments, and their location, the main hydrogeological basin is divided in three sub-basins: Kochi, Aweytu, and Kitto.

The mean annual rainfall of the basin is 1476.89 mm. 822.29 mm of the precipitation is lost as actual evaportanspirtion while 654.60 mm of the precipitation is a surplus in the basin. Of the surplus value of the precipitation, 90.77 x 10^6 m^3 of water leaves the basin through Boye river.

The alluvial sediments are the main aquifers in the basin particularly in the western part where vegetation coverage is high, which help in increasing the infiltration capacity of the sediments. The Kitto well field near the airport is an aquifer of medium transmissivity which is capable of supplying much

more water than is being withdrawn at the present time. A transmissivity value of 18.39 m^2 / day and a permeability value of 3.31 x 10^{-4} cm/sec. have been recorded in Aweytu sub-basin for the basaltic aquifer, while transmissivity and permeability values of 1.89 m^2/day and 1.62 x 10^{-5} cm/sec. have been computed in the Kochi sub-basin respectively for both alluvial and rhyolitic aquifers. The rhyolitic rocks lack primary and secondary permeability and are considered poor aquifers. The basalts, however, have well developed secondary permeability and primary features that causes permeability within them eventhough the morphological setting of the outcrops discourages the occurrence of groundwater.

The amount of water which is actually available to recharge the groundwater circulation within the hydrogeological basin is 51.14 x 10^6 m^3. The total rated capacities of the various sources supplying the basin for domestic use is 41.9 lit./sec. Assuming these sources could be operated at full rated capacities this represent a daily production of 3620.16 m^3 /day.

In the studied area the 2010 projected population is 268,000 (present population is less than 138,000)*. Assuming the average water consumption per capita per day for domestic use in the basin is 30L per person per day, the annual consumption based on the design population of 268,000 would be 2,934,600 cubic meter. Out of 53.33 x 10^6 m^3 of the total available water, the remaining 50.395 x 10^6 m^3 can be used for

industrial and agricultural purpose. Water for irrigation can be taken from Boye river by constructing an earth dam in the southeastern part of the study area or from Kitto river southeast of the airport.

The two sub-basins and the upper part of the Kochi sub-basin play the most important recharging function, while the lower part of the Kochi sub-basin is known to have the highest groundwater potential. From the shape of the groundwater level contour lines it was confirmed that the two sub-basins and the upper part of the Kochi sub-basin converge towards the main aquifer occurring in the lower part of the Kochi sub-basin in the area adjacent to the Boye river which is considered as a medium through which the discharge of the whole hydrogeological basin takes place. The general trend of the groundwater flow direction is North-South.

The runoff from Boye river can be used to augment the groundwater for future use by means of artificial recharge of basin aquifers.

The waters (both groundwater and surface water) in the basin are alkaline bicarbonate and magnesium - calcium bicarbonate types. Whereas, the lagahar spring is magnesium-calcium chloride type. There is sanitary waste contamination in this water supply. It appears to be virtually impossible to protect it from pollution. This facility should be abandoned as soon as possible as a water sources.

The present water supply, in most of the wells is carried

out by direct pumpage and the distribution is limited by the quantity of the discharge. There are small reservoirs associated with some of the springs but only the Agaro road reservoirs are significant in the context of future storage capacities. It is recommended to construct reservoirs to meet the increasing supply of water with proper chlorination chamber attached to it.

In the basin, to achieve the most economic and trouble-free operation, it is recommended that the wells should be properly designed and their pumps also has to be properly selected.

There are many small springs in the basin: these springs probably each yield 2 l/s. or less. The decision about what to do with each of such springs should be based on an assessment of the following:

- Is the springs safe from pollution and if not can it be made safe?
- What is the flow at the end of the dry season?
- Can it serve an area without pumping?
- How does the capital cost of a small local system based on the spring compare with the cost of supplying water from the main Jimma system?
- Can the spring water be better used for irrigation, stock watering, or industrial use than to supply a small domestic system?

Proper geophysical surveys and well performance tests

should be made in the basin. These must be substantiated by periodical monitoring of wells. This would help in understanding the exact amount of water in the aquifers and would give early warnings when shortages arise.

Development of groundwater in the basin mostly did not follow an orderly managerial procedure. The pattern, depth, and capacity of individual wells were initially constructed in unspecified manner.

In the studied area, proper management program should be carried out by an appropriate organization that has the ability and the power to implement the program and its related policies. Generally, the functions of groundwater management in the basin is recommended to be as follows:

1. Regulation of water consumption. Water consumption can be regulated either directly by allocation or indirectly by a fee or tax on consumption. The objective of this function is to maintain the aquifer yield at a satisfactory level and to prevent the mining of the aquifer when water withdrawals through a specified period of time exceed the aquifer recharge during the same period.

2. Augmentation of water supply. Several methods are used to increase the water supply, such as artificial recharge, relocation of wells, or importing water.

3. Aquifer restoration. Certain measures should be taken to restore the integrity of the aquifer against pollution and excessive withdrawal. The latter effect would deplete the

groundwater levels or piezometric heads, which might require deepening the wells or increasing pump lifts.

