ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

GROUND WATER RESOURCES EVALUATION OF WALGA RIVER BASIN CENTRAL ETHIOIPIA, SOUTH WEST SHOA

KASSAHUN BEYENE

A thesis submitted to The School of Graduate Studies of Addis Ababa University
In partial fulfillements of the requirements for the Degree of Masters in Hydrogeology

June 2005

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GROUND WATER RESOURCE POTENTIAL EVALUATION OF WALGA RIVER BASIN

SOUTH WEST SHOA ,CENTRAL ETHIOPIA

By

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Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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(Research felloew)	

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ABSTRACT

Hydrometreological, geological, hydrogeological, hydrochemical investigation, basin & lake water balance calculation were made for groundwater resource potential evaluation of Walga Basin.

Walga basin is part of the western central Ethiopian plateau.Geological investigations reveal that Walga area is found in the east-west trending Yerer-Tullu Welel volcano –tectonic structures and three litho-stratigraphic succession prevail in the area, which include Precambrian basement, Mesozoic sedimentary rocks and Cenozoic volcanics.

Annual precipitation of the basin calculated from long term mean monthly rain fall data is 1259mm.The actual and potential evapotranpiration for the basin are 853mm and 1080mm respectively. The amount of evaporation from open water body (lake) is 6.6 Mcm.Of the total rain fall ,17.9% leaves the basin in the form of surface runoff and 13.8 % water infililtrate with in the basin which is the annual recharge of the basin.

Most perennial streams emerge from the base of mountains in this area and drain the basin as gaining streams throughout & showing structurally controlled frow path.This also indicates that groundwater plays very crucial role in the hydrology of the basin.

Based on qualitative and quantitative analysis of aquifer characterstics,the basin is categorized in to three aquifer sytemswhich are low,medium & high productivity aquifers.The scoraceous basaltic aquifer around Woliso area is the best well field with high well yield & permeability.

Hydrogeological and geological maps are prepared from areal photographs and Satellite images & Field observations.Land sat –TM image is used also to identify lineament or structures in the basin together with areal ophotographs.

The hydrochemistry of the basin is also analysed and the waters are categorized in to fresh water excluding two thermal spring waters lying along Ambo-Butajira fault line & having deep geothermal contact.Exept the two thermal springs and some waters in the low areas,most water bodies have Ca-Mg-CO3 type water showing fast shallow ground water circulation from meteoric source which is the characterstics of recharge area waqter undergone low geochemical evolution.But,the two thermal spring waters show deep regional circulation & undergoing high geochemical evolution processes.

The low TDS fresh waters of the area have concentrations below permissible limit for water supply, irrigation & industrial uses. High fluoride concentration are observed in the thermal spring waters & in Chitu spring which lie along the Ambo-Butajira fault line .So volcanic inhalation & thermal effect could supply the waters with high fluoride concentration.Eventhough they are with in the permissible limit ,some anthropogenic effects like NO3 & Cl are observed in waters of unprotected springs & poorely constructed well heads.

From hydrogeological and hydrochemical data analysis the groundwater flow direction is from the highlands of Wenchi to southeast low lying plains.

The results of this study can be used as data source for future sustainable development and management of walga basin.

(Key words :Groundwater Recharge,Water quality,Fluoride,Conceptual groundwater flow model,Walga ,Central Ethiopia)

CHAPTER -1
INTRODUCTION

1.1. Statement of the problem

Walga basin has an area coverage of 1,786.75 km^2 and a total population of about 350,000.Except some of the inhabitants in the towns who engage them selves in small trade businesses and a few governmental employment opportunities, for most rural households in the basin agriculture (animal husbandry and crop production) is the main economic activity to generate their means of income. Vast fertile soil, good water resources potential (both surface & ground water with hot & cold springs) & a beautiful Wanchi crater lake panorama give good potential for agricultural & ecotourism, etc development in the area.

Woliso town is currently supplied with potable water from Rebu stream. This steam is used both on its up stream & down stream side of the town for irrigation purpose which as a result of the up stream irrigation activities some times the water supply for the town is interrupted for two or three days. The problem of such increasing competitive demand of the water resources for domestic, agricultural & other purposes in the area due to the rapid population growth along with increasing living standard & intensified irrigation agriculture & other developmental activities like tourism indicate the need for efficient utilization through further investigation of the water resources potential, particularly the ground water.

In recent years there has been a considerable agricultural practices & land cover change with increasing tourism activity in Wanchi crater lake area. Some human treats like inappropriate management of the water basin, depletion of water through pollution & environmental degradation has become apparently clear. During summer rainy season almost all the soil washed from the bare land of the lake catchment enters directly to the lake. Eventhough not properly monitored, due to this, sedimentation in the lake is thought to be increasing progressively which later could possibly alter the storage capacity of the lake.

Despite the above facts, no detailed studies has been carried out about the over all water resource potential of the area, particularly about the ground water; and no detailed ecological considerations in relation to both the water and land resources development and management aspects are available that make possible the effective utilization of the resources with sound ecological balance to bring about integrated sustainable development in the region.

Some previous works in the area include:

- Kondo (1964) investigated thermal springs of Ethiopia.
- Mohr (1971)
- Potable Water supply Design reports for different towns /& rural areas by the regional Bureau & other organizations.
- Smeds (1964) studied the volcanic activity in Ethiopian plateau, particularly in wanchi area
-Tsegaye Abebe (1998) on Yerer-Tulu welel Volcano- tectonic lineaments.

As indicated above in the previous works, hydrogeolgical investigation in the basin is not conducted in detail. Therefore, to bring about integrated sustainable development through efficient utilization of the water resources potential, proper land use planning & conservation of the ecosystem, understanding the origin of, interrelationship between and pollution treats to different water bodies is important, which is the aim of this research work.

1.2 Research objectives

The general objective of this research work is to evaluate ground water resources potential of the Walga river basin by identifying different physical parameters which have potential effect on the hydrology of the area.

Specific objectives:

Estimate the ground water recharge conditions

Investigate the hydrogeological character of the basin

Show some water quality aspects in the basin

Provide data base that can assist the sustainable development & management of the water resources of the area with ecological balance.

1.3 Methods of present investigation

Geomorphological, lithological, structual,hydrogeological & hyrogeochemical,etc,studies to construct maps & the conceptual gruond water flow model of the basin.

Hydrometeorological investigations & recharge estimation by using conventional baseflow separation and water balance methods

Synthesis of the different study appraoches to come up with conclusions & recommendations

CHAPTER- 2

GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location, Accessibility and areal extent

The Walga river catchment basin is found around Waliso area, south west Shoa, in central part of Ethiopia. It is the sub-basin of the Omo-Ghibe river catchment at its upper northern upstream flank.It has a total area of about 1786.75 km^2.It starts at about 100 km drive southwest of Addis Ababa around Dilela town along Addis Ababa-Jimma main asphalt road. Most Parts of the basin are accessed by networks of all-weather & dry-weather roads.

The area is bounded within geographic grid reference 8^0 19’ 30’’-8^0 48’ 43’’ N latitude and 38^0 35’ 30’’ -38^0 08’ 00’’ E longitude starting from Wenchi Lake and Dilela town to the river Gauge of Walga (around Walga town). The location map of the study area is shown in figure 2.1.

2.2. Physiography

The topographic elevation in the basin ranges from 1510 M.a.s.l. at Walga River gauging station to above 3100 m.a.s.l. on mount Wenchi. The total catchment area of Walga river basin is about 1786.75 km^2 with North-east to south-west elongated drainage basin. The entire basin is drained by Walga river and its tributaries, most of which are perennial streams.

The watershed has generally, NS inclined rolling topography which is thought to be the result of Northwest-Southeast trending steps of normal faults dipping to SE that created down thrown blocks of the lower basalt. Tsegaye Abebe (1998).

Mountain peaks like mount Wenchi and isolated buttes in the area are the result of recent volcanic of central volcanoes and scoria cinder cones which were erupted along Eastwest structures .These mountains include Simela (2,883 m.a.s.l) , Karfefe (2,744 m.a.s.l), Rogda (1,702 m.a.s.l), Arbatansaye(3,312), Sankole(2,425), Haro and Bilacha chain of mountain ranges of Wenchi (3,357).

Gullies and stream channels are observed dissecting almost throughout the watershed. The central and Southwestern parts of the watershed are almost plain which are covered by thick soils of depositional products of the upper basalic lava flows. Small southeast dipping escarpment that is formed by Ambo-Butajira fault line is also demarcated at the northern upper side of the basin.

