ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

WATER BALANCE AND EFFECT OF IRRIGATED AGRICULTURE ON GROUNDWATER QUALITY IN THE WONJI AREA / Ethiopian Rift Valley

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Abstract

Wonji basin covers a total area of 357 Km^2 and has a population of 290,703 out of which 50,000 are sugar estate farm workers. The main source of domestic water in the area is groundwater. Awash river passes in the area dividing in to two equal parts whose water is mainly used for cattle drinking and industrial purposes.Meteorological and hydrological data were used to establish and calculate water balance in the Wonji basin. Groundwater recharge was estimated to be 557.75 x 10^6m^3 per year. Different methods some with many parameters and others with few were checked side by side to obtain more realistic actual evapotranspiration. Their average gave 702 mm mean annual actual evapotranspiratin. The mean annual rainfall is 785 mm in the area.

Based on joint data along with mathematical treatment and pumping test results, lithological units have been characterised into different permeability groups. From the results of water chemistry and compositional diagrams, 5 groundwater systems with some interconnections were identified. Direction of regional groundwater flow of the basin is from west to east. Two horizons of cold water of deep aquifers occur at an average depth of 120 and 170 in the region. Using temperature of thermal springs, depth of geothermal water circulation has been calculated to be 242 m below the surface. This has been also confirmed by the drilling data of borehole 26. However this depth could vary up to 400-500 m under Gadamsa caldera rim, Boku ridge and Koka escarpment high lands. The estimated groundwater demand in the basin ranges up to $4.7x10^6m^3$, which is much less than yearly recharge.

Fluoride concentration showed zonal variability from low lying parts of the basin to the high lands of the study area corresponding to compositional variation of the rocks and thermal activity. Concentration of total dissolved solids in the groundwater, exhibited positive relation with irrigated sugar plantation. Pollution from inorganic fertiliser (NO_3) is not however, observed under sugar cane farm. This is suggested to be due to high groundwater inflow dilution from Koka reservoir. Subsurface water in the region is generally of good quality for drinking purposes. But some dug wells and hot springs are of non promising quality for irrigation.

CHAPTER ONE

INTRODUCTION

Water is decisive natural resource for living things to exist on the earth and it is a back bone of modern civilization. This resource is used for irrigation industries, drinking and cleaning purpose as well as for plant growth. Groundwater is also one of the major source which contribute a lot to world water demand. Shortages of groundwater in areas of excess exploitation calls for corrected estimates and proper development, regulation and protection of supplies inorder to insure the continued availability of this key natural resource. Groundwater usage has increased at an accelerated rate in recent years, and indicates that this trend will continue. This suggests that its quality thus has to be insured.

Wonji is located in the Main Ethiopian Rift 15 km south of Nazareth. The area is used both for industrial agriculture and cereals. The occurrence of several hot springs attracts people to create recreational center. Development of tourism activity could be also another concern of the region. Eventhough it serves as a wide economic source from both tourism and industrial products quality and volume of groundwater is not yet well studied. A long lasting utilization of agricultural chemicals might have contributed negative impact on groundwater qualiy. Its extent and degree of pollution has not been ever discussed for the area.

In Wonji plain groundwater has a high significance as drinking water resource exploited by means of boreholes, springs or abstraction from shallow dug wells. Therefore, construction of boreholes and spring development are common practices, but carried without knowledge of water bearing zones and groundwater quality. Thus, their water yielding capacity are minimum.

Hence the present work will give insights on these points including:-

- the effect of irrigated agriculture and fertilization on the groundwater quality
- estimation of the water requirements for drinking purposes
- identification of promising areas for future development of ground water resource.
- determination quality, resource and type of groundwater of the region.
- aquifer characterization
- water balance of the basin.

1.1 Back ground of the study area.

Detailed hydrogeological study of Wonji basin has not been conducted in the past. Water budget calculation which in turn can be used to estimate groundwater reserve was not considered by previous investigations. In the area, though industrial agriculture has long been practiced, no work has been carried out to assess its impact. Wonji sugar plantation is one of the area, where irrigation is best excersized in Ethiopia. Its sugar production covers about 50% of total production of the country that contributed a lot to elevate the economy.

Over 10 villages, and about 50,000 factory workers live in the Wonji plantation. From existing infrastructure of the plantation, it is clear that there are number of activities such as: factory work and exporting of finished goods. All these activities directly or indirectly need water of good quality. On the other hand surface water is scarce, in particular in localities like Dera and surroundings. People of these localities travel long distance about 8-12 km to fetch water. This dictated the present research to analyze water of the area from different aspects and considerations.

1.2 Scope of the study

In the area shortage of surface water, at some places is a serious problem; particularly during the dry season. The alternate means to overcome this problem is to use subsurface existing groundwater. Therefore, evaluation of its volume in the basin was one of the aim of the study. Irrigation is highly practiced, factory wastes are common, many people live; all may have impact on water quality of the area. Thus, analysis of this impact and its extent was one of the main concern (scope) of the work.

The expected outcome of the research is to understand the hydrological and hydrochemical conditions of the Wonji plain and the effects of irrigated agriculture on groundwater quality.

The study may also serve population of the basin to plan their future water development strategy program, to carry out proper construction that help to exploit existing water resource with reasonable management.

Urban population of the area and decision makers will benefit from this study in planning integrated long term water supply systems and city development of the basin

1.3 Previous Work

Several works have been carried out in Wonji area. But the target of most of them was: geology, geothermal and master plan study of the region. In particular no work has been conducted aiming at irrigation impact on water quality of the area under consideration. Regional hydrological study that include the Wonji basin was carried out by Getahun Kebede (1987). Hydrogeology of adjoining area of Nazareth was studied by Woldu Ameneshoa (1994).

Fluoride occurrence in the East African rift system has been described by George Darting et .al., (1996), B. Gizaw (1996) and of the Ethiopian rift Valley by Ashley and. Burely (1994). Detailed geology of the Nazareth - Dera area with a map of scale1:50,000 presented by Alula Damte (1990); which was used as base map for hydrogeological mapping of the present work. However, some lithological units of this geological map classified as different units have been regrouped together, taking into consideration their similar hydrogeologic characteristics. Other important works that considered the geology of the area are the works of Di Poala (1972), Mohr (1987), Kazmin and Seife (1987) and Electroconsult milano italia (1987). Geophysical study by Skutan et al. (1982) gave a clue of subsurface geology of the Wonji basin.

1.4 Methodology

The starting point of the study was collection literature data, that are relevant to the present work which also included topo sheets and aerial photographs. Then boundary of the study area established using toposheets in conjunction with aerial photographs. Technique of water shade dividing points was followed to mark the boundary line of the area.

Within the delineated area, water point inventory has been carried out and plotted on the map. The exact location and elevation for all boreholes, dug wells and springs were recorded in the field using GPS and altimeter respectively.

Depth to the groundwater was measured using electrical dipper water level measuring equipment. Aerial photo interpretation, was carried out to mark geological structures, which finally used to classify aquifer characteristics of lithounits..

Conductivity meter, and pH-meter have been used, in the field to collect chemical parameters, which also used to check the laboratory results. Discharge of springs measured in the field using floating method. Water samples were collected from all existing water points both ground and surface water points giving emphasis to water quality and impact of irrigated agriculture on this parameters. Sample bottles were renised with distilled water and collected samples dispatched to EIGS central laboratory analysis section soon after collection. At the points where in the field Ec of < 500 µs/cm measured, one litter of water samples were collected from each water point and for those with > 500 µs/cm 1/2 litter samples were collected for the analysis.

Sampling also included water of Koka reservoir to evaluate whether this lake is saline or not with respect to other water points. All existing data like pumping test meteorological and census, which support the present work were collected from relevant offices and extremely used for interpretation. Graphs of water chemical analyses, were drawn to study: water types, water mixing, and groundwater systems of the area.

CHAPTER TWO

THE STUDY AREA

2.1 Location

Wonji the investigated area lies between $8^0\ 20^1$ to $8^0\ 35^1$ N and $39^0\ 10^1$ to $39^0\ 25^1$ E in the central east part of the Main Ethiopia Rift system. It is used mainly for sugar plantation where over 50,000 workers are participating both in the farm land and sugar factory. It is located 105 Km south east of Addis Ababa, (Fig. 2.1.) covers total area of 357 Km^2

Sodere hot spring recreation center is the extreme eastern boundary, where Koka reservoir marks the western limit of the area. The north and south part of the region is delineated by Boku and Dera high standing surface water divide ridges respectively. The lower concave shaped central Wonji basin is the core of the investigated area.

2.2. Physiographic out line.

In general the area has gently slopping flat plain with undulating topography. In the extreme northwest part, mountainous terrain with deep cuts and dissected morphology with variable slopes are dominant. Parallel lining NNE - SSE stretching Wonji fault are also remarkable feature of the area at south east border of the region. They cross the region extending to the north running through and by the east side of Gadamsa volcano.

Some of the extension of these faults are clearly manifested at the north west border of the area forming Ketchema ridge. Their discontinuity in the Wonji plain, might be due to the back fill of sediments in the graben and denudation by the Awash river. The highest point

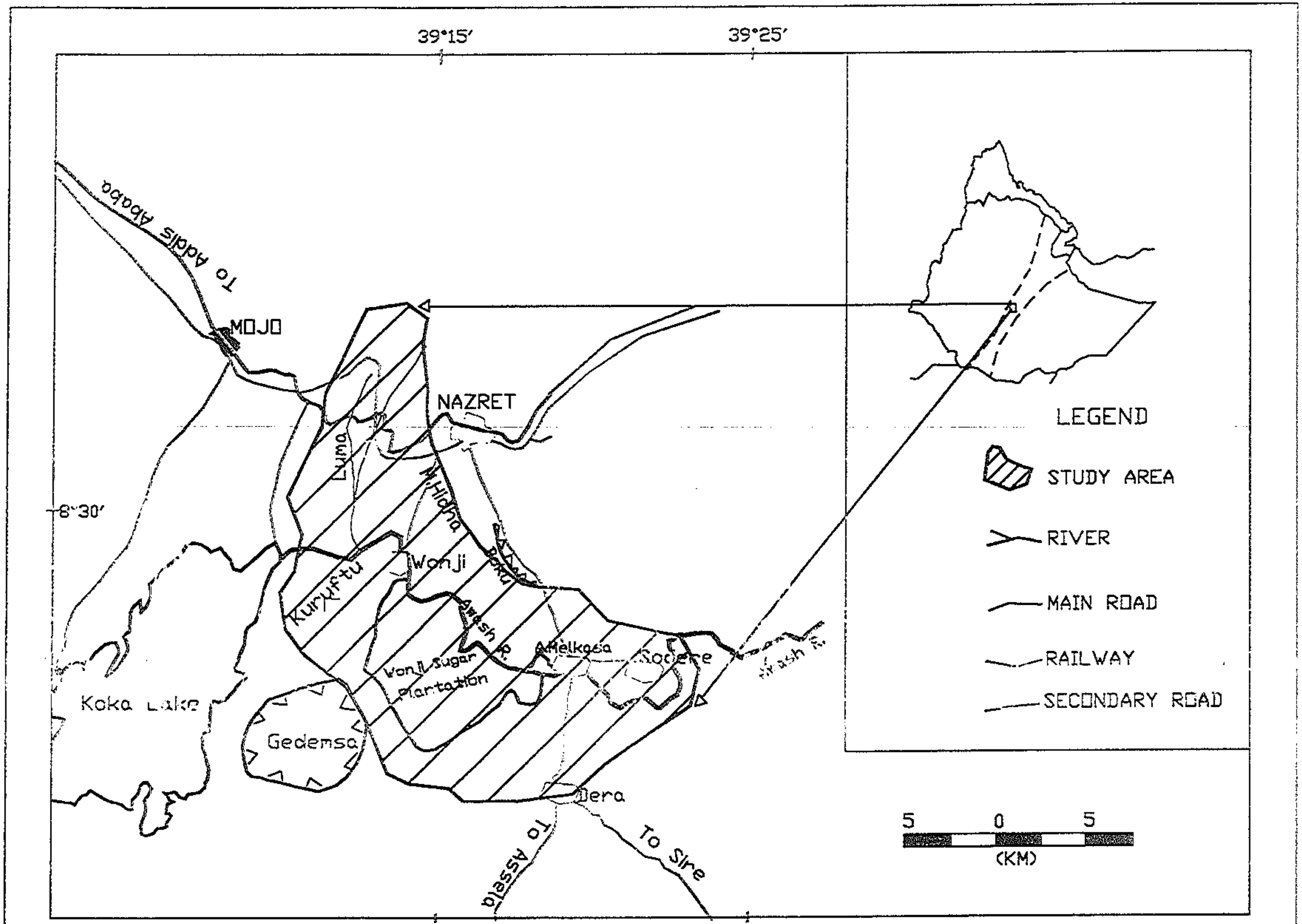


Fig. 2.1 Location map of study area

of the area reaches 1972 m a.s.l at Ketchema mountain and the lowest point ranges up to 1533 m a. s.l.

Awash is the only perennial river, which cross the area dividing approximately into two equal parts. Levees and estuaries are also features of flood plain of Awash river commonly exist up streams of Awash Melkasa reseviour.

Luma, the biggest seasonal stream has a deep gully cut, filled by coarse grained recent alluvium. It joins the main Awash river at Tedecha and contributes much run-off during rainy season. The water course of Luma is suspected to be a continuation of Wonji faults that marks the high elevated west escaspment of Nazareth. It is distinguished by steep slope volcanic rocks.

Awash river has a wide shallow channel down stream of Koka dam because flow velocity of the river decreased by considerable amount due to the dam that reduced erosion capacity . As a result it drops bed and suspended load soon after the reservoir which filled the channel.

This gave rise shallow and gentle slope for the Awash river. Hence Awash river has higher elevation around the Wonji Sugar estate.

2.3 Accessibility

Addis- Asela main asphalt road connects the area to major near by towns and villages such as Nazareth, and Dera. All weather gravel road connects Wonji and Nazareth. Due to its industrial activity, the area is connected to all surrounding important towns and villages. Many parts of the study area, can be reached by a four wheel drive vehicle. In the plantation high quality interlined pavement roads lead to every points within the sugar farm and served to monitor all water points in the farm.

2.4 Climate

The study area is characterized by warm weather with a mean annual rain fall of 785mm and mean annual temperature 20.4 C^0. The climate is marked by long dry period and short duration of precipitation from June to September, hence can be considered as semi-arid to semi-humid climatic zone.

Topography of the area is a controlling factor of land use and land covers of the region. Natural vegetation is very minimum almost it is nil except on the slopes of ridges where tropical thorn bushes are existing. Most of the area is agricultural land for cereals and industrial sugar plantation. The sugar plantation uses high amount of water throughout the year except during the rainy months.

Hottest months have maximum temperature of 23 C^0; while lowest temperature of the year usually reaches as minimum as 17 C^0 in the months of December and January. The area receives the highest rainfall in the months of July and August and the lowest in the month of December.

CHAPTER THREE

GEOLOGICAL SETTING

3.1. General

The great East African Rift system has been of particular interest to earth scientists for several decades. It has 3 major rift segments including the Main Ethiopian Rift (MER) the Red Sea Rift, and the Gulf of Aden Rift. These rift segments joint at Afar region.

The MER where the study area found is a low-lying region separating two remarkable plateaus, namely the North Western Ethiopian plateau and the South Eastern plateau. The margins of these high lands facing into the rift valley are marked by large topographic scarps often over 1,000 m high. Most of these scarps are major structural down warps generally modified by normal faults.

These main plateaus which are separated by MER are made up at the base of folded and foliated basement of Precambrian age overlain by sub-horizontal Mesozoic transgressive and regressive sedimentary strata separated by a marked Paleozoic unconformity, and covered on top by Tertiary Volcanics.

3.2. Regional geologic setting

3.2.1. Regional stratigraphy

The regional stratigraphy of the Nazret region (NC37 - 15) has been studied by Kazmin and Seifemichael Berhe (1978). According to this work, the area is covered by the following major geological units as are described from the oldest to youngest.

Alaji Basalts

This unit consists of aphyric basaltic flows which are underlain by Mesozoic sediments of upper Jurassic limestones and Cretaceous sand stones. The contact between basalts and underling sedimentary units is clearly demarcated by eroded surfaces thus the basalts lie unconformably on the sedimentary units.

As noted by Kazmin et al (1978), the thickness of this unit reaches up to 800m. Based on the age determination by Kuntz et al., (1979) using K-Ar, the unit is 28 to 15 My old. The same authors have also described that the top most members of the succession are mainly of porphyritic varieties and near Asebe Teferi dated as 14 My. old.

Anchar basalts and Arba Guracha silicics

In the Anchar area this group is represented by about 400m of basalts with several intercalations of ignimbrites. The age of the oldest unit may range up to 12.4 My. In the Guracha valley and in the vicinity of Asebe Teferi the unit is mainly or completely silicic with age ranges between 13.7 - 11 (Kuntz et al., 1975)

Nazret group and associated units

This unit constitutes ignimbrites, unwelded tuffs, ash-flows, rhyolite and trachyte flows. Eventhough on the rift shoulders only a few meters of ignimbrites are generally observed the group attains a maximum thickness of up to 250m in the rift. Many widely distributed rhyolitic domes have been observed and indicates that central- type explosive eruptions played a significant role in the formation of the Nazret Volcanics. According to Kazmin and Seifemichael Berhe (1978), the age of Nazret group is be between 9.5 and 3 My.

Arba Gugu basalts

This unit is a maximum of 300 m thick and can be traced along the upper margin of the rift escarpments. According to K-Ar age determination the unit is 8.5 My. old.

Chilalo and Badda trachytes

Chilalo and Badda trachyte volcanoes were developed in the upper Pliocene on both sides of the rift. According to Di Paola (1972) the origin of these volcanoes is related to the opening of the Ethiopian Rift, probably with the important stage of rifting about 4.5 to 4 My. ago.

Bofa basalts

The Bofa basalts are found within the rift floor and represent episode of fissural eruption which was followed by major faulting. Kazmin et al (1978) obtained a date 2.5 My for the lower part of the Bofa basalts, where as according to Mohr (1971) it may include older flows up to an age 3.5 My.

Wonji Volcanics and Rift sediments

The Wonji volcanic group includes all volcanics that have been formed after the last major episode of rift faulting, Dino ignimbrite is the oldest of the group followed by pantelleritic volcanic centers, and finally by recent fissural basalts. The oldest unit of the group dated to be 1.5 My. The majority of pantelleritic volcanic centers exhibit alignment along segments of Wonji fault belt. The main component of these centers are: rhyolites, trachytes, obsidian, and recent fissural basalts.

The age of lacustrine rift sediments is contemporaneous with the Wonji volcanics. They are mainly of volcano clastic sediments and tuffs with silts, clays and diatomites; silts and clays are the dominant once. Alluvial deposits are also common in the rift, associated with flood plains and at some places mixed with volcanoclastics.

3.2.2. regional rift tectonics

The Main Ethiopian Rift extends over 1000 km in a general north-north-east (NNE) direction and covers a total area of 150,000 km. This structural depression starts in the north from Hartale and extends in the south up to lake Langano. It' s width varies mostly this rift is 60 km on average and ranges up to 80 km. According to several authors in the Eocene the regional up lifting occurred, as a part of Afro-Arabian swell, which later gave rise to large scale faulting with clear western and eastern fault margin scarpments of MER. There exists morphological differences between the eastern and the western scarpments. The eastern is characterized by well defined lineaments through out its length, while the western progressively die out in its south western extreme sector that the feature of rift scarpment is hard to define.

The MER is characterized by many step faults, with a down through of a single step fault may reache 300 m. The total difference of altitude between the top of plateau and the floor of the valley exceeds 1000 m.

3.3. Geology of the study area.

3.3.1. Stratigraphy

The area is characterized by a number of variable volcanic units of acidic flows and ejecta of different age and stratigraphic position. The oldest rift floor and marginal complex ingnimbrite is the largest outcrop of all the volcanic units in the area . It outcrops mainly on the western Nazareth escarpment and Dera-Sodere areas. Quaternary sedimentary deposits occupy the largest portion of the study area.

Based on field study and existing data a summarized stratigraphy of the study been compiled. Accordingly rocks of the same age and composition are grouped in the same stratigraphic position; apart from some minor differences in their structure and texture. The followings are important lithological units and are described below one by one from bottom to top.

3.3.2. Description of lithologic units

3.3.2.1. Ignimbrite of the rift floor and the rift escarpment.

This unit covers the western Nazareth escarpment, Dera-Sodere area and is exposed as small patches at Melka Hida. It consists of strongly welded ignimbrites with typical fiamme and pumice. As a whole the rift floor ingnimbrite is a coarse grained, while as it stretches to the margin of the escarpments it gets relatively medium grained . It has a typical light green color. The oldest recorded age of this unit rages up to 1.7 My (Alula Damte, 1990)

Rift floor ignimbrite can be correlated with " Pliocene welded tuff' (Mohr 1968) and with the upper portion of the "Balchi formation" (Justin Visentin et al; 1974). It is mainly characterized by dark vitropic fiamme of up to 40 cm in size and lithic fragments inter leaved with aphyric flood basalts and paleosoils. Petrographycally this unit contain large crystal fragments of K-feldspar, Quartz and Plagioclase in the matrix containing lithic of basaltic and trachy composition. The thickness ranges from 80 to 100m near western fault scarp of Nazareth. Texturally the ignimbrite layer shows variation from bottom to top. The bottom and the top portion are less welded with relatively abundant lithic fragments; while middle portion on the other hand is densely welded and characterized by lenses of fiamme and lithic fragments.

Petrographically the lithic fragments are basaltic and silicic composed of alkali feldspar quartz, hornblende and pyroxene. The middle portion is also characterized by columnar jointing, with the joint opening sometimes reaches 15 cm. Di Poala (1972) stated that this unit most probably wase erupted from fissures since centers of eruption were not found. Textures with flattened pumice and glass shards are common at places. The unit is well exposed at the western scarp of Nazareth extending to the south up to Melka Hidha area. Another major exposure is found in the surroundings of Sodere- Dera ridges and also along the north eastern faults of Gedamsa. Eventhough this unit is considered as a single stratigrcphic unit it has minor differences in texture from one locality to the other. The Dera- Sodere unit is characterized by larger size fiamme and light green color. On the other hand, the ignimbrite west of Nazareth is relatively constituted of medium grained fiamme and gray color. Kazmin and Berhe (1978) grouped these acidic units under a single Nazareth formation including those found on the rift floor extending from the eastern to the western escarpment.

Based on close observation this unit has three distinct horizons in the study area. The lowest ignimbrite is characterized by massive texture and greenish gray variety while the middle portion is distinguished by fragment of reddish and gray rhyolitic and basaltic lithics. The top most portion of the unit displays fiamme of vesicular structure and relatively compacted towards the bottom. Xenoliths are abundant throughout the upper part of this unit.

3.3.2.2 Lower acidic lava flows.

This unit forms a large part of Boku ridge. Four normal faults trending northeast southwest cross the unit which are oriented parallel to each other. Boku ridge is made up of fractured pantalleritic lava flows and domes with layers of obsidian and pumice fall. Some of the flows show flow bands and are aphyritic, while the upper part is partly vesicular.

The thickness of this rock unit reaches up to 100 m and with flow structures separated by intervening of obsidian. Phenocrysts are composed of plagioclase, sanidine and microcrystals of amphibole. Layers of ash and pumice are encountered at places. According to Bigazzi et al., (1981) this flow is 0.8 My old. It represents the oldest unit next to rift floor ignimbrite. However, in the field it was difficult to distinguish clear stratigraphic relation with respect to the surrounding rock units.

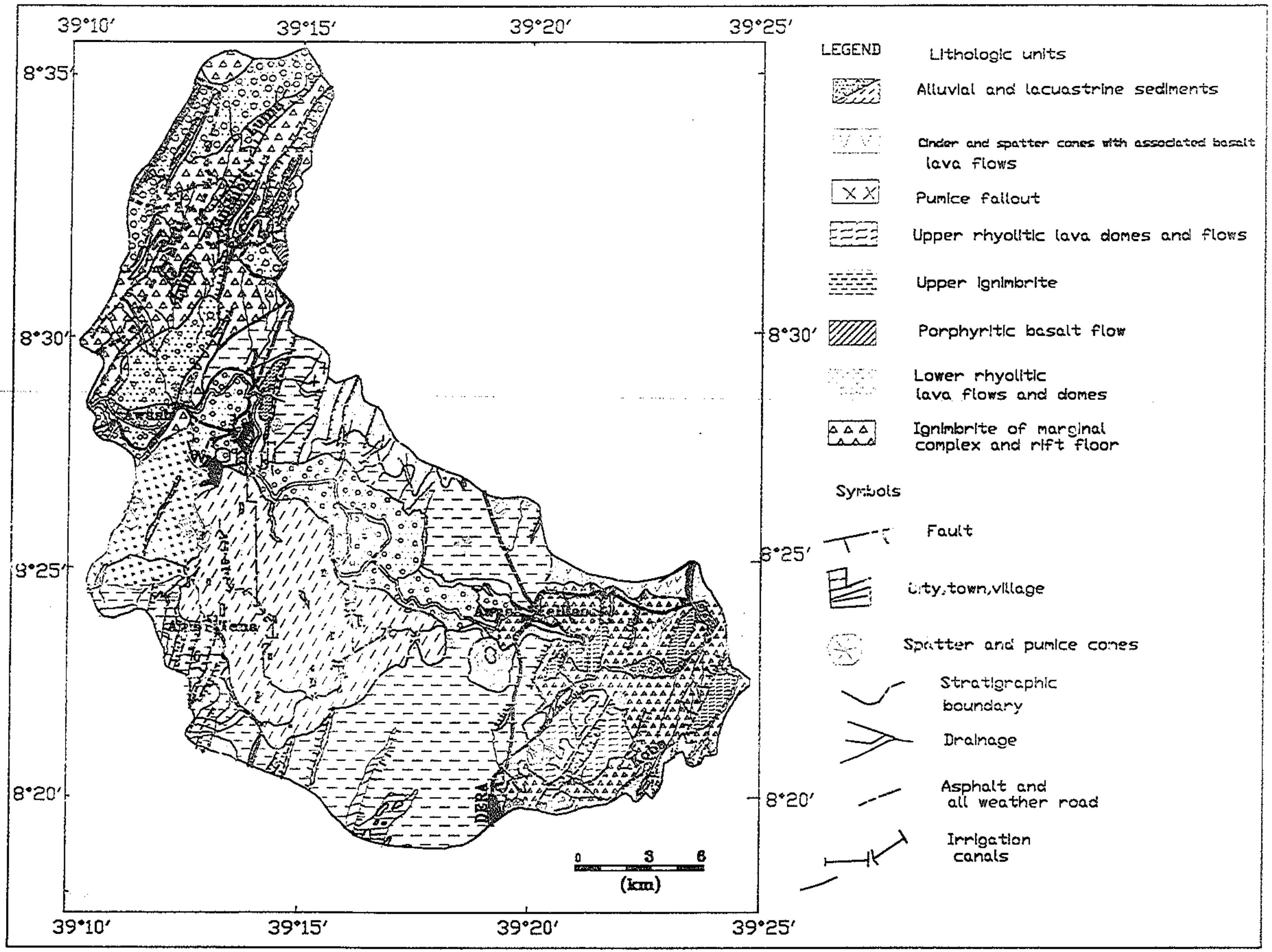


Figure 3.1 Geological map of Wonji area

3.3.2.3 Porphyritic basalt flow

This unit represents lava flows which are out expossed about 5 km west of Dera and as small patch as observed 2.5km west of Nazareth along Addis-Asab road.