Year	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT	NOV.	DEC	TOTAL
1952	42.0	25.0	91.9	179.8	106.2	282.7	398.6	210.7	256.2	115.6	0.9	2.5	1712.2
1953	7.5	30.3	97.0	184.8	93.3	210.4	193.6	213.5	152.3	26.5	19.9	115.7	1346.8
1954	40.6	41.4	88.1	134.5	94.0	298.4	234.5	244.0	168.8	42.1	36.3	22.2	1444.29
1955	91.3	24.8	99.7	108.7	96.3	182.6	288.3	253.5	215.0	50.2	16 0	96.3	1522.7
1956	28.6	3.5	93.1	284.5	141.5	226.0	169.1	194.7	248.6	117.5	2.5	2.5	1507.5
1957	0.0	51.6	117.2	214.6	224.7	277.9	185.3	188.1	81.6	68.1	24.8	11.4	1445.3
1958	42.8	85.9	52.5	138.0	141.2	202.9	202.9	215.6	287.5	87.3	15.6	42.2	1514.4
1959	81.0	140.2	85.5	130.2	102.5	170.3	272.4	198.2	151.4	130.1	5.0	32.0	1446.8
1960	11.0	33.1	104.4	145.0	284.0	213.11	135.1	208.2	212.0	37.7	5.0	26.2	1423.8
1963	27.2	86.0	98.3	224.6	197.2	237.0	272.0	262.4	97.2	221.0	73.3	242.6	2038.8
1964	40.4	57.1	130.6	115.6	106.4	205.9	221.0	206.3	225.4	164.2	24.2	108.7	1605.8
1965	43.2	4.4	38.5	203.1	101.8	248.6	205.3	191.8	58.2	113.8	116.1	24.9	1349.7
1966	21.1	72.9	100.3	153.7	122.1	161.2	306.8	172.4	138.9	55.7	16.5	12.5	1333.1
1967	4.1	15.2	198.3	81.7	163.4	272.9	207.2	283.3	249.5	132.4	215.1	1.5	1824.6
1968	3.0	73.8	63.4	105.0	154.3	233.2	172.7	248.1	209.9	30.6	59.3	54 6	1407.9
1969	55.1	61.2	199.3	90.8	108.6	165.2	188.6	185.3	104.3	84.7	34.8	5.4	1283.3
1970	77.9	134.6	90.7	180.4	96.8	287.7	197.2	162.7	148.1	149.0	0.0	0.0	1633.1
1971	81.1	3.0	57.7	81.3	267.0	152.9	205.0	203.9	201.1	123.5	116.3	44.4	1474.2
1972	11.6	74.1	127.7	114.9	101.3	160.5	158.4	193.1	167.1	58.3	182.60	0.0	1349.6
1973	28.3	10.5	7.2	143.3	146.3	179.7	296.9	159.9	180.7	58.5	10.3	9.7	1235.3

Year	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1974	5.0	56.2	76.4	103.4	319.5	165.0	208.6	264.6	239.7	25.3	0.9	1.3	1465.9
1975	4.0	65.2	100.0	170.9	120.1	197.6	252.1	194.3	150.8	98.3	6.6	54.6	1414.4
1976	36.3	85.1	106.5	111.3	189.0	323.5	211.4	232.8	189.8	92.9	110.4	25.0	1723.0
1977	72.8	55.8	54.2	15.6	129.5	196.5	203.2	267.7	190.5	229.4	61.4	14.5	1491.1
1978	4.7	70.8	42.2	138.2	203.5	222.2	183.6	215.4	202.7	63.7	57.2	37.6	1441.8
1979	32.4	117.8	110.6	23.0	116.0	231.9	153.3	163.5	114.6	75.0	8.9	22.3	1169.3
1980	23.4	42.1	100.1	301.3	108.1	189.0	96.1	164.2	140.8	108.7	26.5	27.7	1328.0
1981	0.9	7.2	135.8	62.0	252.0	113.6	192.5	250.0	164.4	30.8	126.9	1.2	1337.3
1982	105.0	42.5	60.9	136.0	210.8	222.9	141.1	191.7	156.8	94.4	211.5	37.0	1610.6
1983	20.2	39.6	97.1	160.5	228.1	165.7	173.8	228.9	298.7	141.2	53.8	6.8	1614.4
1984	23.9	10.7	32.2	82.8	190.5	183.1	211.4	166.3	187.0	12.2	138.2	49.7	1288.0
1985	25.1	19.5	77.4	147.2	203.3	135.9	267.6	168.2	127.6	63.1	49.9	11.9	1296.7
1986	0.0	48.2	81.7	114.8	150.7	256.1	232.5	133.9	163.1	88.5	15.9	47.4	1330.8
1987	26.4	88.5	157.7	59.8	187.7	204.3	185.5	180.0	135.8	116.4	45.6	51.9	1439.6
1988	81.3	59.0	30.9	87.1	181.8	165.1	184.6	294.0	291.9	171.9	1.5	0.0	1549.1
1989	27.8	46.8	138.2	178.9	102.2	178.6	232.0	213.3	204.1	106.8	28.3	170.0	1627.0
1990	24.6	46.0	132.9	96.0	193.6	320.1	206.9	280.2	244.6	22.9	93.5	18.7	1639.0
1991	79.4	80.9	61.9	157.3	109.5	228.5	200.4	244.5	135.6	63.3	7.6	78.1	1457.2
AVE.	33.37	53.07	92.84	135.78	159.67	212.33	211.78	212.87	181.38	91.31	53.27	39.82	1476.89

Latitude :- 7 40' N Longitude 36 50'