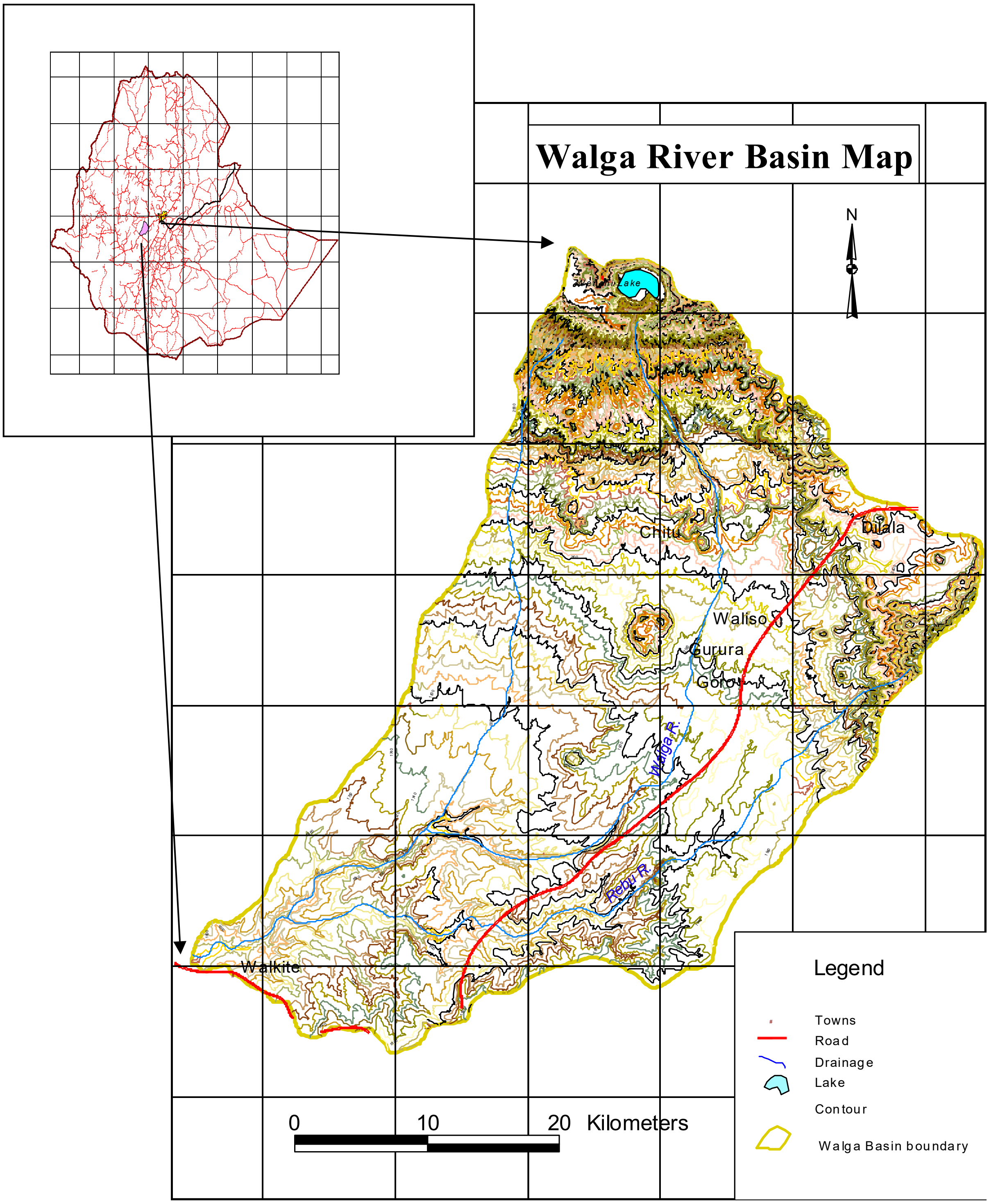

Figure 2.1a. Location Map of Walga River Basin

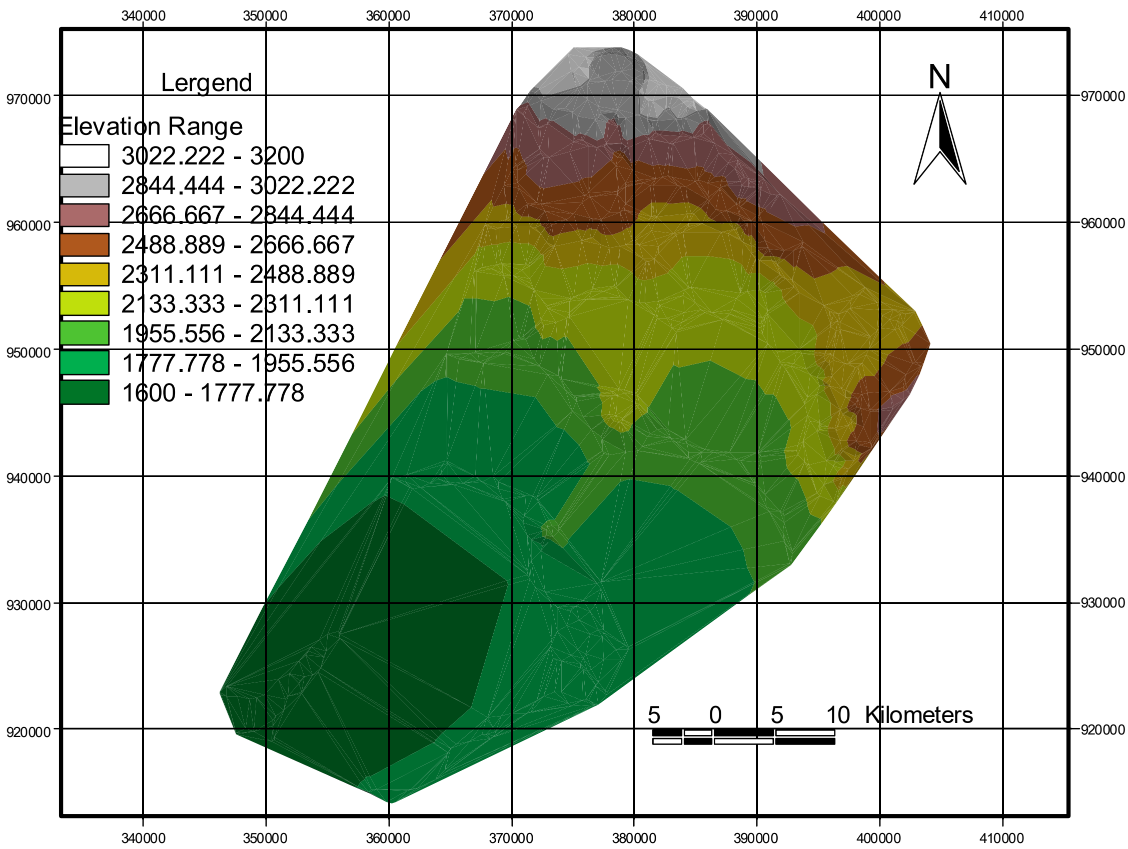

Figure 2.1b.Topographic Map of Walga Basin

2.3.Climate and Vegetation

The area has bimodal rainfall pattern with the main rainy season in summer (June-Sept.) and the smallest rains in autumn and spring . Winter is dry season in the area.

The maximum total annual rainfall in the watershed is 1641 mm at Dariyan gauging station & the minimum total annual is 901mm at Ghibe farm station in the watershed . The maximum and minimum recorded temperatures are 23.33 and 12.74 ^{0}C respectively in March and November with about 19.03 ^{0}C annual average.

The vegetation in the basin has been greatly modified by the effect of land use. The vegetation in the area can be categorized as:

-Natural Juniperous procera (Tid) and podocarpus forests on mountain slopes of Wenchi and the Surrounding,& along streams in the highlands.

-Carissa Edulis and Ilex Mitis shrubs on the mountain peak of Wenchi

-Grass lands in the lower plain areas

-Planted Eucalyptus trees cover most part of the basin ,specially residential areas.

Plate2.1.Vegetation on Wenchi Mountain Peak

2.4. Drainage system

The main water bodies that characterized the drainage system of the Walga basin are Lake, rivers and streams. Wenchi crater Lake is located at the upper northern flank of the basin. Walga and other perennial streams emerged from the side of this ridge and flow downwards following the general relief towards Southwest.

Walga, Rebu, Ejersa and Ameya are the large perennial rivers flowing in the basin. The other intermittent streams drain into Walga river that drains throughout the entire basin.

Table 2.1. Morph metric characters of the Walga river

River	**Outlet**	**Area (km^2)**	**L (km)**	**P (km)**
Walga	Ghibe R.	1786.75	86.25	431.25


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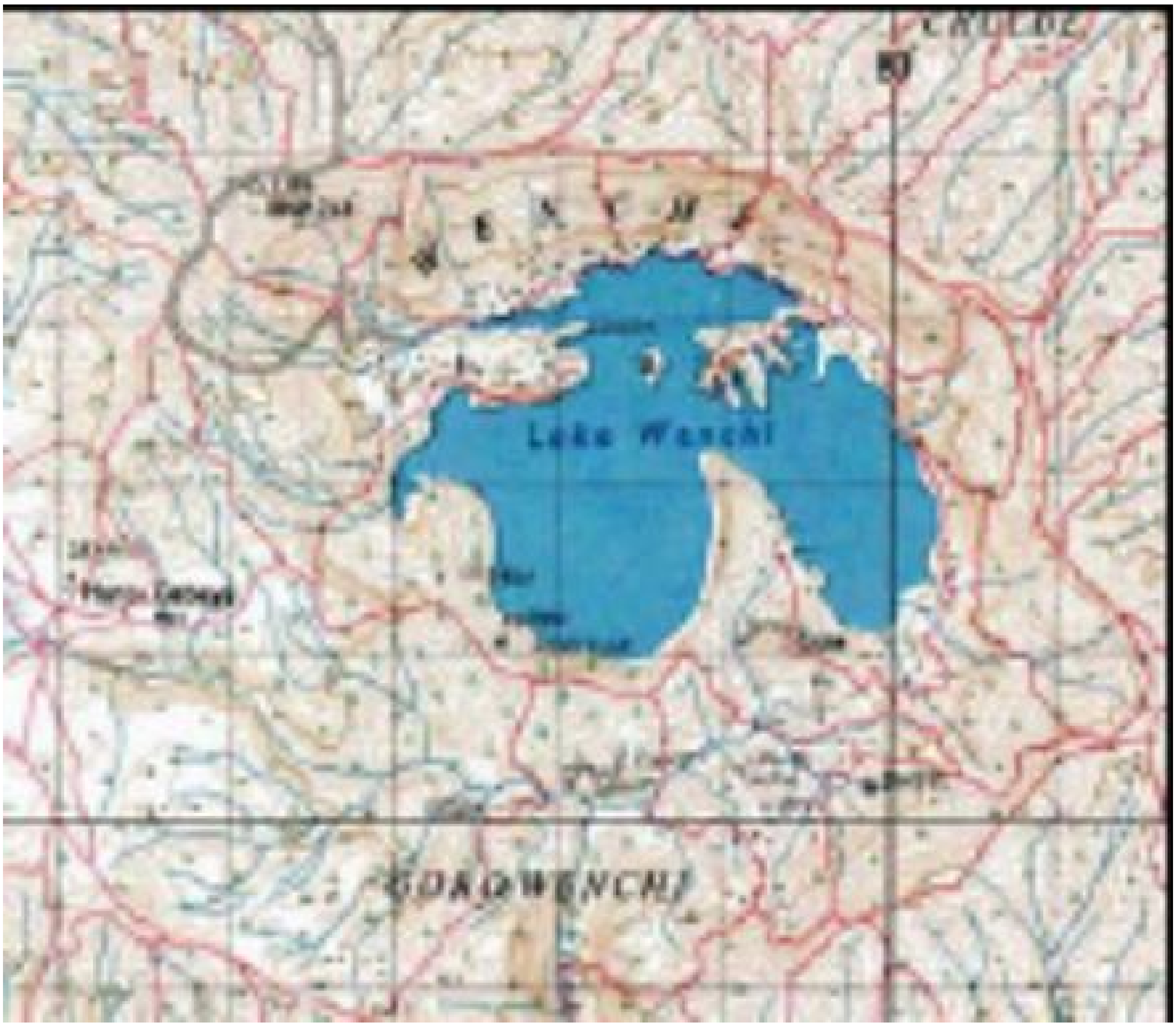


Plate 2.2. Lake Wenchi a) SSE-NNW overview, b) Areal Photograph, c) Topo map

Physical parameters	**Wenchi Lake**
Altitude (m)	2889
Basin area (km^2)	14.616
Lake Catchment perimeter (km)	17.855
Lake area and islands (km^2)	4.771
Shore line length (km)	9.480
Depth (m) maximum	75
Depth (m) mean	36.9

Table 2.1.b Morphometric characters of the lake Wonchi.

2.5 Population, settlement, land and water use

The total human population of the area is about 350,000. The settlement conditions are densely populated in urban residential areas like Woliso, Dilela, Gurura, Chiltu and other big villages, & Sparse in the form of family/or relatives in most rural peasant associations.

Cultivation has covered most of the study area except some areas left as grazing plots on high hills and steep slopes. On regional scale, the area is classified as moderately cultivated, BCEOM, et. al (2000).

As discussed above, the land is mainly used for cultivation and the main crops in the area include, wheat (triticum aetivum), Barley, and Kocho (Ensete Venter cosum).

Many streams are in use for irrigation activities (both traditional and modern) in the basin. While still some water development works are in progress in the basin, the total population supplied with potable water in urban areas (~80%) by far exceeds the rural areas (>4 fold).

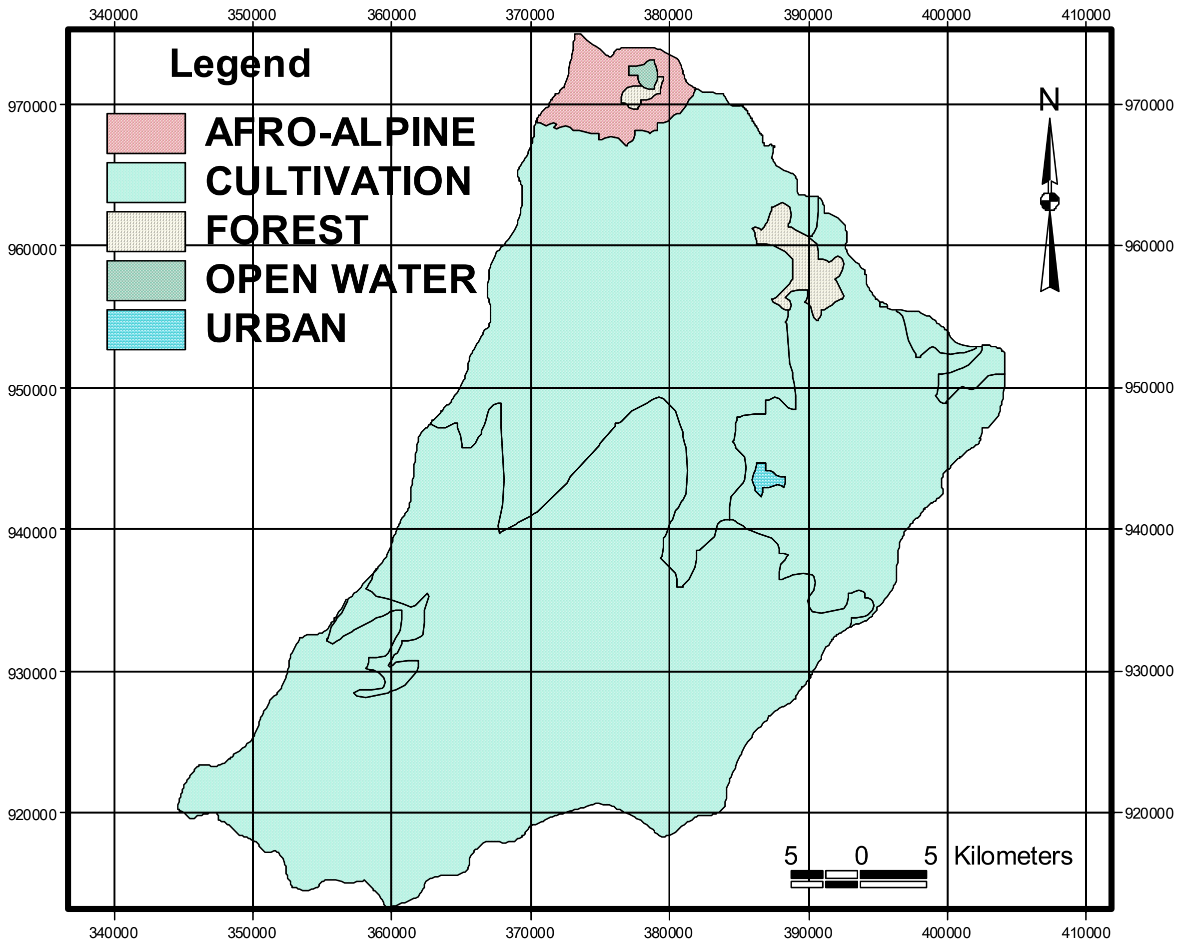
Ranking water use in the basin shows still more surface water utilization than ground water for domestic purpose and animal population is common.

The existing water supply condition in the basin for drinking purposes is from shallow, deep ground water and springs sources except for Waliso town which is from Rebu river. But the actual demand and supply calculations could not be accurately provided because of lack of information.

Table 2.2.Areal Coverage of LandUse/Land cover

No	**Land Use/Cov.**	**Coverage(km^2)**	**Weighted Area(%)**
1	Cultivation	2716.29	97.29
2	Forest	24.55	0.88
3	Afro Alpine	37.78	1.35
4	Open Water	4.88	0.17
5	Urban /Town	8.50	0.31

Figure 2.2.Land Use/Cover Map of Walga River Basin.