The extrusion of these basalts is mainly related to northeast-south west trending Wonji normal faults. From petrographic analysis by Alula Damte et. al., (1992) these flows contain phenocrysts of plagioclase, clino pyroxene, olivine, opaque minerals and plagioclase composed ground mass. The size of these phenocrysts varies from place to place, with length up to 2 cm have been found at places.

From the filed observation this unit has attained maximum thickness of about 8 m in the localities of Badusa. It has been given the stratigraphic position below a unit of older pumice fallout; that is 0.4 My. The origin of these flows is believed to be fissural eruptions.

3.3.2.4 Upper ignimbrite

Tthis unit outcrops at low lying topography of the study area and on the flanks of volcanic cones of Gadamsa, Dera and Boku. It is also found between Awash Melkasa and Melka Hidha parallel to the Awash river.

In the south sector it occupies gently sloping low lying areas of south eastern Wonji Sugar plantation. In particular this rock unit is marked by pumice clastics and lithic fragments at the northern slope of Gadamsa volcano. It shows textural variation from place to place and from bottom to top. At Gadamsa the top of this unit is represented by intensive welded ignimbrite with dark large glassy fiamme. This unit typically characterized by loose welded basal ignimbrite with iterbeding of paleosoils at places. As it has been determined by Damte et al (1992), the intermediate part of this unit has given an absolute age of 0.2-0.25 My. Fragments reach up to 3 cm and are constituted of basaltic and pumice clast. Crystal clast present are composed of plagioclase, quartz and pyroxene.

3.3.2.5 Upper rhyolitic lava domes and flows

These volcanic rocks are found at Dera forming a well defined alignment with subordinate faults. The Boku domes mark the north central water divide of the area. East of Awash Melkasa this unit also outcrops as small scattered bodies which is a continuity feature of Dera ridge.

This unit consists of light colored rhyolite lavas associated with dark colored obsidian flows as intercalation. This flow has an over all thickness of about 30 m and some times reaches up to 45 m. The unit shows prophyritic texture with phenocryst of Alkali feldspar and quartz. Its glassy groundmass is texturally perlitic and marked by flow structures.

The basic minerals hornblende and pyroxene are evident in the hand specimen as phenocrysts. Stratigraphic position of these flows is not well determined . Absolute age for the unit is not available,though morphological considerations suggest very young ages.

3.3.2.6 Pumice fallout

These are unwelded pumice deposits with associated volcanic ashe. At places they are interbeded with paleosoils of about 10 cm thick. Ash flows of ignimbrites and pumice deposits that belong to Gadamsa volcanism are the main constituent of the unit.

The unit is well exposed in the areas of Kuriftu and Wonji shoa villages. Commonly it is characterized by angular clasts which sometimes has size of lapilli. About 5 meter exposure has been found along Wonji-Nazareth road near the bridge on the Awash river.

The unit sometimes shows different layering of pumice which is separated by paleosoils and covered by surge. At places the deposit displays an upward textural variation, fine grained at bottom. Proportion of lithic texture are higher in the lower part, that are rhyolitic and ignimibrite rocks fragments.

The thickness of the pumice fallout decreases away from Gadamasa caldera. This has been confirmed by observed thickness at Awash river bridge. At this locality pumice fallout overlies ignimbrite. The ignibmrite is densely welded and fine grained with no visible fragments.

3.3.2.7 Cinder & spatter cones with associated basalt flows

These are the youngest volcanic units in the area which are associated with basaltic lavas erupted by number of emission centers, specially in the vicinity of Awash Melkasa reservoir. They also outcrop throughout the area forming well distinguished cinder and spatter cones. North of Kuriftu village only one cone is present in the Melka Hidha area.

These volcanic products are recent, relatively older equivalents are observed south of Awash Melkasa and west of Sodere. The relatively older units can be distinguished by their geomorphic features. Their activity is probability related to tensional tectonism of recent Wonji fault episode. Though they are found as scattered cones, close observation reveals that they have a certain pattern of arrangement. Starting from north of Gadamasa rim and Dera, these cones show north-south alignment. This is the same trend as the recent Wonji faults, which can be suggests that these units are related to the last Wonji fault.

Well stratified scoria units and pyroclastic bombs are common rock types found near the vents. Basaltic lava flows of dark vesicular type are associated with these cones at some places. The basaltic lavas contain small quantity of phenocryst composed of olivine and plagioclase. Relatively steep and well preserved feature of these cones indicate that they are of very recent age in the volcanic history of the area. As it has been noted by Bigazzi et al (1981) the age of these spatter and cinder cone could be younger than 0.06 My.

3.3.2.8 Undifferenciated recent alluvial and lacustrine deposits

From obtained data of shallow boreholes these surfacial sedimentary deposits attain a maximum thickness of 90 m at Wonji. They cover mainly the central main Wonji flood plain, and some low-lying flat land in the north . As it has been revealed from drilling data these sediments lie directly on ignimbrite and scoria. Away from Wonji plain this unit is mainly composed of alluvial sediments with variable thickness of 6-25m. At Melka hida it has a maximum thickness of 25 m overlying tuffs, ignimbrite and volcanic ash. From observation of borehole 17, it has a thickness of 12 m at the extreme north of the area.

As a whole this unit consists of recent alluvial and lacustrine sediments with few colluvial deposit at foot slope at places. The grain size ranges from clay to silt to gravel, sometimes to cobble, where gravel dominates at the bottom of river channels. Though lacustrine deposit is mainly fine to medium grained, coarse grains are also contained as reworked volcanic material of different size. Lenses of fine sands are common within the thick layer of lacustrine deposit. On the contrary outside of Wonji plantation and in the flood plains sand and gravel are the dominant size of the unit, particularly angular coarse grained particles are not uncommon at foot slopes. Mostly sediments are poorly consolidated except at places in Melka Hidha area.

Thin intercalation of pumice, tuff and different type of pyroclastic material are also present in the unit. Lacustrine sediments of Wonji area are lake deposits in small graben within Wonji faults. According to Di Paola (1972) lacustrine sediment is believed to be deposited in the lake during Holocine time.

A patch of diatomite outcrops at the foot of Melka Hida fault and Kuriftu village whose thickness reaches up to 8 m at these places. Sedimentary deposits are mainly medium grained in the flood plain of Awash.

3.4. Tectonics of the study area

3.4.1. Wonji fault belt

The Wonji fault belt which is a part of MER has a significance implication in the study area. It is characterized by short normal type of faults, oriented in NNE-SSW direction and marks the axial portion of MER. These faults (WFB) are observed through out the length of MER extending up to Tendaho graben. The faults are commonly associated with volcanic activities. Generally the faults are younger in the central part and get older towards the rift margins. The WFB forms a swarm of fractures that are arranged in the form of an "en echelon" feature, commonly in a right stepping arrangement.

3.4.2. Description of tectonic structures

The majority of meso-structures, related to the major Wonji fault belt (WFB) are manifested by short normal faults, joints and fissures. In the region a clear feature of lineaments are demonstrated by pantelleritic volcanic cones and domes. Mostly joints in the study area are of columnar type particularly associated with welded ignimbrites. Some of the joints have a wide opening up to 10 cm and spacing of 0.5 m.

Few of these joints are filled by secondary materials such as clay, calcite and fragmented rocks at places. As observed down stream of the Koka reservoir, these joints have much significance as conduits to transport groundwater from Koka to the Wonji basin. Wonji faults which are observed on both north and south sides of the Wonji plantation have similar orientation. They might have a continuity unless other wise they have been buried under lacustrine sediments. In conformity to this Skutan et al; (1978) reported that some faults to be presently found under the lacustrine sediments.

Prominent fault scarps are observed on the western part of the study area in particular along the western limit of the area. These faults are also arranged in " en echelon" system being in right stepping fashion. The height of this scarps ranges up to 70m in the south, but as low as 4m in the north.

Meso-structures are common throughout the area where older ignimbrite is out cropping, particularly observed east of Koka dam and west of Nazareth. At this particular locality these structures also form columnar jointing at places. Other major and minor normal faults are aligned parallel to each other which have resulted from Quaternary volcano-tectonic activity.

CHAPTER FOUR

HYDROLOGY

4.1 Introduction

The source of all water points on the earth surface is primarily from precipitation; it is thus so for the study area. In view of hydrology the area is very complex. There are a number of water points including artificially impounded lakes like: Koka and Awash melkasa. Irrigation is practiced through out the year both by estate and local people. Hot as well as cold springs are frequently observed in the region. Since the study area is located in the graben; it receives surface inflow from high lands. These and others coupled with high surface discharge and groundwater inflow from Koka dam, made the area hydrologicaly more complex. In view of the understanding of these conditions, hydrometeorolgical and hydrological parameters were treated one by one, which latter used for calculation of water balance.

4.2 Rainfall

Rainfall is part of the atmospheric water that falls on the earth surface in the form of a liquid.

The area under investigation is located in the equatorial zone between 8° 20' and 8° 35' N. Some of the Rainfall in this zone can be caused by local weather condition. That is when air mass moves over land at higher temperature, the air is heated and forced to rise by convection as a result it cools to form cloud, which finally will give rise convective type of rainfall.

Fig. 4.1 Mean Monthly Rainfall(mm)

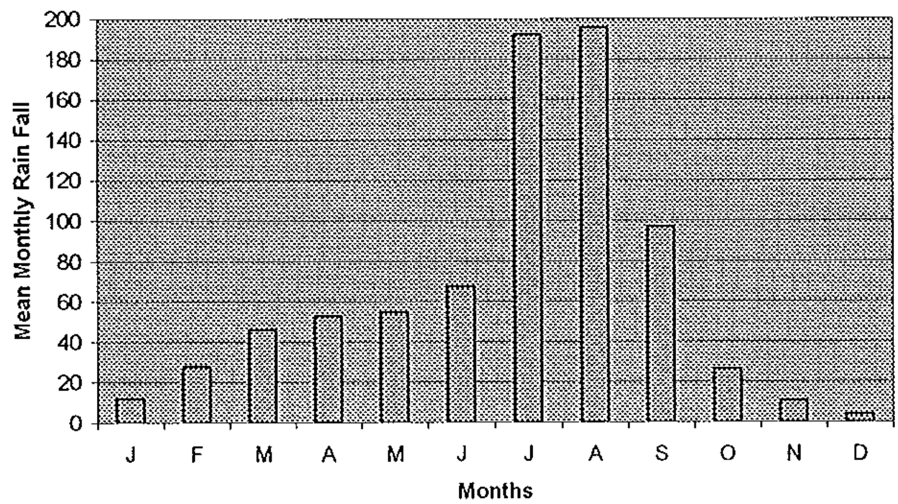
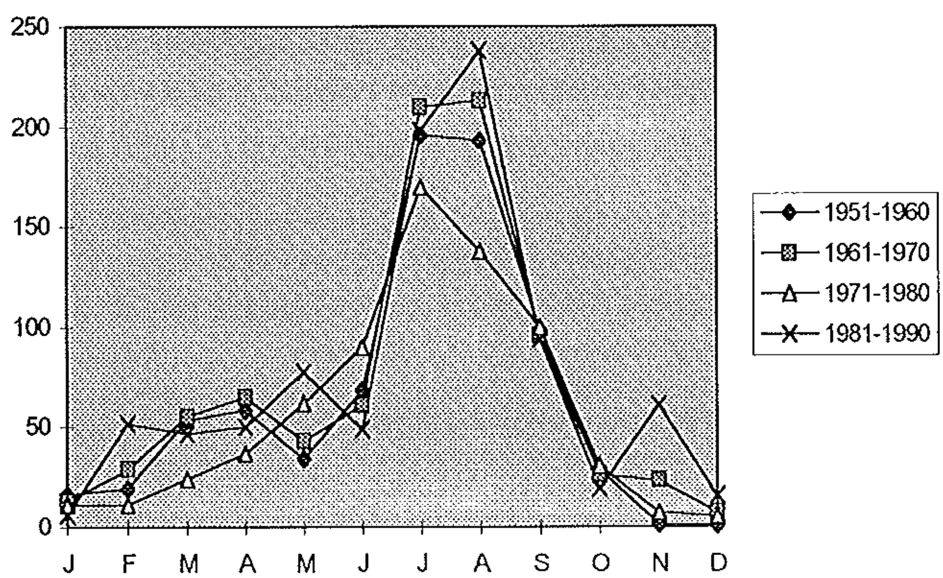


Fig. 4.2 Rainfall pattern (mm)



The area also receives rain fall from south westerly and south easterly monsoon winds, from south western Atlantic. As these winds pass over the south Ethiopian high lands drops large amount of rain water. High amount of rainfall of the area is in the summer months (kiremt).

Recording of the rainfall data, for the area started long ago from early 1940's. There are five rainfall gauging stations in the area and the vicinity. The data of forty years were analyzed for Wonji station, and mean monthly rain fall graph has been drown (Fig 4.1). It shows that there are two distinct seasonal pattern, one rainy and the other dry season. The rainy season includes months of June to September (Keremt) and months of March, April, and May (Belg) are months of little rainfall. The rest months of dry season have minimum rainfall which reaches as small as 3.8 mm of rain fall in the month of December.

According to the obtained records of the Wonji station the area has received maximum rainfall in the year 1981 to 1990 and the minimum from 1971 to 1980 (Fig 4.2) but as a whole, the rainfall follow rainy and dry season rainfall pattern; through the 40 years period. As it is indicated on the figure 4.3, Dera station has the highest record of all stations. The records of Awash Melkasa show 705.12 mean annual rainfall.

The Awash melkasa station has lowest rainfall value in the region, may be due to geographic condition in the locality. It is located at the northern foot slope of Dera ridge and away from the south easterly rain fall as well as it is also shadowed by Boku ridges from the south westerlies rainfall, which all these finally dictated the station to have lowest amount rain fall in the region.

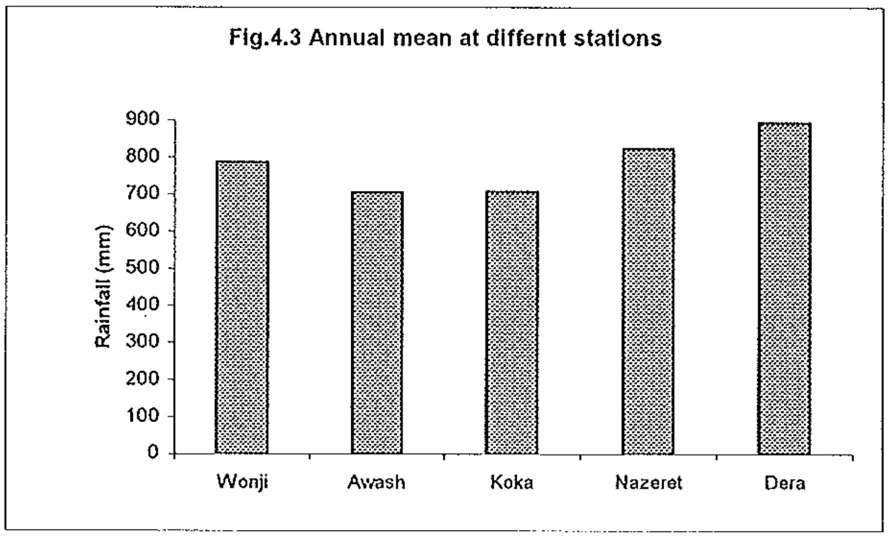
To have complete knowledge of monthly distribution, "rainfall coefficient" has been calculated for Wonji station, which is a ratio between mean monthly rainfall and rain fall module (Annex. 2).

Accordingly the end of the rainy season is marked by clear demarcation in the value of the monthly rainfall coefficient. The season of steady rain fall is demonstrated by June, July, August and September, with maximum rainfall record in the months of July and August. Months of October, November, December and January are months of lower rain fall values. The weighted mean monthly rain fall in the basin varies from 3.8 to 195.5 mm and the mean annual precipitation depth record for the area is 785 mm (Annex 3).

For rainfall calculation, Wonji station has been used as a basic data, because other stations are with many missing data, except Nazareth station which is a little bit far from the study area to be used as a basic data. Data of Wonji station were obtained on monthly basis for 40 years period from 1951 to 1990 and has been used for analysis purposes. Calculated rainfall coefficient indicates that 3 main rain fall periods can be identified in the area. The "big rain fall period" is occurred from June to September with RFC greater than 1 represents 70% of the annual mean of rainfall in the region. The others "small rain period" which has RFC of 0.6 to 0.9 are occurred in the months of March to May and "dry period" with less than 0.6 RFC together represents 30% of the rainfall in the area.

4.3. Rain fall and altitude relation

As a general principles the value of rain fall mostly have direct relationship with altitude. That is the higher the altitude it may have relatively high amount of rainfall unless there is an effect of measurement and location of measuring apparatus. In order to see the relationship between altitude and rainfall, correlation have been worked out for all 5 stations (Fig. 4.4) located in the vicinity. Mean annual precipitation data values for the available measured periods for each station (Table 4.1) have been used. Graph drown shows correlation of rainfall and altitude have coefficient of 0.80 which confirms that the rainfall and altitude have a good relation.



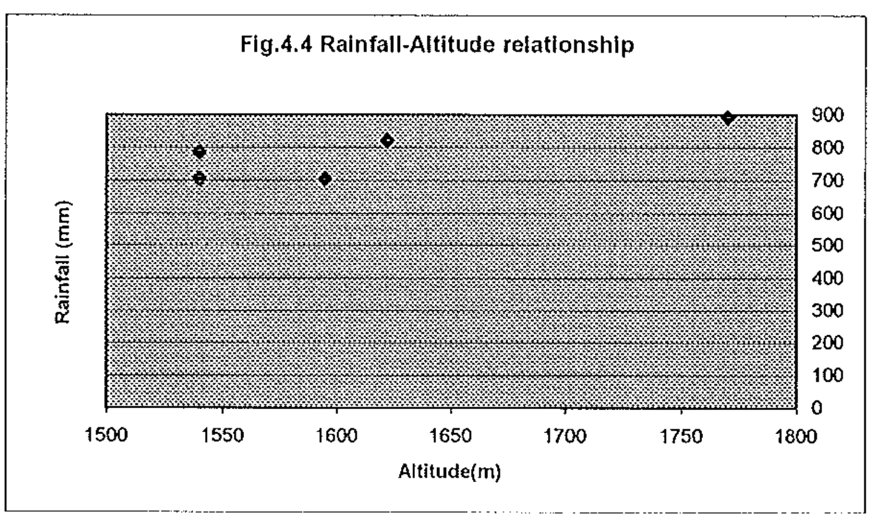


Table 4.1 Annual mean value of rainfall at different stations

Station	Mean annual rainfall (mm)	Altitude (m.a.s.l)	Period
Wonji	785	1540	1951-1990
Awash Melkasa	705.12	1540	1977-1996
Koka	706.25	1595	1943-1982
Nazareth	822.53	1622	1953-1992
Dera	840.31	1770	1976-1989
Mean rain fall	771.84		

The calculated data indicates that rainfall gradient with respect to altitude is about 0.82 mm/m, exception is for the Koka station, which does not follow this general trend in the area. This might be due to error in the data reading or location of station within the site.

Arithmetic mean annual of all existing station over the area gave value of 772 mm. This value is very close to mean annual rain fall at Wonji station. Therefore, value of 785 mm of Wonji station is used to calculate water balance of the basin.

4.4 Estimation of Evapotranspiration

Evapotranspiration is one of the hydrological parameters that appear to deprive much of the rainfall water in the rift system. It is the conversion of water to vapor by evaporation and transpiration and transport away from the water shed surface in the atmosphere (axon, 1982). Considering this, therefore treating this important parameter has to be handled with a greater emphasis.

Several methods have been developed to estimate evapotranspiration; using pan evaporimeter up to empirical formulas. Some of the empirical formulas make use of few meteorological data, but some others give relatively accurate estimation of this element. Techniques for estimating evapotranspiration are modified from time to time. Development during the past three decades have been significant. This era was indicated by theoretical work like that of Christiansen (1968) in which he tried to use more meteorological data and pan evaporation studies. Some of these empirical formulas have been treated, to select best estimated actual evapotranspiration for the future water balance calculation.

4.4.1. Potential Evapotranspiration

Pan evaporation method

This method has been started to be used very long ago. It is one of the oldest and most common methods of estimating PET from a shallow pan of water. Around the world many types of evaporation pans are used, but the most common ones are: Colorado class A pan, sunken screen pan, floating pan etc.

Data that are obtained from evaporation pan are an indirect integration of the meteorological parameters related to evaporation. Considering some standard shape, size and environmental setting researchers have developed estimation of potential evapotranspiration, from pan evaporation Ep using pan coefficient.

This in given by a relation:

$$PET = C_{ET}\ Ep \qquad (4.1)$$

Where PET : Potential evapotranspiration

C_{ET} : pan coefficient

Ep : pan evaporation

In the region development activities are intensive and meteorological data are relatively available. Colorado pan evaporation data of 10 years for the period 1963-1972 have been obtained for the area (Table 4.2). The calculated weighted mean annual pan evaporation gave 2434 mm. As it was suggested by (Jensen, 1973) the pan coefficient varies from 0.70 to 0.83 and averaged 0.77.

Table 4.2 Monthly pan evaporation at Wonji (mm)

Year	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1963	251.1	249.2	313.1	171.0	198.4	213.0	179.8	155.0	162.0	223.2	192.0	195.3	2504
1964	226.3	249.2	300.7	252.0	241.8	192.0	164.3	158.1	150.0	204.6	231.0	176.1	2547
1965	181.1	268.8	297.6	243.0	303.8	273.0	232.5	204.6	165.0	223.2	216.0	232.5	2842
1966	235.6	162.4	220.1	213.0	279.0	204.0	189.1	145.7	165.0	195.3	228.0	-	
1967	248.0	232.4	254.2	210.0	226.3	240.0	164.3	164.3	138.0	204.6	192.0	182.9	2458
1968	217.0	131.6	238.7	207.0	224.9	-	195.3	161.2	150.0	-	192.0	186.0	
1969	176.7	145.6	244.9	210.0	217.0	207.0	165.0	171.0	181.1	235.6	216.0	232.5	2403
1970	192.2	201.6	189.1	234.0	232.5	243.0	201.5	173.6	141.0	-	207.0	-	
1971	210.8	218.4	241.8	207.0	186.0	195.0	179.8	161.2	159.0	198.4	204.0	170.5	2332
1972	213.9	165.2	254.2	189.0	260.4	216.0	192.2	170.5	171.0	213.9	-	189.1	

Therefore using pan coefficient of 0.70 and 0.77 estimated value of 1704 and 1874 mm potential evapotranspiration was found respectively. In the areas where limited meteorological data, are available, potential evapotranspiration can be used to calculate actual evapotranspiration. Thus different methods were checked to calculate AET along with different value of PET obtained by different methods (1948).

Christiansen (1968) method

Prediction of evapotranspiration from land surfaces, requires considering many atmospheric variables, plant characteristics, and soil parameters. This indicates that process of evaporation is much complex, which needs to use many data to calculate. Some useful estimation methods avoid consideration of some or most of these factors. The method of Christiansen (1968) considers many meteorological parameters. This method is checked along with other methods, whether it gives better estimate of PET or not, and whether AET be well estimated or not using in value in the table of long term water balance calculation of Thornthwait method.

The empirical formula of Christiansen (1968) relates Pan evaporation Ep to extraterrestrial solar radiation Rt (in equivalent cm depth of evaporation) by the relation:

$$Ep = 0.324\ Rt\ C_T\ C_W\ C_H\ Cs\ C_E \qquad (4.2)$$

TABLE 4.3 MEAN MONTHLY SOLAR RADIATION AT THE TOP OF THE ATMOSPHERE, Rt, IN UNITS OF EQUIVALENT DEPTH OF EVAPORATION (cm) AT 20°C*

Latitude	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
North												
50	11.7	16.7	29.6	38.4	48.3	50.3	50.1	43.0	31.7	22.1	13.1	9.7
40	19.1	23.4	34.8	42.1	49.7	50.5	50.8	45.8	36.7	29.1	20.4	16.9
30	26.7	29.5	39.8	44.6	50.0	49.8	50.5	47.4	40.7	35.0	27.4	24.5
20	33.9	34.8	43.7	46.0	49.1	47.9	49.1	47.8	43.5	40.0	33.9	32.0
10	40.2	39.1	46.2	45.9	46.9	44.8	46.4	46.8	44.8	44.1	39.5	39.0
Equator	45.3	42.2	47.3	44.5	43.5	40.6	42.4	44.5	44.9	46.8	44.1	45.0
South												
10	49.3	44.2	46.9	41.7	38.9	35.4	37.4	40.9	43.6	47.8	47.5	49.6
20	52.1	44.9	45.2	37.8	33/3	29.4	31.5	36.1	40.9	47.5	49.7	52.7
30	53.7	44.6	42.2	32.7	26.9	22.7	24.8	30.5	37.1	46.2	50.4	54.8
40	53.9	42.8	37.9	26.6	19.8	15.7	17.7	24.1	32.2	43.5	49.9	55.5
50	53.0	39.7	32.2	20.3	12.9	9.1	10.6	16.0	26.2	39.2	48.4	55.0

* Source: American society of Agricultural Engineers (1982)

or to incoming solar radiation, Rs (in equivalent depth of cm evaporation), by

$$Ep = 0.482\, R_S\, C_T\, C_W\, C_H \qquad (4.3)$$

Each of the above coefficients are calculated by the following relationships:

$$C_T = 0.463 + 0.425\ (T/T_O) + 0.112\ (T/T_O)^2 \qquad (4.4)$$

$$C_W = 0.672 + 0.406\ (W/W_O) - 0.078\ (W/W_O)^2 \qquad (4.5)$$

$$C_H = 1.035 + 0.240\ (H/H_O) - 0.275\ (H/H_O)^3 \qquad (4.6)$$

$$C_S = 0.340 + 0.856\ (S/S_O) - 0.196\ (H/H_O)^2 \qquad (4.7)$$

$$C_E = 0.970 + 0.030\ (E/E_O) \qquad (4.8)$$

Where

T = mean air temperature (^{0}C)

To = 20°C

W = mean wind velocity 2m above ground (km/h)

Wo = 6.7 Km/hr

H = mean relative humidity expressed decimally

Ho = 0.60

S = mean sunshine expressed decimally

So = 0.80

E = elevation (m)

Eo = 305 m.

For this method monthly values of solar radiation at the top of the earth's atmosphere (Rt) have been used along with equation 4.2.
Using this method, evapotraspiration of 798mm has been calculated for the area. The estimation was employed all available meteorological data and Rt from table 4.3 for 10° N latitude. Ultimate target of the calculation was to obtain actual evapotranspiration. Basic technique of Thornthwaite and Mather (1957) has been used for this purpose but as it has been expressed by Leopord and Dunne (1978) (Table 4.4). From 1st up to the 5th row listed are available meteorological data of Wonji station.

Altitude of Wonji station is listed in the 6th row. Calculated result of PET, by the method of Christiansen are in row 7 for each months. All the other procedures to obtain AET are as out lined by Leopord and Dunne (1978). Complete hydrological cycle for evapotranspiration from land surface requires energy inputs, water availability and transporting media. This indicates that evapotanspiration varies spatially as a result of these elements. However, generalization can not be made; because local elevation, slopes, orographic affects, and cropping pattern can cause large, ET, changes.

In our case, the effect of crops and soils is considered in a sense of combination and large scale averages. Thus, Wonji basin is considered to be covered by same type of crop and silty clay with 0.50 m root depth and 150 mm available water holding capacity of soils (15% or 150mm of water per meter depth of soil)

Table 4.4 Long - term average monthly water balance for a soil with available water capacity of 150 mm.
The soil is silty clay under moderately deep rooted vegetation with rooting depth 0.50 m.