Subject :- Mean Monthly Temperature (C) Station :- Jimma Altitude 1725 m

Year	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	AVE.
1952	17.60	17 85	19.80	19 35	19.60	19.70	19.50	18.35	19.25	20.10	18.15	16.90	18.43
1953	17.30	16.60	19.70	19.55	19.75	19 45	18.10	18.85	19.60	19.60	18.60	18.80	18.83
1954	17.85	18 85	19.85	20 10	20.25	19 15	17.75	18.30	19.15	18.10	17.15	17.05	18.63
1955	18.40	18.05	19.80	19 90	19.25	18 85	19.20	18.00	19.15	18.65	17.80	17.15	18.57
1956	16.60	18.05	19.95	18 30	19.30	18 45	17.60	17 85	18.95	18.75	16.40	15.60	18.07
1957	17.40	19.40	19.50	20.35	19.60	20 10	18.35	18.75	19.40	19.05	18.90	16.60	18.95
1958	19.25	20.05	20.25	21.30	20.75	19 95	18.80	19.05	19.80	18.95	16.35	16.75	19.27
1959	20.85	19.75	20.05	20.80	20.50	20.05	19.40	19.30	19.60	19.70	18.05	17.85	19.66
1960	18.05	18.85	20.35	20.60	20.45	18 95	19.45	18.35	19.75	19.00	18.25	17.60	19.14
1961	-	-	-	-	-	-	-	-	-	-	-	-	-
1962	-	-	-	-	-	-	-	-	-	-	-	-	-
1963	17.40	19.25	19.45	19.45	19.35	19.00	18.55	18.55	19.00	18.45	19.95	18.55	18.91
1964	17.05	18.65	20.40	19.95	19.65	18.95	17.95	18.20	19.00	18.70	17.45	18.15	18.67
1965	17.80	18.10	19.90	20.10	19.50	19.00	18.75	18.55	19.05	19.00	18.85	17.90	18.88
1966	19.00	19.60	20.30	20.10	20.00	19.05	18 80	18 55	19.10	18.95	17.85	16.40	18.98
1967	16.15	18.65	20.25	20.10	19.70	18.60	18.20	18.30	18.90	17.90	18.65	16.30	18.48
1968	16.50	18.55	18.95	19 90	20.00	19.00	19.00	18.85	18.85	18.15	17.30	17.10	18.50
1969	19.10	19.25	20.10	19 95	19.90	19.30	18.20	18.45	19.05	18.45	17.20	14.75	18.64
1970	17.75	18.95	20.05	20 20	20.20	19.30	18.85	18.60	19.15	19.4.	18.15	15 85	18.70

Year	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	AVE.
1971	17.85	16.95	19.20	20.05	19.70	18.50	18.45	17.75	18.75	19.00	17.60	15.85	18.30
1972	17.80	19.15	19.40	20.20	19.25	18.40	19.15	19.00	19.20	18.95	18.55	17.60	18.89
1973	18.80	18.70	20.65	21.75	20.00	19.40	18.75	18.55	19.10	18.40	17.60	15.15	18.90
1974	17.60	19.30	20.30	19.40	19.80	19.10	18.30	19.05	18.90	18.05	15.50	16.55	18.49
1975	17.40	19.55	20.75	20.15	19.65	19.05	18.05	18.05	18.95	18.60	16.55	16.45	18.60
1976	17.10	19.80	19.90	19.75	19.15	18.40	18.45	18.55	19.15	19.00	18.30	17.20	18.73
1977	19.05	19.50	20.00	20.55	20.30	18.80	18.50	19.05	19.45	19.95	18.70	18.20	19.33
1978	17.45	18.90	20.90	20.80	19.75	19.25	18.40	18.95	18.70	18.95	16.95	17.80	18.90
1979	18.35	19.45	19.80	19.65	20.10	19.20	18.75	19.30	19.50	18.95	17.55	18.20	19.07
1980	18.50	20.00	20.90	20.95	20.30	19.55	18.60	18.55	19.50	18.65	17.85	17.00	19.20
1981	18.60	18.70	21.05	20.35	20.55	19.55	18.15	18.80	19.10	18.65	17.55	16.70	18.98
1982	18.75	18.45	19.10	20.20	19.50	19.25	18.70	18.50	19.15	18.55	18.70	17.95	18.90
1983	16.80	19.55	20.95	20.75	20.75	20.05	19.65	19.50	19.30	19.00	18.10	16.95	19.22
1984	17.05	17.05	20.35	21.30	20.35	19.20	18.40	18.45	18.70	17.15	19.00	18.00	18.75
1985	17.80	18.95	20.60	20.40	19.90	19.05	18.10	18.20	19.05	18.30	17.95	17.15	18.79
1986	17.75	20.50	19.20	19.95	20.40	19.35	18.75	18.85	18.85	18.40	17.85	17.80	18.97

Appendix 2

(CONTINUED)

Year	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	AVE.
1987	18.10	19.05	20.35	20.35	20.10	19.85	19.55	19.30	19.45	19.60	18.40	17.60	19.31
1988	18.60	20.35	20.10	20.95	21.00	19.75	18.75	19.25	19.45	19.15	16.75	16.40	19.21
1989	17.70	18.50	19.70	19.85	19.35	19.20	18.75	19.25	19.25	18.65	17.80	18.80	18.90
1990	17.45	19.40	20.05	20.40	20.00	19.65	18.80	19.15	19.45	18.55	18.45	17.10	19.04
1991	19.05	19.40	20.10	20.35	20.20	19.60	19.25	18.45	19.70	17.75	17.50	16.90	19.02
AVE	17.84	18.94	20.05	20.20	19.94	19.13	18.60	18.67	19.19	18.77	17.80	17.13	18.86