2.6. Soils

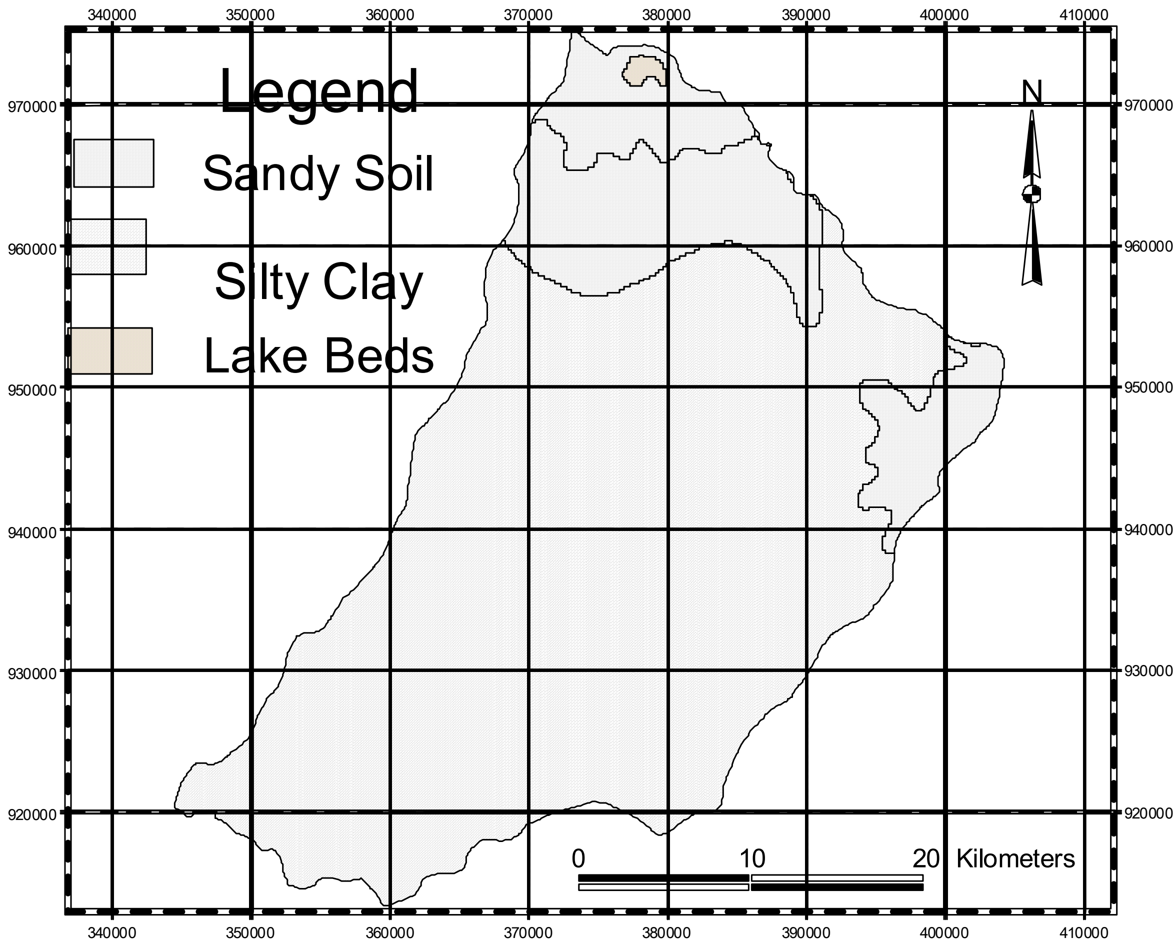
Two soil categories characterize the basin depending on parent material and topography. The watershed and valley slope parts of areas like mount Wenchi are covered by thin sand dominated permeable and well drained soils derived from pyroclastic deposits. While the low lying planes and valley bottoms are covered by thick black cotton less permeable soil with impeded drainage.

Table 2.3.Soil Type & Their actual coverage in the basin Basin

No	Soil Type	Area coverage in (Km^2)	Weighted Area (%)
1	Sandy Soil	1622.6	90.55
2	Silty- Clay	164.56	9.18
3	Lake Beds	4.88	0.27

Plate 2.3.Soil thichness exposure along gully in Dariyan Area.

Figure 2.3 . Soil Map of Walga River



CHAPTER -3
GEOLOGY

3.1. Regional geology

Complex geological processes (metamorphism, erosion/deposition, volcano-tectonics) which took place from Precambrian to recent times are responsible for geology and geomorphologic features of present Ethiopia.

Thee major groups of lithostratigraphic successions with varying geochronologic orders are identified regionally in the country. These rocks include:
Precambrian metamorphic basement
Mesozoic sedimentary successions & Paleozoic/recent sediments.
Cenozoic volcanics

The Precambrian basement rocks are the oldest in the country. It is the result of complex tectonic and metamorphic history during protrozoic early Paleozoic times. It consists mostly of metamorphic rocks of greenshist, amphibolite and granulite facies.

It's exposure is limited to peripheral parts of the country like in the northern (Tigray) the southern (Sidamo and Bale) and the wester (Wellega and Gojam).

The metamorphic basement is overlain by one or more Sedimentary or volcanic products of the post continental accretion. It means depending on the prevailed major geological process in the region, it is either overlain by Mesozoic sedimentary succession, Paleozoic sediments, Cenozoic volcanic, quaternary sediments or directly exposed to the surface.

The Paleozoic times are known in the country for intensive denudation processes eroding the pre-Cambrian rocks to a vast penplain.

In late Paleozoic era, valleys and low areas were filled by continental and glacial deposits. These sedimentary rocks include the sandstones of Enticho and Wayu (Ogaden) and glacial deposits of Edaga Arbi (Tigray) and they are found exposing only iin limited parts of the country.

During the Mesozoic era, the geodynamic process of epirogenic tilting (sinking) and then rising (uplifting) of Horne of Africa has brought about sea transgression-regression, vast Volcano tectonic activities as well as development of the main Ethiopian rift system respectively.

In early Mesozoic times, SE-NW marine incursion deposited continental and marine Sedimentary rocks that cover much of the eastern part of the country and some deep valley gorges. The central and western parts of Ethiopia remained a continental land area throughout the Mesozoic, with a thin unit of presumed continental sediments being the only record of deposition (Mohr, 1971).

The complete stratigraphic successions of the Mesozoic sedimentary rocks that are formed by sea transgression-regression (like in Abay basin) consisting both marine and continental depositions are sandstone (lower& upper); limestone, shales, mudstones and marls (Antalo) (Kazmin, 1975).

In Eocene, widespread regional up lift started as a result of the internal thrust and convexo movements with in the mantle under the earth's crust. This up lift brought marine sedimentation to an end.

This uplifting which is associated with the initial development of the Red sea and East African Rift system was accompanied by extensive volcanic activity that out poured huge thickness of the basaltic lava (flood basalts) from long fissures which opened along the line of rifts which now form the foundation of the of the Ethiopian plateau called the trap series. Other acidic laves (ignimbrites) were erupted contemporaneously from different volcanic centers (Davidson, 1983), with a progressive evolution from dormant basaltic lavas.

In late tertilely and early Pleistocen, as a result of this release of large amount of magma and the gradual widening, a continental scale collapse occurred and gave rise to rifting.

At early Pliocene, the main Ethiopian rift fully developed (Davidson, 1983) with which began a period of felsic volcanism called the Aden series includes rhyolites and trachytes that covered the rift graben and extended over much of the central part of Ethiopia.

This early Pliocene felsic volcanic outpouring had buried most of the localized lakes and swamps which were developed during the late Pleistocene over the top of the flood basalt. As a result the shallow water lacustrine deposits were substituted by volcano-lacnstrine products in the remnant lakes.

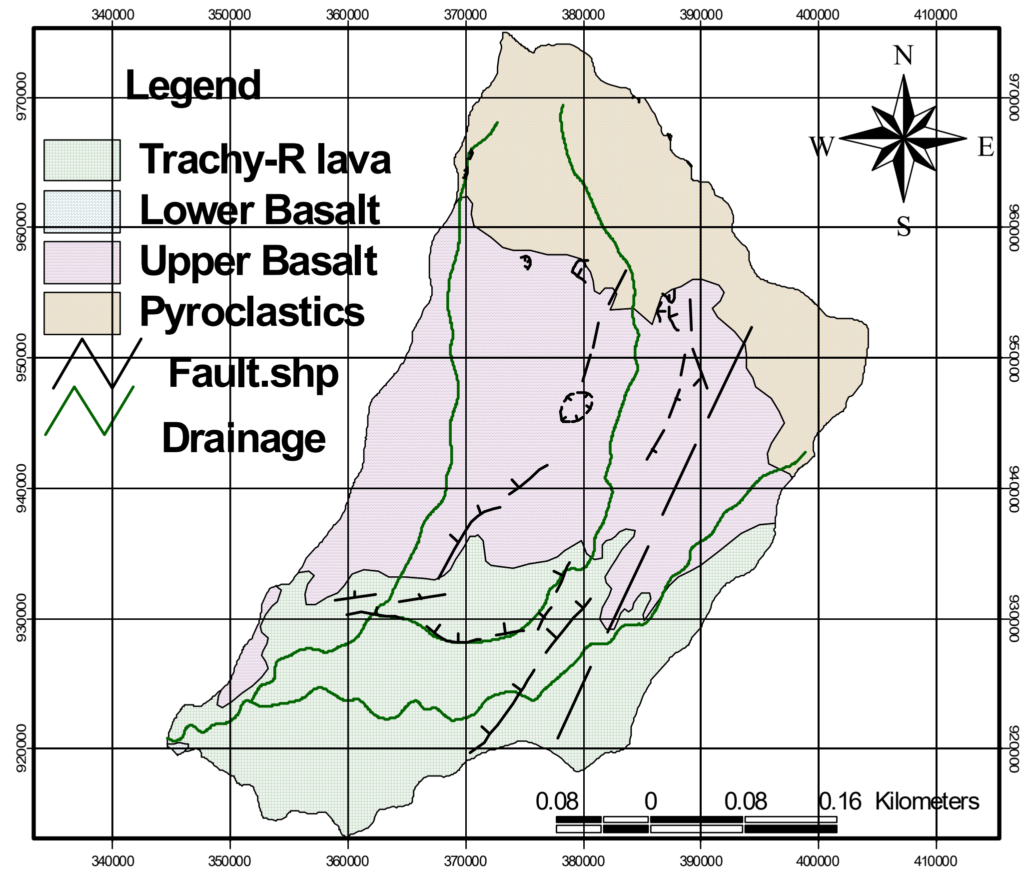
During late Miocene, in the western up lifted Ethiopian volcanic plateau, an Eastwest to East-Northeast-West-Southwest trending structures having dominantly oblique, right lateral kinematics occurred traverse to the Ethiopian rift(MER) in order to accommodate the movement along the MER. One of these structures which comprise the study area is called the Yerer- Tullu Wellel volcano-tectonic lineament (T. Abebe, 1998).

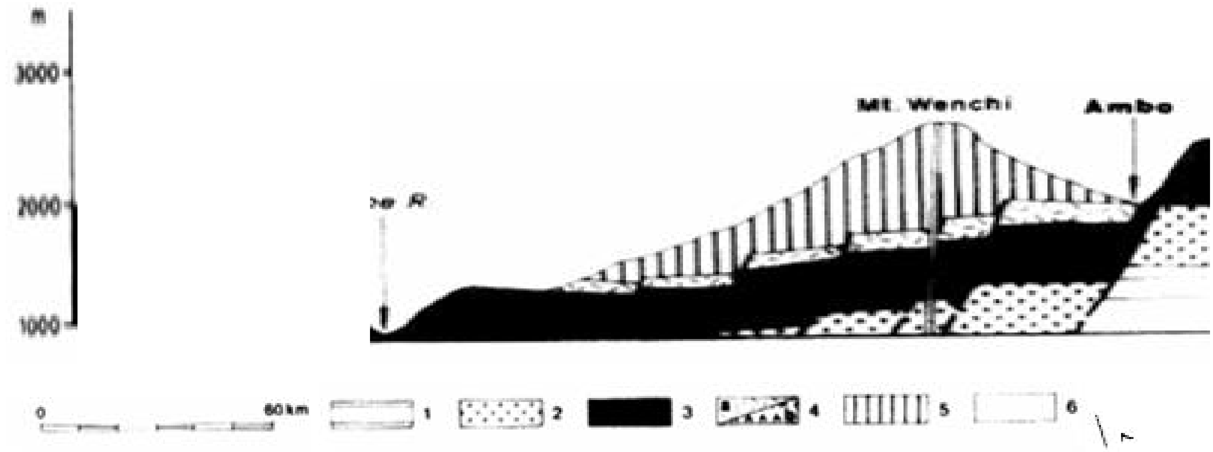
After this fracturing had developed, the influence of thermal anomaly linked to MER prevailed, focusing the igneous activity in the eastern most part of the structure (Wenchi to MER).

3.2. Local Geology

Walga basin is part of the western central Ethiopian plateau. According to previous works in the area by Tsegaye Abebe (1998),the three litho-stratigraphic successions that prevail in the study area include Precambrian basement, Mesozoic sedimentary rocks and Cenozoic volcanics. Figure 3.2 shows a geological map of the study area modified and compiled during this study from this work other works.

Figure 3.1.Geological Map of Walga basin





.Geological sketch map of the Study area & its Vicinity (modified after T.Abebe et al., 1979). Legend. 1: Precambrian basement; 2:Mesozoic cover; 3: Oligocene volcanics (Ethiopian Volcanic Plateau); 4: Late Miocene volcanics (a: pyroclastics; b: lava flows); 5: Quaternary volcanics; 6: alluvial cover; 7: faults; NW-SE trace of the geological section.

3.2.1. Precambrian Basement complex

The outcrop of this rock is not observed in the study basin but their age and stratigraghic relationship was developed from regional Yerer Tullu Wellel volcano tectonic lineament study by T. Abebe (1998).