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Tc	17.9	20.2	22	22	22.7	22.8	21.1	20.6	20.9	19.2	17.5	17.9	
Rt	40.2	39.1	46.2	45.9	46.9	44.8	46.4	46.8	44.8	44.1	39.5	39.0	
W	3.5	3.2	3.1	2.7	2.7	3.2	3.4	2.9	1.8	2.5	3.2	3.4	
H%	54.7	49.9	52.6	52.0	52.2	51.8	56.1	66.8	64.7	57.3	51.6	53.3	
Sn (hr)	9.1	8.2	8.2	7.5	9.0	8.5	7.1	7.2	7.7	9.3	9.7	9.2	
E	1540	1540	1540	1540	1540	1540	1540	1540	1540	1540	1540	1540	
Ep (mm)	91.55	68.39	83.23	76.46	84.84	75.76	36.01	40.71	48.69	53.34	65.31	73.43	797.72
P (mm)	12.0	27.7	45.9	52.5	54.3	67.2	192.1	195.5	97.0	26.5	10.5	3.8	785.00
p-Ep	- 79.55	-40.69	-37.33	-23.96	-30.54	-8.56	156.09	154.79	48.31	-26.84	-54.81	-69.63	14.12
APWL (mm)	-234.83	-275.52	-312.85	-336.81	-367.35	-375.91	-	-	-	-26.8	-81.65	-151.28	
Sm	40.00	20	12	9	8	7	150	150	150	140	90	41	
Δ Sm	- 1	- 20	- 8	- 3	- 1	- 1	143	0	0	- 10	- 50	- 49	
AET (mm)	13	47.7	53.9	55.5	55.3	68.2	36.01	40.71	48.69	36.5	60.5	52.8	568.81
D	78.55	20.09	29.30	20.96	29.54	7.56	0	0	0	16.84	4.81	20.63	228.28
S	0	0	0	0	0	0	13.09	154.79	48.31	0	0	0	216.19
TRO	8.04	4.02	2.01	1.00	0.5	0.25	13.09	160.88	128.75	64.37	32.18	16.09	
RO	4.02	2.01	1.00	0.5	0.25	0.13	7	80.44	64.36	32.19	16.09	8.05	216.06
DE	4.02	2.00	1.00	0.5	0.25	0.13	6.09	80.44	64.37	32.18	16.09	8.04	

T = mean monthly temperature, Rt = Tersterrial radiation at N 10^0; W: mean monthly wind speed; H: mean monthly relative humidity; Sn: mean monthly sun shine duration; E: elevation a . s. l of meteorological station; Ep: potential evapotranspiration; P: mean monthly precipitation; APWL: accumulated potential water loss; Sm: soil moisture; ΔSm: change in the soil moisture during the month; AET: actual evapotranspiration; D: soil moisture deficit; S: soil moisture surplus; TRO: total available for runoff; RO: runoff; DE: detention.

The graph for table 4.4 has been worked out to analyze their realistic interrelationship of meteorological parameters (Fig. 4.5).

In the months of March to June amount of AET is higher in the area, which are characterized by higher temperature. From the same graph (Fig. 4.5) it can be clearly understood that relative humidity and terrestrial radiation have direct relationship, where as AET and temperature do not show clear relation to these parameters. The graph has been drawn for Thornthwaite water balance (Table 4.4) to observe water balance pattern of the region (Fig. 4.6).

On the other had, since relative humidity increases as air temperature falls, a decrease in temperature may result in a decrease in the rate of evaporation. Thus in cold weather of July to October AET smaller in the region, simply because of the overlying air is able to hold only small amount of water vapor below saturation level.

The other thing is that wind does not cause evaporation but permits a given rate of evaporation to be maintained. This suggests that the quality of empirical formula can not be justified only with number of parameters it uses. Thus the Christiansen method can not be considered as better than other methods, only because of its many parameters.It underestimates the evaporation.

As graph 4.5 indicates the highest rate of evaporation is experienced in dry seasons, which is 42 percent (233 mm) of evaporation occur in months of March to June and only 335 mm (58 percent) occur in the rest months from July to February.

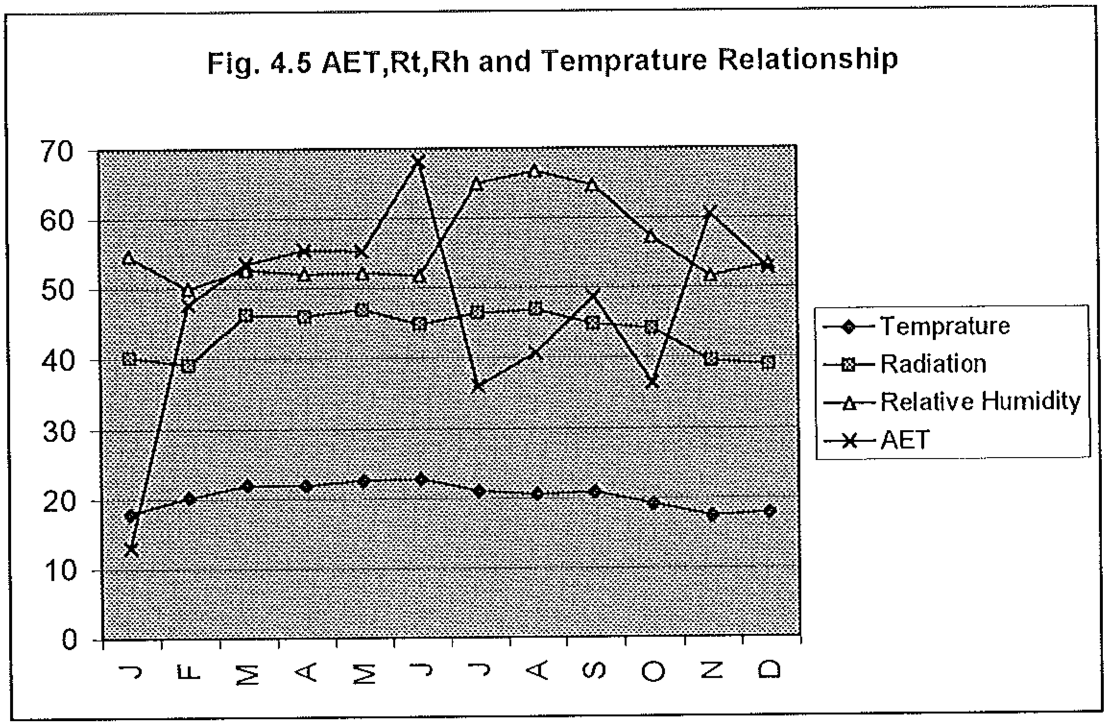


Fig. 4.5 AET,Rt,Rh and Temprature Relationship
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
Temprature
Radiation
Relative Humidity
AET

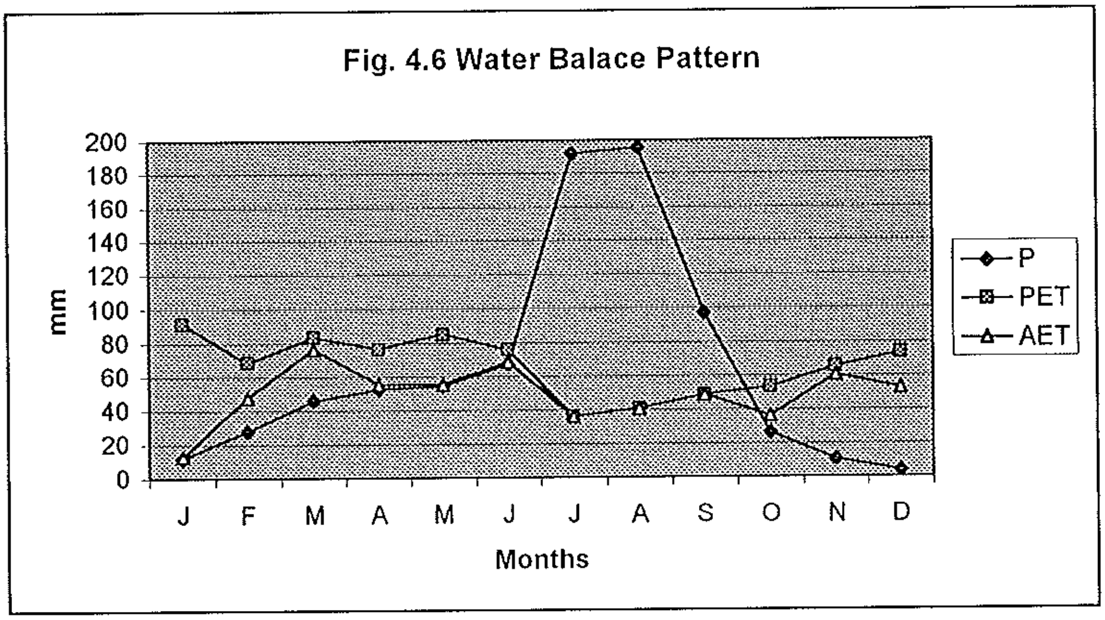


Fig. 4.6 Water Balace Pattern
200
180
160
140
120
100
80
60
40
20
0
mm
J
F
M
A
M
J
J
A
S
O
N
D
Months
P
PET
AET

Thornthwaite method

In the year 1948 Thornthwaite has developed an empirical formula to calculate potential evapotranspiration. For the past 4 decades it has been intensively used through out the world. Though it generally underestimate PET, still it is used where limited meteorological data are available. This method uses air temperature as an index of the energy for evaporation. The formula is based on the following relation:

$$ETo = 16 \ (10t/I)^{a} \qquad (4.9)$$

Where Eto : monthly potential evpotranspiration (mm)

t : mean monthly air temperature (°C)

I : annual heat index.

Summing the monthly heat index (i)

$$i = (t/5)^{1.514} \qquad (4.10)$$

$$I = \sum_{m=1}^{12} i \qquad (4.11)$$

$$a = 0.49239 + 1792 + 10^{-5} \ I - 771 \times 10^{-7} I^{2} + 675 \times 10^{-9} I^{-3} \qquad (4.12)$$

Potential evapotranspiration was estimated using this empirical formula. According to this, the weighted mean annual PET over the basin is 825 mm, which is very much less than pan PET, (Table 4.5).

Table 4.5: Value of PET using different methods

Method	0.77 x PE	0.7 x PE	Thornthwaite	Christiansen
PET (mm)	1874	1704	825	798

* See tables: 4.4, 4.7, 4.8,

PE = average value of pan evaporation of each month for the year 1963 to 1971.

4.4.2. Actual evapotranspiration

As it has been earlier discussed, evaporation plus transpiration from vegetated surface with unlimited water supply is known as potential evapotranspiraton and it constitutes the maximum possible loss rate due to the prevailing meteorological condition (Shaw,1988). But actual evapotranspiration considers portion of potential evapotranspiration that is actually evapotranspired under the existing moisture supply. It is also defined as "the amount of evapotranspiration that occurs under field condition" (Fetter, 1988).

The study area is located in warm rift system: In such hot areas evapotranspiration has a significant impact on hydrological conditions and has to be treated carefully. Therefore, to choose best method and for comparison purposes different methods have been tried to calculate actual evapotranspiration.

One of them is Turc method, which tries to determine actual evapotranspiration directly from mean annual precipitation; based on the empirical formula which is expressed as:

$$Et = P/(0.9 + (P/L)^2)^{1/2} \qquad (4.13)$$

P = annual precipitation (mm)

L = 330 + 25T + 0.05T

T = mean annual air temperature (^{0}C)

This method gave an actual evapotranspiration of 687 mm which is 88% of the total rainfall of the region. As it has been noted, actual evapotranspiration little exceeds or equals the precipitation in the rift. Thus Turc method underestimated this parameter and can not be applied for the study area. From this it can be justified that another best fit method has to be found. To obtain this, pan evaporation with different pan evaporation coefficient was calculated (Table 4.6)

Table 4.6 Summarized values of PET, AET, and their relation to precipitation based on different methods.

Method	PET (mm)	PP (mm)	AET (mm)	Different from PP (mm)
Christiansen	797.72	785	568.8	+ 216.2
Thornthawaite	825	785	617	+ 168
Turc	-	785	687	+ 98
Pan				
Cet = 0.77	1874.36	785	842.58	- 57.58
Cet = 0.7	1703.8	785	793	- 8

* Average precipitation = 785 mm

Average AET = 702

The above table clearly indicates that relatively realistic value of actual evapotranspiration can be obtained from direct Pan potential evapotranspiration of coefficient 0.7, being this farther calculated by the long term water balance method of Thornthwaite and Mather (1957), which was expressed by Leopord and Dunne (1978) (Table 4.8).

Table 4.7 Calculated AET based on Cet = 0.77

	J	F	M	A	M	J	J	A	S	O	N	D	Annual amount
P(mm)	12.0	27.7	45.9	52.5	54.3	67.2	192.1	195.5	97.0	26.5	10.5	3.8	785
PET	152.08	170.52	196.69	164.47	184.04	169.65	142.74	127.47	121.97	163.51	160.68	120.54	1874.36
P-PET	-140.08	-142.82	-150.79	-111.97	-129.74	-102.45	49.36	68.03	-24.97	-137.01	-150.18	-116.74	
APWL	-568.98	-711.8	-799.59	-911.56	-1041.3	-1143.75	-	-	-24.97	-161.98	-312.16	-428.9	
Sm	4	0	0	0	0	0	150	150	150	50	18	8	
Δ Sm'	- 4	- 4	0	0	0	0	150	0	0	-100	-32	-10	
AET	16	31.7	45.9	52.5	54.3	67.2	142.74	127.47	121.97	126.5	42.5	13.8	842.58
D	137.08	138.82	150.79	111.97	129.74	102.45	0	0	0	37.01	118.18	105.74	1031.78
S	0	0	0	0	0	0	0	0	0	0	0	0	
Ro	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7.8 Calculated AET based on Cet = 0.70

	J	F	M	A	M	J	J	A	S	O	N	D	Annual amount
P(mm)	12.0	27.7	45.9	52.5	54.3	67.2	192.5	195.5	97.0	26.5	10.5	3.8	785
PET	138.25	155.02	178.81	149.52	167.31	154.31	129.77	115.87	110.88	148.68	146.1	109.59	1703.8
P-PET	-126.25	-127.30	-132.21	-97.02	-113.01	-87.11	62.33	79.63	-13.88	-122.15	-135.6	-105.79	
APWL	-503.67	-630.97	-763.88	-860.09	-973.91	-1061.01	-	-	-13.88	-136.03	-271.63	-377.42	
Sm	4	2	0	0	0	0	150	150	150	50	20	10	
ΔSm	-6	-2	-2	0	0	0	150	0	0	-100	-30	-10	
AET	18	29.7	47.9	52.5	54.3	67.2	129.77	115.88	97.0	126.5	40.5	13.8	793.04
D	120.25	125.32	130.91	97.02	113.01	87.11	0	0	13.88	22.15	105.6	95.79	911.04
S	0	0	0	0	0	0	0	0	0	0	0	0	
Ro	0	0	0	0	0	0	0	0	0	0	0	0	

Therefore, this can guide us to the conclusion, that, actual evapotranspiration for the area, can be better found by pan method, calculated along with long term water balance method of Thonthwaite and Mather (1957). For this particular area the method indicates that only a value of $\pm$ 8 which is $\leq$ 0.01 % error is obtained.

When available soil moisture is depleted the actual evapotranspiration will be limited to the monthly precipitation (Fetter, 1988) this is thus true for the study area, since the soil moisture of the area is depleted annually.

But it is assumed that it is much better to use mean value of different methods to get more confident result of AET. From this, therefore AET of 702 mm is justified. This result thus accepted as basic data for water balance calculation.

4.5 Runoff analysis

4.5.1. Runoff characteristics

Runoff is a component of stream water which generates from precipitation as flowing water in a basin. Commonly it arrives stream channels by a number of flow paths. It takes place when the rate of precipitation exceeds the rate of infiltration into a soil. Topography, vegetation, geology and climate are controlling factors of runoff over an area. At a general level the relationship between stream flow and precipitation can be expressed in terms of the continuos circulation of water through the hydrological cycle. In the study area, rivers and streams receives inputs of precipitation and transforms it into a stream flow.

Out put from the catchment system is continuos, but the inputs of precipitation are discontinuous. In this respect the discharge of the study area shows short periods of suddenly increased discharges associated with rainfall (Table 4.9). During the rainy months June to August the out put is quite large, where as in the dry seasons the out flow is limited to the base flow.

Table 4.9 Rainfall - Discharge (1973 - 1996)

Parameter	J	F	M	A	M	J	J	A	S	O	N	D
Rain fall (mm)	12	27.7	45.9	52.5	54.3	67.2	192.1	195.5	97	26.5	10.5	3.8
Discharge m^3/s	3.7	3.4	3.4	4.2	4.8	5.5	6.9	6.3	4.8	3.8	3.6	4.0

The above table is a record of monthly mean discharge of the upper Wonji basin that was calculated from data of Koka and Wonji stations and mean monthly rain fall of Wonji station. It was used to compare rainfall and runoff relation in the basin.

4.5.2. Runoff estimation

One of the best methods to calculate runoff from a cachment can be, to use existing discharge records of an area. This was obtained from data bank of Ministry of Water Resources Development for Koka and Wonji stations (Period 1969 -1997). Further more it was used to analyze runoff conditions in the region. Staff gauge at Koka station is located about 10 Km upstream of Wonji station. Readings of this station are discharge value of Awash basin, existing upstream of this point. Records at Wonji station represents the total value of upper Wonji basin and the rest upper Awash basin.

It was observed that readings of Wonji station are greater than discharge readings of Koka station, except rarely they are equal at some months in the year. This clearly indicates that the runoff difference between the two stations (Wonji and Koka) gives the runoff value of upper Wonji basin. To arrive at this result, 1st average value of maximum and minimum discharge measurements of each months of each year was calculated for each station. Then the obtained value of Koka station of each month in each year was subtracted from respective month and year of Wonji station (Annex 6). This gave mean annual discharge of 4.3 m^3/s, which is runoff value only from upper Wonji basin. In consistency and scarcity of data for certain years has been recognized. Therefore, data over the period of 1973 - 1996 which are relatively consistent and realistic have been used. Accordingly 135×10^6 m^3 annual mean of runoff has been calculated for upper Wonji basin has a surface area of 140 sq.km.

In the upper Wonji basin there are number of springs which are also contributing much water for the total yearly amount of runoff over the catchment. As it has been noted by (Tenalem Ayenew, 1998) most of the springs in the rift system have less than 5 l/s but some exceed and this 100 l/s value also correlable to the springs of the study area as it has been measured in the field. Therefore, this is quite true for the basin to produce weighted mean of 4.3 m^3/s discharge through out the year.

The study area is considered as upper and lower Wonji basin for the convenience of runoff calculation over the entire area. Lower Wonji basin has no discharge measuring staff gages. So it was very difficult to calculate runoff value over this basin.

Therefore, Chow's (1988) runoff coefficient method has been tried. This is given by

$$C = R/\sum_{m=1}^{12} P_m \qquad (4.14)$$

Where;

C : runoff coefficient

R : depth of runoff (mm)

Pm : monthly rainfall (mm)

As it can be noted from natural conditions, the upper Wonji basin is quite different from other part of the study area. It owns steep topography, which will cause faster runoff and shorter gathering time than a flatter catchment of the other parts of the study area. It is also covered by sparse vegetation. Land surface is rocky as compared to lower part of the basin. These and the presence of many springs, dictated not to use the runoff coefficient of this basin for the whole area.

The calculated runoff coefficient for upper Wonji basin does not suit to the topography of the lower Wonji basin. The runoff coefficient method of chow (1988) can be adopted in estimating runoff, if and only if different basins have comparable natural conditions. In this respect it is not appropriate to use the runoff coefficient of upper Wonji basin.

Tamiru Alemayehu (1992) determined runoff coefficient of 0.138 for Mojo basin and Sharman (1983) gave runoff coefficient for different land types. Comparing these two facts the runoff coefficient of 0.4 suggested for runoff calculation, of other parts of study area (Annex 7). Because this value is correlable to the type area under investigation. The rainfall depth of the entire study area is 785 mm and the lower basin covers 217 sq.km.

Accordingly the runoff is given by

$$Ro = (A \times P)K \qquad (4.15)$$

Where: Ro : runoff

A : area

K : runoff coefficient

P : precipitation

Even though there is no documented study of flooding, information of local people reveals that, there were flooding in the area some times. It has been occurred 2 months ago before the field work. But, there is no record of this flood, more than oral tell of the local people. The study of runoff condition, thus may help to give a clue of flooding nature of the region.

Table 4.9 indicates that the biggest discharge occurred in the months of July and August. This may also coincides with the flooding periods in the study area. It was so confirmed from the information of local people during the field work. The estimated value of runoff from the lower basin ranges up to about 68.14×10^6 m^3. The maximum peak discharge that occurred over the past 24 years reaches 6.9 m^3/s for the study area (Table 4.9) exceeding extreme flooding.

CHAPTER FIVE

WATER BALANCE

5.1 Groundwater recharge estimation

A quantitative estimation of a groundwater that will recharge the basin can be evaluated from the components of the hydrological cycle. That is if components of input and output are subject to separation and measurements. This evaluation is given different names in various parts of the world, the most common being "hydrological balance", "hydrological budget".

Each catchment can, therefore, be regarded as a system that receiving inputs and transforming these into outputs of evaporation and stream flow. Allowing for changes of storage within the system input must be equal to the output under steady state. The water sheds, in which surface water divides and groundwater divides coincide, and for which there are no external inflows or outflows of groundwater, the water balance equation would be given as stated by Freez (1979).

$$P = Q + E + \Delta S_S + \Delta S_G. \qquad (5.1)$$

Where P: precipitation

Q: runoff

E: evaporation

S_S, S_G: change in surface and groundwater storage.

But for most natural condition this does not suite due to certain geological structures and topographic situation.

For instance in the study area, surface water divide does not coincide with groundwater divide at some portion of boundary line. There also groundwater inflow from Koka lake through big fractures. Therefore the water budget equation will take the most general form (Fetter, 1988) which is expressed as:

$$Pi + Si + Wim + Gi = So + Go + Et + Eo + Wex \pm \Delta g_S, \Delta S_S \quad (5.2)$$

Where:
Pi : precipitation
Si : surface water inflow
Wim : imported water
Gi : groundwater inflow
So : surface water outflow
Go : groundwater outflow
Et : evapotranspiration
Eo : reservoir evaporation
Wex : exported water
Δg_S : change in groundwater storage
ΔS_S : change in surface water storage.

As it can be noted from the above equation the amount of water going into the region under consideration in a given time equals the amount of water going out of the region or zone in the same period, plus or minus the change of storage within the zone during the period. Storage includes surface storage, groundwater storage and storage in vadose zone. It is clear that the change in storage may be zero on one or both sides of the equation. The above equation considers all possible parameters of the hydrological balance.

Assuming that there is no groundwater abstraction and no contribution to the groundwater from Awash river surface water inflow groundwater recharge is given by:

$$\Delta g_S = (Pi + Wim + Gi) - (Et + Eo + Ro + Wex) \pm \Delta S_S \quad (5.3)$$

Where Ro is a runoff from over the study area that is a components of surface water outflow and groundwater outflow from Wonji basin.

In some circumstances where sufficient water chemical data of different months and years is available, hydrological balance can be calculated using the chemical mass balance equation.

The chemical mass balance is given in the form:

$$CQ = CpQp + CoQo + CsQs + CgQg \tag{5.4}$$

Where: Q : is the discharge in L^3/T and C is the discharge concentration.

Qs : subsurface flow

Qg : groundwater flow

Qp : direct rain fall

Qo : overland flow

In this equation Qs and Qo, together gives direct runoff (Qd).

Thus rearranging the above equation:

$$Qg = Q \left(\frac{C - Cd}{Cg - Cd} \right) \tag{5.5}$$

Where Cg : chemical concentration in groundwater

Cd : concentration of soil - zone seepage or surface drainage

C : discharge concentration (runoff con.)

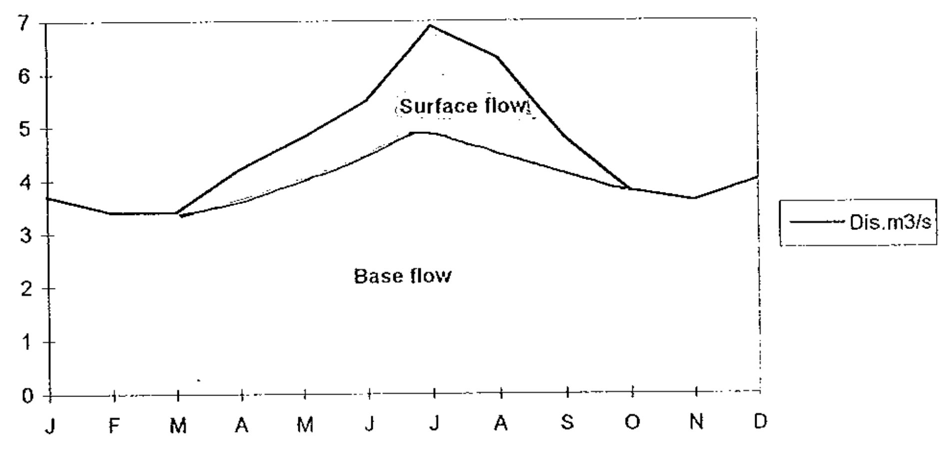
Qg : groundwater discharge

Q : runoff

As it has been obtained from water analysis the average value of Cl^- concentration in groundwater (Cg), runoff (C), and in soil - zone seepage (Cd) are : 39 mg/l, 8 mg/l and 2 mg/l respectively. In the field direct seepage water sample collection was not possible, thus the soil chemical analysis was carried instead. The concentration of Cl^- in the soil horizon up to the depth of about 50 cm was nil. It is therefore the value of 2 mg/l Cl^- concentration is considered, as it has been determined by (Tenalem Ayenew, 1998) for the rainfall Cl^- concentration in the rift that can represent concentration of seepage or surface drainage in the region.

Substituting these in the above equation the value of $0.6 m^3/s$ groundwater (base flow) component was obtained. This amounts 12% of the runoff over the upper Wonji basin. In this case the chemical mass balance equation under estimated the amount of base flow component. The chemical data that was used to calculate the base flow was, of one period and the discharge was only of the upper Wonji basin. Therefore the above value can not be considered as correct amount of groundwater component for the whole basin.

Fig. 5.1 Hydrograph separation



* Average discharge values in m^3/s for year (1973-1996)

Thus graphical method of hydrograph separation (Fig. 5.1) has been tried and gave about 65% base flow component for the upper Wonji basin ($88 \times 10^6 m^3$) which is relatively more realistic. But to calculate the ground water recharge for the whole basin, water balance computation equation was used which can be simplified based on the available initial data. This include purpose of the computation and type of the basin, of which the water balance is considered.

Halcrow (1989), calculated the groundwater outflow from Koka lake, which is inflow for the Wonji basin to be 733 x 10^6 m^3/yr.

Table 5.1. Data sets for water budget calculation

Parameters	Amount	Parameters	Amount
Total area (km^2)	357	Precipitation depth (mm) (pi)	785
Melkasa reservoir (km^2)	1.85	Precipitation (Pi) (Mm^3)	280.2
Land surface area (Km^2)	355.15	Water import (Wim)	0
Et depth (mm)	702	Water export (Wex)	0
Et from land (Mm^3)	249.3	Runoff (Ro) (Mm^3)	203
PET depth (mm)	1704		
Eo from water body (Mm^3)	3.15		
Groundwater inflow(Gi) (Mm^3)	733		

* Et = actual evapotranspiration

PET = potential evapotranspiration

Eo = potential evapotranspiration from Awash Melkasa reservoir

Gi = groundwater inflow

In some areas up stream of sugar estate head office, river contributes to the groundwater system. This calculation does not account this local contribution. Hence based on the above measured and calculated data (Table 5.1) the groundwater recharge in the whole basin can be given by:

$$\Delta g_s = Pi + Gi - Et - Eo - Ro \qquad (5.6)$$

In the calculation of water budget for the basin, the following assumptions have been noted:

- change in surface water storage assumed to be zero.
- groundwater abstraction considered to be zero.
- no water export from the basin

- water losses from flowing water is assumed to be negligible
- no water import

Accordingly, a total of 557.75 x 10^6 m^3 of the groundwater recharge was calculated for the whole basin.