Year	JAN	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL	ANN. M
1969	-	104.44	121.83	153.60	122.76	-	55.80	62.93	103.20	156.24	114.90	141.05	1136.75	113.68
1970	89.28	122.08	138.88	140.10	129.89	96.90	97.65	84.01	113.10	144.15	150.30	158.10	1464.44	122.04
1971	147.35	172.20	173.91	159.30	124.93	97.50	97.03	97.34	133.50	134.54	137.40	120.28	1595.18	132.93
1972	137.93	116.48	162.13	136.50	109.03	123.00	83.39	130.51	115.10	163.68	170.40	141.67	1640.22	136.69
1973	142.19	158.76	204.91	204.00	144.77	134.10	121.21	99.20	133.20	149.11	141.00	151.23	1783.83	148.65
1974	174.53	175.00	167.71	181.80	135.77	137.70	105.71	94.86	120.30	147.25	150.90	156.86	1788.39	149.03
1975	171.43	165.76	192.20	138.30	150.97	107.70	73.16	79.05	98.70	141.05	145.90	152.51	1616.64	134.72
1976	163.58	155.68	177.94	158.10	140.74	112.80	86.80	112.84	145.20	157.48	116.10	134.23	1661.59	138.47
1977	129.58	122.08	166.16	167.40	167.09	120.60	51.15	86.18	111.00	48.67	128.70	130.82	1429.43	159.12
1978	160.27	131.60	64.79	162.30	137.02	112.50	71.30	79.36	113.70	139.81	132.30	134.54	1439.49	119.96
1979	129.27	117.88	156.55	155.70	134.23	102.90	106.64	111.60	126.90	148.18	134.40	150.04	1574.29	131.19
1980	145.39	148.68	170.50	189.00	161.51	109.20	71.92	105.09	138.30	140.08	140.40	140.12	1665.19	138.77
1981	167.09	157.92	139.19	136.50	135.47	134.40	68.20	123.38	113.40	163.68	152.70	136.71	1628.64	135.72
1982	136.40	121.24	174.84	147.90	137.33	146.10	96.10	116.87	140.70	141.36	126.30	129.89	1615.03	134.59
1983	123.07	120.40	155.31	153.00	159.34	136.20	125.24	127.10	136.50	131.75	139.50	134.23	1641.64	136.80
1984	141.05	149.80	197.16	168.60	143.22	124.20	94.24	115.94	141.30	159.96	141.90	138.57	1715.94	143.00
1985	148.18	145.88	183.21	156.60	162.06	116.70	104.16	111.29	135.00	147.56	150.00	134.85	1696.49	141.37
1986	146.01	144.76	153.14	134.70	159.34	138.30	113.46	124.31	141.00	150.35	142.80	132.68	1680.85	140.07
TOT.	2452.1	2530.6	2900.	2843.4	2646.47	2050.8	1623.16	1861.86	2261.1	2569.9	2515.8	2518.44	28774.03	2416.8
MEAN	144.24	140.59	161.13	157.97	147.03	120.64	90.18	103.44	125.62	142.77	139.77	139.91	1598.56	134.27

Appendix 5

HYDROMETRIC DISCHARGE DATA

Station :- Gilgel Ghibe near Asendobo
Drainage Are :- 2966 sq. km.
Basin :- Ghibe Omo

Year	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1972	17.86	15.05	15.69	46.05	53.95	83.43	261.03	339.48	225.23	76.35	70.24	60.78	1265.14
1973	28.65	9.71	2.70	6.20	44.52	104.59	288.66	379.92	336.09	154.63	38.83	18.45	1412.95
1974	11.71	6.80	10.68	7.96	49.50	148.01	233.72	350.10	327.90	105.99	28.59	13.84	1294.80
1975	7.86	8.65	7.71	20.48	15.91	97.48	209.2	263.24	241.54	143.77	27.40	13.75	1056.99
1976	7.89	5.81	7.62	6.27	26.3	111.4	291.06	309.93	255.21	61.55	72.17	20.98	1176.19
1977	18.99	16.25	16.53	9.24	11.65	110.66	246.56	307.96	293.63	151.65	169.40	38.46	1382.98
1978	13.04	11.34	13.96	11.96	68.48	137.33	257.17	422.38	278.73	186.71	39.51	26.52	1467.13
1979	19.42	30.23	19.45	25.44	45.97	93.91	191.10	217.85	123.25	77.42	18.18	15.36	877.58
1980	9.58	5.68	8.22	15.95	25.18	135.71	169.80	263.3	146.57	55.72	19.46	10.13	865.30
1983	24.96	13.84	9.06	19.17	25.61	111.92	114.99	211.97	396.11	575.55	155.74	51.64	1710.56
1984	25.10	9.37	5.85	9.76	25.09	142.37	249.35	245.66	200.76	52.19	22.75	16.97	1005.22
1985	6.83	4.02	3.31	11.45	34.36	208.84	206.98	289.53	233.62	98.53	32.84	16.00	1149.31
1986	5.63	6.20	10.91	9.24	11.65	108.73	215.56	181.66	222.66	88.22	26.52	18.73	905.71
1988	10.33	10.35	4.40	3.73	9.17	47.89	167.14	416.43	315.34	253.78	53.11	19.67	1311.34
1989	12.95	12.05	9.36	54.74	30.50	90.88	156.61	204.43	201.31	111.34	38.66	45.77	968.62
1990	31.81	15.54	25.72	23.02	43.59	146.05	260.62	203.20	311.09	15.46	239.86	25.37	1331.33
AVE.	15.16	11.31	10.70	17.72	32.59	117.45	219.97	287.94	256.82	138.05	65.83	25.38	1198.82