3.2.2.Mesozoic Sedimentary rocks

The existence of Mesozoic sedimentary sequence in the basin stratigraphy is also inferred from outcrop in the Abay basin opposite adjacent to the basin in Ambo area. Rather still no Mesozoic sediment outcrop is observed. Only thin layers of quaternary sediments occur in the areas along the lower plains of the basin around Walga Area.

Some travertine and silica sinter secondary deposits are observed along Ambo-Butajira Fault lines like in Ghiyon Walga Hotel compound. They are commonly associated with thermal spring waters supersaturated withrespect to Calcite & Silica.Their occurrence could help us to infer the possibility of the presence of Mesozoic sediments, particularly limestone in the stratigraphy of the area underlying the basalts.

3.2.3 Cenozoic volcanic Rocks

Generally Cenozoic volcanic rocks in the area can be grouped into
Tertiary- pre rift- Aden series Volcanic rocks &
Quaternary- post rift-trap series rocks
or these can be further grouped in to two classes
Lava flows-Which comprises basalts and trachytes
Pyroclastic deposites-Which manly comprises of unwelded tuffs.

3.2.3.1.Lava flows

The older Oligocene-Miocene (31-20.6 ma of age) volcanic lava flows are exposed in the south western lower part of the basin around Walge town. It has a thickness of about 400 m. They are down thrown about 500m in the area by steps of normal faults compared to the other parts of Western Ethiopian plateau (Tsegaye Abebe,1998).They are thought to have dominantly mantle plum contribution & low or no crustal contamination during their genesis.In areas where continental sand stone or marine deposits are not expected this unit directly overlays the basal .

The other quaternary basaltic lava flows of late Miocene volcanics which is found interbeded with the pyroclastics cover large parts of the study area mainly the plains.

Plate 3.1.Scoraceous Basltic out crop around Wenchi town

The basalts are generally either aphyric or porphyritic, containing olivine or plagioclase phenocrysts or even both. Olivine is the most common phenocryst mineral, with pyroxene and plagioclase phenoerysts being less common, while augite phenoclysts are rare. These phenocrysts make up as much as 20% of the rock. Plagioclases laths in the groundmass are random to well oriented and in the massive basalt types they show an opnitic texture. Small chalcedony agate and amethyst occur in the vesicular flow tops in many places. The main sequence of basalts ranges in age from 42.7-19.4 mys (Davidson, 1983).

In the basin and around north and northwest of woliso town, there is a large area made up of basaltic shield. It is composed of basaltic flows that have spread outwards from the central complexes, where there are numerous cinder cones,scoria domes & and collapse craters, many of them are perfectly preserved. The highest part of the shield complex the Wenchi caldera (3387m) lie on the watershed between Omo-Ghibe,Awash and the Abay rivers basins.

North west of Weliso is underlain by basaltic flows, usually porphyritic with large phenocrysts of pyroxene, olivine and plagioclase. The basalt is columnar or vesicular, the vesicles filled with zeolite and chalcedony. It overlies rocks of Nazaret group.

Both trachyte flows and felsic ignimbrite of Miocene to Pliocene age, cover the surface of most of the basin. The dominant rock type of the unit is trachyte which contains feldspare phenocrysts (sanidine) and whose colour ranges from light pink and violet-grey. The subordinate rhyolite contains both quartz and alkali feldspare phenocrysts. Ignimbrites and tuffs composed of felsic fragments and feldspere crystals are interbeded with the felsic flows. This lava flows are suggested to be probably related by fractional crystallization to the basaltic lava flows having the same mantle plum source (Dereje Ayalew,1999).

Rhyolite – Trachyte flows and ignimbrite deposition of the younger sequences of the Nazareth group was accompanied by shield volcanics of late pliocence age (2-3 million years) (Kazmin et. Al 1978,1980).

3.2.3.2 Pyroclastic and Scoria deposits

Miocene to Pliocene volcanics compose a series of rhyolite-trachyte plugs, stratoids flows, ignimbrites, pumic, ash fall tuffs and characteristics lacustrine sediments.

The age of this rocks range from 10 to 3 million years (Kazmin, 1979; Kazmir et.al 1978,1981). The group crops out along south eastern part of the basin south of Weliso to Welkite. It unconformable overlays the flood basalt, with minor intercalation of basalts being found at the base of the group.

Lacustrine sediments of this unit occur in the Walga river west of Welkite .These are intercalated with waterlain volcano-clastic sediments composed of coarse-grained tuffaceous sandstones and white fine-grained silt stones. These sediments range from 30 to 50 m thick and rest on the flood basalts.

These young volcanics are well preserved with little erosion of the cones and craters, and some contain small crater lakes (like wenchi in the study area). Several of these crater centers like Wenchi, lie on a NNE alignment suggestive of formation along a major fault line (Ambo

Buta jira fault line (Tsegaya Abebe 1998). The Wenehi caldera is built up of poorly consolidated ash and tuffs containing pumic and other rock fragements and overlain by trachytes.

Plate 3.2.Volcanic ash on Wenchi Mountain peak

Plate3.3.Scoria cinder cone in Sankole area.

3.2.3 Geological Structures

The area lies in the Yerer-Tullu-Wellel volcao-tectonic lineament zone. According to the conclusion given on the analysis made on the Yerer-Tullu-Wellel volcao-tectonic lineament (by Tsegaye Abebe 1998), four main azimuthal strands which are north east east-west, north west and north south are identified in the region which correlate with the main regional physiographic features of the MER, the southern margin of Gulf of Aden, the Red sea and the Afar Rift (Western margin), respectively. The alignment of the volcanics along the YTVL is strictly linked with the development of the east-west trend and those volcanos are located at the intersections of north west and north east trends.

The north west to south east trending and south east dipping Ambo-Butajira line, along which the geothermal hot springs are alligned relatively youngest structure in age.This structure cuts all the lithost ragraphic secessions in the northern side of the basin.

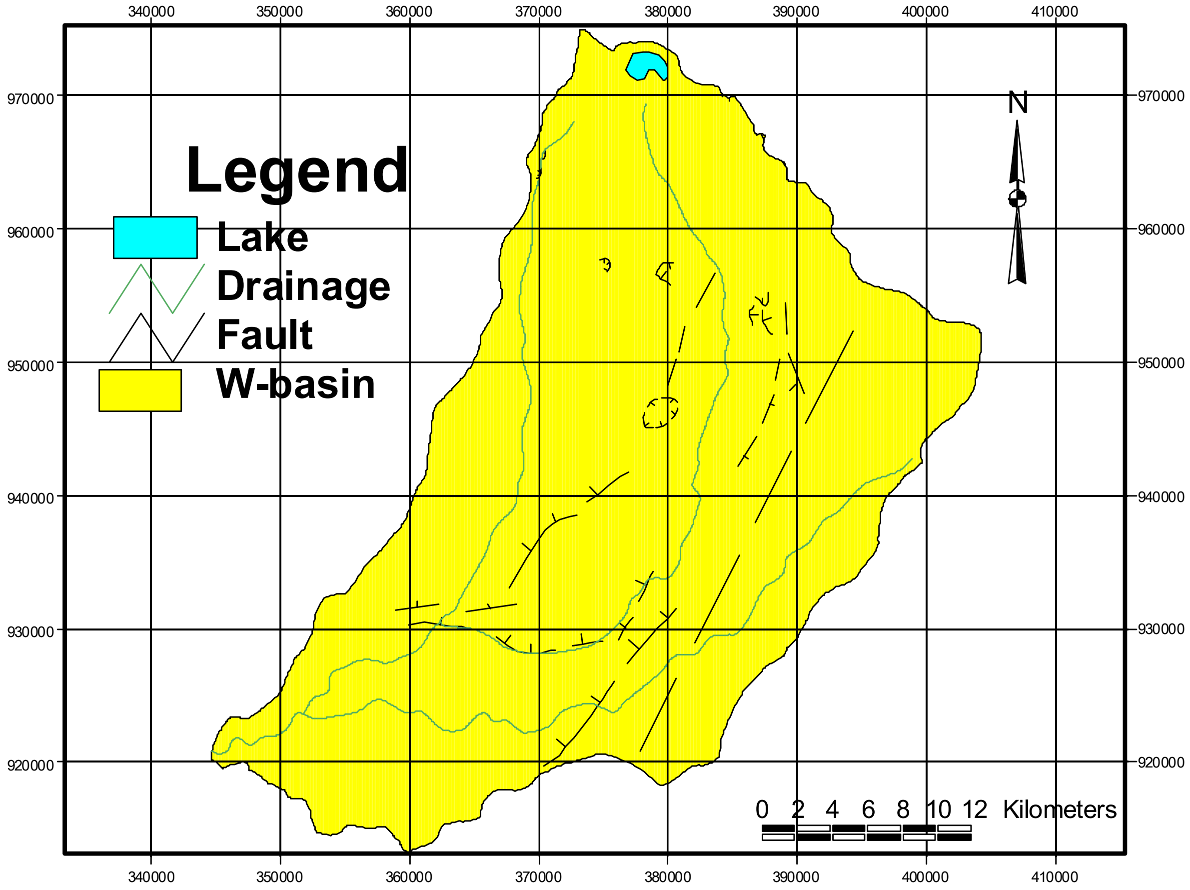


Figure 3.3.Volcano –tectonic lineaments map along Walga River Basin

The volcanic activity is closely related to the development of the structural grain of the region,therefore, the on set age of the upper volcanic sequence (upper Miocene) is considered to reflect the age of the beginning of the tectomic movements responsible for the formation of the YTVL. (Tsegaye Abebe 1998)

In the basin steps of normal faults are thought to cut and down throw the blocks about 500 m with respect to the EVP regional erosional surface (2700m)the oligocen-lower miocen sequence which is considered to belong to the uplifted Ethiopian volcano. This structure is covered by resent quaternary volcanics.

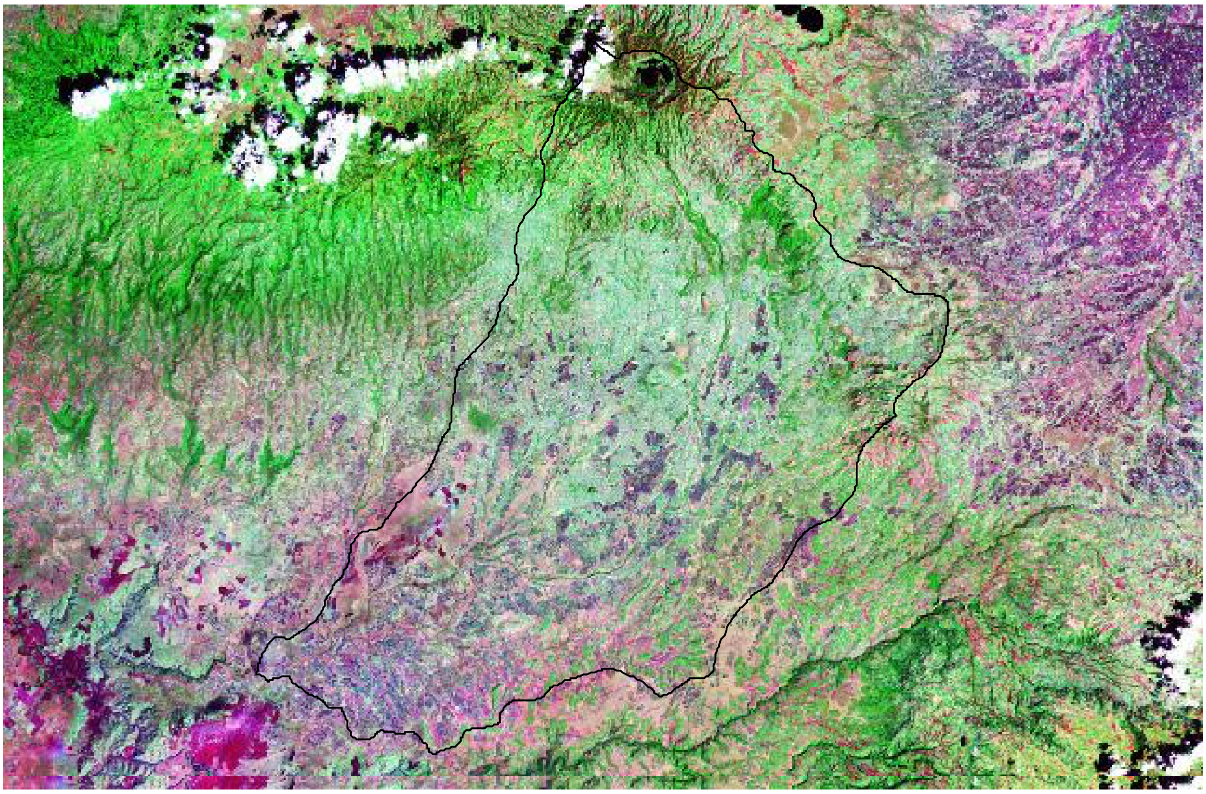


Plate 3.4. False colour composite of Walga Basin

CHAPTER -4

HYDROMETEOROLOGY

4.1. Metrological parameters

The data of eight metrological stations were collected for the study area.Records from1982-2003 have been used supplementing for the missing and non-continuous records. Among the eight stations, two (Ameya & Ghibe farm) out of the basin adjacent to it. The meteorological data collected from different stations include rainfall, temperature, relative humidity, wind speed,duration of sun shine,& Pan evaporation are summarized in table 4.1.with their record period.