5.1. Concluding remarks

The water balance estimation was encountered a number of different parameters with some limitations. Therefore, the estimated groundwater recharge has to be considered with caution. The long term water balance calculation based on different approaches indicates that the groundwater recharge (surplus water) from precipitation appears to be nil or very minimum. This shows that evaporation tends to be equal or greater than the precipitation in the region.

Changes in the groundwater storage, is thus mainly from groundwater inflows of the external basin. For water balance calculation, PET was used in the case of Awash melkasa reservoir. Because this water body covers very small area and it was considered as land surface with at no time there is a deficiency of water in the soil for the use of vegetation (PET).

CHAPTER SIX

HYDROGEOLOGY

6.1 Hydrogeological characteristic of lithological units

Water is present in all geological formations, the term "groundwater" includes only water that can flow through the formation and can be released by it through drainage or pumping (UN publication ST/ESA/3). Groundwater storage of geological formation depends on pore spaces contained in rocks; where the main ones are faults, joints, stratification etc. Geomorphological features are also another factors that control the extent of groundwater reservoirs. Quantities of groundwater in geological formation also depends on parameters such as: distribution and infiltration areas, hydraulic properties of lithounits, and boundaries of aquifers.

Detailed geological descriptions of stratigraphic units have been presented in chapter 3. These lithounits have been grouped in to three aquifer classes based on hydraulic parameters and field observation of porosity condition. Pumping test analyses using Jacobs method was the primary approach to assign the permeability group (Fig 6.1)

i) Low permeability group: permeability value < 0.5 m/d

ii) Moderate permeability group: permeability value 0.5 - 5 m/d

iii) High permeability group: permeability value > 5 m/d

The following section will discuss the major hydrogeological characteristics of these group as has been observed during the field and result of pumping data.

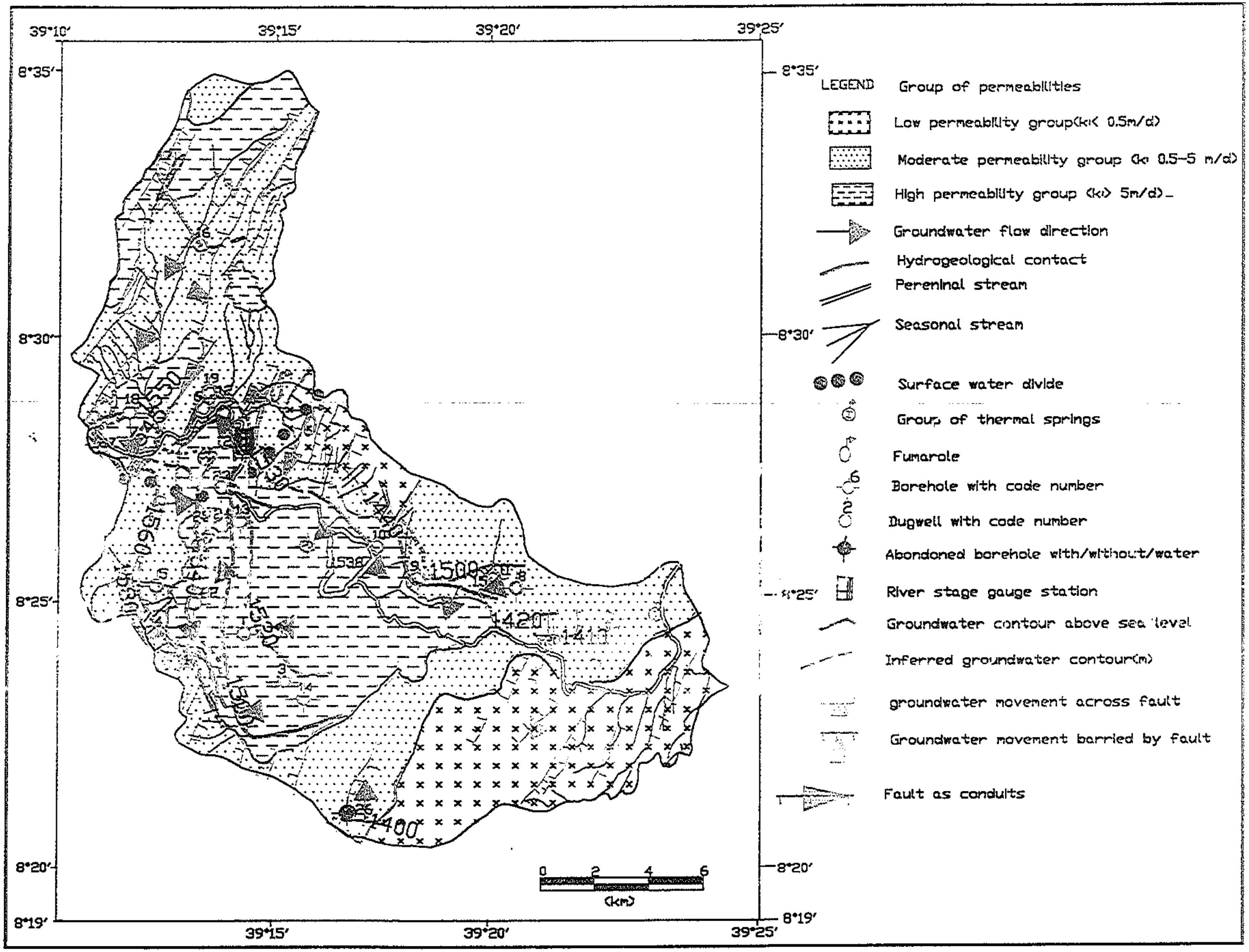


Fig 6.1 Hydrogeological map of Wonji Area

6.1.1 Massive rhyolitic ignimbrites, Rhyolitc and obsidian lava domes (Low permeability group)

As it has been noted from borehole 26, areas south of Sodere and surrounding of Dera town are characterized by very deep low permeability aquifers. Due to poor groundwater potential, number of boreholes which have been drilled for groundwater exploitation have been failed to give proper quantity of water supply for Dera town.

One borehole which was drilled 5 km west of Dera (BH - 26) striked the water table at 256 m below ground surface and was also found hot to be used as drinking water by the community. This group covers the minimum area, which includes unfractured welded ignimbrites, obsidian lava domes, and massive rhyolitic ignimbrites.

As it has been qualitatively estimated, from existing surface structures, lithological textures, geomorpholoical condition as well as explored aquifer, this group has assigned a least permeability group having a value of less than 0.5 m/d.

Farther this has been justified by field data of joints using emprical formula of Serafim (1968) expressed as:

$$K = \frac{e^3 \gamma_w}{12\, d\mu} \qquad (6.1)$$

Where e: joint opening

d: joint spacing

μ: viscosity of water at (30°C) - Fig 6.2

γ_w: unit weight of water

* Source: Bell (1990) Engineering geology, South Africa

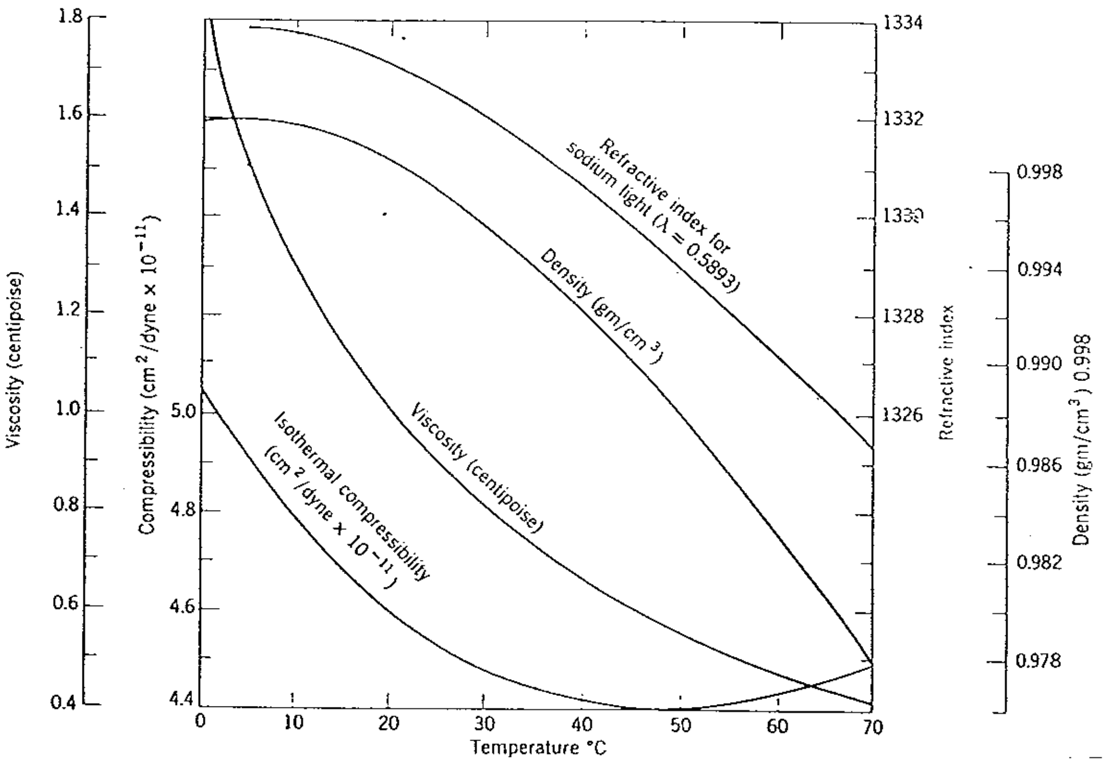


Fig. 6.2 Some of the physical properties of water which vary with temperature

* Source: Davis,1966. Hydrogeolgy

Majority of joints that were measured, during the field have an average spacing of 0.5 m and an opening of 0.1m. Most of the openings of these joints are devoid of secondary filling materials, while a few of them are filled by crushed rocks or clay materials. Average temperature of water points in the area is 30°C.

Thus according to Serafim formula the permeability through a rock mass of Sodere and Dera area is:

$$K = \frac{(0.1)^3}{12x0.5\ (7.2x10^{-3})}$$

$$= 0.023m/d$$

Particular around the Dera town is known by its fine grained texture and with very low jointing ignimbrite. These and other factors such as secondary infilling of clay and calcite minerals reduce infiltration capacity in this particular sector of the study area. As a result surrounding lithounits owned the least conductivity value as compared to the rest of the localities.

The panteleritic lava domes of obsidian lava flows with a patch of pumice fall out is largely exposed east and north east of Dera is characterized by glassy ground mass has very poor hydraulic conductivity, because it is devoid of primary porosity and the secondary porosity; such as fault and joints are also at a low level to hold a good groundwater potential

Data from borehole 26 defines that what so ever variable lithological units are existing vertically, no water was encountered until the greatest depth of 256m where ignimbrite with older basalt intercalation is served as aquifer.

This suggest that the younger units of these particular localities are poorly affected by secondary porosity until specified depth that they can not store groundwater or facilitate surface water movement into the ground that may recharge the underneath groundwater reservoir.

Topography has also imposed great impact at these localities to acquire poor groundwater potential. Because at this particular zone, land elevation is high, vegetation cover is also poor. It is, therefore over land flow is rapid and contribution of infiltration is less, since there is no spare time for such processes.

Rhyolitic lava domes of Boku ridge also considered under this group. But away in either sides of the ridge number of boreholes have been inventoried. Which this can give an indication that it might be serve as a potential recharge zone to low laying bordering areas; rather than as potential groundwater source area.

Texturally it is porphyritic with glassy ground mass, with primary perlitic structures. Perlitic structures formed small concentric cracks, that are not interconnected to serve as good hydraulic conductivity unit. Hydrothermal activity has also reduced the permeability.

This coupled with, geomorphological feature of Boku ridge gave rise poor permeable rhyolitic unit at this locality.

6.1.2. Fractured ignimbrite, cinder and spatter cones of basaltic lava flows (Moderate permeability group)

These formations covers the wider part of the basin, including fractured ignimbrite, tuffs and pumice, out cropped at a fault escarpments, on flank of Gadamsa rim, and at the vicinity of Awash Melkasa.

These rock units are characterized by faults and joints and assumed to have a good permeability. This justified by data of well hydraulics that gave permeability value of 0.5 - 5 m/day. Faults and the associated fractures are a potential recharge zone and transmit water from direct rainfall to deep groundwater reservoir. In general these formations, can be considered as potential aquifer areas in respective localities and structural conditions.

Cinder of glassy vesicular volcanic fragments and spatter cones, associated with basaltic flows are a part of this group. They are outcropped as scattered cones through out the area, being more concentrated west of Wonji plantation, around Sodere and Wofi-Wake localities.

Eventhough they are poor in primary porosity, there secondary porosity are well developed. During the field work water seepage were observed, at the foot slope of spatter and cinder cones, right after the rain fall.

This suggests that some of the joints of these cones serve as water conduits to the groundwater. Therefore, these cones can be considered as moderate permeability group within the study area. Though, because of topographic nature they can not be considered site for groundwater exploitation, the vicinity of their foot slopes could be potential area for groundwater resources. But they are important recharge zone in the region.

Under geology chapter this unit also includes pumice fall outs and ashes of Gadamsa rim. They own moderate permeability due to structure of their primary pore spaces. The jointing and fracturing of these formations are both vertical and horizontal. Thus expected to have good secondary permeability than the other volcanic rocks and facilitated both vertical and horizontal groundwater movement.

The topographic rank and permeability nature of this unit suggests that the unit can be good recharge zone. It can easily release water from precipitation because of its fracturing nature.

Boreholes drilled for Awash Melkasa and NACID water supply are from this formation. This indicates that the unit is good recharge zone as well as potential aquifer if it occurs at favorable topographic position.

Boreholes in the compound of Institute of Agricultural Research and Awash Melkasa palace, revealed that the aquifer unit is fractured basalt (BH-15, 20). But near by Aluminum sulfate factory and Wakityo boreholes indicated volcanic ash is an aquifer. This might indicate that basalt is localized aquifer unit while ignimbrite and associated loose pyroclastic materials serve as regional aquifer systems.

6.1.3. Alluvial and Lacustrine sediments (High permeability group)

Alluvial and lacustrine sediments have variable permeability due to grain size differences. The grain size of sediments in the flood plain of Awash river is getting coarser upstream of the river. Like wise the permeability also increases. In the locality of Melka Hidha the permeability is much higher than any other areas in the region. This might indicate the aquifer is mainly coarse sand at this particular well field.

Coarse grained sedimentary deposits have high primary permeability (> 5 m/d). This value have been justified from pumping test data of Melka Hidha and Wonji plantation well fields. They are deposited along river courses and flood plain loose sediments of sand, gravel, cobbles, and pebbles, with subrounded to rounded angularity. Since the thickness of these units within the study area is very large, are very important potential aquifers. Melka Hidha is situated down slope of high land recharge zone. It receives much water from large joints of these high lands. It also observed that productivity of wells is getting less away from the Awash river. This shows that near river channel the sediments are coarser than the flood plain.

By some authors it believed that well fields of Melka Hidha receive recharge from Awash river. But from water chemical analyses and groundwater table map it seems this condition seems unlikely.

Results of water chemical analyses from water points of Melka Hidha well field and Awash river falls in different systems (Fig. 7.9). Groundwater contours are converging, being pointing upstream, indicates that rather Awash river may be receives water from Malka Hidha aquifers. Since chemical analyses and groundwater contour map show contradictory concept, farther isotopic study is needed to proof the condition. Water chemical analyses and groundwater contour can not be used as justifying evidence, for this particular area, since evaporation affects groundwater chemistry and groundwater table also attain topographic feature in such shallow unconfined alluvial aquifer. Down stream from Main head office of Wonji estate farm, groundwater contours stretches parallel to the river.

This confirms that there is no water interaction between Awash river and shallow aquifer of Wonji plantation and down of this point. If recharge exists from Awash river, groundwater contours should have been pointing down stream direction (Fig 6.1).

The other point is that, from condition of topographic elevation the only possibility that can appear is groundwater can not recharge the Awash river near Wonji plantation, since it is occurred below the level of Awash river at these points. Thus probable location where shallow groundwater leave the basin as a base flow may be starting from down stream of Awash Melkasa, through big fractures and faults.

Another alluvial sediments are exposed in localized closed patch of basin west of Nazareth. These local river in fill sediments are not a promising area for groundwater exploitation, since they don't have large recharge areas and they are not thick enough to serve as an aquifer. This indicates that Wonji graben alluvial and lacustrine sediments are good groundwater potential areas except those found as a patch in intermountain deposits. As a whole gravels and coarse sands are important aquifers characterized by high permeability, whereas silt and clay are aquitards. Within sediments it seems that aquifers are of the same system, but few are of different layers due to variable layering of deposition. For example borehole 2 and 3 are assumed to be purched aquifer deducing form the result of chemical analyses. Even though many boreholes of sedimentary formation are of the same system, dug wells that of Kuriftu and Gafarsa show indication of pollution.

As it has been noted from borehole 18 and Batitifu borehole (BH-27), scoria and volcanic ash are an aquifer within the flood plain near foot slope of fault escarpment and Gadamsa (Dw-1). This suggests that at the contact zone of sedimentary layer and bed vocanic rocks, good aquifers are expected where high lands die out; being fractured top part of volcanic rocks serving as an aquifer. This portion of bedrock beneath the mountains may receive direct recharge and then feed the valley fill sediments.

It is a general truth that water table is closer to the surface in the lower elevations of intermountain basins than it is at the edges of next to the mountains. It is also true for the study area, as it was observed from borehole data of NACID area.

Eventhough the idea of Awash river recharging the Melka Hidha borehole field is questionable, at the locality of the Batitifi (Gargadi) flood plain, it recharges the groundwater. This has been confirmed by groundwater contours (Fig. 6.1) that crossing the river at 90°. Hence, shows that groundwater and river are at the same level and the river feeds the groundwater, particularly in the rainy season, when river level is elevated greater than the groundwater level.

Table 6.1 Data on water points of the study area

Ref. No.	Location	Coordinate	Elevation (m)	Water level(m)	Yield (l/s)
BH-1	Wonji camp-F	N 8° 24′ E 39° 14′	1534	10.64	3
BH-2	Wonji camp-K	N 8° 22′ E 39° 14′	1534	5.26	5.5
BH-3	Wonji camp-M	N 8° 23′ E 39° 15′	1530	4.71	-
BH-4	Showa No. 1	N 8° 24′ E 39° 12′	1580	2.70	2
BH-5	Showa No. 5	N 8° 25′ E 39° 12′	1540	-	-
BH-6	Malka Hidha	N 8° 29′ E 39° 13′	1532	10.55	16
BH-7	Wonji camp-A	N 8° 26′ E 39° 13′	1538	3.44	5
BH-8	Awash Melkasa World vision-BH	N 8° 24′ E 39°19′	1570	-	-
BH-9	Waki Tiyo	N 8° 24′ E 39° 18′	1550	103.5	5.00
BH-10	Wakihima (Wofi)	N 8° 26′ E 39° 17′	1540	7.00	
BH-11	Aluminium sulfate factory	N 8° 24′ E 39° 20′	1550	125.20	4.4

BH-12	Malka Hidha	N 8° 29′ E 39° 13′	1538	11.24	18.52
BH-13	Wonji hospital (camp-B)	N 8° 27′ E 39° 14′	1540	12.00	3
BH-14	Wonji camp-L	N 8° 24′ E 39° 14′	1536	6.85	3
BH-15	I.A.R	N 8° E 39°	1550	107.5	3.8
BH-16	NACID # 3	N 8° 33′ E 39° 13′	1780	119.95	5
BH-17	Deldima	N 8° 34′ E 39° 12′	1870	204.18	2.63
BH-18	Wonji catholic church	N 8° 29′ E 39° 12′	1560	11.01	7.00
BH-19	Malka Hidha	N 8° 29′ E 39° 14′	1540	11.43	8.17
BH-20	Awash Malkasa palace	N 8° 23′ E 39° 21′	1560	150.90	4.5
BH-21	Wonji camp - C	N 8° 26′ E 39° 14′	1536	5.50	-
BH-22	Wonji camp - E	N 8° 24′ E 39° 13′	1538	3.22	-
BH-23	Wonji head office	N 8° 27′ E 39° 13′	1540	5.20	-
BH-24	Near sweat factory	N 8° 27′ E 39° 13′	1538	5.37	-
BH-25	Northeast of camp - A	N 8° 26′ E 39° 13′	1538	8.47	-

BH-26	5 km west of Dera		1720	256	-
BH-27	Batitifi		1550	1.67	-
Dw - 1	Alemtena (Detamo dug well)	N 8° 23′ E 39° 13′	1590		
Dw - 2	Wonji kuriftu (Desalgn - Dw)	N 8° 27′ E 39° 13′	1548	10.95	-
Dw - 3	Gafarsa (Badada Bune-Dw)		1545	5.43	

6.2. Groundwater flow, recharge and discharge

6.2.1. groundwater flow

Topography and the geology are the primary controlling factors of the flow systems of groundwater. Depending on these facts flow systems may have local; intermediate and regional components or either single, double of these components. Along with topography and basin shape, structures and tectonics of the area have a significant role in dictating groundwater flows and recharge condition.

Tectonism and many major and minor structures have highly affected the area under investigation. Thus groundwater occurrence of the region is of much complex. But the general flow direction of groundwater is from highland recharge areas to low laying basin, finally outflow through the east direction. Orientation and dip direction of faults and fracture systems also influenced groundwater flow and direction. Most of fault controlled groundwater of the region move parallel to the direction of fault strike. At some localities there exist a groundwater flow across the fault line through fracture to discharge areas; or aquifer.

Volcanic cones and ridges are formed by accumulation of pyroclastics and flows around volcanic vent respectively. These lands and fault escarpments act as surface water divide. The largest part of the basin recharge come from this ridges, cones and escarpments. Therefore, fault zones can act either as barriers to groundwater flow or as groundwater conduits based upon the nature of the material in the fault zone. Except the structural orientation no groundwater barrier was observed due to secondary fillers in the fractures. This indicates that cabonitizaion process in the areas is minimum.

a: Segno gebeya escarpment west of Nazreth
b: malka hidha zone
c: Boku ridge zone
d: Kurftu volcanic cone
e: Dera ridge east extreme
f: Fault
St: stream
AR: Awash river down stream malkasa reservoir

Water flow lines along fault conduit
Water flow lines across the fault lines
Estimated average groundwater table
1660 Static water level asl.
FGW Fault controlled deep groundwater circulation
Dr Direct runoff
Hr High land recharge
Lf Local shallow fast flow
Fu Fumaroles

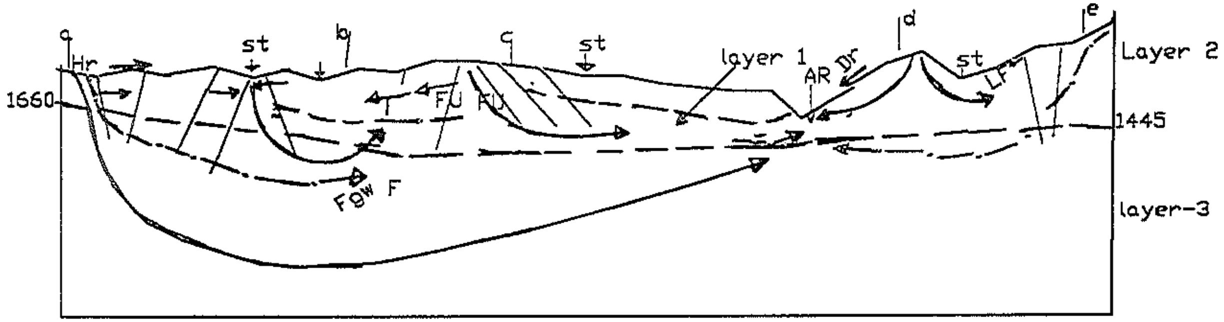


Fig. 6.3 Schematic conceptual model profile representing surface water-groundwater relation

H: 1:200,000

V: not to scale

Water table of shallow unconfined alluvial and lacustrine sediments have the same shape as the topography in the area since it receives much recharge from highlands have greater potential energy, than flat low laying flood plains of Awash river (Fig. 6.1)

It is evidenced from existing springs and geological structures that there is a groundwater inflow to basin from Koka reservoir. The general gradient of the basin decreases towards the east. Borehole data indicated that groundwater in the study area is found at different elevations being coinciding with local zone. Average groundwater table above sea level is 1660 m at scarpment, 1530 m in the alluvial sediments and 1445 m in Awash Malksa areas. Figure 6.1 shows that the general flow pattern of groundwater is to the low laying central basin from all directions finally goes out of the basin to the east.

But movement of groundwater at some places is complex and guided by geological structures or lithology to any direction. As a whole inflow to the basin is from the west while the general out flow is to the east.

As the area is structurally highly disturbed a series of local shallow fast flow groundwater systems occur at near top surface of the region (Fig. 6.3). Local groundwater flow system also related to shallow alluvial intermountain sediments deposits on the west escarpments as well as to lacustrine and alluvial main sediments of the basin.

Western fault escarpment has quite large depth to accomodate all types of the flow systems. Hence, there exist local, intermediate and regional flow systems. The Dera ridge has both intermediate and local flow systems. At the point of discharge the water from the regional flow system is likely to have relatively high mineralization and an elevated temperature due to the geothermal gradient (Fetter , 1988) and this was evidenced by Sodere hot springs of the area where regional groundwater from highlands of the area, spilled at this point having high temperature and TDS.

Intermediate flow system of west escarpment assumed to feed the Malka hidha well field (Fig. 6.3), and the concept was confirmed by water analyses of boreholes 16, 17 and 19, 21, are clustering at the same point on the finger print diagram (Fig. 7.10).

The major Adama graben has displaced the central portion of the study area trending north east - south west direction, particularly being well manifested through the Awash melkasa zone. Fault lines related to this structure could act possibly as groundwater conduits. This was supported by the field evidence of large number of springs existence at Sodere area, which yield large quantity of water from fault zone that intercepts regional groundwater table from the upper slopes.

Many of the major fractures trending east-west direction act as connector of local structurally controlled different groundwaters, hence flow paths. Prominent large fractures transmit huge amount of water from Koka reservoir to the basin.

Gadamsa major faults do not manifested by springs. Because their foot slopes were covered by sedimentary deposits. Thus they conduit water directly to the lacustrine sediments. This is also true for those faults cross the Boku ridge. They supply large quantity of water to low laying formations areas. Some minor faults scattered in the area, have no importance from hydrogeological point of view.

Fumaroles are emanating, and condensed steam were emerging through lava tubes at some localities of Boku ridge. This indicates that source of magma tube is at shallow depth at this particular place.

6.2.2. Groundwater recharging zones

Classification of the area into different recharge zones was not a simple task. No perennial stream was found in the area only one river Awash has water through out the year. There was no means to measure base flow for the other streams and categorize the region into different recharge zone.

Base flow data of Awash river measured at Wonji station helped only to rank west fault escarpment and immediate down slope areas as very high recharge zone. The rest localities considered based on their rainfall intensity and drainage density. In this respect; area of Gadamsa rim, Dera and Boku ridges considered as high recharge zones (Fig. 6.4).

The major Awash flood plain which is found down stream of pumping station (sugar estate head office), mainly receive limited surface recharge during the rainy season and considered as medium recharge zone.

The rest parts as of sugar plantation and Cheka areas do not have seasonal streams, even during the rainy season. The lacustrine deposit are fine grained and surficialy does not receive considerable amount of infiltration from direct rainfall. Therefore these localities are assumed as zone of low recharge places within the area under investigation.