Appendix 6

Values of $W(u)$ for Values of u

u	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
$\times 1$	0.219	0.049	0.013	0.0038	0.0011	0.00036	0.00012	0.000038	0.000012
$\times 10^{-1}$	1.82	1.22	0.91	0.70	0.56	0.45	0.37	0.31	0.26
$\times 10^{-2}$	4.04	3.35	2.96	2.68	2.47	2.30	2.15	2.03	1.92
$\times 10^{-3}$	6.33	5.64	5.23	4.95	4.73	4.54	4.39	4.26	4.14
$\times 10^{-4}$	8.63	7.94	7.53	7.25	7.02	6.84	6.69	6.55	6.44
$\times 10^{-5}$	10.94	10.24	9.84	9.55	9.33	9.14	8.99	8.86	8.74
$\times 10^{-6}$	13.24	12.55	12.14	11.85	11.63	11.45	11.29	11.16	11.04
$\times 10^{-7}$	15.54	14.85	14.44	14.15	13.93	13.75	13.60	13.46	13.34
$\times 10^{-8}$	17.84	17.15	16.74	16.46	16.23	16.05	15.90	15.76	15.65
$\times 10^{-9}$	20.15	19.45	19.05	18.76	18.54	18.35	18.20	18.07	17.95
$\times 10^{-10}$	22.45	21.76	21.35	21.06	20.84	20.66	20.50	20.37	20.25
$\times 10^{-11}$	24.75	24.06	23.65	23.36	23.14	22.96	22.81	22.67	22.55
$\times 10^{-12}$	27.05	26.36	25.96	25.67	25.44	25.26	25.11	24.97	24.86
$\times 10^{-13}$	29.36	28.66	28.26	27.97	27.75	27.56	27.41	27.28	27.16
$\times 10^{-14}$	31.66	30.97	30.56	30.27	30.05	29.87	29.71	29.58	29.46
$\times 10^{-15}$	33.96	33.27	32.86	32.58	32.35	32.17	32.02	31.88	31.76

Appendix 7A

Pumping Test

Pumping Date :- January 2, 1981 EC
Location :- Jimma
Owner :- Jimma Agricultural Collage
Pump setting depth :- 75.50m
Elevation of well :- 1750m
Discharge :- 1.5lit/sec.
Static water level :- 12.8m
Well size :- 6"
Total depth :- 77m (BGL)

Time Since Pump started t, in min.	Water Level BGL in meters	Drawdown, s, in meters
0	12.21	0
1	14.49	1.68
2	14.95	2.14
3	15.30	2.49
4	15.56	2.75
5	15.81	3.00
7	16.28	3.47
8	16.50	3.69
9	16.70	3.89
10	16.90	4.09
12	17.26	4.45
14	17.60	4.79
16	17.92	5.11
20	18.65	5.84
21	18.72	5.91
22	18.88	6.07
23	18.97	6.16
24	19.19	6.38
26	19.39	6.58

(Cont'd.)

27	19.53	6.72
28	19.65	6.84
30	19.90	7.09
35	20.60	7.79
40	21.00	8.19
60	23.03	10.22
70	23.90	11.09
80	24.74	11.93
90	26.73	13.92
100	26.79	13.98
150	32.75	19.94
200	37.45	24.64
300	41.70	28.89
400	42.35	29.54
500	42.78	29.97
600	43.23	30.42
700	43.23	30.97
800	44.22	31.41
900	45.97	33.16
1000	48.00	35.19
1200	51.05	38.24
1400	53.91	41.10
1600	55.21	42.40

SOURCE :- Southwestern E.W.W.C.A Office

Appendix 7B

Time Recovery Test

Date :- 03-05-81 EC.
Location :- Jimma
Owner :- Jimma Agricultural Collage
Pump Setting depth :- 75.50m
Discharge (Q) :- 1.5 lit/sec
Static water level :- 12.81m
Elevation :- 1750
Well depth :- 77m
Ended at :- 04-05-81 EC

Progressing Time		Ratio t/t'	Water level (M)	Residual drawdown SR. (M)	Recovery 'S' (M)
Time Since Pump Stopped, t' (min)	Time since Pump started, t (min)				
0	1600	-	55.21	42.40	0
2	1602	801	47.12	34.31	8.09
3	1603	534.3	43.80	30.99	11.41
4	1604	401.0	41.95	29.14	13.26
6	1606	267.67	40.00	27.19	15.21
7	1607	229.57	39.57	26.76	15.64
8	1608	201.00	39.25	26.44	15.96
9	1609	178.78	39.05	26.24	16.16
10	1610	161.00	38.90	26.09	16.31
12	1612	134.33	38.84	26.03	16.37
14	1614	115.29	38.70	25.89	16.51
16	1616	101.00	38.64	25.83	16.57
20	1620	81.00	38.55	25.74	16.66
21	1621	77.19	38.52	25.71	16.69
22	1622	73.73	38.50	25.69	16.71
23	1623	70.57	38.48	25.67	16.73
24	1624	67.67	38.46	25.65	16.75

(Cont'd.)