Table 4.1.Summary of mean monthly value of metrological data for the study area

No	Parameters	stations	Altitu.	UTM	months													Annual
				East	North	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sep	Oct	No	Dec	
1	**Rain fall**	Woliso	2000	388100	945100	15	30	60	77	111	168	252	278	167	41	11	13	1223
2		Welkite	1550	369600	913800	18	34	66	82	106	165	248	257	152	58	16	10	1212
3		Dilela	2400	395400	952800	18	31	70	68	99	157	255	261	174	71	8	9	1221
4		Daryan	2590	961200	378400	35	41	98	122	148	254	319	350	180	64	15	15	1641
5		Haro Doyo	2590	972050	379000	23	17	69	87	85	198	340	348	167	75	32	10	1451
6		Chitu	2100	951450	381150	25	28	68	79	100	194	313	342	165	31	8	15	1368
7		Ameya/Gindo	1970	362400	947000	25	33	71	85	125	151	256	275	177	68	15	13	1294
8		Gibe farm	1290	343900	910200	14	28	43	51	81	139	219	182	85	39	12	8	901
	Total					173	242	545	651	855	1426	2202	2293	1267	447	117	93	8116
	Av.					21.625	30.25	68.125	81.375	106.88	178.25	275.25	286.625	158.37	55.875	14.625	11.625	1288.88
1	**Sunshin Hour**	Woliso	2000	388100	945100	8.83	10.08	8.03	6.91	7.89	6.81	5.59	3.7	4.15	5.69	8.86	9.8	7.195
1	**Relative humidity**	Woliso	2000	388100	945100	37.6	28	41.6	38.8	48.2	66	76.6	75.6	66.35	44.6	28.8	37.4	49.13
	at 1200 (%)																	
1	**Pan evap.** (mm)	Woliso	2000	388100	945100	199.5	228.34	187.6	181.8	118.5	61..5	36.74	41.7	59.2	99.1	197	231	1641.3
1	**Wind speed (**m/s	Woliso	2000	388100	945100	3.96	4.28	3	2.94	1.28	1.18	0.9	1	0.93	2.44	3.44	3.62	2.23
1	**PET (mm)**	Woliso	2000	388100	945100	103	99	112	104	97	72	57	58	70	103	100	105	1080
1	**Temp.(^{O}C)**	Woliso	2000	388100	945100													
	Max.					26.35	28.15	27.13	27.6	27.23	23.43	21.03	23	23.68	25.58	25.13	25.58	25.32
	Min.					11.98	13.03	13.58	13.65	12.6	12.5	12.44	12.84	12.05	12.04	13	13.15	12.74
	Av.					19.165	20.59	20.355	20.625	19.915	17.965	16.735	17.92	17.865	18.81	19.065	19.365	19.03

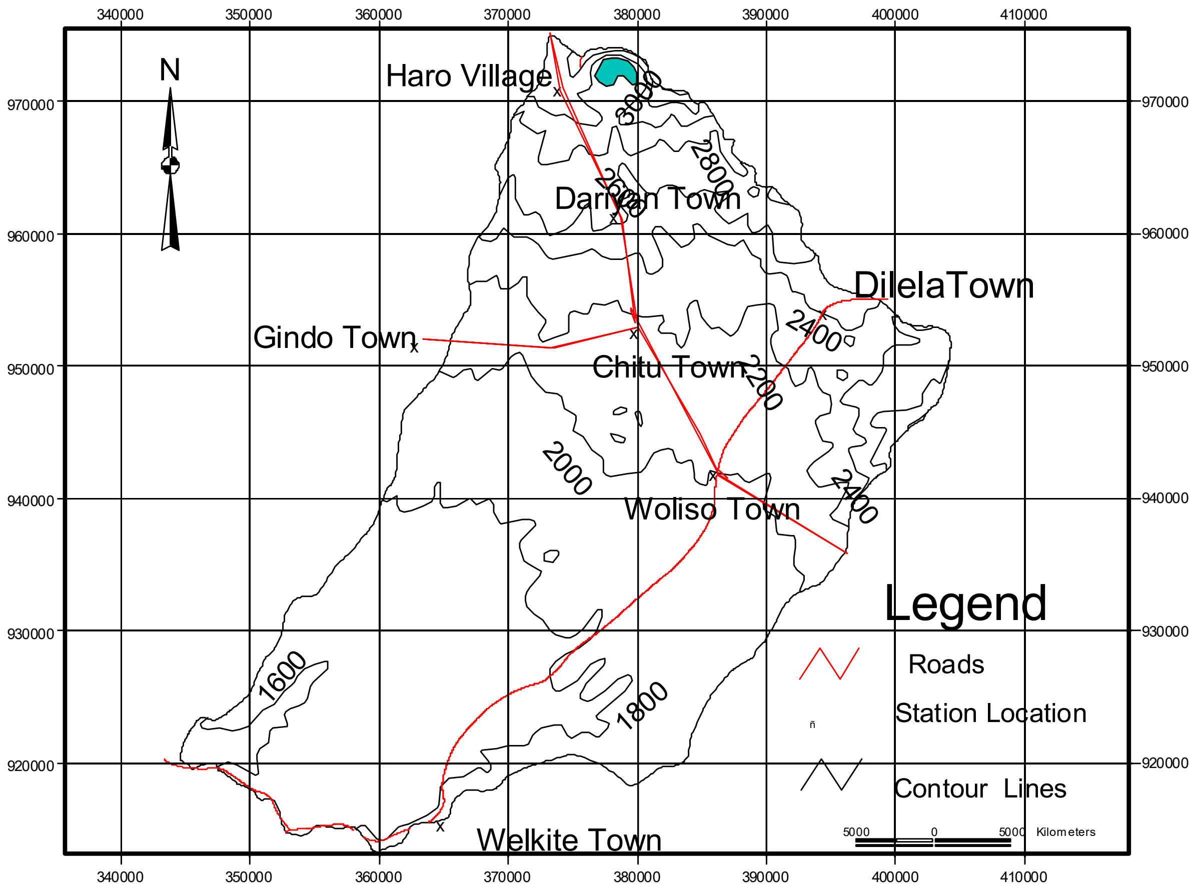


Figure 4.1a. Meteorological Stations in the Walga Basin

4.2 Precipitation Analysis

The study area is found in the tropical regions of central western Ethiopian highland plateau. Therefore, rainfall is the main form of precipitation and the Atlantic equatorial westerly wind is responsible for the formation of rainfall in the area.

4.2.1.Determination of Areal depth of precipitation

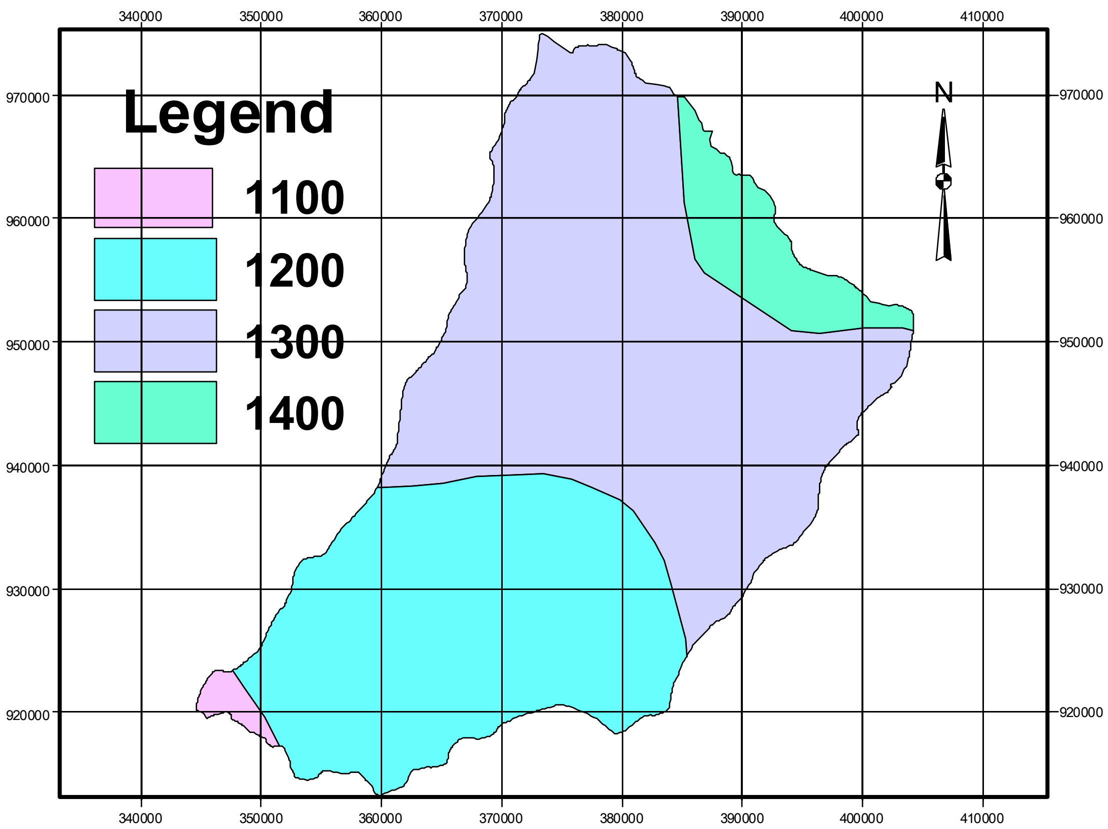
To obtain more reliable annual average representative areal rainfall depth for Walga river basin the isohyetal method is chosen over Arithmetic Mean & Thiessen polygon methods.

This is because of its advantage in considering non-uniform gauge distribution, high variation in record between individual gauging stations & orographic effect. The annual precipitation estimated from this method basin is 1259.912 mm (Figure 4.1. & Table 4.2.).

Table 4.2.Isohytal method of calculating annual rainfall depth in Walge river basin**.**

Isohyetal Range(mm)	Average Isohytal Value (mm)	Enclosed Area in km^2	Weighted area in (%)	Weighted Rainfall (mm)
1050-1150	1100	17.726	9.915	1.092
1150-1250	1200	660.52	36.97	443.6
1250-1350	1300	980.6	55	715
1350-1450	1400	127.904	7.038	100.22
Total		1786.75	100	1259.912

Figure 4.1b. Isohytal map of Walga river basin showing average rainall depth for each region in the basin



4.2.2. Rainfall Characteristics

4.2.2.1. Distribution with time and space

The rain fall in the basin is mainly controlled by altitude and moisture laden wind Direction (Fig 4.1)