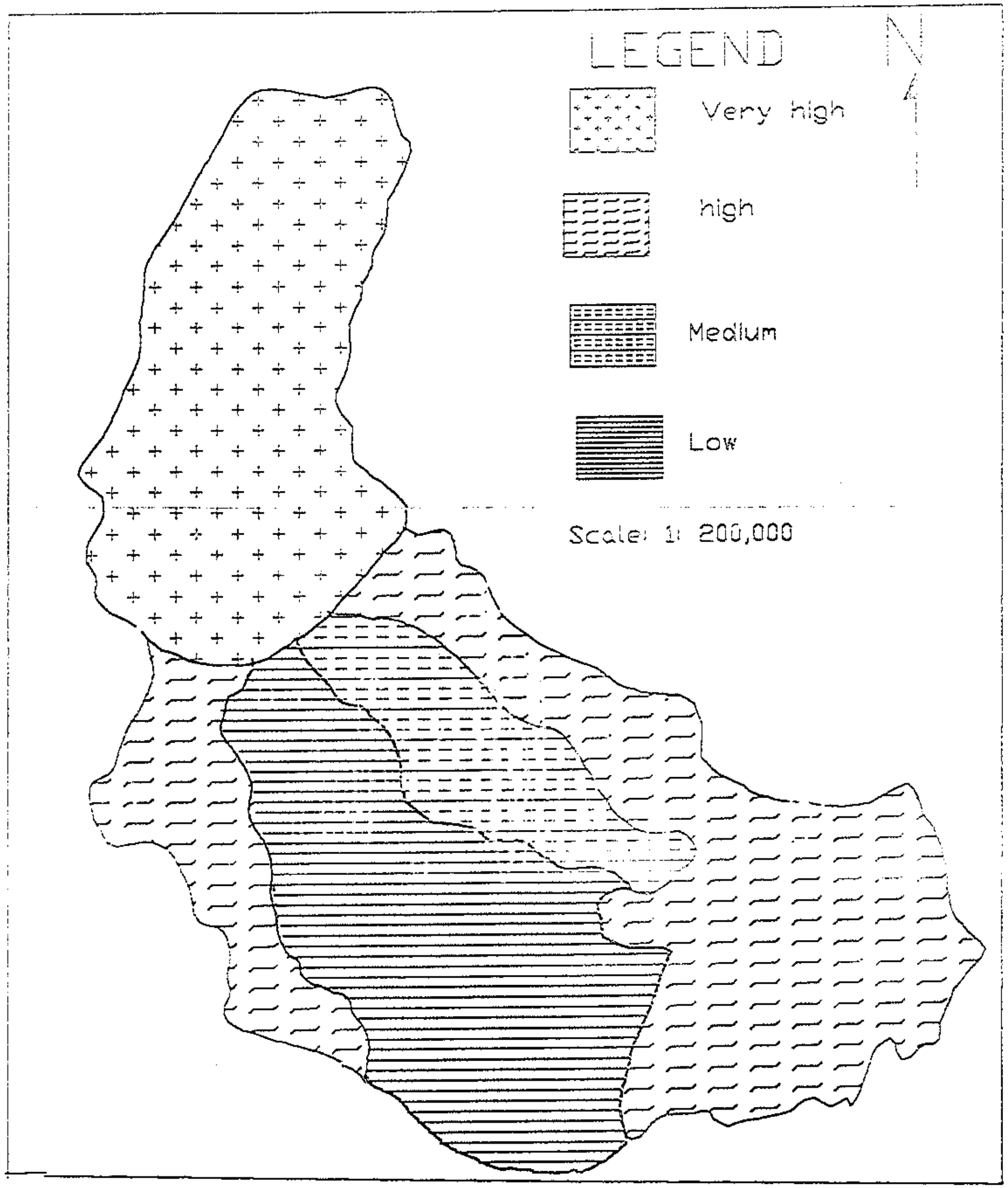


Fig. 6.4 RECHARGE ZONATION MAp

6.2.3. Groundwater discharge

Groundwater can be discharged, artificially or naturally. In the region, the community exploit underneath water both by boreholes and hand dug wells. Discharge estimation from these artificial water points has been conducted based on data of boreholes and dug wells.

i) Boreholes and dug wells

The boreholes and dug wells that inverted are all supplying water for the community; except that of Dera area (BH-26). Thirty boreholes as well as about 40 dug wells are found in the study area. At an average each borehole has a pumping capacity 5 l/s of water. This amounts 4.73 x 10^6 m^3/year.

ii) Springs:

All existing springs: hot and cold are located along tectonically active zones and are aligned on the fault lines. Prominent group of springs is found down stream of Koka reservoir. They emanate mainly from Koka reservoir through big fractures.

During the field work, it has been tried to mark all of them, but some started to die out and considered as seepage zone. Totally about 8 springs were observed at this point. Discharge of some of them was measured using floating method, ranges from 4 l/s to 5 l/s.

The other group of springs was located at Sodere and the vicinity which all are thermal springs. The maximum measured temperature of the group ranges up to 59°C. Discharge capacity of this group also the same as Gargadi. Four springs were found at this locality and all together 12 springs are in the region. Considering the maximum average discharge of each springs to be 5 l/s, 1.9 x 10^6 m^3 of goes as surface flow in rivers.

iii) Seepage

Seepage zones are also observed in the Gargadi area, where discharged groundwater not developed to flowing springs. Seepage points are marked by local swampy lands and green grass covered small ditch like gullies. At some places, they are manifested by thin concretion of salt deposits on the earth surface.

The present estimation does not include base flow and evapotranspiration. These has been discussed in chapter 5. Therefore, a total of 7.5×10^6 m^3 of groundwater, will be discharged by all water points (boreholes, dug wells, springs, seepage zones).

As it has been calculated in Chapter 5, the basin has 557.75×10^6 m^3 groundwater recharge. Even if the maximum abstraction of water points be two fold, still the basin may have 543×10^6 m^3 groundwater storage. The annual abstraction is very small as compared to the storage. Hence, the remaining water will leave the basin through deeper regional horizons along fault lines (Fig. 6.3).

It can be noted from earlier discussions and the present, there are number of uncertainties. For example to calculate regional groundwater recharge (Chapter 5), different methods gave different AET value. Which their average was used, and still should not be taken as 100% correct. Therefore, when farther water resource development study is carried it should be supported by isotope and geophysical methods.

6.3 Water requirement for domestic use

The area covers a total of 357 km^2. Within this extent, 5 towns and 18 peasant associations exist. Statistical data of human population in the study area has been obtained from 1994 population and housing census of Ethiopia at a country level (Annex 9).

Accordingly 290,703 people live in the area, including house holds. As was estimated by CSA for the country as a whole, the average annual population growth rate ranges 2.9 percent between 1995-2000. Thus the gross population density in the year 1999 will be 375,5007. For water demand estimation emphases was given to domestic use purposes.

Development activities such as factory, irrigation as well as live stock, use water from Awash river. During the field work, it has been also observed that rural people use water from ponds and springs for their cattle.

According to Gabre-emanuel Teka (1977) the amount of water required for domestic use varies from country to country, and from one community to another depending on:

- availability of water
- cost of water
- living standards
- climate
- habits of the people
- existence of washing facilities
- the distance over which water must be carried
- type of extra disposal system.

Though no clearly established per capital consumption of water exist in Ethiopia, estimates range from 5 liters to over 120 liters.

The municipalities department uses 15 l/d consumption for project design purposes (Gabre - emanuel Teka, 1977). As it has been suggested by the same author it is acceptable to use consumption of 15 to 20 l/d for rural areas and 50 to 60 for cities for design purposes.

Taking a value of maximum for rural areas and minimum for surrounding towns, 20 and 50 l/d respectively water requirement was estimated. The rural population in the area is 52025 and of towns is 238,678. Calculating water required per capita per day, with the respect localities a total of $4.7 \times 10^6 m^3$ of water is needed for domestic use in the region per year.

Previously it has been mentioned that at least $543 \times 10^6 m^3$ groundwater storage is exist in the basin. From this perception it is clear that, groundwater utilization in the basin can be carried with no fear. Thus, caution should be given to water quality and selection of borehole sites for farther groundwater development strategies.

Many boreholes abstract water from unconfined sedimentary aquifers but few are from confined or perched once. Hence extremely over pumping probably can cause ground subsidence. Therefore, even much amount of subsurface water is existing in the basin care has to be maintained for what so ever.

6.4 Groundwater development possibilities

Groundwater pool occurred due to structural barrier or physical property of lithologic units. As lithologic units characterized by vertical or lateral change, water stored in rock can be characterized by vertical or lateral change too.

Eventhough both factors have significant roles in the study area, structural trappings are the main once in volcanic aquifers, where as lithologic storages are important in low laying sediments.

Permeability is not the only factor to get good aquifers, but rocks should be also render favorable condition for accumulation. Moving water has to be stopped by natural conditions to give exploitable groundwater.

As it is indicated in figure 6.3, there exist 3 exploitable layers in the region. The shallow sedimentary layer found between 1520-1580 m, above mean sea level, and deep volcanic aquifer on west escarpment found at an average level of 1660 m a.m.s and the major Adama graben related aquifer found between 1410-1445 m a.m.s.l.

The most favorable exploitable groundwater could be upstream catchment area in the localities such as Melka Hidha, Batitifi (Gargadi area) and in the vicinities of Catholic Church. The low lying sugar estate localities and foot slope of Buku areas as well as Wofi, Waki Tiyo and west escarpments are good exploitable groundwater potential areas.

As it has been discussed earlier, localities of Dera and Buku ridge are not promising areas for groundwater developments. As a whole sediment deposits of the Awash valley and the vicinity are good groundwater potential zones.

Development of some cold springs could be also another alternative means. Additional detailed studies may identify some local aquifer horizon within small intermountain sediments of west fault escarpment.

Fault lines act as water conduits, hence the basin losses water to deeper horizons, mostly may down of the Awash melkasa areas.

CHAPTER SEVEN

HYDROCHEMISTRY

7.1 Introduction

Hydrochemistry is a very important tool to provide existing conditions related to quality, origin and history of natural water. It is also source of information since chemical reactions are time and space dependent. Chemistry of water can provide data about presence or absence of carbonate minerals, degree of weathering and the extent of reaction with silicates.

Circulation of groundwater in the hard rock terrains will be limited to weathered zone. But a little components may be originated from deeper sources through joints, faults and fractured parts. Shallow groundwater represent sample of solutes derived from natural sources. They are useful to provide information about the processes in the near surface environments.

Composition of water represents products of water rock interaction and vary according to rock type, existing mineral, solubility, pH and rates of geochemical reaction. In this respect EC or TDS is so useful to determine the extent of water rock interaction with both silicate and carbonate rocks.

The change of water composition through reactions may provide information about the environment through which the water has circulated. This intern can be used to investigate the correlation between water quality (type) and the geological environment (Lathern et. al; 1990)

7.2. Major properties of water samples

Measurement of some important parameters have been carried right in the field. These have also been used to check the accuracy of the laboratory analyses. The chemical analyzes been carried out at central laboratory of E.I.G.S. Some properties of water samples were calculated based on the result of chemical analyses.

Representative water samples were collected from existing water bodies, which have been surved to study water mixing condition and to classify water types. Water quality and their use for certain purposes have been determined based on chemical analyses. To enrich the chemical information additional data were also collected from different previous works. Particularly the work of Ashley and Burely are of the greatest value.

In situ measurement of Temperature, PH and EC has been done with scientific instruments. Other physical properties including color, taste, odor, are not naturally measurable quantitatively. But their condition were assessed in the field. No particular situation was observe concerning these parameters.

Table 7.1 Value of main anion and caution of water samples (meq/l)

	Chemical Constituents						
Water body	Ca	Mg	Na	K	HCO_3	SO_4	Cl
Boreholes: BH-1	2.49	1.31	16.96	0.28	20.48	0.02	1.86
BH-2	1.74	0.49	10.87	0.30	9.98	1.16	2.84
BH-3	6.23	3.29	13.48	0.61	15.99	2.99	1.97
BH-4	1.74	0.90	10.44	0.46	10.96	1.51	1.38
BH-5	0.99	0.41	12.61	0.46	10.58	1.12	1.89
BH-6	3.03	0.79	2.66	0.29	5.99	x	0.56
BH-7	3.99	3.70	11.31	0.53	10.16	9.07	1.63
BH-8	2.19	1.48	5.13	0.33	7.83	0.41	0.84
BH-9	2.34	1.39	1.95	0.20	4.19	0.24	0.64
BH-10	1.49	1.31	10.00	0.43	9.99	1.83	1.94
BH-11	3.27	2.71	4.43	0.28	7.99	1.43	0.80
BH-12	0.95	3.68	1.70	0.33	5.99	x	0.75
BH-13							
BH-14							
BH-15	2.16	1.67	4.95	0.31	7.19	0.52	1.19
BH-16	1.39	0.49	2.13	0.33	3.96	0.00	0.19
BH-17	1.64	0.74	1.87	0.33	4.32	0.12	0.16
BH-18	1.92	0.96	7.39	0.30	8.79	0.85	0.64
BH-19	3.27	0.79	2.07	0.32	5.59	x	0.80
BH-20							
Dugwells: DW - 1	0.44	0.16	15.0	0.40	11.06	1.24	2.42
DW - 2	0.29	0.24	15.87	0.46	12.68	0.19	1.97
Hotsprings HS - 1	0.59	0.57	29.14	0.84	23.84	2.91	4.96
HS - 2	0.19	0.08	9.13	0.30	7.50	0.60	0.76
River AR - 1	0.89	0.32	0.60	0.10	1.40	0.04	0.19
AR - 2	1.39	0.41	1.26	0.23	2.85	0.29	0.31
AR - 3	0.79	0.32	0.69	0.10	1.63	0.04	0.19
AR- 4	0.84	0.32	0.39	0.10	ND	0.04	

* ND : not detected, x : no data

Water samples were collected using plastic bottles. Before the use of these bottles they were carefully renised with distilled water. They have also been washed in the field by the water to be sampled; prior to collection of water samples.

Sampling from boreholes were conducted soon after pumping out of water. This was to have actual representative samples. For surface water bodies and springs they were collected from appropriate sampling sites. All have been sent to the respective laboratory soon as much as possible.

Table 7.1 records the results of the chemical analyses of all samples from the area; was used for farther interpretation and calculation.

7.2.1. Electrical conductivity

Electrical conductivity is mainly influenced by amounts of ions in solution or ionic activity. Higher values of electrical conductivity have been measured, in the areas where high total dissolved solids were recorded.

Despite different salts have different specific conductivity, their average composition was considered to determine the EC of some water samples. The majority of EC, except for few, data obtained from other works, all are measured in the field or in the laboratory.

The ability of electrical conductance of solution may provide a clue of ionic concentration of water sample. Chemically pure water has a very low electrical conductance, indicating that it constitutes small amount of ions in solution. Even very small amount of dissolved minerals can alter the EC of water. To compare this figure 7.1 has been drawn, using laboratory EC results, since field EC can be influenced by temperature. Accordingly figure 7.1 indicates that these two parameters have shown quite very good correlation factor.

Table 7.2 indicates that there is a general pattern of EC increase in groundwater toward the Wonji plantation. At some local points, particularly in the settlement areas, there is an indication of relatively higher EC values; corresponding to higher No_3 concentration. This might suggest, the presence of pollution sources at this particular area.

According to the obtained data, EC shows zonal variabilities. The maximum values are related to Sodere hot springs while the minimum is to Awash river.

Fig.7.1 TDS - EC relationship

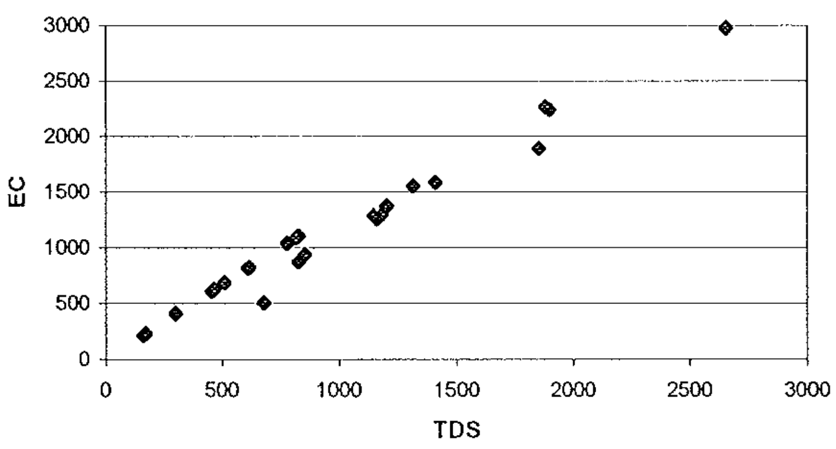


Table:-7.2 TDS, EC, and pH values of water samples of the study area

water points	Location	TDS (ppm)	EC (μs/cm) Laboratory	pH Value
1.Boreholes				
BH1	Wonji Camp F	1852.34	1889	7.22
BH2	Wonji Camp K	1161.7	1259	7.63
BH3	Wonji Camp H	1899.53	2240	7.14
BH4	Shoa No 1	1180.06	1295	7.82
BH5	Shoa No 5	1201.38	1375	7.52
BH6	Melka hidha	617.17	823	7.9
BH7	Wonji Camp A	1880.26	2267	6.98
BH8	Awash M World Vision	828.69	872	7.73
BH9	Waki Tiyo	679.13	505	7.29
BH10	Waki Hima	1148.87	1285	7.63
BH11	Aluminum Sulphate	828.23	1104	7.5
BH12	Melka Hidha	611.8	816	7.5
BH15	I.A.R	779.65	1039	7.5
BH16	NACID # 3	457.44	610	7.53
BH17	Deldima	468.44	624	7.84
BH18	Catholic Church	819.9	1092	7.8
BH19	Melka hidha	511.9	683	
2.Springs				
HS1	Sodere	2655.55	2976	7.59
HS2	Gargadi	855.18	936	8.56
3.Dug wells				
DW1	Alemtena Detamo BH	1314.2	1550	8.07
DW2	Wonji Kuriftu	1411.2	1586	8.45
4.River				
AR1	Awash R.Near camp O	160.29	213	7.72
AR2	Awash M.Reservoir	300.83	410	7.64
AR3	Awash R.Near main offi	172.91	230	7.89
AR4	Koka Lake	ND		

* ND : not determined

7.2.2. Total dissolved solids (TDS)

As water flows through rock media or on the earth's surface it may dissolve many salts and some types of organic matter. The amount of dissolved materials in natural water is one of the basic measure of the water quality. Dissolved materials can also be added to groundwater by human activities.

The total dissolved solid (TDS), thus include all the solid material in solution. Therefore, it may be determined from the weight of dry residue remaining after a sample of water has evaporated. But for the practical purposes it is calculated by adding the concentration of all ions in the water.

Field measurements of total dissolved solids can be obtained from the field data of EC. John D. Hem (1992) noted that EC values can be converted to total dissolved solids using mostly a coefficient of 0.55 to 0.75. Thus multiplying the field EC values by 0.55 to 0.75, it is possible directly to obtain the TDS. Values of EC for some chemical data, obtained from other works calculated on this principle using coefficient value of 0.75.

The values of total dissolved solids have direct correlation to the EC showing zonal variation corresponding to the EC values

The zonal variability of this parameter can be summarized as follows; with respect to water bodies and aquifer systems.

- < 200 ppm: river
- 200 - 500 ppm: deep aquifers (North Koka, I.A.R area)
- 500 - 1200 ppm: periphery of irrigated areas (shallow aquifers)
- 800 - 1900 ppm: irrigated areas (shallow aquifers)
- > 1900: Sodere hot spring areas.

This indicates that the higher total dissolved solids are more concentrated in shallow aquifer areas, where irrigation is very active.

Driscoll (1995) indicated that at deep zone, so little water moves, that mineral leaching extremely active; producing a high content of total dissolved solids. But in the study area the oppositte is true, where irrigation is practiced might be due to evaporation and irrigation effect. Detailed discussion of the irrigation impact and map showing the spatial variation of TDS are given in the forthcoming chapter 8. Based on the Freez's (1979) groundwater classification (Table 7.3), over 55% of analyzed water samples do fall in the range of brackish water type.

Table 7.3 simple groundwater classification based on total dissolved solids.

Category	TDS (mgl^{-1})
Fresh water	0 - 1000
Brackish water	1000 - 10,000
Saline water	10,000 - 100,000
Brine water	> 100,000

* Source: Freez (1979)

The measured TDS for hot springs are not correleable. Sodere hot spring have highest TDS value (2656 ppm), whereas Gargadi area's show smaller total dissolved solids up to 855 ppm. That might be due to dilution from groundwater inflow of Koka lake.

Sodere hot springs attained such highest total dissolved solids, which could be due to the influence of geothermal heating deep into the ground. All the water points are in the allowable range for drinking purpose, except few of the boreholes with TDS > 1500 mg/l and Sodere hot spring. Boreholes, west of Nazareth (16, 17) are in the general acceptability limit (500 mg/l). Water points at this locality are the best of all waters in the area for drinking purposes from concentration of F or TDS point of view.

7.2.3 pH

Davis (1966) noted that a pH of above 8.2 is a measure of carbonate ions present. That below 8.2 is a measure of bicarbonate ions. Below a pH of 4.5 indicates most of the bicarbonate ions are converted to carbonic acid molecule. This concept has been confirmed in the study area, that a small amount of carbonate ion (6 mg/l) was found only in two water points (dug well 2 and hot spring 2), where the measured pH was greater than 8.2, 8.45 and 8.56 respectively. In the entire area many water points have pH values less than 8.2, therefore it can be suggested that the bicarbonate ion is the dominant anion, while CO_3 is almost nil. Appelo (1994) also suggested that at pH values less than 8.3, less than 1% of the carbonic acid is present as CO_3^{2-}; the idea which strengthen the concept of Davis (1966).

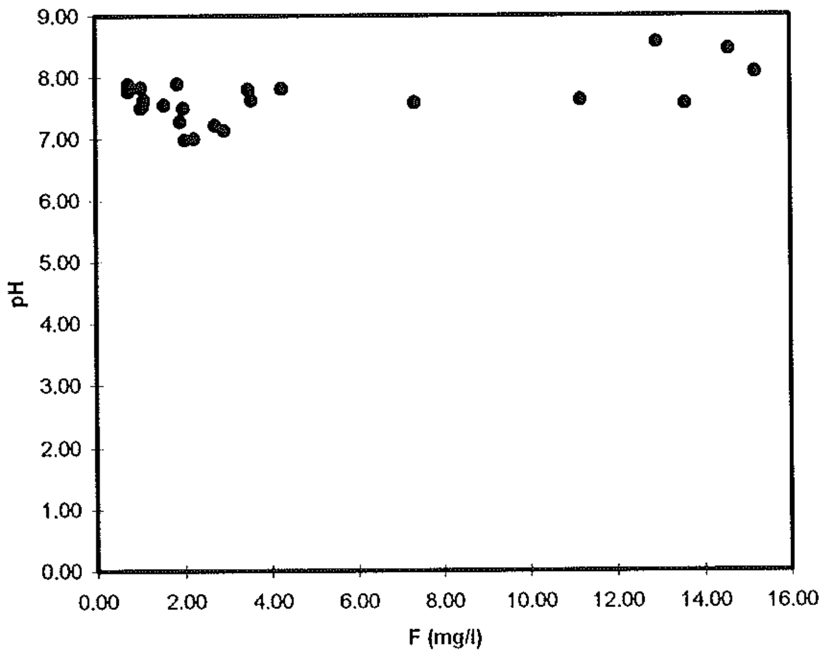


Fig. 7.2. pH-Fluoride relationship

The ionic radius of fluoride is nearly the same as that of the hydroxide. It is thus substitution of hydroxide ions for fluoride is likely in water of high pH. Therefore, figure

7.2 indicates that some waters that contain large amount of fluoride do have high pH value.

7.2.4. Hardness

Hardness of water is mainly due to the presence of calcium and magnesium ion in water solution, although other ions can react as hardness. Hardness of water is the sum of calcium and magnesium expressed as an equivalent amount of calcium carbonate ($CaCO_3$) (Chow, 1964). Generally hardness of water is calculated from results of water sample analyses expressed in the form:

$$TH = 2.5\ Ca + 4.1\ Mg \qquad (7.1)$$

Compounds of calcium, magnesium, bicarbonate, carbonate and sulfate are principal chemical sources for calcium and magnesium ions (Driscoll , 1995)

Hardness of water is defined as its content of metallic ions in water which react with sodium soaps to produce solid soaps or solid scale when the water is evaporated. The unit of hardness is generally given by mg/l

According to Freez (1979) water with hardness value greater than 150 mg/l is considered as hard. But water with a value of less than 60 mg/l designated as soft water.

Total hardness for the study area, ranges over 136 mg/l. The highest hardness values are mostly recorded for boreholes, where it has over all average value of 179.8 mg/l. The smallest value is calculated for dug wells with the value of 29 mg/l. Hot springs have average value of 36.4 mg/l of hardness, whereas for rivers it ranges up to 66.6 mg/l.

Table 7.4. Range of hardness

Description	Hardness range (mg/l of $CaCO_3$)
Soft	0 - 60
Moderately hard	61 - 120
Hard	121 - 180
Very hard	More than 180

Source: John D.Hem (1995)

There is no specified range of limit for hardness in drinking water; but Hem (1995) has suggested hardness in water, for ordinary domestic purposes does not become objectionable until it reaches a level of 100 mg/l or so. According to table 6.4, water in boreholes are in the range of hard type, while all the others are in the category of soft. River waters are in the range of moderately hard.

Locally, very high value of Ca concentration has been observed in the borehole 3 which might be associated to local variations in litholgy. Perched groundwaters can acquire such high value of Ca which could be due to small water movements and longer residence time in this environments.

7.2.5 Temperature

Average annual air temperature is 20.4°C in the study area. All groundwater temperature that were measured in the field are much higher than this value. The minimum recorded temperature is 25°C with a maximum of 59°C at Sodere hot spring.

As it can be understood from these results, the study area is under the influence of geothermal activities, particularly in Gargadi, Sodere, and northern Boku ridge where hot springs steams are observed. Borehole 5, which is located at the foot of Gadamsa caldera has high temperature value of 39°C. This can also suggests that this locality is also under the of influence thermal activities.

Considerable amount of CO_2 are also recorded in the area. Gases typical of geothermal reservoirs are rich in compounds such as carbon dioxide, hydrogen sulfide, methane, are generally indicative of deep aquifer origin (ELC, 1987). Therefore the higher temperature value of the region could be related to this deep geothermal activities.

Depth of thermal groundwater circulation can be calculated from temperature records; since groundwater is commonly temperature equilibrated with the aquifer rocks (Mazor 1991).

The relation is given by

$$\text{depth (m)} = \frac{Tm - Ts}{\Delta T/6} \qquad (7.2)$$

where: Tm : temperature of spring or well measured in the field

Ts : local average annual air temperature

ΔT : local geothermal heat gradient

1°C/6m

Groundwater temperature can be affected by many factors. It could be getting cooler as ascending to the ground surface. Recharge from the surface or groundwater inflow can also minimize the actual temperature of groundwater. In view of these facts temperature value of Sodere hot spring (59°C) is used to calculate the minimum possible depth of thermal water circulation. Therefore the source of hot springs is at minimum depth of 242 m below the ground surface.

There exists much temperature variability. As a whole the marginal ridges of the study area have relatively higher temperature value.

7.3. Major cations and anions

These dissolved materials coupled with physical parameters could give different types of waters. Many are from natural water rock interaction, while some are from human influences. Natural water has especial property to dissolve many substances.