25	1625	65.00	38.44	25.63	16.77
26	1626	62.54	38.42	25.61	16.79
27	1627	60.26	38.40	25.59	16.81
28	1628	58.14	38.39	25.58	16.82
29	1629	56.17	38.38	25.57	16.83
30	1630	54.33	38.37	25.56	16.84
35	1635	46.71	38.32	25.51	16.89
40	1640	41.00	38.23	25.42	16.98
50	1650	33.00	38.11	25.30	17.10
60	1660	27.67	38.03	25.22	17.18
70	1670	23.86	37.90	25.09	17.31
80	1680	21.00	37.78	24.97	17.43
90	1690	18.78	37.70	24.81	17.59
100	1700	17.00	37.61	24.80	17.60
150	1750	11.67	37.09	24.28	18.12
200	1800	9.00	36.57	23.76	18.64
300	1900	6.33	35.84	23.03	19.37
400	2000	5.00	35.30	22.49	19.91
500	2100	4.20	34.40	21.59	20.81
600	2200	3.67	33.80	20.99	21.41
700	2300	3.29	-	-	-
800	2400	3.00	-	-	-
900	2500	2.78	-	-	-
1000	2600	2.60	-	-	-
1200	2800	2.33	-	-	-
1400	3000	2.14	-	-	-
1440	3040	2.11	27.07	14.26	28.14
1600	3200	2.00	26.70	13.89	28.51

SOURCE : Southwestern E.W.W.C.A Office

Appendix 8 A

Pumping Test

Pumping Date :- 18-07-82 to 19-07-82 (EC)
Location :- Jimma SSE of Agip
Owner :- E.W.W.C.A.
Pump setting depth :- 102m Total depth :- 144m
Elevation :- 1680m
Discharge :- lit/sec.
Static water level :- 13.38m
Diameter of borehole :- 12"
Diameter of casing :- 6"

Time Since Pump started t, in min.	Water Level BGL in meters	Drawdown, s, in meters
0	13.38	0
1	15.35	1.97
1.5	15.85	2.47
5	22.78	9.40
10	25.51	12.13
15	26.89	13.51
50	33.78	20.4
100	38.28	24.90
150	40.38	27.00
200	41.52	28.14
250	41.90	28.52
300	42.24	28.86
350	43.40	30.02
400	43.69	30.31
450	43.89	30.51
500	44.50	31.12
550	45.00	31.62
600	45.45	32.07
650	45.50	32.12
700	45.61	32.23
750	45.71	32.33
800	45.80	32.42
850	46.20	32.82

(Cont'd.)

1300	46.74	33.36
1350	46.45	33.07
1400	46.66	33.28
1450	46.81	33.43
1500	46.83	33.45
1550	47.26	33.88
1600	47.26	33.88
1650	47.69	34.31
1700	47.47	34.09
1750	47.50	34.12
1800	47.70	34.32
1810	47.80	34.42

SOURCE :- Southwestern E.W.W.C.A Office

Appendix 88

Time Recovery Test

Date :- 19-07-82 EC
Location :- Jimma SSE of Agip
Owner :- E.W.W.C.A
Pump Setting depth :- 102m
Discharge (Q) :- 1 lit/sec
Static water level :- 13.38m
Diameter of Borehole :- 12"
Diameter of casing :- 6"
Elevation :- 1680m
Well depth :- 144m

Progressing Time		Ratio t/t'	Water level (M)	Residual drawdown SR. (M)	Recovery S' (M)
Time Since Pump Stopped, t' (min)	Time since Pump started, t (min)				
0	1410	-	47.80	34.42	0
1	1411	1411	44.90	31.52	2.90
5	1415	283	36.70	23.32	11.10
10	1420	142	29.04	15.66	18.76
15	1425	95	26.09	12.71	21.71
30	1460	29.20	21.58	8.20	26.22
100	1510	15.10	20.21	6.83	27.59
150	1560	10.40	19.57	6.19	28.23
166	1576	9.49	19.40	6.02	28.40
334	1744	5.22	18.36	4.98	29.44

SOURCE :- Southwestern E.W.W.C.A Office

Appendix 9A

GROUNDWATER AND SURFACE WATER CHEMICAL ANALYSIS

Name and location/Constituent or characteristic		Kitto Borehole No. 2	AADU EELPA Borehole No.22	AADU Jiren Borehole No. 23	San Gabriel spring No. 1	Jiren Spring No. 2
Appearance		Colourless	colourless	Colourless	Colourless	Colourless
Odour		Odourless	Odourless	Odourless	Odourless	Odourless
Taste		Testeless	Tasteless	Tasteless	Tasteless	Tasteless
Colour		Colourless	Colourless	Colourless	Colourless	Colourless
Turbidity (NTU)		Clear	Clear	Clear	Clear	Clear
pH		8.4	8.0	7.3	6.5	6.3
Electrical Conductivity (μmhos/cm)		460	816	397	90	115
Total dissolved solids(mg/l)		537.34	795.73	442.14	137.02	176.07
Carbonat Alkalinity	mg/l (as $CaCo_3$)	45	20	NIL	NIL	NIL
Bicarbonate Alkalinity	mg/l (as $CaCo_3$)	320	460	220	40	62
Total Hardness	mgll as $CaCo_3$	25	32	38	42.5	50
Carbon dioxide (Co_2)	mg/l	-	-	-		-
Hydrogen sulphide (H_2S)	mg/l	-	-	-		-
Boron (HBO_3)	mg/l	-	-	-		-