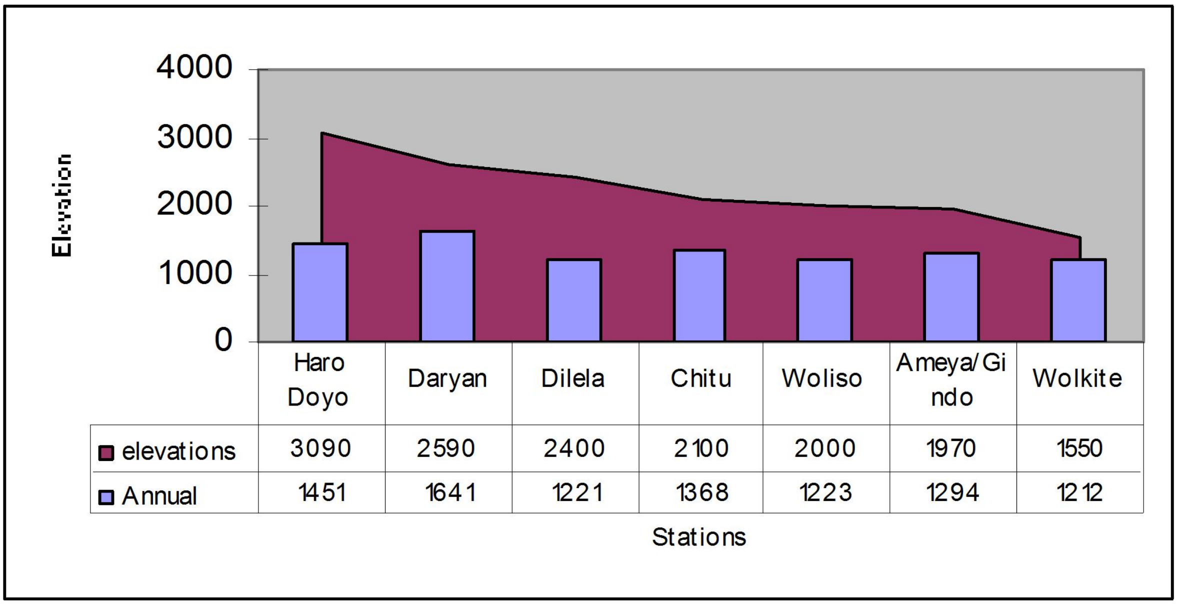


Figure 4.2a.Annual Rain fall plot of different stations

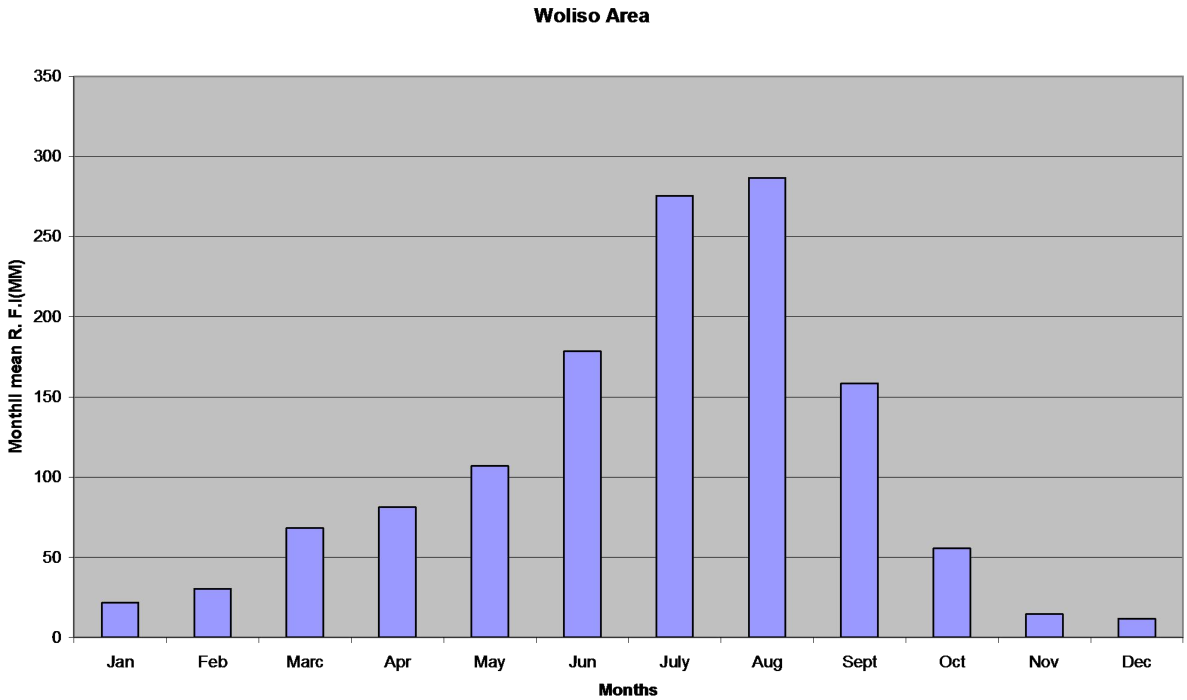


Fig.4.2b. Rain fall Pattern in Weliso area

The northeastern highland parts of the basin around Dariyan and Dilela town receive mean annual rainfall of about 1641 and 1451 respectively with the highest rainfall between July and August. While the south western low land area around Walga town receive about 1000 mm.

The temporal variability in rainfall has brought about two main seasons one dry and one wet in the area.

According to rainfall coefficient (R.C) which is mean monthly rainfall and the other twelve's of the annual mean of the total Rain (Dainel Gemechu ,1977), the seasons are quantitatively classified as follows:

R.C=12pm/pa

Where R.C= rainfall coefficient (unit less)

Pa= annual total rainfall of the area

Pm= mean monthly rainfall

Dry month (R.C < 0.6) : October, November, December, January and February.

Rainy months (R.C. > 0.6): This can be further grouped

Small rain (0.6-0.9) : March and April

Big rain (>1.0).

Moderate concentrations (10.0-1.9): May, June and September

High concentrations (2.0-2.9) : July and August

Very high concentration (>3.0).

Table 4. 3. Mean monthly rainfall (p_m) and Rainfall coefficient (R. C.) for the study area.

months	Jan	Feb	Marc	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
P_m(mm)	21.625	30.25	68.125	81.375	106.88	178.25	275.25	286.625	158.375	55.875	14.625	11.625	761.755
R.C	0.2	0.282	0.634	0.758	1.00	1.66	2.56	2.67	1.474	0.52	0.136	0.11	
	Dry	Dry	Dry	S.R	Moder	Mod	High	High	High	Dry	Dry	Dry	

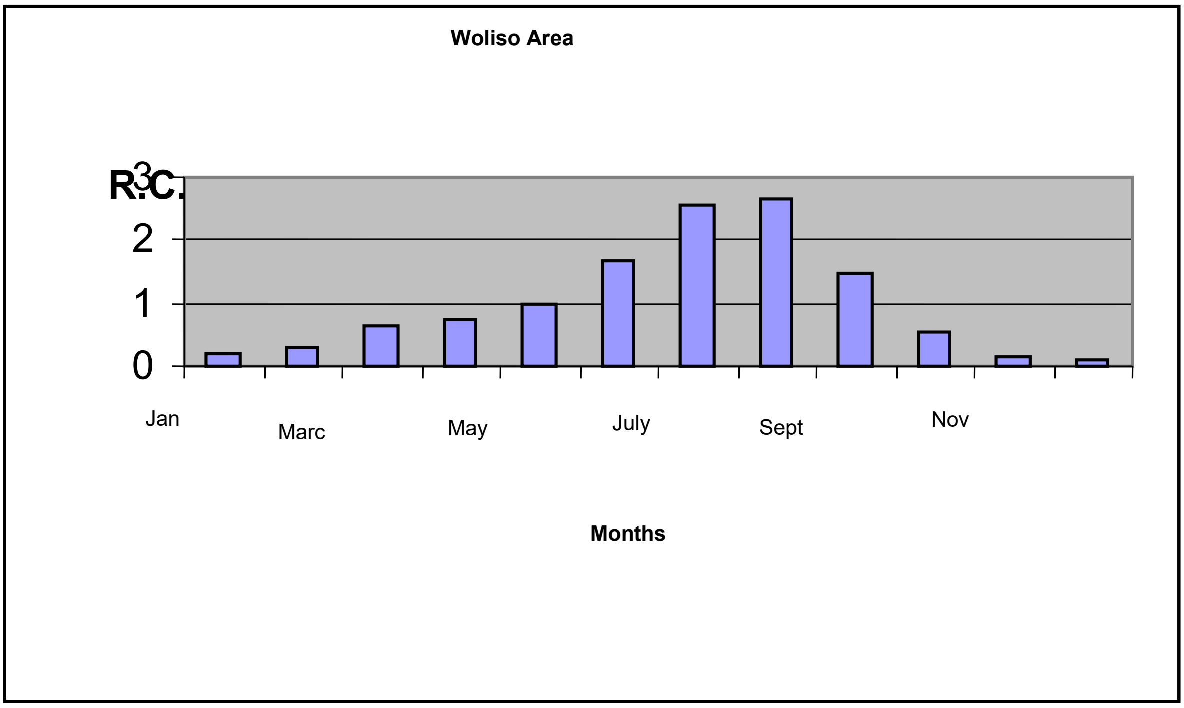


Fig.4.3. Mean monthly rainfall (p_m) and Rainfall coefficient (R. C.) for the study area

4.2.2.2.Rainfall Relations with Altitude

The eight rainfall stations taken for the basin has almost good spatial coverage even though they are unevenly distributed. Therefore, the mean annual rainfall correlation with respective altitude is done to show orgraphic effect. Accordingly, a correlation coefficient of R = 0.42 is obtained . (Table 4-2 and figure 4.2).

The relationship between the altitude and the rainfall in the area indicates for every 100 m change in altitude, there is about 24 mm change in rainfall. Generally, rainfall amount in the basin tends to increase with altitude.

Table 4.4.Elevation & Mean Annual Rain Fall for 8 stations

stations	elevations	Annual Av.R.F
Gibe farm	1290	901
Wolkite	1550	1212
Ameya/Gindo	1970	1294
Woliso	2000	1223
Chitu	2100	1368
Dilela	2400	1221
Daryan	2590	1641
Haro Doyo	3090	1451

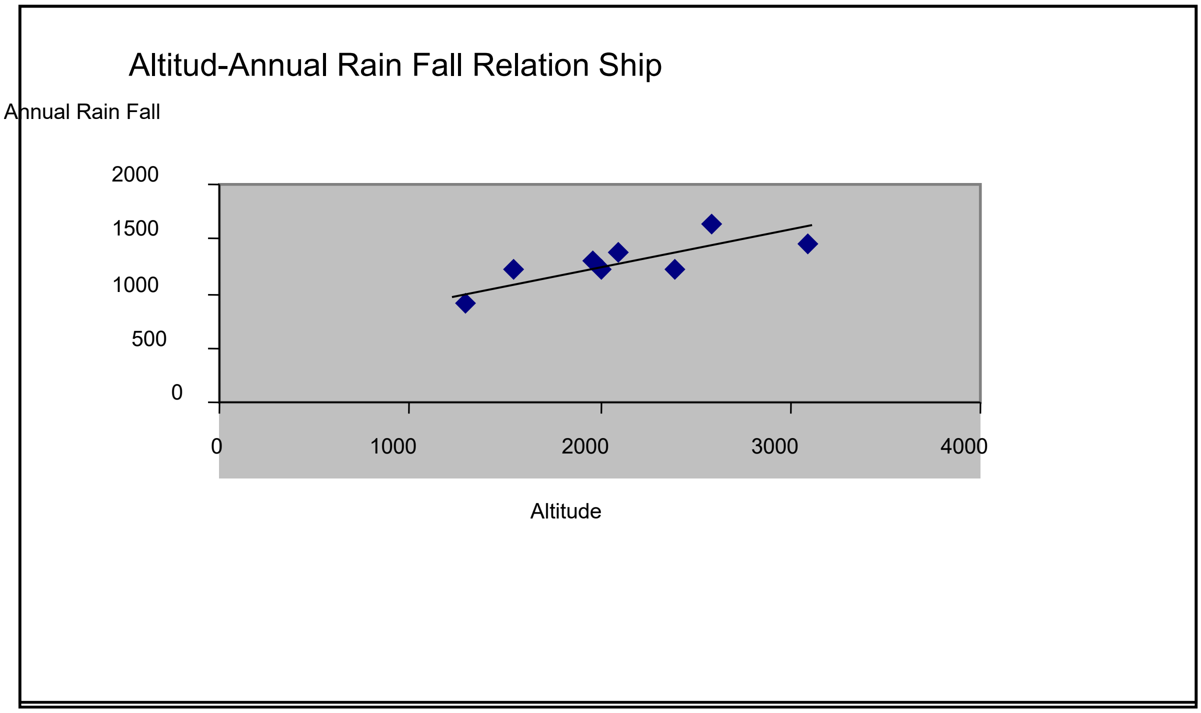


Figure 4.4.Graph of Altitude versus Rain Fall for selected Stations

4.3. Other relevant Meteorological data

Weliso station is the only 1st class having complete metrological data .The data values of mean monthly temperature, relative humidify, wind speed and sunshine hour for Weliso are station summarized table in 4.1 and their inter relationship, specially with rainfall is shown in Figure 4.5 below

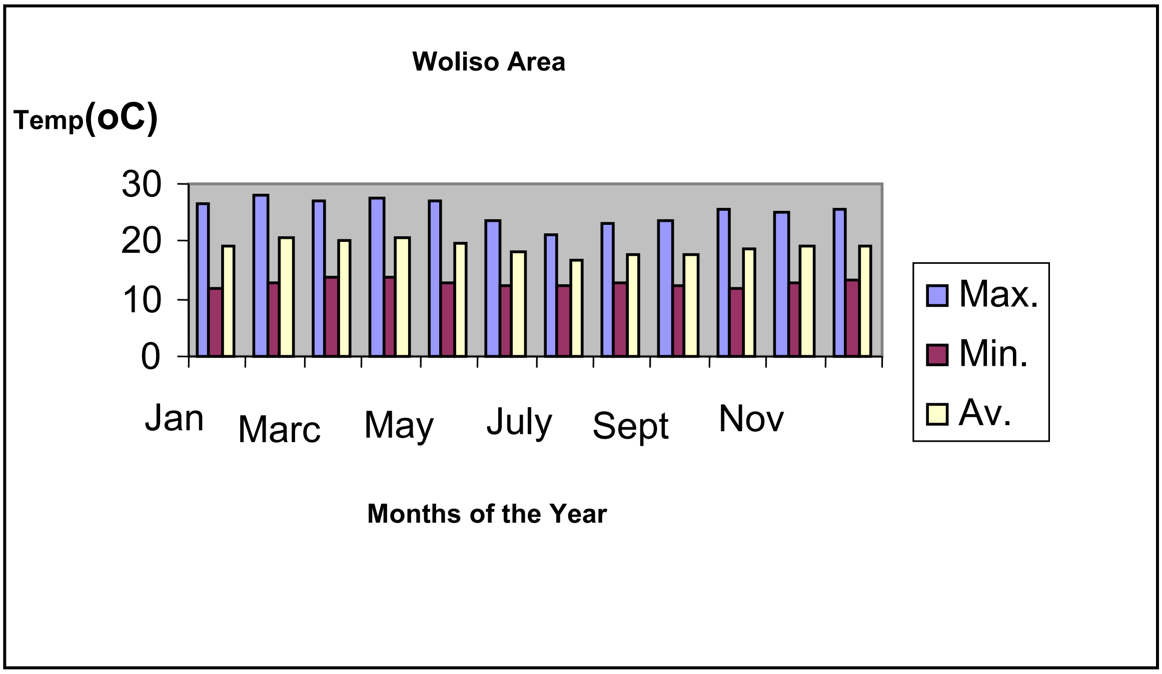
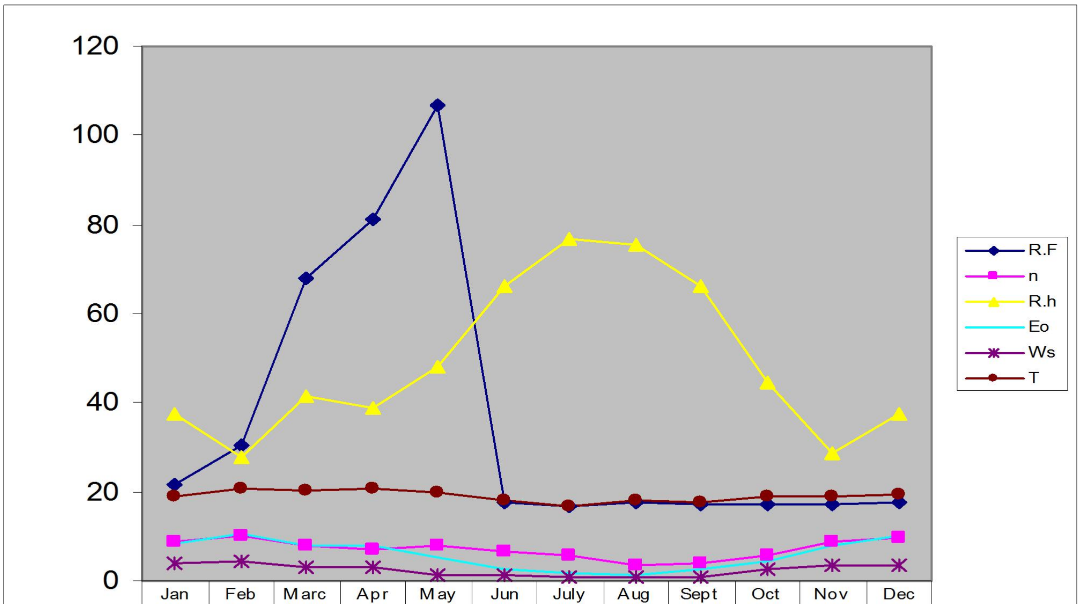


Fig 4.5. Graph of relationship of mean monthly rainfall with temperature in Weliso.