Chemical species of natural waters are expressed by their equivalent weight (meq/l). Standard conversion tables (Annex 8) have been used to change mg/l values of the laboratory results.

The precision and accuracy of all analyses was verified by ionic balance and all were within ± 7%. The conductivity value that was measured in the field was also used as a second method of quality control on the data.

7.3.1. Cations

Out of analyzed constituents of water sample Na and Ca are the dominant cations for both surface and groundwater bodies. Sodere hot spring has the highest sodium concentration (29.14 meq/l) then it is followed by hand dug wells (18.87 meq/l). Boreholes have an over all average value of 7.05 meq/l or with in the range of 1.7 to 16.96 meq/l and rivers have the least concentration of 0.39 meq/l, of sodium concentration.

Concentration of calcium cation also shows higher variabilities. Samples from hot spring range from 0.2 to 0.6, dug wells 0.3 to 0.4, boreholes 1.0 to 6.0 and river 0.2 to 1.4 meq/l. In large number of boreholes potassium is the least concentrated cation. Hot springs and river samples show a little higher potassium concentration than calcium and magnesium.

The concentration of sodium does not show specific pattern rather than higher Na/Ca ratio is observed. The much higher sodium concentration compared with potassium, in the study area may demonstrates plagioclase most probably albite is much more reactive than k-feldspars. This in turn also indicates that the study area is more covered with acidic volcanic rocks. This indicates also cation- exchange process.

The over all higher Na/Ca ration also suggests that carbonate minerals are very minimum or not exist at all in the region. That is the relatively law calcium over large of the region points to the general absence of carbonate in many rock types and the dominance of Na relative to Ca in silicate minerals.

It is probably that most of the dissolved silica observed in the water samples results from the chemical breakdown of silicate minerals, rich in sodium feldspars; than the other minerals considered.

7.3.2 Anions

The main anions of water samples of the study area in of their decreasing order are: bicarbonate, sulfate, chloride, fluoride and nitrate. Concentrations of these anions show distinct aerial variability.

Boreholes located out of Wonji estate plantation and deep aquifers north of Koka lake and around Awash melkasa area have relatively smaller bicarbonate concentration. It ranges from (468 - 828 mg/l). Irrigated sugar estate areas, and the vicinity records very high bicarbonate concentration reaches up to 1250 mg/l.

Table 7.5 Result of chemical analysis (mg/l)

Ref. No	TDS PPM	Co3	HCO3	Cl	SO4	F	No3	Na	K	Ca	Mg	HBO2	SiO2	CO2	PH	C°
BH-1	1859.43		1250	38	1	2.73	1.1	390	11	50	16	1.6	91	119	7.22	31
BH-2	1126.7		609	66	56	11.2	1.1	250	12	35	6	1.4	79	25	7.63	32
BH-3	1770.53		976	70	144	2.93	2.7	310	24	125	40	1.9	74	114	7.14	25
BH-4	1180.06		669	49	73	4.26	0.6	240	18	35	11	1.2	79	16	7.82	29
BH-5	1201.38		646	67	54	13.6	0.58	290	18	20	5	1.2	86	28	7.57	39
BH-6	617.17		366	19.9	Nill	1.87	0.5	61.2	11.6	60.9	9.7		85.5		7.9	
BH-7	1880.26		864	58	466	2.03	8.1	260	21	80	45	<0.13	76	142	6.98	27
BH-8	828.69		478	30	20	1.56	30	118	13	44	18	<0.13	76	22	7.56	28
BH-9	679.13		256	23	12	1.94	11	45	8	47	17	<0.13	66	22	7.29	27
BH-10	1148.87		610	69	88	3.57	2.2	230	17	30	16	2.1	81	24	7.63	28
BH-11	0		488	28.4	68.9	1.03	30	102	11.2	65.7	33				7.5	
BH-12	0		366	26.9	Nil	2	2.5	39.1	13	19.2	44.8		98.3		7.5	
BH-13																
BH-14																
BH-15	779.65		439.2	42.5	25.1	2.25	0.5	113.9	12.5	43.3	20.4		80		7	
BH-16	457.44		242	7	<0.42	1.08	0.74	49	13	28	6	<0.20	110	21	7.53	
BH-17	468.44		264	6	6	1.04	2	43	13	33	9	<0.40	91	8	7.84	
BH-18	819.9		536.8	22.7	41	3.5	3.2	170	12	38.5	11.7		52.5		7.8	
BH-19	511.9		341.6	28.4		2.4	3.6	47.6	12.9	65.7	9.7					
BH-20		0														
DW-1	1314.2	0	675	86	60	15.2	25	345	16	9	2	2	79	7	8.07	32
DW-2	1411.2	6	774	70	44	14.6	23	365	18	6	3	1.6	86		8.45	31
HS-1	2655.55	0	1455	176	140	7.35	12	670	33	12	7	5.2	138	59	7.59	59
HS-2	855.18	6	458	27	29	12.95	1.1	210	12	4	1	<0.13	94		8.56	43
AR-1	160.09	0	86	7	2	0.76	1.4	14	4	18	4	<0.13	23	3	7.77	
AR-2	300.83	0	174	11	14	1.1	2.6	29	9	28	5	<0.13	27	8	7.64	
AR-3	172.91	0	100	7	2	0.74	<0.40	16	4	16	4	<0.13	23	3	7.89	
AR-4	ND	ND	ND		2	ND	<0.40	9	4	17	4	<0.13	24	ND	ND	

The relatively higher concentration value of chloride in the irrigation area is attributed to evaporation effect. As evaporation is proceeding the water molecule is removed, leaving salt constituents in solution. As a result this increased the concentration of salts in ground water.

Over much of the area, the concentration of NO_3 are less than 2 mg/l. Greater anomaly which ranges up to 30 mg/l apparently defines groundwater pollution around the settlement areas. Boreholes 1, 3 and 7 are marked by high concentration of bicarbonate exceeding 900 mg/l.

The noted anomalies could be, the result of several factors. These boreholes may marks local confined groundwater (perched) or locally different geological unit, that may contribute to such anomalies.

Fluoride shows consistent concentration in alluvial sediments except in borehole 2; which may be attributed to analyses error. The distribution of sulfate closely follows that of chloride and has more concentration in boreholes of irrigated area (Boreholes 1 to 5).

A distinct enrichment in SO_4 is found associated with factory areas (BH - 5 and BH - 7), probably from waste input of sugar factories. The contribution of sulfate in the study area could be also from the influence of fumaroles, hot springs, and volcanoes, since these parameters are active in the area and are good source of H_2S gas. Hem (1992) observed that the influence of chloride from hot springs and volcanic gases. This is evidenced by the high concentration of Cl in Hot spring 1 (HS - 1) of the study area.

Hot spring 2 could have been shown the higher value, too, but because of groundwater inflow dilution to this part of the area, it has relatively smaller chemical constituents than Sodere hot spring. Chloride may also show relative high concentration in central lower part of the study area. This may be explained by the idea of Hem (1992), that chloride ion is physically large compared to many of the other major ions, in water, it could be expected to be held back in pore water in clay and shale while water itself is transmitted.

7.3.3 Fluoride

Fluoride shows much differences in concentration from low elevated areas to ridges and escarpments. As it has been noted by Dereje Ayalew (1994) it increases sharply passing from intermediate to acidic rocks reaching concentration of some thousand ppm at Gadamsa Caldera. According to the same author there is also the secondary enrichment process evidenced by the presence of fluorite filling cavities. Binary graph of Ca versus F (Figure 7.3) shows that control on the concentration of fluoride is solubility of calcium fluoride (CaF_2). Thus variation in fluoride concentration can be related to changes in calcium concentration which itself is resulted from dissolution of calcium minerals. As it has been pointed out by Hem (1992), rocks rich in alkalimetals, and, also obsidians are higher in fluoride content than most other igneous rocks. Farther he noted fluoride often is associated with volcanic or fumarolic gases. These are true for the area under investigations, since acidic volcanic rocks including: ignimbrites, rhyolites, obsidian, pumice, pyroclastic deposits are the dominant lithologic units; so also volcanic or fumarolic gases are active in the region gave rise much concentration of fluoride in the area.

Farther from the rift floor these conditions are getting smaller which intern the concentration of fluoride also decreases in the escarpment areas (Figure 7.4). For example minimum value of 1.04 mg/l is recorded in the boreholes 16,17,on the escarpment west of Nazareth. World health organization recommends a guide level maximum of 1.5 mg/l fluoride (WHO, 1984) in drinking water. Almost all except few water points (BH - 11, 16, 17 and Awash river) are above this limit, caused dental and skeletal fluorisis symptoms on some of the Wonji population.

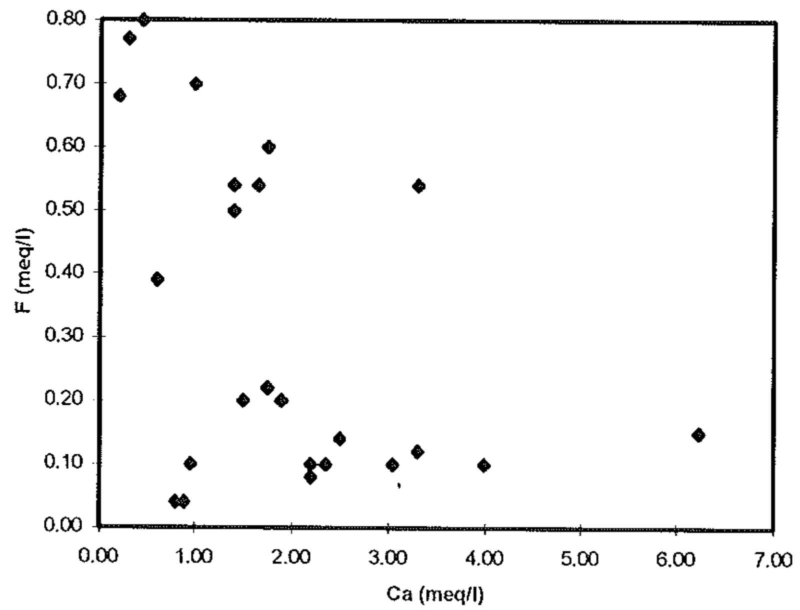


Fig. 7.3. Calcium-Fluoride relation

Fluoride complexes are also likely to be associated with aluminum and silicon in water whose PH < 7, but in the study area pH is greater than 7, that these complexes are unlikely to be found.

Awash river has least fluoride concentration than all water bodies, even smaller value than zones with minimum records (escarpment and I.A.R areas)

According to figure 7.3 shallow sedimentary aquifers with relatively higher calcium should have smaller fluoride concentration, than deep volcanic aquifers, which are relatively with smaller concentration. The opposite is true in our study area, and the reason is questionable. But based on existing situation and understanding the following points can be suggested.

- volcanic or fumoratic gases are more active in rift floor (shallow sedimentary aquifer area) than escarpment zone and may be contributed larger concentration of fluoride in respective rift floor zone.
- both shallow sedimentary and deep volcanic aquifers are in different geological environments, that calcium has no similar impact on fluoride anion.
- out gassing are more susceptible near the earth surface than in the deep ground.

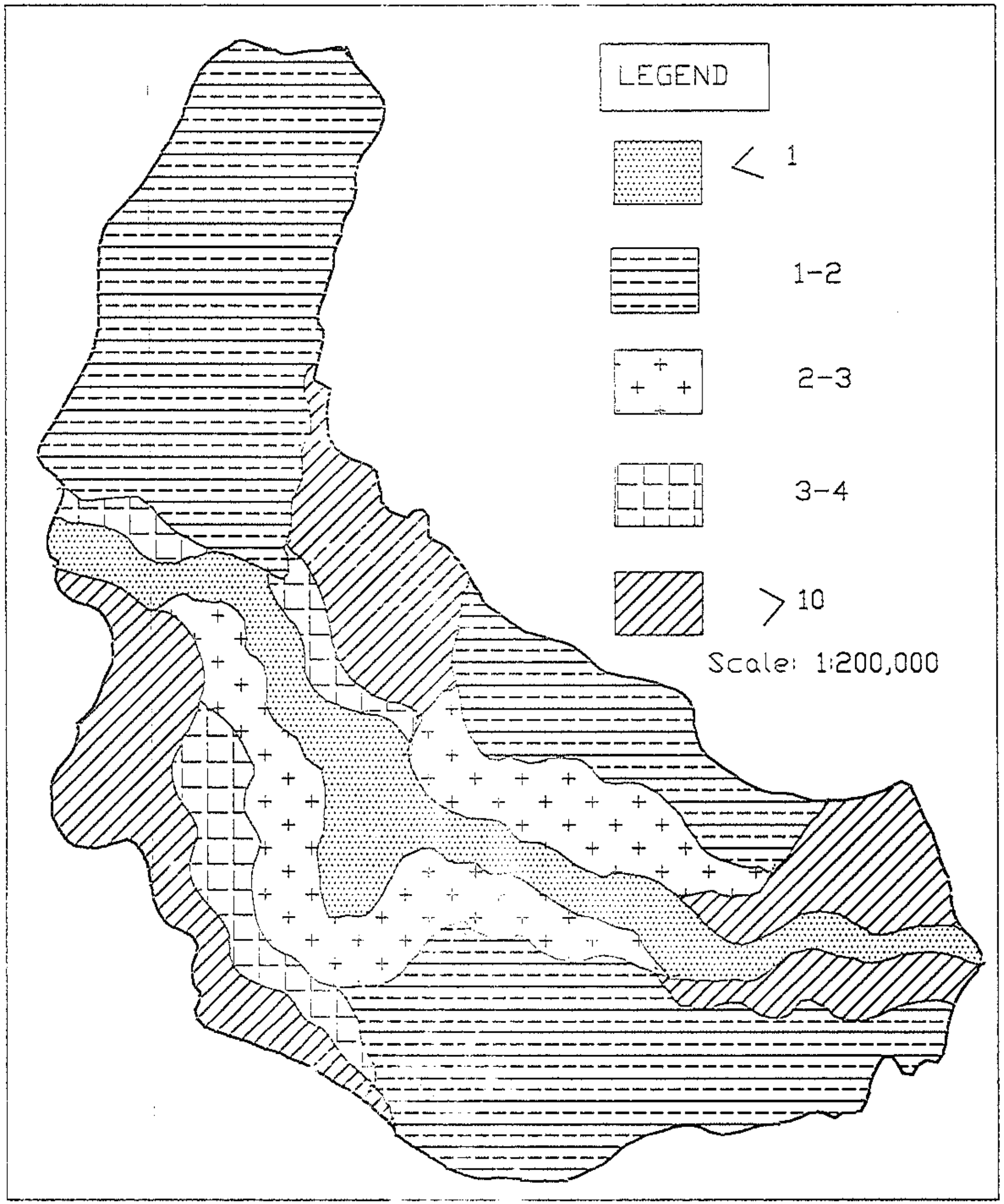


Fig. 7.4 Zonal variation of Fluoride

7.4. Water types

Though there exists different methods for water classification, it is believed that method based on the dominant ions is the best for practical purposes. This type of classification uses a percentage of milli equivalents per litter of the anions and cations. It combines two chemical families of main constituents of anions (Ca, Mg, Na + K) and cations (HCO_3 + CO_3, SO_4, Cl) to classify water type

In the central diamond diagram SO_4 + Cl and Ca + Mg are grouped together. Two triangular fields at lower either side of the diamond diagram are used to plot major cations anions, from where they are projected to common points on the trilinear diagram (Figure 7.5)

This method is also better than other methods in a sense that it shows mixing effects between waters, if two projected lines cross each other. The degree of mixing can be directly read from the crossing point or it may tell the water of the same origin.

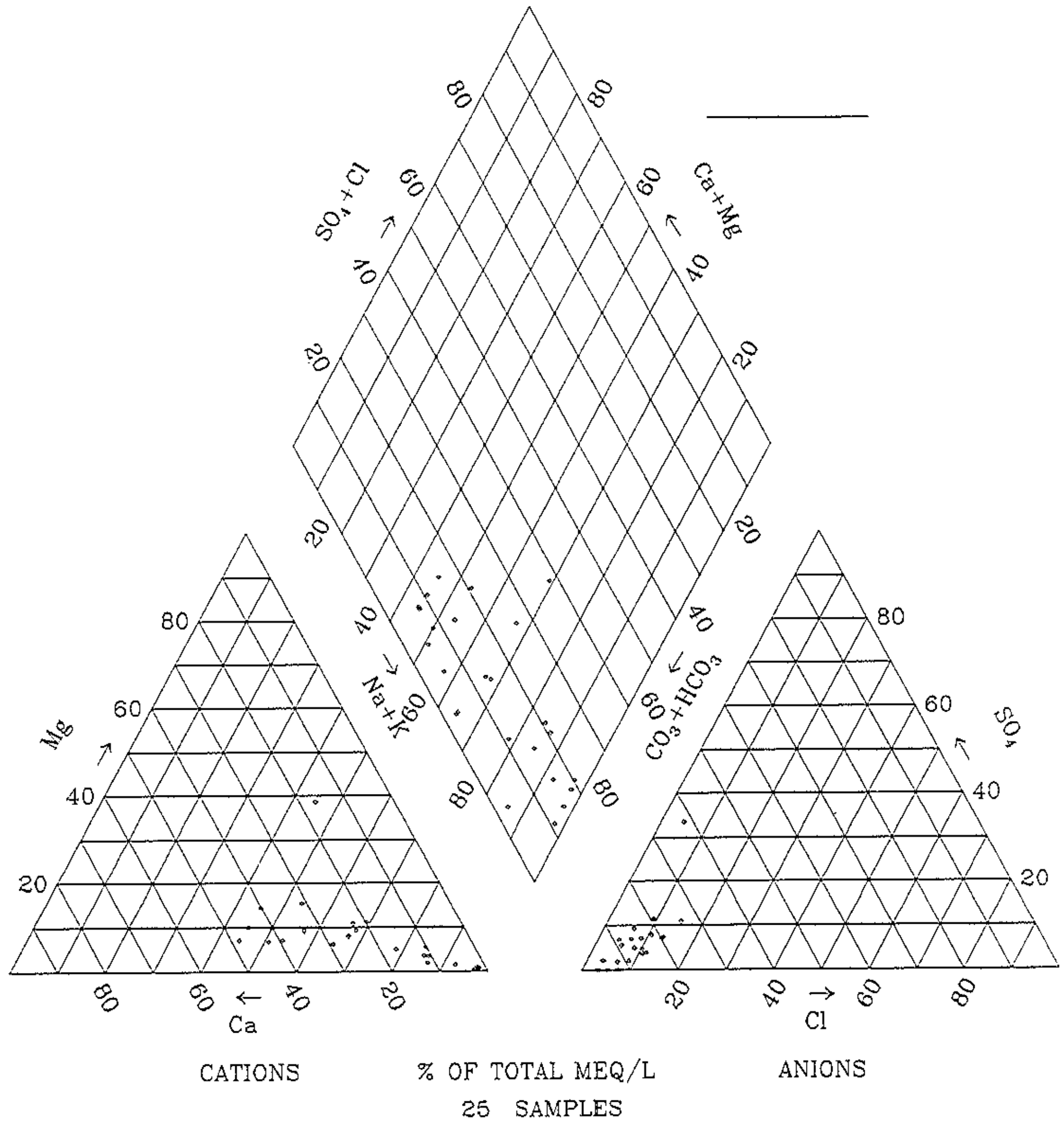
Therefore, piper diagram method was used to classify types of water samples. Accordingly two groups of water types have been identified:

a) Sodium, Potassium bicarbonate, and
b) No dominant cation or anion type (all 50 % meq/l).

Sodium, Potassium bicarbonate water type may include groundwaters which have been modified by further water interaction of volcanic and sedimentary rocks. Water points of shallow boreholes, hand dug wells and hot springs are of this category.

Type of water is without dominant ions represents surface waters and deep volcanic aquifers. The water in the deep volcanic aquifer that are located North of Koka and I.A.R (Institute of Agricultural Research) area are tends to be fresh water, because of high recharge from rainfall and surface water respectively through big fractures.

Trilinear diagram of Wonji and the surrounding area



Water sample
From Wonji Area

Fig. 7.5

Thermal waters are characterized by high total dissolved values, containing relatively higher Ca and Mg than deep volcanic aquifer of escarpment areas, but less than shallow sedimentary aquifers. Therefore, water from Sodere hot spring is high in Na, K, Cl, SO_4 and HCO_3.

The no dominant type of water includes also surface water that constituting products of rainwater interaction with local surface rocks.

7.5. Characteristic of water systems

I Hot springs:

Hot springs of Gargadi area are highly affected by groundwater recharge from Koka reservoir. Because of this and may be down slope continuos increase of mineral dissolution as well as thermal effects Sodere hot springs record the highest ion concentration in the region.

Like other water bodies bicarbonate is also dominant anion in these water points. If there was no discontinuity due to lower elevated sediment covered areas the location of springs seems as if they follow a particular trend that run parallel the Awash river in East - West direction. Thus it appears that they have the same thermal origin despite of the Gargadi springs are diluted by secondary processes.

Maximum of 2656 mg/l of TDS has been measured in Sodere hot springs and the highest value of bicarbonate (HCO_3) 1455 mg/l is also recorded at same location.

II Shallow boreholes

All the shallow wells are in the range of 4 m up to 12 m depth below the ground surface. Despite of their existence in the same geological environment, they do variable chemical composition. Some shows extraordinary chemical anomaly. For example boreholes 2 and 3 have 101 mg/l and 199 mg/l of chloride respectively, which is by far very different from others in the region.

Also borehole 3 has the highest value of calcium (125 mg/l), which is by no means correlable to other calcium concentration value in the study area.

This indicates that though the boreholes are in the same geological environments, there exists minor local variations underneath the ground; such as Calcium carbonate ($CaCO_3$) lenses, perched groundwater or local dissolution.

It has also suspected that shallow boreholes around Catholic church, have good interaction with Awash river, due to the lithological coarse grading as we go upstream of the river.

III. Hand dug wells.

Only three hand dug wells have been inventored so far, where all are located in the settlement areas. Their chemical analyses shows the anomalous concentration of nitrate, which suggests that there exists groundwater pollution from human activities (Septic tanks) around the residential areas.

Borehole 8 and 11 seems free from human influences, but have recorded anomalous nitrate concentration up to 30mg/l. This could be resulted from pollution leakage from distant settlements. The specified anomalous nitrate concentration has no health risk, since no indication of health problem record world wide up to 45 mg/l of NO_3. This does not mean that it will continue like wise, but there will be increase of NO_3 concentration through time, since the use of fertilizer is active in the region.

IV. River

Water samples collected from Awash river at different points. All result of chemical analyses indicate minimum concentration of cation and anion irrespect of the others in the region.

Though, there is no significant variation as such there exists difference in chemical concentration from point to point in the Awash river.

For example sample AR - 2 from Awash Melkasa reservoir records relatively higher TDS, value which indicates more concentration of anion and cation at this particular point due to evaporation; or it may show increase of chemical concentration as we progress down stream of the rive.

7.6 Manipulation of chemical data

Chemical data can be used for various purposes:

- to tell the degree of rock water interaction
- to indicate source rock or geological environment
- to classify water type
- to study mixing of water

In view of these, different variation diagrams have been prepared for some chemical data pairs of measured parameters were plotted on x - y axes. These drawings in turn used to discuss certain picture of surface and groundwater system of the region. Thus explanation and interpretation were given for selected chemical data drawings.

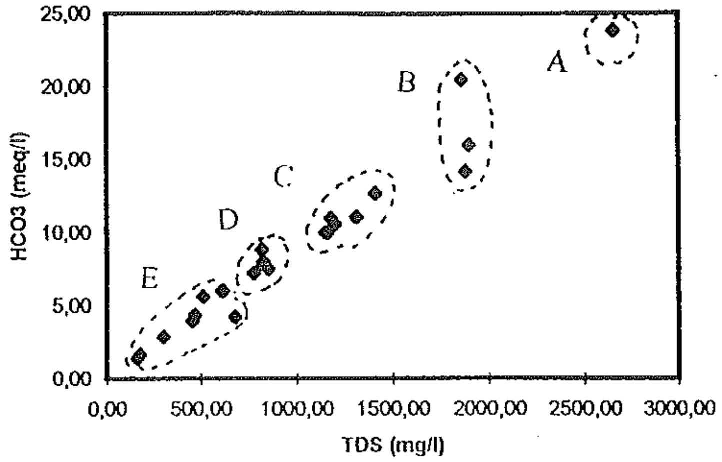


Fig.7.6 Compositional digram of HCO_3 Vs TDS

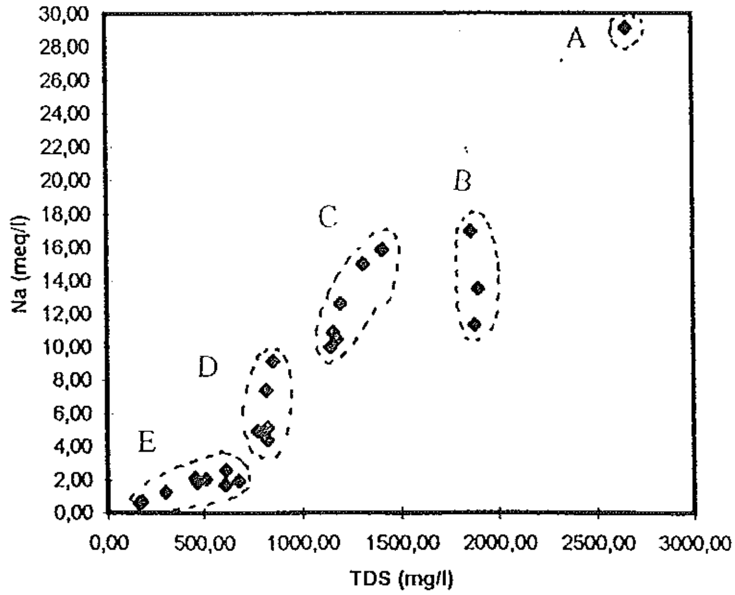


Fig. 7.7 Compositional diagram of Na Vs TDS

Figure 7.6 reflects a very good correlation between bicarbonate (HCO_3) and total dissolved solids (TDS) as a line extrapolated through scattered points to the zero. It suggests that waters from Awash river and deep volcanic aquifers are categorized as fresh water. The concentration of bicarbonate thus one of the controlling factor of water quality in the area. If the concentration of HCO_3 increases hence TDS is also increase respectively and the highest bicarbonate was recorded for Sodere hot spring where the value of TDS is also the highest. Figure of bicarbonate versus total dissolved solids (diagram 7.6) depicts about 5 different water groups of different origin or different systems, but with some interconnections.