App. 9A

(Continued)

	Silica (Si)	mg/l	39.00	25.00	56.00	33.00	58.00
	Ammonia (NH_4)	mg/l mg/l %	NIL	0.3 0.02 0.21	0.58 0.03 0.63	NIL	0.13 0.01 0.64
	Sodium	mg/l meq/l %	146.3 6.72 89.83	200.6 8.72 90.27	85 3.70 78.22	3.4 0.25 26.91	6.4 0.28 17.72
CATIONS	Potassium	mg/l meq/l %	8.1 0.21 2.97	7.00 0.18 1.86	5.3 0.14 2.96	1.6 0.04 3.64	1.6 0.04 2.53
	Calcium (Ca)	mg/l meq/l %	7.0 0.35 4.94	8.00 0.40 4.14	9.6 0.48 10.15	10.4 0.52 47.27	14.6 0.73 46.20
	Magnesium (Mg)	mg/l meq/l %	1.8 0.15 2.12	2.9 0.24 2.48	3.4 0.28 5.92	3.1 0.28 25.45	3.7 0.31 19.62
	Iron (Fe)	mg/l meq/l %	0.17 0.01 0.14	1.8 0.1 1.04	1.7 0.09 1.90	0.15 0.01 0.91	3.2 0.17 10.76
	Manganese (Mn)	mg/l meq/l %	NIL	NIL	0.3 0.01 0.22	0.5 0.02 1.82	1 0.04 2.53
	TOTAL	mg/l meq/l %	163.37 7.08 100	220.6 9.66 100	105.88 4.73 100	21.45 1.1 100	30.63 1.58 100
ANIONS	Chloride (cl)	mg/l meq/l %	8.9 0.25 3.46	9.9 0.28 2.91	7.1 0.2 4.20	24.8 0.71 40.47	3.6 0.1 6.25
	Nitrite (No_2)	mg/l meq/l %	0.01 0.00002 0.003	0.03 0.001 0.01	0.06 0.001 0.02	0.02 0.0004 0.02	NIL
	Nitrate (No_3)	mg/l meq/l %	3.1 0.05 0.69	0.9 0.01 0.1	0.9 0.01 0.21	5.8 0.09 5.13	NIL

App. 9A

(Continued)

Fluoride (F)	mg/l meq/l %	2.82 0.15 2.08	2.3 0.12 1.25	2.2 0.12 2.52	2.82 0.15 8.33	2.82 0.15 9.37
Bicarbonate (HCo_3)	mg/l meq/l %	230 3.77 52.19	512 8.39 87.21	268 4.39 92.21	49 0.80 45.60	76.00 1.25 78.08
Carbonate (Co_3)	mg/l meq/l %	90 3 41.53	24 0.8 8.32	NIL	NIL	NIL
Sulphate (So_4)	mg/l meq/l %	NIL	1 0.02 0.21	2 0.04 0.84	NIL	5.00 0.10 6.25
Phasphate (Po_4)	mg/l meq/l %	0.14 0.004 0.06	NIL	NIL	0.13 0.004 0.23	0.02 0.001 0.06
TOTAL	mg/l meq/l %	334.97 7.2242 100	550.13 4.621 100	280.26 4.761 100	82.57 1.7544 100	87.44 1.661 100
TOTAL IONS	mg/l meq/l	498.34 14.30	770.73 19.28	386.14 9.49	104.02 2.85	118.07 3.18
RATIOS BY WEIGHT Ca/Na	mg/l	0.05	0.04	0.11	1.93	2.28
Mg/Ca	mg/l	0.26	0.36	0.35	0.33	0.25
K/Na	mg/l	0.06	0.03	0.06	0.30	0.25
HCo_3\cl	mg/l	25.84	51.72	37.75	1.98	21.11
So_4 \cl	mg/l	-	0.10	0.28	-	1.39
F\Cl	mg/l	0.32	0.23	0.31	0.11	0.78

Annex 4b

GROUNDWATER AND SURFACE WATER CHEMICAL ANALYSIS

Name and location/ Constituent or characteristic		Hirmata Dug Well	Lagahar Spring	Aweytu River (near to the centre of the town	Aweytu River (above EELPA)
Appearance		colourless	colourless	not clear	not clear
Odour		Odourless	Odourless	Odourless	odourless
Taste		Testeless	Tasteless	Tastless	Tastless
Colour		Colourless	Colourless	Muddy	Muddy
Turbidity (NTU		Clear	Clear	8	14
pH		7.3	5.2	6.2	7.3
Electrical Conductivity (µmhos/cm)		406	531.00	71	71
Total, dissolved solids(mg/l)		385.53	462.71	133.84	113.36
Carbonat Alkalinity	mg/l (as $CaCo_3$	NIL	NIL	NIL	NIL
Bicarbonate Alkalinity	mg/l (as $CaCo_3$	175	60	10	40
Total Hardness	mg/l as $CaCo_3$	45	162.5	35	32
Carbon dioxide (Co_2)	mg/l	-	-	-	-
Hydrogen sulphide (H_2S)	mg/l	-	-	-	-
Boron (HBO_3)	mg/l	-	-	-	-