The above graph shows that during high rain fall peak record from July-August low mean monthly sunshine radiation hour, low temperature, low PET, Eo, high wind speed and relative humidity records are observed in the area.



	Jan	Feb	Marc	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
R.F	21.63	30.25	68.13	81.38	106.9	17.5	16.83	17.61	17.22	17.38	17.27	17.77
n	8.83	10.08	8.03	6.91	7.89	6.81	5.59	3.7	4.15	5.69	8.86	9.8
R.h	37.6	28	41.6	38.8	48.2	66	76.6	75.6	66.35	44.6	28.8	37.4
Eo	8.58	10.5	8.07	8.08	5.1	2.73	1.58	1.36	2.63	4.26	8.08	9.94
Ws	3.96	4.28	3	2.94	1.28	1.18	0.9	1	0.93	2.44	3.44	3.62
T	19.17	20.59	20.36	20.63	19.92	17.97	16.74	17.92	17.87	18.81	19.07	19.37

Figure 4.6. Relation ship between ra infall & Other Meteorological parameters in Woliso

4. 4. Estimation of Potential Evapotranspiration, PET

Eventhough there are different formulae for calculating evaporanspiration, for the purpose of this research work penman combined method is used. This is because of the limited data available and penman method gives more reliable result by considering different factors affecting evapotranspiration and also the method is preferable in tropical regions like the study area (Heopold and Qunner, 1978).

Penman Method :- combines the energy balance and the mass transfer methods:

$PET = (AH_n + E_a\gamma)/ (A+\gamma)$

Where: PET = daily potential Evapotranspiration in mm/day

A = Slope of saturation vaopor pressure versus temperature curve, in m Mercury/ ^{0}C

H_n = Net radiation in mm of evaporable water per day

E_a = Mass transfer evaporation

γ = Psychometric constant = 0.49 mm Hg/ ^{0}C

$H_n = H (1-r) (a + bn/N) – \delta T_a^4 (0.10 + 0.90 n/N)(0.56-0.09H$

a = a constant depending up on the latitude Φ, and is given by a = 0.29 cos Φ, For the study area Φ = 9^0 00'00' N; Hence, a = 0.29 x cos 9^0 – 0.28643 $\sqrt{e_d}$)

b = a constant with an average value of 0.52.

n = actual duration of bright sunshine in hours

N= Maximum possible hours of bright sun shine (it is the function of latitude)

δ= Stefan-Boltzman constant = 2.01 x 10^{-9} mm/day.

T_a = Mean air temperature in degrees Kelvin

HA = incident solar radiation out side the atmosphere on a horizontal surface, expressed in mm of evaporable water per day. it varies with latitude and period of the year.

r = reflection coefficient (albedo), usually varies between 0.15 – 0.25 for bare land & , 0.05– 0.45 for sparcely , and 0.05 densely vegetated areas.A reflection coefficient of 0.35 is taken for the study area as high vegetation density is only on top of Wenchi mountain.

$E_a = 0.35 (1+U2/160) (e_w-e_a)$

E_w = saturation vapor pressure at mean air temperature in mm Hg

E_a = actual vapor pressure

U_2 = Mean wind speed at two meter above ground in Km/day.

Table 4.5. Potential Evapotranspiration PET (mm/moth) values for woliso area using penman method

Moths	Jan	Feb	March	April	May	Jun	July	Aug	Sp	Oc	No	Dec.	Annual
PET	103	99	112	104	97	72	57	58	70	103	100	105	1080

4. 5. Actual Evapotranspiration (AET)

Turc method

To estimate the real evapotranspiration that takes place under the existing This method estimates the mean annual Actual Evapotranspiration, AET , of a river basin directly from precipitation and temperature by an empirical formula .It could be applied in humid or arid climates, either hot or cold, Shaw (1988).

It is given by the formula:

$$AET = (P)/(\sqrt{[0.9 +(p/L)^2]})$$

Where AET= Actual Evapotranspiration of a year in mm

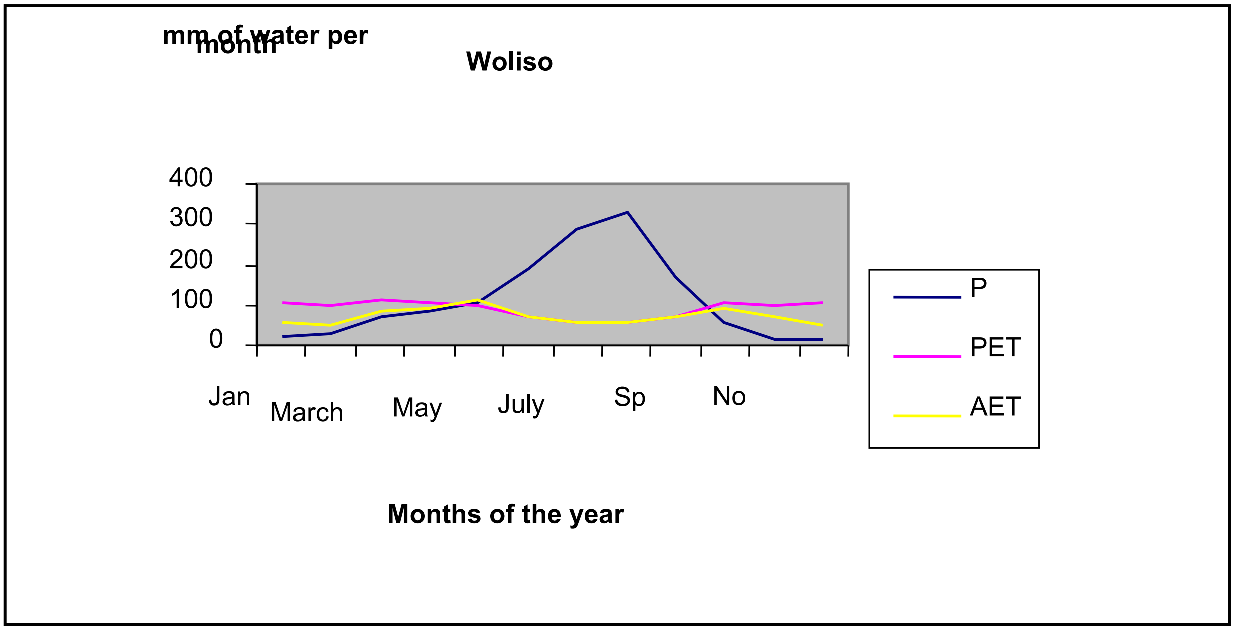
P = annual mean precipitation in mm=1259.921

T = annual mean air temperature in °c=19.03

$L = 300 + 25T + 0.05T^3$ in mm=1120.33

Therefore,AET is calculated to be 853.6

Figure 4.7. Comparison of precipitation (p), potential alevapotranspiration (PET) and Actual evaporation in Woliso area showing coarse soil with limited soil moisture storage ,warm dry summar & cool,moist winters.



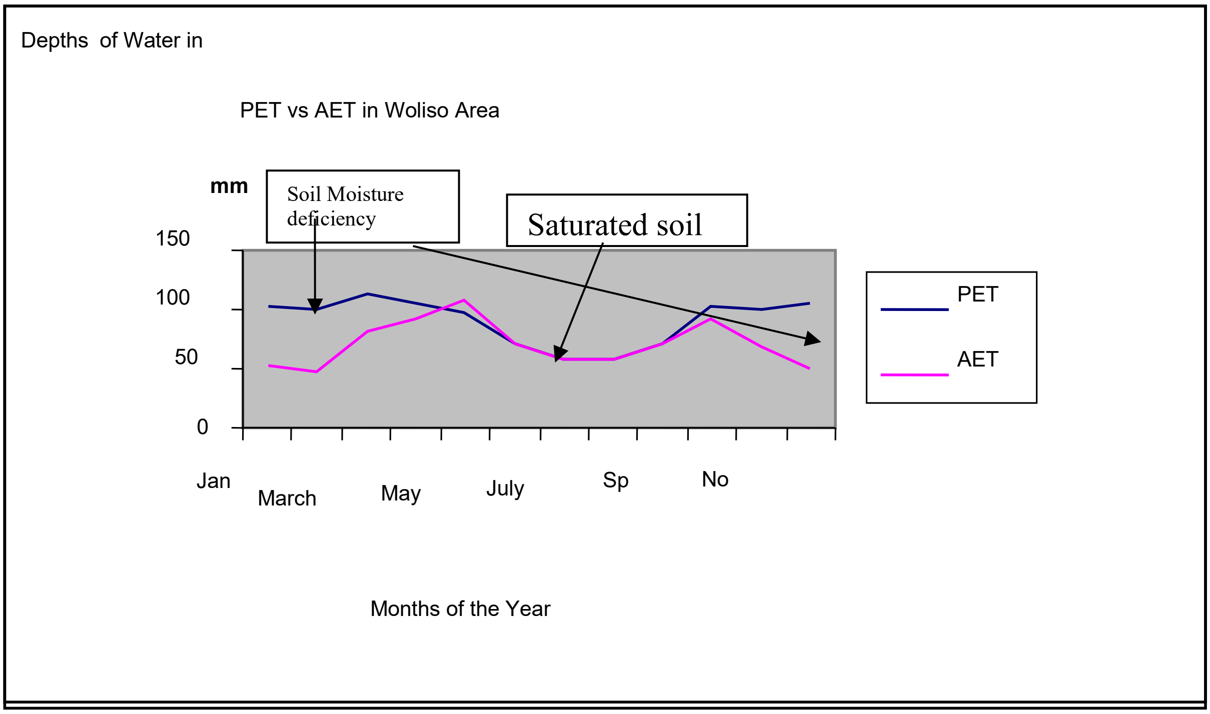


Figure 4.8. Graph of PET vs AET Showing Soil moisture in Woliso area.

4.6. Lake water evaporation

Pan evaporation method

Pan evaporation method is used to estimate the evaporation from lake Wenchi. Previous study by Seifu Kebede (1999) shows a pan coefficient between 0.75 and 0.85 is usually to be taken for open water evaporation of Ethiopian Rift. For crater lakes in Bishoftu area ,he used a pan coefficient of 0.79 by reasoning out that crater lakes are more protected from wind effect as compared to other lakes.

Accordingly,using Pan evaporation data(shown in table 4.1) for Wenchi area & normalizing it with a pan coefficient of 0.75 to account for moderate turbulence as it is partly protected from wind & difference in heat storage capacity between the pan & the lake as well as the difference of the lake's location on the plateau to the crater lakes of the Ethiopian rift (the result is tabulated in table-4 below).

Therefore,thye following formula that is developed based on the law of Dalton & on the assumption of the same constant C & wind functions for the pan & the lake ,

$$Epan=c(esp-ea)(1+0.25u)$$

$$Elake=c(esl-ea)(1+0.25u)$$

Where,

ea=actual vapour pressure

esp=saturated vapour pressure at water temperature in the pan

esl= saturated vapour pressure at water temperature in the lake

u=wind speed in m/s

c=constant

$$Elake=\frac{esl-ea}{esp-ea}Epan=c \times Epan$$

Table 4.6 Summary of Wenchi lake water evaporation using pan evaporation method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oc	No	De	Total
evaporation(mm)	199.5	228.34	187.6	181.8	118.5	61..5	36.74	41.7	59.2	99.1	197	231	1641.3

4.7. Surface Hydrology

4.7.1.Stream Discharge records , Base flow, run off coefficient and run off depth

Walega, Rebu and Ejersa are the major perennial streams in the basin. Walaga drains almost all the basin emerging from northern high land areas (Wenchi Mountain).The central and eastern parts of the basin are drained by Ejersa and Rebru rivers.