This again proved by compositional diagram of sodium versus TDS (Fig 7.7) which clearly indicates that there exist 5 different water systems of groups which will include

Group A: Hot springs of Sodere area

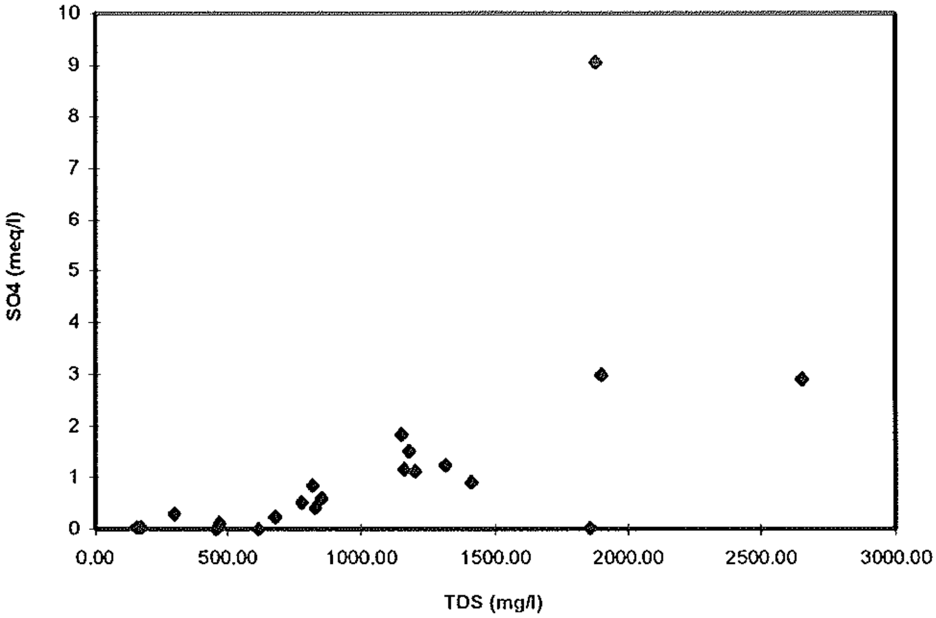
Group B: Localized shallow groundwater (perched) system

Group C: Shallow boreholes and hand dugwells

Group D: Deep boreholes in volcanic rocks

Group E: River samples

The fact that the above water points are not from the same origin farther proved by compositional drawing of SO_4 against TDS and which it also supported by drawing of Cl Vs TDS, are indicating random distribution points (Fig. 7.8). This suggests that water samples are from water sources of different origin with different composition. Diagram of calcium against TDS (Fig.7.8) also reveals the same concept.



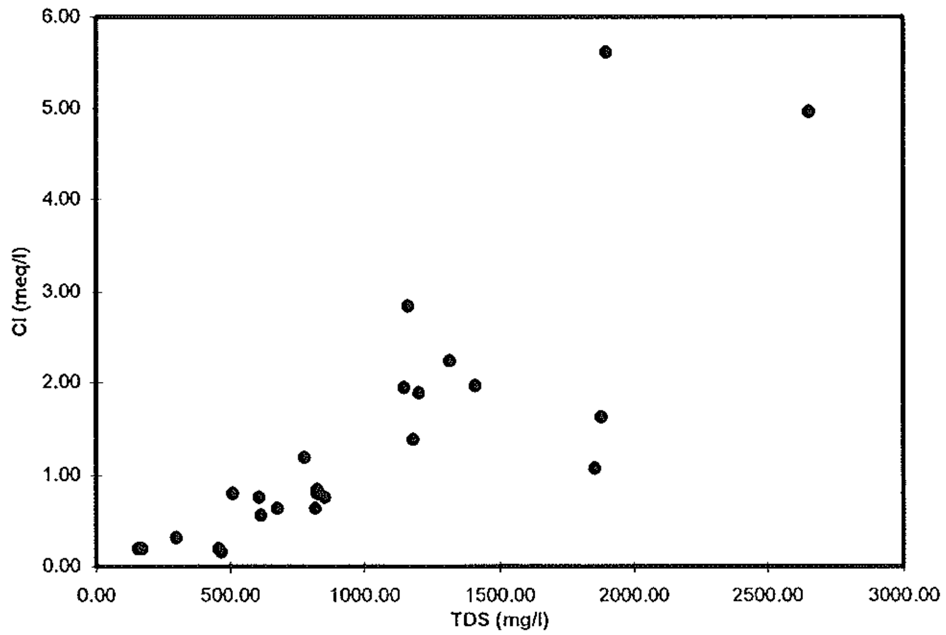


Fig. 7.8 Compositional diagram of different results

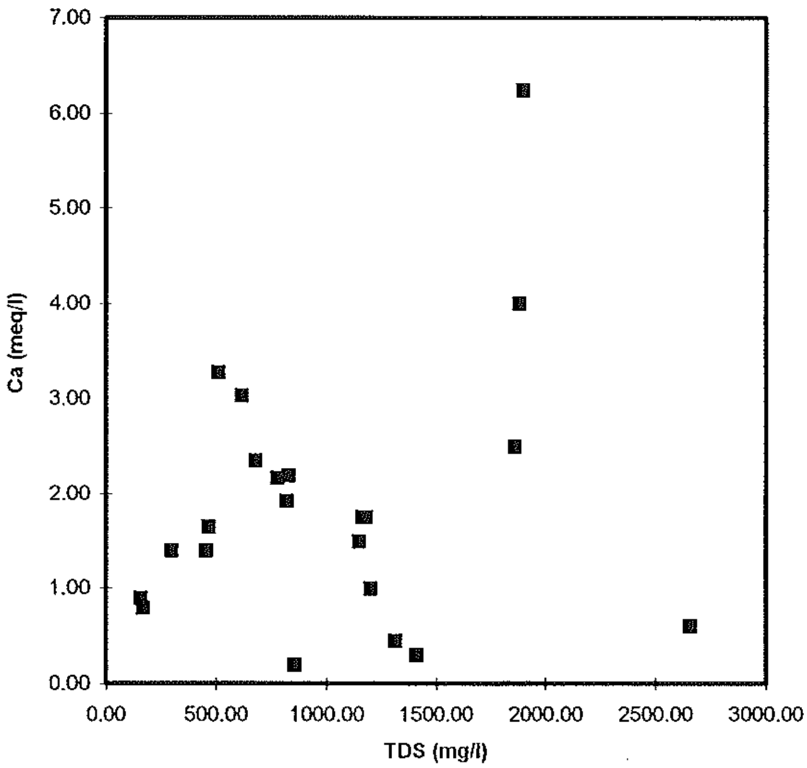


Fig. 7.8 Compositional diagram of Ca Vs TDS

These figures have been used to identify number of water groups. From compositional diagrams it can be observed that there exists close relation- ship between water samples from Awash river, deep boreholes and Gargadi springs. This suggests that there is tendency of mixing between these water groups which is manifested by the cluster of points that are grouped near each other on the plot of compositional diagrams. Otherwise deep boreholes and Gargadi spring indicate higher chemical concentration; due to longer residence time and thermal effect respectively.

Group of shallow boreholes (group C) show a tendency to have higher TDS value which is due to evaporation effect. As a result boreholes in Wonji irrigation area have relatively higher total dissolved solids than those outside the irrigation area. For example boreholes 6, 18, 19 have less chemical concentration than boreholes 2, 4, 5. It seems there exist ionic exchange between Na and Ca which gave rise higher value of sodium concentration in systems A, B and C.

7.7. Sodium Adsorption Ratio (SAR)

Water for irrigation purpose usually be influenced by climate, soil type, amount of water used and plant types. Permeability of soil has also an effect on an irrigation. If it has higher permeability, the irrigated water will remove salt concentration and will minimize the salinity hazard.

The study area, particularly Wonji sugar estate area, is covered with lacustrine and silty clay, that own less permeability and susceptible to salinizasion . The study is located in the rift zone where evapotranspiration is high where high temperature area will remove large amount of moisture and thereby total dissolved solids will be increased in the water and soil; which will cause salinity hazard, unless it is compensated with proper drainage and of irrigated water. Concentration of sodium has also effect on irrigation water quality, intern on plant growth, since it reduces permeability of soil. From view point of irrigation water quality this effect is considered as Sodium Adsorption Ration (SAR), which is expressed by the following formula:

$$SAR = \frac{Na}{(Ca + Mg/2)^{1/2}}$$

where the value of Na, Ca and Mg are denoted by meq/l

Based on the above equation SAR was calculated for all water samples of different water points. The calculated have been plotted on figure 7.10 along with the EC values. Figure 7.10, thus reflected that water points of boreholes are in the category of low SAR and medium to high salinity hazard. But dug wells and hot springs are in the class of unsatisfactory for irrigation purposes. Awash river has good water quality for irrigation.

The sodium danger is caused if sodium will be exchanged for calcium, because soil structure will be destroyed owing to dispersion of the clay particles. In the study area permeability of lacustrine sediments is minimum therefore salinity hazard is suspected, unless other wise proper amount of good quality water type is used for irrigation. This helps to reduce excess water from the soil and consequent evaporation.

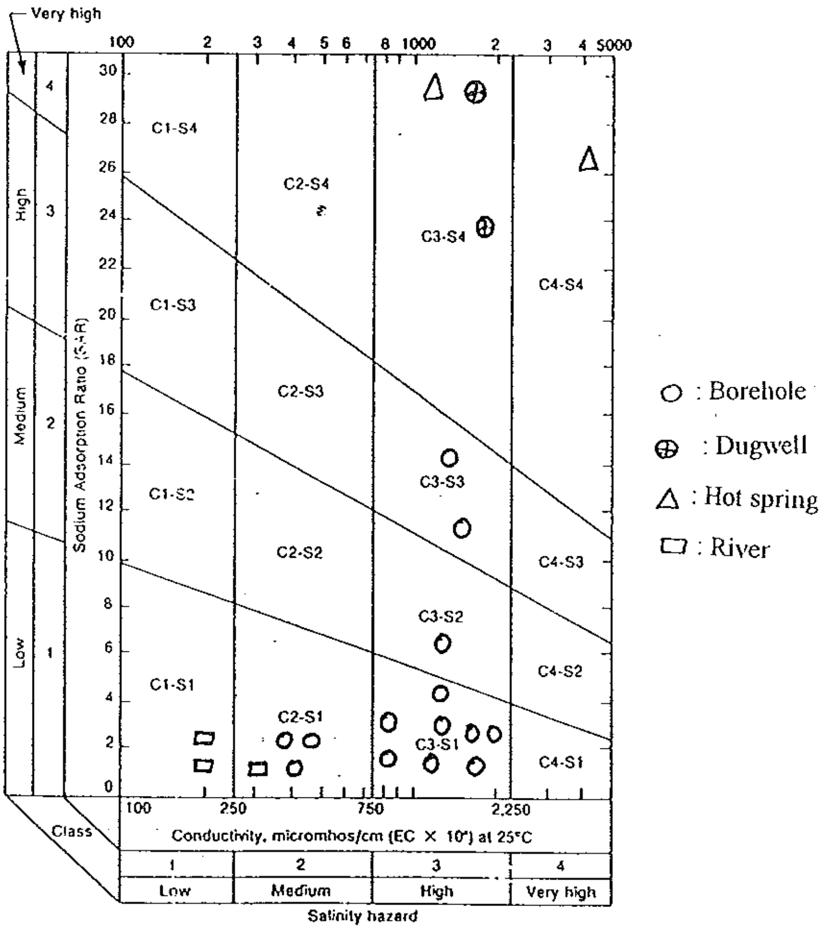


Fig. 7.9 Classification of irrigation water based on SAR and conductivity

Excess salt decreases soil permeability consequently sufficient water can not reach the root zone. But waters with enough calcium and magnesium help soils to mentain good permeability and is preferable for irrigation purposes. Or using calcium fertilizers or humus will correct this problem. According to Todd (1959) recommended water classification for sodium absorption ratio is:

SAR	Water Class
< 10	Excellent
10 - 18	Good
18 - 26	Fair
>26	Poor

Therefore most of water points from boreholes and all river samples are in the range of excellent for irrigation purposes.

CHAPTER EIGHT

IMPACT OF AGRICULTURAL ACTIVITIES ON GROUNDWATER

8.1 Introduction

Through time hunting man became agricultural man. The advancement of science and technology helped the modern society to increase agricultural production using fertilizers. In 1960-1970 which was so-called "green revolution" the consumption of inorganic fertilizers doubled (IAH V01.5, 1986). As doing so agricultural ecology suffered environmental problem.

Heavy loss of top fertile soil and groundwater pollution due to such activities started to be intensified. The original ecosystem and geosystem have been changed. Agricultural activities such as: ploughing, fertilizing, and irrigation affected soil, water and rock interaction. This put forward negative impact on natural phenomena. Groundwater pollution, desertification, salinization and water logging of soils started to be manifested.

The nitrate concentrations of groundwater of the study area not exceeded 50 mg/l of drinking limit. There should be caution that current fertilizer applications lead to a high risk of nitrate concentrations in groundwater exceeding the current WHO recommendations of 50 mg/l.

Long term soil irrigation can result salinization in soil and groundwater. Traditional farming produces large quantities of natural manure in some places, which leakage from waste disposal of manure stockpiles can be source of pollution of the groundwater.

8.2 Irrigation activities in the area

Irrigation has been started in the region soon after the establishment of the Wonji sugar factory in the early 1960's. Sugar plantation is the main focus by the estate farm in the region. In Wonji plain 2 - sugar, 1 - sweat and 1 - paper factories are existing.

The basic raw material for all factories is sugar cane. Sugar estate farm thus irrigates 7000 ha to produce required amount of raw material. Irrigation practice is carried by rotation principle. That is when some fields are ready for harvest the others are irrigated for the next season. Therefore even though the total estate farm area is 7000 ha, all are not irrigated at the same time, with full scale. Accordingly half of the land are on due to supply sugar can for the factories while the rest 3500 ha will be the only farm land for irrigation yearly.

Eight water lifting pumps serve for irrigation purpose in the region. Interconnected open canals are taking water from this source to intended lands. Artificial ponds are also existing at some places, to store water temporarily for irrigation. The volume of water stored in ponds is not known. There also hardly able to find the exact figure of water used for irrigation daily.

But pumps for drinking purpose in the factory area lift 5 l/s. Based on this figure thus the irrigation pumps may lift 20 times greater than this. Hence each will pump 100 l/s which makes a total of 800 l/s water lifted from the Awash river; which is $25x10^6m^3$ per annum.

About 200-600 kg/ha Urea is used in the estate farm, that will amount a total of over two million kilogram per year. Application of inorganic fertilizer is carried systematically. For the Raton crop (left behind roots) fertilization is carried immediately after harvesting, but for plant cane 2.5 - 3 months after.

Application of fertilizer in certain fields depend on age of sugar cane and the soil type. The maximum age of Raton is 6 years (5 cycles).Consumption of inorganic fertilizer (Urea) for the first cycle is 200 kg/ha in all fields, but this will range to 600-780 kg/ha for the last 4th or 5th cycle (year). (Table 8.1)

Table 8.1. Fertilizer application in Raton, rates of urea (kg/ha)

Soil type	Cutting				
	I	II	III	IV	V
A_1	200	600	700	-	
A_2	200	600	650	700	
Ba_2	200	400	450	600	
B_{14}	200	450	500	600	
C_1	200	450	600	500	600

A = Black soil
B = Brown soil
C = Sandy soil

I - V cutting cycle
I : 2 years after
II - V: 1 year after

Herbicides and insecticides are also used in sugar estate farm. Different types of herbicides are used for different purposes. Gasapax combi (500 FW mg/l) and 2, 4-D- amine (720 gm/l) for grass 6 l/ha and broad 4 l/ha for broad leafed weed killers respectively. The use of insecticides is seldom in the farm. BHC (Benzene hexa chloride) rarely used in the region based on the following table 8.2

Table 8.2 BHC (Benzene hexa chloride) application.

Soil type	1st app^{n} kg/ha
Black soil	6
Brown soil	3
Sandy soil	3

The application of BHC varies from soil to soil. Black cotton soil (heavy soil) consumes greater amount of insecticide respect to other types of soils.

Physical and chemical properties of soil has to be checked from time to time to regulate fertilizer and pesticide consumption. Hence detailed soil sample analyses was carried in the year 1986. (Table 8.3).

Table 8.3a physical - chemical characteristics of Wonji/ shoa sugar estate soil [Data analyzed 1986]

Field No	Soil type	soil depth (cm)	Texture (%)				pH 1:1		EC (mhos/cm)	N (%)	C : N
			Sand	Silt	Clay	Textural class	H_2O	HCl			
		0-30	17.0	4.8	78.2	clay	7.2	6.1	1.39	0.10	
130	A1	30-60	17.9	6.8	75.3	"	7.3	6.1	1.79	0.10	
		0-30	28.8	20.7	50.5	"	7.2	6.3	3.58	0.11	
178/79	C1	30-60	26.8	23.7	49.5	"	7.3	6.3	1.84	0.11	
		0-30	26.7	25.7	47.6	"	7.3	6.3	2.19	0.10	
194	C1	30-60	24.3	24.8	50.9	"	7.4	6.4	2.06	0.19	
		0-30	17.1	13.9	69.0	"	7.2	6.3	3.24	0.14	
197	C1	30-60	21.1	5.9	73.0	"	7.4	6.3	3.40	0.13	
		0-30	21.1	15.7	63.2	"	7.4	6.3	2.12	0.17	
239	A1	30-60	22.8	15.9	61.3	"	7.2	6.1	2.19	0.14	

							$CaCo_3$ (%)	CEC		O.M (%)	C:N
168	C1	0-30	27	25	48	7.3	1.40	49	0.14	2.48	10:1
91	A1	0-30	16	13	71	7.1	0.70	68	0.14	2.60	11:1
267	C1	0-30	49	19	32	7.9	2.10	38	0.13	2.44	11:1

Table 8.3b Soil Property categories

	Low	Medium	high
O.C (%)	< 0.8	0.8-1.5	>1.5
CEC (ml/100 soil)	<16	16-36	>36
N (%)	<0.083	0.083-0.16	>0.16

Source: FAO 1982 No. 8 soil bulletin

* OC : organic carbon, CEC : cation exchange capacity, N : nitrogen

Table 8.3 indicates that the cation exchange capacity of all soils is in the high category while percent of nitrogen content of most soils is medium. This indicates that the natural nitrogen content of the soil is at lower level that addition of inorganic nitrogen fertilizer (urea) is needed to be used by plants

8.3. Possible sources of pollution by agricultural activities in the region

It is known that in the region where agricultural activities are intensive, groundwater is liable to pollution. The main agricultural sources of groundwater pollution are: fertilizers, and pesticides besides septic tanks from domestic sources.

8.3.1. Septic tanks

Wonji plain is active agro-industry area. Large number of population related to this agricultural activities are living in the Wonji estate farm and the surroundings. Kuriftu, Gafarsa, Alemtena and Awash Melkasa are areas of high density population. In these localities there exist many septic tanks. Water sample analyses from these particular areas has been showed high nitrate concentration.

For instance borehole 7 near - main head office, boreholes 8, 11, around Awash Melkasa, dug well 1 in Alemtena as well as dug well 2 in Kuriftu has 8, 30, 30, 25 and 23 mg/l of nitrate concentration respectively. This clearly explains that those areas with high population has relatively nitrate polluted groundwater. The source of this pollution could be human waste from septic tanks. Farm houses, residences and villages usually discharge domestic wastes through septic tanks and cesspits. The pollution of the farm wells and boreholes may occur, but is less likely to have health implication.

The overland flow due to rainfall from farm buildings and yards contains suspended solids and organic substances. It generally contains much faecial colliform bacteria. There is an evidence of pollution of farm wells and residence areas by such wastes observed in dug wells 1 and 2 as well as borehole 8. Human waste pollution varied from place to place, but almost all densely populated residence areas wells show some pollution.

8.3.2. Inorganic fertilizer

As it has been mentioned earlier 10,000-20,000 quintal of Urea is used in the estate farm per year. Movement of agrochemical in the unsaturated zone is usually considered to be one dimensional processes namely in the vertical direction. Water samples from all groundwater points were collected and checked for NO_3 concentration. No particular value was observed in groundwater under the sugar estate farm where huge amount of urea is used.

Adsorption as well as residence time and mobility of fertilizers in soil determines the degree to which the quality of groundwater is affected. Local farm plots use small quantity of fertilizer, farmers use urea only for teff crop. Though larger area is under the hold of farmers they use small quantity of fertilizer compared to sugar estate farm. But no variation of NO_3 concentration was observed in the groundwater respect to applied fertilizer quantity. The pollution of inorganic fertilizer in groundwater may be mainly controlled by resisting time, plant uptake etc.

I. Residence time in the vadose zone.

The residence time of deep percolation water in the vadose zone should be known because it determines the arrival of pollutants (Bower et al, 1983). According to Bower (1983) an estimate of the average residence time can be obtained by the relationships between hydraulic conductivity and water content for different soils.

Accordingly the average hydraulic conductivity of the soil of the region was estimated to be 1.57 m/year and the moisture content found from the laboratory result gave 60%. The average groundwater level below the earth surface was 8 m. The estimate average residence time then can be obtained by the relationship.

$$Wt/Dd$$

Where Wt = total water stored in vadose zone (expressed as depth)

Dd = average yearly deep percolation.

Then the total water stored in vadose column will be 4.8 m. This will give an average residence time of 3 years for shallow aquifers under the sugar cane farm. In the region, application of inorganic fertilizers have been started 40 years ago. Therefore, the applied fertilizers expected to contribute some thing to the groundwater. Thus underneath water to show up relatively higher value of NO_3 than the surroundings. But this did not happened in the study area may be due to the following reasons.

- The plant uptake of inorganic fertilizer is high, sugar cane highly uses nutrients, because of continuos crop cover with strong root development.
- External groundwater recharge from outside the fertilizer areas is extremely high that, dilute the concentration of subsurface water.
- Subsurface water flow is high, thus also NO_3 is mobile anion to be removed away from under sugar cane farm.

- The other possible explanation for these low nitrate concentration (1.1-2.7 mg/l) is that dentrification is active in the anaerobic conditions of irrigated, saturated soil. In this condition, the main losses of nitrogen seems to be volatilization, dentrification, within the soil and crop uptake. Thus leaching of the nitrate to groundwater is relatively small compared to the applied fertilizer.

Hence result of nitrate concentration did not show unique value under the estate farm. It appears from these that high nitrate concentration level does not related to the irrigated region, but that the occurrence of high nitrate in groundwater is common in densely populated residence areas.

8.3.3. Pesticides

Pesticide is a collective name of herbicides and insecticides. The rate of application of pesticides is very low in the region. Inevitably, some of the sprayed pesticides may fall into irrigation canals and ponds, so that some minimum pollution is expected.

Unfortunately since water analyses laboratories in Ethiopia do not test these substances the effect is not known. Hence identification of pesticides in the water of present area was not attempted. But from view point of chemical behavior of these substances (less persistent), it is assumed that their danger both in groundwater and surface water is nil in the region. In general the groundwater of the area is little polluted by agriculture or other human activities.

8.3.4. Waste disposal from ago-industries

Sugar processing plants are the main factories but sweat and paper producing industries are also additional in the region. Particularly sugar factories use some amount of sulfur and other additives. It is usual to hold waste from industries in ponds where evaporation can be of help and dilution of precipitation to remove the wastes. The waste products of four factories together is not of little quantity. It may reach 100's of tones per year.

Even though the impact of these waste products was not yet reported, it is believed that there will be some pollution to the groundwater. But what has to be mentioned here is that danger of waste products of these factories is not considered. Because molasses, the left back part of sugar cane by factories has no identified health risk. Thus the local people use for cattle feeding and expensive in the region.

8.4. Some observed impacts of agricultural activities in the area

8.4.1. Impact on groundwater quantity

In the Wonji basin over 557.75 x $10^6 m^3$ groundwater reserve was estimated. Extraction, part of these reserve is made up of $4.7x10^6 m^3$ for domestic purposes. This amount of water is used by people directly or indirectly related to agriculture in the region. In the Wonji plantation 50,000 population are dwelling which consume 912500 m^3 volume of water. Rural people and rest surrounding small towns all together use $3.8x10^6$ m^3 groundwater for domestic purposes. This gave an overall $4.7x10^6 m^3$ groundwater abstraction in this active agricultural area.

Amount of these groundwater extraction which is used in agriculture region only be estimated in a general manner. Agricultural purposes include: domestic supplier for rural people and farm yards, small villages horticulture and the related uses. There is virtually no irrigation using groundwater in the region.

8.4.2. Eutrophication:

Eutrophication is the term used to describe the biological effects of an increase in concentration of plant nutrients usually nitrogen and phosphorus (Harper, 1992). Increased levels of these nutrients are released into streams by man from agricultural fertilizers and domestic sewage, and by removing the natural limits to aquatic plant production this may result in excessive growth of algae, called algae blooms. These may cause problems for water supply abstractions as they affect the taste and smell and cause filtration problems. They may, in some cases, cause sever oxygen depletion when the algae die, and can lead to the death of fish and other aquatic life (Ward, 1990).

Even though no identified problem of eutropication exists, algae blooms were observed at Awash Melkasa reservoir, near Awash river edges and at some abandoned ponds. "Such development of algae growth is due to nitrogen nutrient supplied from sugar estate farm and the surrounding. There is clear algae bloom variation from localities susceptible to nutrients and the others free from inorganic fertilizer.

It was observed that upstream far from the estate farm the density of algae blooms were getting smaller. From this, one can deduce that there is a little impact of eutrophication in the area from agricultural activities.

8.4.3 Variation of total dissolved solids

Many times, the impact of agriculture on groundwater is considered only with reference to pollution from wastes of different types. In this presentation the degradation of water quality due to salt concentration that resulted from agricultural evaporation and irrigation is considered.

The evapotransipiration from sugar plantation, together with irrigation, as well as additives of inorganic fertilizer has increased the TDS in the estate farm.

TDS concentration varies considerably from irrigation areas to farm lands and the vicinity. Water sample analysis indicate that anomaly of 500 to 1100 from non irrigated land to irrigated land. The irrigated soil cover of the plain coupled with high evapotranspiration make the underlying groundwater vulnerable to high TDS originating at the land surface. In addition TDS content in groundwater will of course be affected by dissolution of minerals of rocks as well as aquifer types which was manifested by variations of HCO_3 and

Cl concentration in boreholes 1, 2 and 3. Concentration of total dissolved solids varies distinctly between sugar estate farm and the surroundings (Fig 8.1).

This specifically can be explained by the difference of evapotranspiration between the two farm regions. Dug wells out side of the plantation where high NO_3 was observed also show high Cl concentration.

The overall level of concentration is greater in the sugar estate farm definity due to high evaporation concentration. Salt concentration in the high evaporation regime increases as a result of water loss. Because evaporation is a reverse of dilution of solutions. Thus as evaporation removes water molecules it concentrates the solutes. It is clear that from figures 7.6, 7.8 and 7.8 high TDS values are mainly related to increases in the content of ions, which again for the part due to evaporation. Therefore a good correlation was observed between the land use and TDS concentration in the underlying groundwater.

In the plantation water logging problem due to irrigation was observed, but since it is temporary condition and of small area particular consideration was not given.