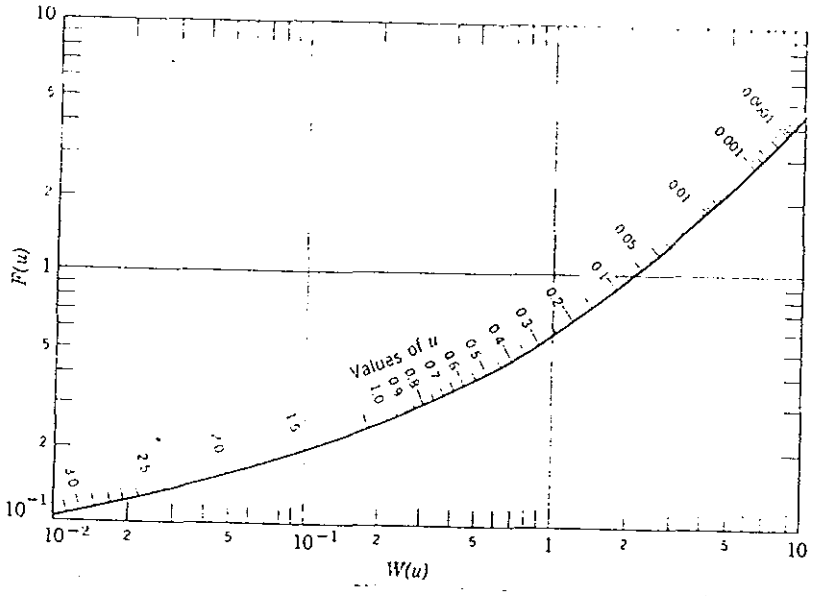
(Continued)

	Silica (SiO_2)	mg/l	64	24	28	33.5
CATIONS	Ammonia (NH_4)	mg/l meq/l %	0.06 0.003 0.08	0.12 0.01 0.16	0.13 0.01 0.69	0.98 0.05 4.80
	Sodium (Na)	mg/l meq/l %	62.9 2.73 70.13	66.0 2.87 46.12	13.6 .59 40.97	5.4 0.23 22.12
	Potassium (k)	mg/l meq/l %	9.4 0.24 6.16	2.2 0.06 0.96	2.2 0.06 4.17	2.2 0.06 5.77
	Calcium (Ca)	mg/l meq/l %	10.0 0.5 12.84	42.1 2.11 33.91	10.0 0.5 34.72	8.0 0.40 38.46
	Magnesium (Mg)	mg/l meq/l %	4.9 .41 10.53	14.0 1.17 18.80	2.4 0.2 13.89	2.9 0.24 23.08
	Iron (Fe)	mg/l meq/l %	0.19 .01 0.26	0.06 0.003 0.05	1.41 0.08 5.56	1.2 0.06 5.77
	Manganese (Mn)	mg/l meq/l %	NIL	NIL	NIL	NIL
	TOTAL	mg/l meq/l %	87.45 3.893 100	124.48 6.223 100	29.74 1.44 100	20.68 1.04 100
ANIONS	Chloride (cl)	mg/l meq/l %	10.6 0.30 7.34	85.1 2.43 38.62	11.5 0.33 21.64	7.1 0.2 18.67
	Nitrite (No_2)	mg/l meq/l %	0.003 0.00007 0.002	NIL	0.01 0.0002 0.01	0.06 0.001 0.09
	Nitrate (No_3)	mg/l meq/l %	4.2 0.07 1.71	145.3 2.34 37.19	2.7 .04 2.62	1.6 .03 2.80
	Fluoride (F)	mg/l meq/l %	3.0 0.16 3.91	2.78 0.15 2.38	2.72 0.14 9.18	0.44 0.02 1.87
	Bicarbonate (HCo_3)	mg/l meq/l %	213 3.49 85.35	73 1.20 19.07	49 0.8 52.45	49 0.8 74.70

(Continued)

ANTIONS	Carbonate (Co_3)	mg/l meq/l %	NIL	NIL	NIL	NIL
	Sulphate (So_4)	mg/l meq/l %	3.0 0.06 1.47	8 0.17 2.70	10.00 0.21 13.77	1.00 0.02 1.87
	Phasphate (Po_4)	mg/l meq/l %	0.28 0.009 0.22	0.05 0.002 0.03	0.17 0.005 0.33	NIL
	TOTAL	mg/l meq/l %	234.083 4.08907 100	314.23 6.292 100	76.1 1.5252 100	59.2 1.071 100
	TOTAL IONS	mg/l meq/l	321.53 7.98	438.71 12.52	105.84 2.97	79.88 2.11
RATIOS BY WEIGHT	Ca/Na	mg/l	0.16	0.64	0.74	1.48
	Mg/Ca	mg/l	0.49	0.33	0.24	0.36
	K/Na	mg/l	0.15	0.03	0.16	0.11
	HCo_3/cl	mg/l	20.09	0.86	4.26	6.90
	So_4 \cl	mg/l	0.28	0.09	0.87	0.14
	F\Cl	mg/l	0.28	0.03	0.24	0.06

Appendix 11 . RELATION AMONG F(u), W(u), and u (After Chow)



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