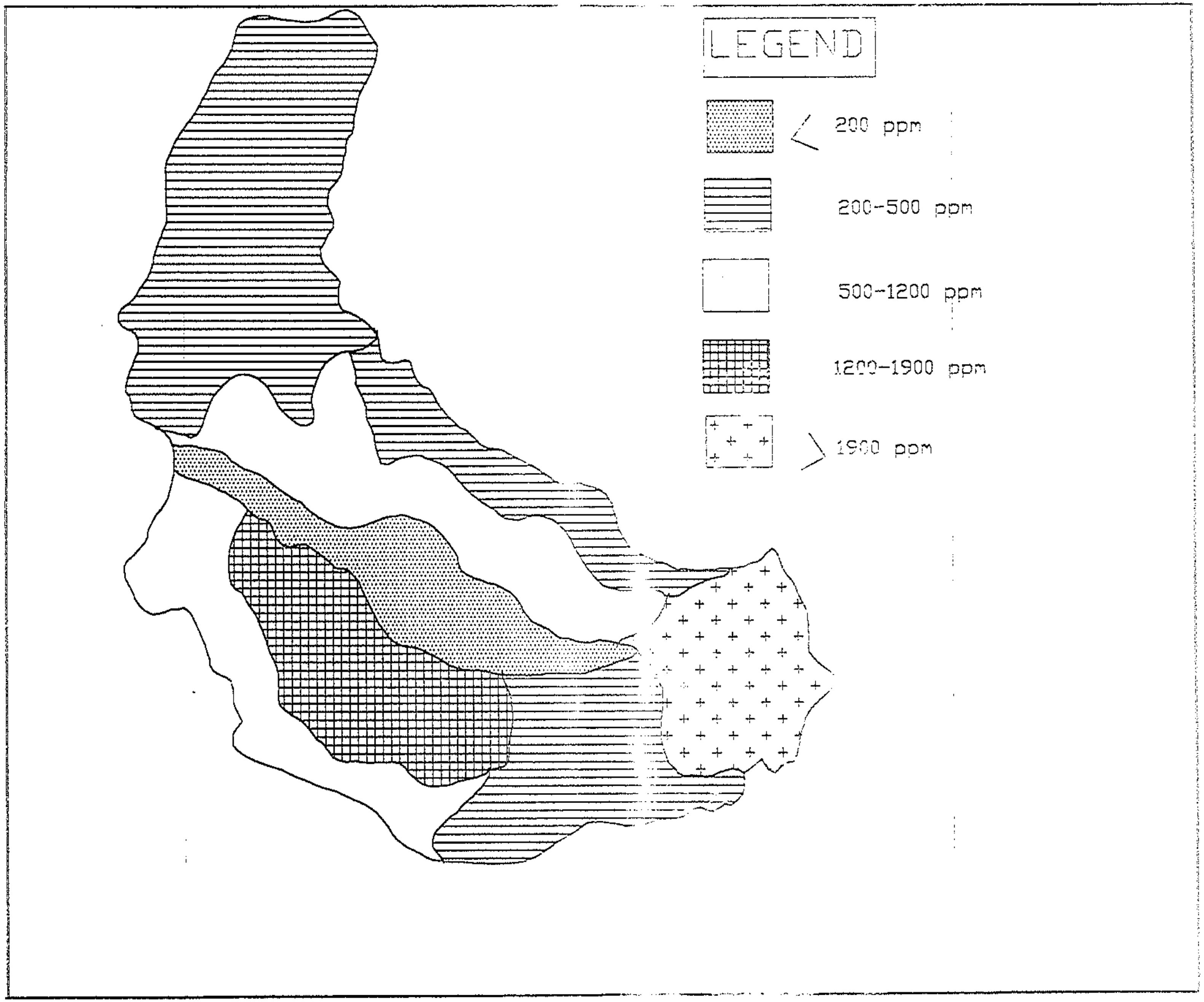


Fig. 8.1 Variability concentration of TDS

CHAPTER NINE

SUMMARY AND CONCLUSION

Irrigation activity and fast developing of urban as well as industry, initiated a particular concern to study hydrogeological condition of the basin. The main target of the study is to evaluate and understand comprehensive hydrological and hydrochemical situation of the basin and the effect of irrigation on groundwater quality of the area.

Detailed study of geological structures and lithounits gave a clue in defining the basic hydrogeological factors controlling the occurrence, movement and storage of groundwater in the basin. Estimation of actual evapotranspiration coupled with water balance calculation have important contribution in estimating the groundwater recharge of the region.

Rainfall shows variations from station to station corresponding to differences in elevation. The runoff characteristic also varies with seasons that the Awash river basin generate huge runoff during the rainy season, but small surface flow of Gargadi springs in the Wonji basin in the dry season. The upper Wonji basin has a higher runoff coefficient than the lower basin due to steep topography and springs contribution to the runoff.

Surface and groundwater divide do not coincide. The high elevated escarpments, ridges, domes as well as calderas are forming the surface water shades, but huge amount of groundwater inflow from Koka reservoir recharges the groundwater through big fractures running in east-west direction, crossing the west boundary fault escarpment. These structures are possible groundwater ways for the recharge of the west part of the basin. The presence of groundwater inflow and good rainfall recharge from west and northwest escarpment made Melka Hida as well as Gargadi area good groundwater potential areas.

The hydrogeological characteristics of the geological units indicated that, alluvial and lacustrine sediments of low elevated Wonji basin are important water bearing units, while deep seated ignimbrites and scoraceouse basalts of West escarpment and Awash Melkasa area respectively are considered as medium permeability aquifers and are also of good groundwater resource units. The principal rainfall recharge occurs within the highland ignimbrite of west highlands, and Gadamsa rim loose pyroclasts. These units could be potential aquifers at the foot of the slopes where the weathered upper horizon serves as aquifer near the contact of alluvial and lacustrine sediments.

In the region geological structures have important role as a groundwater conduit and as a local groundwater barrier particularly in the northwest of the study area and also some groundwater movement was expected across fault lines through some big secondary fractures. Sink of surface flow of seasonal streams into the loose sediments along fracture zones during the rainy seasons, reveals that subsurface and surface recharges pass to deep groundwater flow and the general flow is towards the center of the basin locally and to the east totally.

As it has been noted, the basin loses the recharge both to deeper and shallow horizon. Thus the groundwater can be exploited from both deep and shallow aquifers at the depth of 100-150 and 4-12 respectively. Water balance calculation gave that $557.75 \times 10^6 m^3$ from both surface and subsurface recharge annually. Some of the parameters such as actual evapotranspiration was found based on an average results of different methods, and one has to note that different value of groundwater recharge could be expected if different methods were used separately.

Water sample chemical analyses indicated that there exist 5 groundwater systems with some interconnection within the basin. Except water from hot springs and dugwells, all are suitable for irrigation purposes. All water points are in the allowable range for drinking, but few boreholes with TDS > 1500 mg/l and Sodere hot springs are above allowable limit.

Groundwater quality problem is related to fluoride concentration, as all the water chemical analyses gave high fluoride content above the WHO limit for drinking purpose. Subsurface water demand for domestic use indicates that, it is much less than yearly groundwater recharge. Hence further exploitation can be conducted in the basin, with certain caution that much over pumping can cause ground subsidence.

Even though application of inorganic fertilizer is so high in Wonji sugar estate, no particular concentration was observed in the subsurface water. This might be mainly due to water dilution from groundwater inflow of Koka reservoir and also dilution from surface irrigation.

This and some unanswered facts need further detailed studies supported by isotopic techniques and geophysical surveys. The present work gave study out come, which established groundwater systems of the basin, formulated water balance of the area, determined aquifer horizons and regional groundwater flow direction as well as subsurface water demand and storage, which may serve for future development planning and program.

Though the effect of irrigated agriculture is not as such significant, it is believed that high evapotranspiration and evaporation from the Wonji estate farm increased concentration of certain ions and TDS than the surrounding areas. Hand dug wells in the densely populated areas are susceptible to NO_3 pollution from anthropogenic waste (Septic tanks).

REFERENCES

Alula Damte, 1990. Neotectonics of Nazareth-Dera area. M.Sc. Thesis, A. A. U.

Alula Damte, Boccaletti M., Getaneh Assefa, Mazzuoli R., Tortorici L., 1992. Geological map of the Nazareth - Dera region. S.E.L.C.A. Italy.

American public health association, 1975. Standard methods for the examination water and waste water, 14th edition APHA - AWWA - WPCF

Appelo, C.A.J., 1994. Geochemistry, groundwater and pollution. A.A. Balkema, Roterdam Netherlands

Ashley, R.P. and Burley, MIJ., 1994. Controls on the occurrence of fluoride in groundwater in the rift valley of Ethiopia. In Nash, H. and Mc Call, G.J.H (eds). Groundwater quality. Chapman and Hall, London.

Barrows H.K., 1980. Water power eneering, Mc Graw - hill publishing company Ltd.

Beke G.J., et. al., 1993. Long-term quality of shallow groundwater and irrigated sites; Jor. ASCF, Vol. 119 no. 1. Jan/Feb 1993, P. 129 - 141.

Bell F.G. , 1993 Engineering geology, Blackwell scientific publications.

Bower H., Et. al., 1983. Effect of irrigated agriculture on underlying groundwater, IAHS publ. no. 146, P. 13 - 20.

Brown GI., 1985. Inorganic chemistry, Longman.

Chow Yen Te, 1969. Applied hydrology, Mc Graw-Hill book company.

Chow Yen Te, 1988. Applied hydrology, MC Graw-Hill book company.

Chilton P.J., Lawrence A.R., and Stuart M.E., 1994. The impact of agriculture on groundwater quality, Groundwater quality edited by H. Nash et. al.

Cooke R.U., 1990 Geomorphology in environmental management, Clarendon press-oxford.

Daniel Gamachu, 1977. Aspects of climate and water budget in Ethiopia, A.A.U. press.

Dan H. Yallon, 1964. The concentration of ammonia and nitrate in rain water over

Israel in relation to environmental factors, Jellus XVI (1964), 2, P. 200 - 204.

Darling W.G., Berhanu Gizaw, Arusei M.K., 1996. Lake groundwater relationships and fluid-rock interaction in the east African rift valley: isotopic evidence, Journal of African earth sciences Vol. 22 No. 4, P. 423 - 431.

Dereje Ayalew, 1994. Volcanology, petrology & Geochemistry of the Gedemsa volcano Msc. Thesis A.A.U.

Davis S.N. and De Wiest R.J.M., 1966. Hydrogeology, John Wiley and sons, Inc. London.

Di Paola G.M., 1972. The Ethiopian rift system (between 7°,00' and 8° 40' Lat north) Bull. Volcano; n.36, P. 317 - 560.

Driscol F.G., 1995. Groundwater and wells, Johnson Screens

Dunne T. and Leopord L.B. 1978. Water in environmental planning, W.H. Freeman and company

Edmunds M.W. and Key M.R., 1996. Hydrogeochemistry as an aid to geological interpretation the Glen Roy area, Scotland, Journal of the geological society, London, V.153.

Elc electroconsult milano Italia, 1987. Geothermal reconnaissance study of selected sites of the Ethiopia rift system, EIGS technical report.

Emanuel Mazor, 1997. Chemical and isotopic hydrology, St Edmundsbury press.

Fetter C.W., 1988. Applied hydrogeology, Merrill publishing company.

Fetter C.W., 1990. Contaminant hydrology, Merill publishing conpany.

Freez R.A. and Cherry, 1979. Groundwater, prentice - Hall, Inc. J.

Gabre - Emanuel Teka, 1977. Water supply - Ethiopia: An introduction to environmental heath practice, Addis Ababa University press.

Getahun Kebede, 1987. Hydrogeology of the Nazareth area, NC 37 - 15, EIGS

Gezahegn Yirgu ,1984. Geothermal study in northern lake Abbe area, M.Sc.Thesis A.A.U.

Gibson J. L, 1968. The structure and volcanic geology of an axial portion of the Main Ethiopian Rift, J. Tectonophysics 8,(1969) P. 561-565,Elsevier publishing company,Netherlands.

Gordon D. N., 1995. Stream hydrology, John Wiley and son Inc.

HALCROW, 1977. Survey at the Awash river basin Volume 8, Annex J, EWKA, Technical report

Hann C.T., 1982. Hydrogeologic modeling of small streams, ASAE. No. 5.

Hem J. D. 1992. Study and interpretation of chemical characteristics of natural water, United states government printing office, Washington D.C.

Harper D., 1992. Eutrophication of fresh waters, Chapman & Hall.

IAEA, Vienna, 1967. Isotope in hydrology

IAEA, Viena, 1974. Isotope hydrology

IAEA, Viena, 1993. Isotope techniques in environmental study.

Johnston R.W., 1993 changes in subsurface drainage water salinity and boron concentration J. ASCF, Vol. 119, No. 1. Jan/Feb 1993, P. 201 - 206.

Kazmin V.and Seifemichael Berehe, 1978. Geology and development of the Nazret area Northern Ethiopian Rift. Note No. 100, EIGS.

Kofoed A.D. 1984 Pathways of nitrate and phosphate to groundwater and surface waters,Environments and chemicals in agriculture, Elsevier applied science publishers (proceedings of a symposium Dublin 15-17 October 1984) editor Wintering F.P.W (1985). Brussels.

Kruseman G.P. 1994. Analyses and evaluation of pumping test data, publication 47, International institute for land reclamation and improvement, The Netherlands.

Ladha J.K., 1992. Biological nitrogen fixation for sustainable agriculture, Kluwer academic publishers.

Langmuri D., 1997. Aqueous environmental geochemistry.

Madhu Chery and Geofery D. smith, 1995. Nitrate pollution in groundwater in selected districts of Nepal, Hydrogeology Journal, V.3, no. 1, P. 71 - 76.

Michael price, 1996. Introducing groundwater.

Raghunath, 1987. Groundwater, Wiley Eastern Limited.

Schepers S.J., Frank D.K., Watts G.D, 1983. Influence of irrigation and nitrogen fertilizers on groundwater quality, preceding of the Hamburg symposyum, IAHS. Publ. no. 146, P. 21 - 31.

Selby J.M., 1985. Earth's Changing surface, Clarendon press. oxford.

Shaw E.M. 1988. Hydrology in practice, Chapman and Hall.

Skutan B., Kidane A., and Birhanu B., 1987. Geophysical survey for hydrogeological study in the Nazareth area (sheet NC 37-15), unpublished report, EIGS, Addis Ababa.

Tamiru Alemayehu, 1992. Hydrogeology of Debre Zeit area, M.Sc. Thesis, Addis Ababa University, SINET: Ethiopian. J. Sci.: 20 (2) : 283 - 291.

Tamiru Alemayehu and Vernier 1997. Conceptual model for Boku hydrothermal area (Nazareth), MER valley

Tenalem Ayenew, 1998. The hydrogeological system of the lake district basin, central main Ethiopian rift, PhD thesis, ITC publication number 64.

Tesfaye Chernet, 1982. Hydrogeology of the lakes region/Ethiopia.

Teshome Dechasa, 1995. A study of terrain classification and geodynamic processes in San Lorenzo river basin (Basilicata, Southern Italy) ITC, Enschede.

Teshome Dechasa and Dawit Nire, 1996. preliminary engineering geological report on micro dams. Raya valley development project, Tigray The Netherlands

Todd D.K., 1967. Groundwater hydrology, John Wiley and Sons, Inc.

United nations development programme, 1973. Investigation of geothermal resources for power development Ethiopia EIGS, technical report.

United nations publication, 1975. Groundwater storage and artificial recharge, sales No. E. 74. II. A. 11, St/ESA/13

Ward R.C. and Robinson M. 1990. Principles of hydrology, Mc GRAW Hill book company London

Warren Viersman, JR., Gary G. Lewis, John W.Knapp, 1989. Introduction to hydrology, Harper and Row Inc.

Woldu Ameneshoa, 1994. Hydrogeology of Nazareth. M. Sc. thesis, A. A. U.

Zekai Sen, 1995. Applied hydrogeology for scientists and engineers, CRC press Inc.

ANNEX 1. Existing hydrometeological data and period.

Station	Altitude	Rainfall	Temp.	Pan evap.	Humidity	Sunshine	Wind speed	Discharge
Wonji	1540	1951-1990	1951-1990	1963-1972	1981-1990	1981-1990		1969-1997
Awash melkasa	1540	1977-1996	1977-1996					
Koka	1595	1943-1992	1971-1997					1970-1977
Nazareth	1622	1953-1992	1953-1992		1990-1998	1990-1996	1990-1996	
Dera	1770	1976-1989	1976-1987					

ANNEX 2. Rainfall Coefficient

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Anuual (MM)
Wonji	0.18	0.42	0.70	0.80	0.83	1.03	2.94	2.99	1.48	0.41	0.16	0.06	785.00
Awash melkasa	0.30	0.64	0.80	0.96	0.92	1.08	2.50	2.66	1.42	0.53	0.13	0.10	705.12
Koka	0.22	0.37	0.77	0.79	0.71	0.99	3.18	2.93	1.30	0.34	0.22	0.17	706.25
Nazareth	0.20	0.50	0.70	0.70	0.90	1.00	3.00	3.10	1.50	0.40	0.10	0.10	822.53
Dera	0.24	0.50	0.85	0.91	1.16	0.99	2.00	2.30	1.98	0.78	0.33	0.84	840.31

ANNEX 3. Rainfall record of Wonji Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1951	0	0	145	66	36	59	148	172	86	62	0	0
1952	2	0	63	140	31	62	275	291	59	5	0	0
1953	0	8	33	97	37	73	98	154	39	0	0	0
1954	0	2	32	64	30	130	294	245	54.5	23	2	5
1955	11	0	8	44	31	32	189	148	145	0	x	0
1956	0	11	4	0	5	70	186	230	98	131	2	x
1957	90	46	66	87.5	27	59	137	95	32	23	0	4
1958	48	75	46	25	26	97	355	267	207	30	5	2
1959	12	53	33	41	64	56	170	140	90	7	1	0
1960	2	1	102	20	57	46	106	189	173	0	4	0
1961	0	3	62	51	10	104	116	371	180	22	42	0
1962	0	0	77	23	13	31	191	92	833	52	30	0
1963	1	0	16	139	128	54	277	347	87	0	9	6
1964	11	0	27	103	104	103	166	178	141	22	2	40
1965	28	0	17.6	52	1	30	120	182	61	22	14	12.8
1966	0	95	111	63	31	85	329	302	120	21	0	0
1967	0	0	57	18	61	78	162	116	84	54	120	x
1968	4	51	31	69	4	x	158	156	64	x	22	0
1969	33	90	58	77	47	45	337	159	36	0	4	1
1970	57	49	95	55	34	13	192	226	100	x	0	0
1971	0	0	23	64	63	88	145	284	133	1	18	35
1972	0	50	55	53	24	130	245	199	274	10	x	0
1973	0	0	0	0	90.6	x	136	159	182	73	0	0
1974	x	x	x	3.5	85.3	93.8	183	104	156	2.2	0	0
1975	x	15	x	63.8	79.7	174	398	195	x	x	x	0
1976	0	0	59.7	72.4	92.7	66.2	114	203	70.2	0	11.9	20.2
1977	48	0	19.9	93.9	67.3	121	175	154	85.9	164	28	0
1978	4	2.9	4.8	14.6	0	87.1	53.3	0	0	1	0	0
1979	41	35	32.4	0	117	119	131	80.5	0	6.8	0	0
1980	0	0	4.3	0	0	0	119	0	0	20	0	0
1981	x	248	89.9	30.7	9.7	3.7	265	249	152	12	0	0
1982	8.4	37	31.4	35.1	68.7	38.6	102	242	35.2	86	40.1	9.6
1983	0	33	31.5	40	140	55.4	216	233	147	13	18	0
1984	0	0	17.3	0.2	151	73.1	202	137	67.2	0	0	6
1985	1.2	0	18.8	56.8	107	14	272	311	85.3	1	3	0
1986	0	71	67.9	45.9	38.4	161	171	139	67.9	12	0	0.8
1987	0	14	84.9	39.1	215	7.1	142	214	60.8	9	0	0
1988	46	47	9	50.4	21.4	60.4	183	279	178	38	0	4.8
1989	0	18	70.7	91.7	7.1	68.5	187	319	91.2	x	x	1.7
1990	0	x	x	110	18.3	8.1	241	259	x	34	x	0

* 0 = no rain fall

x = no data

ANNEX 4a. Summary of monthly mean value of different meteorolgical elements

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Temepratture	17.90	20.20	22.00	22.00	22.70	22.80	21.10	20.60	20.90	19.20	17.50	17.90
Wind Speed (km/h)	3.50	3.20	3.10	2.70	2.70	3.20	3.40	2.90	1.80	2.50	3.20	3.40
Humidity (0/0)	54.70	49.90	52.60	52.00	52.20	51.80	65.00	66.80	64.70	57.30	51.60	53.30
Sunshine (hr)	9.10	8.20	8.20	7.50	9.00	8.50	7.10	7.20	7.70	9.30	9.70	9.20
Pan evap.(mm)	19.75	25.15	25.54	21.36	23.90	22.03	18.54	16.55	15.84	20.24	20.87	15.66

ANNEX 4b. Monthly mean wind speed at Nazreth station (km/hr)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1990	4.1	2.8	3.3	2.5	3	3.6	3.4	3.1	1.9	2.9	3.5	3.7
1991	3.7		3.0	3.2	3.2	3.4	3.8	2.9	1.9	2.6	3.5	3.2
1992	3.2	3.2	3.9	2.9	2.7	3.2	3.3	2.9	1.9	2.4	3.3	3.7
1993	3.5	3.4	3.2	2.7	2.4	3.3	3.6	3	2	2.2	3.3	3.6
1994	3.6	3.9	3.2	2.9	2.8	3.6	3.3	2.8	1.7	2.7	3	3.5
1995	3.3	2.9	2.6	2.1	2.4	2.8	3.3	2.8	1.7	2.7	2.9	3.3
1996	3.2	3.2	2.7	2.4	2.1	3.1	3.2	2.5	1.5	2.2	2.8	3.0
Average	3.5	3.2	3.1	2.7	2.7	3.2	3.4	2.9	1.8	2.5	3.2	3.4

Annex 4c Monthly mean relative humidity at wonji station (%)

Year	Jan.	Feb.	Mar.	Apr.	May.	June	July	Augu.	Sept.	Oct.	Nov.	Dec.
1981		80	88	93	85	74	82	86	94	90	83	77
1982		81	80	89	88	78	85	89	92	94	93	91
1983	82	89	88	84	88	85	85	89	86	93	82	
1984	83	72	68	64	84	83	82	87	90	79	77	
1985		73	74	88	88	77	89	89	93	92	81	79
1986	74	75	75	72	70	70	72	69	93	89	75	
1987	74	75	92	90	87	83	82	90	92	84	81	79
1988	82	83	69	79	80	82	83	92	92	93	88	83
1989	84	81	93	80	86	81	89	90	94			87
1990	84	93	93	89	84	75	85	89		90		80

ANNEX 5 Mean Daily Duration of maximum possible sunshine hours of wonji.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1981		8.8	5.6	7.1	10	9.5	6.9	7.3	7	9.5	10.1	9.7
1982	9.1	7	9.1	7.8	8.7	8	6.8	6.2	7.5	8	7.7	8.2
1983	8.3	7.6	8	6.9	7.8	9	8.5		7.7	8.8		
1984	9.4	10.1	9.8	10.3	7.8	8.2	8.2	8.2	7.5	10.1	10	8.8
1985	9.5	9.1	8.4	6.5	8.2	8.7	6.5	7	8.4	9.3	9.7	9.3
1986	9.8	8	8.7	7.3	9.5	6.7	7.1	7.1		8.9	10	8.9
1987		8.5	6.9		8.2	8.9	9.9	6.7	8.5	8.9	10.1	9.4
1988	8.2	8.9	9.9	6.8	10.2		4.8			9	10.5	9.8
1989	8.7	8.7	7.6	7	10.1		6.7	7.8	7.8			
1990	9.9	5.5	8.2	8.2	9.5	9.3	6.6	7.1	7.1	11.2		9.8
Total	72.9	82.2	82.2	67.9	90	68.3	71.1	57.4	57.4	83.7	68.1	73.9
Average	9.1	8.2	8.2	7.5	9	8.5	7.1	7.2	7.2	9.3	9.7	9.2

ANNEX 6 Monthly mean dischage at wojj station, as calculated from Koka and wonji station

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1973	1.43	1.22	0.21		4.5	6.62	9.87	8.11	1.35	10.17	13.55	11.14
1974		1.2	1.46		6.57		5.57				3.18	3.37
1975	10.53	1.9		3.6	7.25	5.8	13.8	22.47			7.19	
1976	8.35	7.55	7.98		10.53		14.23		3.37		6.28	1.73
1977	5.84	5.49	2.72	11.9	.		17.88	17.26				
1978				8.65	5.59	16.97	15.46	1.95	0.58		6.26	18.24
1979	5.15	8	2.38	4.37	11.93	6.17	17.01	1.47				
1980			10.56	1.53		11.06	10.88	14.14	5.24	4.13	4.91	8.86
1981	2.41	10.49	4.85	8.12	14.87					11.39	5.77	5.42
1982	11.45	10.08	11.9	11.1		15.87	13.96		15.89	7.73	2.55	
1983	1.15	5.38		8.07	12.54	18.51					2.08	2.43
1984	3.73	2.59	4.87	3.78	3.12	4.91					8.31	9.24
1985	5.46	8.54	6.24	5.13	6.26	7.44						
1986			7.24	0		14.22		20		2	6.93	4.87
1987	12.43	0.97	4.63	5.09	17.63	6.36		18.87	18.77	4.1		2.48
1988	1	1.5	2.77	8.55	2.54			13.38	8.68	11.27	0.67	0.23
1989						4.9	14.95	12.02			8.79	
1990			0.13	0.83		2.22			7.59	17.77		4.2
1991			9.97	4.44					4.48			
1992	14.5	13.11						3 3	17.63			11.02
1993	3.45		6.99	6.21	4.62		8.37			7.86	0.62	
1994		1.32				8.08	6.92	8.69	17.86	1.54	9.24	8.94
1995	3.78	2.38				1	12.52					
1996			6.09	2.77	4	6.5	5.95			5.88		
AV	3.7	3.4	3.4	4.1	4.8	5.5	6.9	6.3	4.8	3.8	3.6	4

* Average discharge 4.3 m3/s

Annex 7 Run off coefficient over different land types (after Sharma)

Types of catchment	value of (C)
Roky and impermeable	0.80 to 1.00
Slightly permeable, bare	0.60 to 0.80
Slightly permeable, cultivated or covered by vegetation	0.40 to 0.60
cultivated absorbent soil	0.30 to 0.40
Sandy absorbent soil	0.20 to 0.30
Heavy forest	0.10 to 0.20

*Source Woldu Ameneshoa, hydrgeology of Nazreth 1994

Annex 8 Names and formulae of some common chemical species showing their electrical change (Valency), formula weight and conversion factor to equivalent weight units. The concentration (mg/l) divided by formula weight gives micromoles per litre. concentration (mg/l) multiplied by final column (valency / formula weight) gives miliequivalents per litre (based on data in Hem, 1985).

Name	Species	Formula weight (approx.)	mg/l meg/l
Aluminium	Al^{3+}	26.9	0.11119
Almmonium	NH_4^+	18.0	0.05544
Bicarbonate	HCO^-_3	61.0	0.01639
Calcium	Ca^{2+}	40.1	0.04990
Carbonate	CO_3^{2-}	60.0	0.03333
Chloride	Cl^-	35.4	0.02821
Hydrogen	H^+	1.0	0.99216
Hydroxide	OH^-	17.0	0.05880
Iron (ferrous)	Fe^{2+}	55.8	0.03581
(ferric)	Fe^{3-}	55.8	0.05372
Magnesium	Mg^{2+}	24.3	0.08229
Nitrate	NO_3^-	62.0	0.01613
Nitrite	NO_2^-	46.0	0.02174
Phosphate	PO_4^{3-}	95.0	0.03159
Orthoposphate {	HPO_4^{2}	96.0	0.02084
	$H_2PO_4^-$	97.0	0.01031
Potassium	K^+	39.1	0.02558
Silica	SiO_2	60.1	
Sodium	Na^+	23.0	0.04350
Sulphate	SO_4^{2-}	96.1	0.02082

Annex 9 Population of study area

Locality	Population
Nazret town	154613
Awash melkasa town	3839
Wonji gefersa town	15865
Shewa alemtena town	7738
Sire robi town	1307
Sodere town	1945
Koka town	4648
Dera town	20865
Kusaye	2035
Kechema kencheso	1256
Kechema sebeko	1380
Wacho lafu	1665
Arogae adama	600
Lugo	762
Malka hida	1612
Boku Kurabo	2281
Adula boku	1982
Hate ofi	1467
Awash melkasa	1846
Wakie teyo	1762
wakie Hia	1802
Worji tekil	27758
Wonji Kurifta	3818
Bati tifa	1482
Bate alula	1568
Wonji didimtu	1322
Didimotu handech	1336
Bati bora	1622
Bati Kilo	1789
Gedema alielu	1090
Cheka alemtena	1102
Gedemsa etisa	986
cheka shenen	1214
Cheka Selassie	1267
Cheka humo fachesa	596
Cheka humo	808
Cheka ejersa	904
Cheeka Mersa	1175
cheka hufa	1426
Cheka bokoji	1672
Cheka dewero	1850
Koka town	4648
Total	290,703