The main drainage pattern in the area is dendritic, while still parallel drainage patterns are common in highland mountain sides. The catchments has a fourth order river network. Narrow channel, deep stream cuts are observed in the pyroclastic covered areas of Wenchi.

Fifteen years (1971-1984) records of walega river gauge water levels are collected from Ministry of water resources.

The monthly minimum discharge is the best approximation of base flow, especially, for humid climate(Wundt,1978).Therefore, subtracting monthly minimum stream flow as a beseflow from the monthly total gives us overland flow component.

Table 4.7. Run of Coefficient (RC) Calculated for Walga Basin from catchment hydrologic data

Gauging station	Area $(km)^2$	Annual Precipitation(Mm3)	Total annual runoff($Mm^{3)}$	R.c
Walga at	1786.75	2251.16	404.597	0.17973

walaga				

This indicates about 18% of the precipitation component is lost from the catchments through runoff which is controlled by lithology, structures, physiography, vegetation, land use, climate, and soil type.The run off depth is calculated to be:

Ro=RcxPA

Where,

R.c.= Run of coefficient

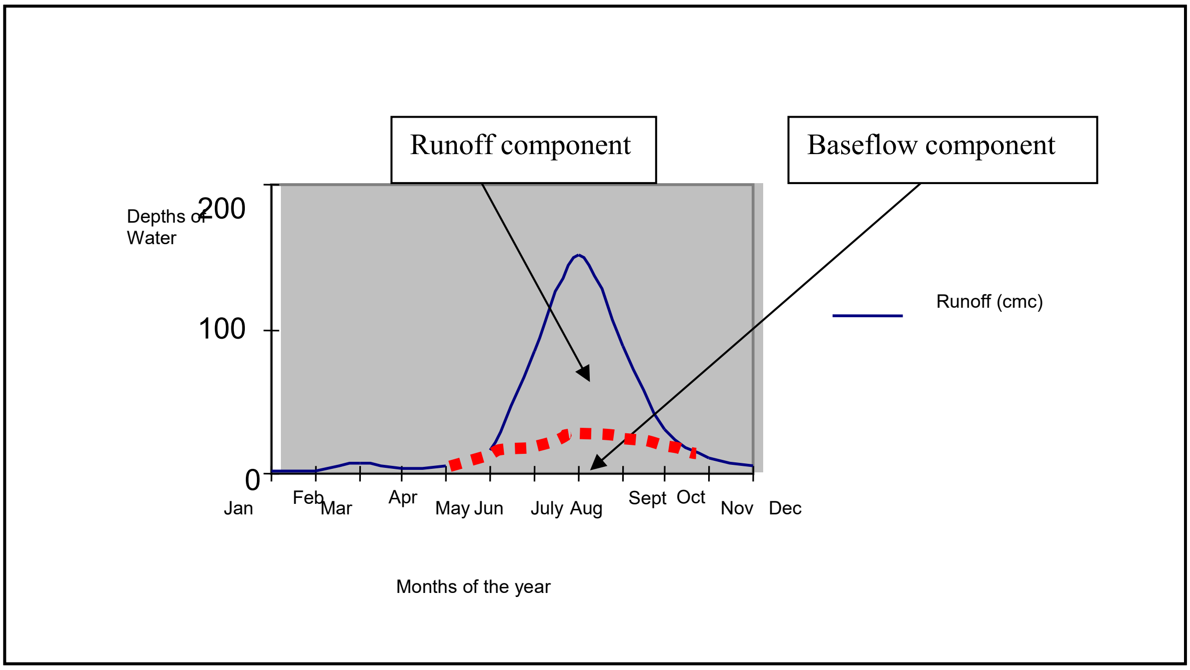
P= annual Precipitation=2251.16 Mm^3=1259.921mm

A= drainage area=1786.75 $(km)^2$

Ro=runoff depth in mm/hr =404.597mcm=226.45mm

The discharge of the river increases downwards showing the control of the the geological structures and other hydrogeological facors over the flow of the stream.

Figure 4.8. Flow nature of Walga River through out the year



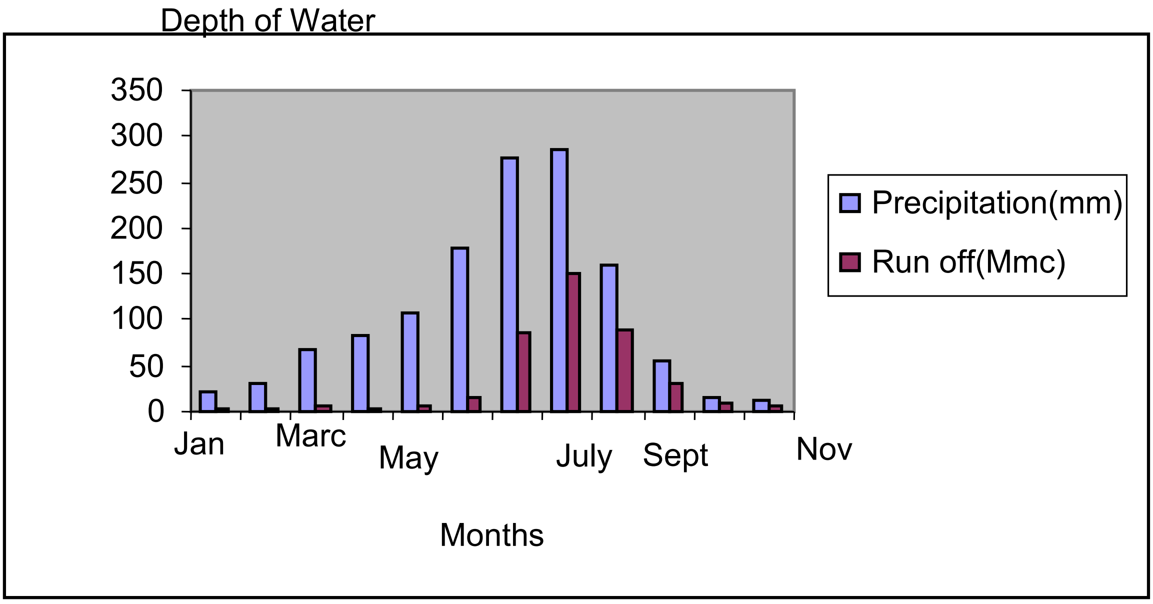
4.7.2..Runoff-Rainfall relationship

From hydrograph of the Walga river in figure 4.8 above & figure 4.9 below showing the relationship of the basin rainfall & runoff,in the basin the time of maximum precipitin and runoff coincides showing high peak during high rainy month & steep recession soon after rain stops.This good temporal correlation & fast responding hydrogeological characterstics of the basin could mean that the area is either almost impermeable or full saturated with ground water which prohibit rain fall from entering in to the ground . But in the case of Walga basin, eventhough spatially there are lithologies of low permeability, from consistent groundwater recession with perennial annual flow & increase of river discharge down stream during dry season,it could be taken as shallow saturated ground water flow system controlled by faults is rather feeding the stream .The other possible reason for fast recession could be the upstream diversion of the stream for irrigation purposes.Generally, about 18 percent of the total amount of rain leaves out the basin in the form of surface runoff.

Parameter	Jan	Feb	Marc	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Precipitation(mm)	21.625	30.25	68.125	81.38	106.88	178.3	275.25	286.63	158.38	55.575	14.625	11.63
Run off(mcm)	1.762	1.579	7.197	3.167	5.221	15.37	85.229	150.62	88.832	30.446	10.1	5.071

AnnualRunoff =404.594mcm

Figure 4.8. Relationship between surface runoff and precipitation



4. 7.Lake

Wenchi crater lake is another surface water body found in the northern highland part of the basin. It is a surface reservoir with no visible surface outlet during winter time.It is accessible both from Woliso & Ambo by gravel road of about 27 & 37 km respectively.Totally it is about 131km away from Addis Ababa through Woliso.Previously ,no detail scientific studies were carried out on the basin.At present the lake is visited by tourists & some Silvicultural activities like fishery is under training by Ambo Agricultural college.The geomorphometric characterstics of the lake is given under chapter 2.4 & the deails of the lake water balance is discussed in chapter 7.3 as well its chemisty is also discussed in hydrochemistry part with some ecological concerns about sedimentation due to land use/land cover change in cnclusion.Otherwise , the lake needs detail study for its important contribution in the development of the area both in ecoptourism & other development areas related to Water resource.

CHAPTER- 5

HYDROGEOLOGY

5.1 General

Hydrogeology can be defined as the study of ground water with particular emphasis given to its chemistry, mode of migration and relation to the geological environment. (Davis, 1996).

Hence, in any comprehensive water resources evaluation, hydrogeological investigation is very important to provide information on:

- Aquifer characteristics (storage, transmissivity) their lateral and vertical extent and the confining condition.
- Hydrologic system of the basin
- Water pollution risk & Ground water potential (depth to water table and productivity of wells)
- Economic and technical aspects concerning the methods of ground water development.
- Identification and selection of alternative development schemes between different schemes of competitive water use (community, irrigation & industry etc.)
- Water and land resources planning

But,in this very chapter only the identification of hydrostratigraphic units & characterization of aquifers is discussed.

5.2 . HYDROSTATIGRAPHIC UNITS & AQUIFER CHARACTERIZATION

Classification of the Cenozoic volcanic rock units & their weathering products in the basin is made based on their hydraulic character (permeablility-storativity), considerations of the recorded yield, areal extent, topographic features and availability of recharge, thickness of lava flows, fracture characteristics and thickness of clay mantle are taken.

Based on the above considerations, the volcanics have generally fractured and intergranular aquifer systems having regional continuity in ground water reservoir characterized by basin wide ground waterflow.

Therefore, three mappable scale lithostratigraphic groups of vocanic rock units in the basin are identified and mapped as three aquifer systems characterized by similar water yielding properties of hydrogeologic importance (figur 5.1).

high permeability

- lava basaltic lava flows inter bedded with pyroclastics
- the Sand sized Pyrocalstics of Wonchi & Scoria ,
- Alluvial soils

Moderate permeability

- the ash dominated pyroclastic deposits of wenchi

Low Permeability

- Trachy-rhyolite lava flows

Figure 5.1.Major Hydrostratigraphic units in Walga Basin

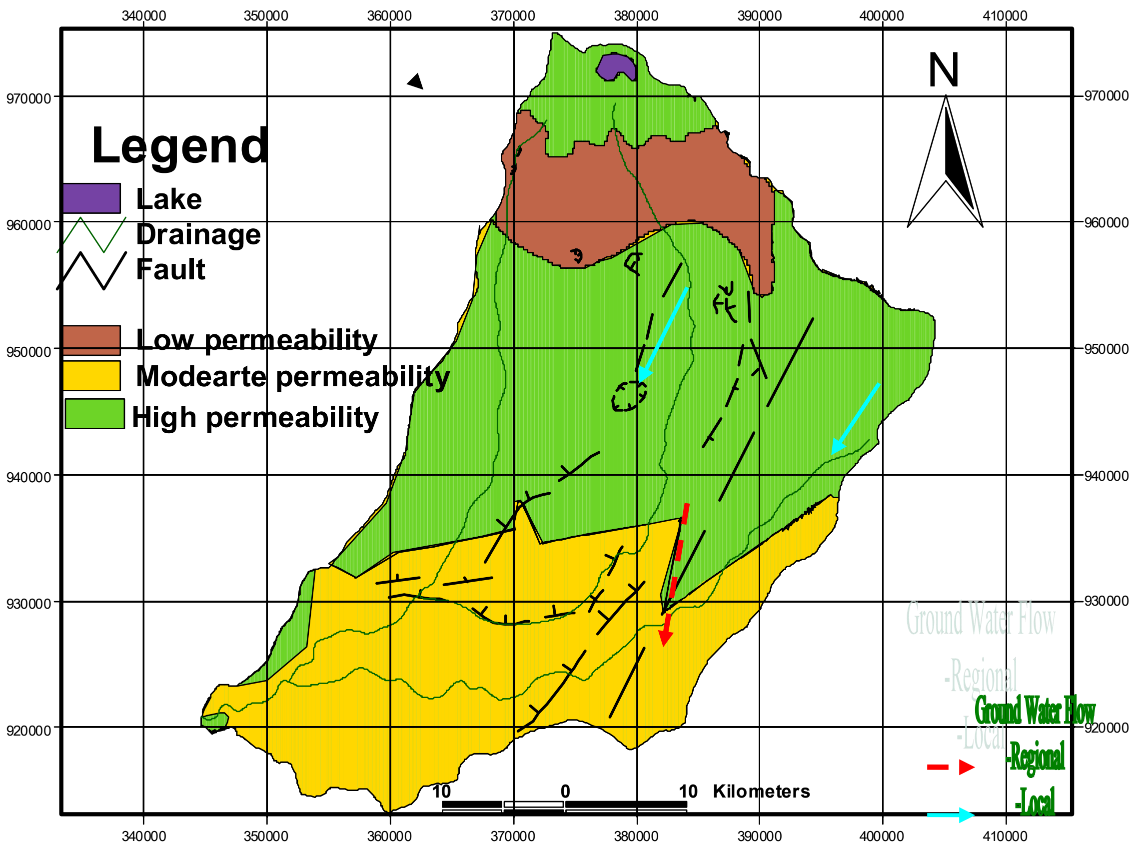


Figure 5.2.Aquifer systems Of the Walga Basin

5.2.1.High permeability aquifer systems

Lower basaltic lava flows

This basaltic flow is the oldest volcanic succession in the region and is unconformably underlain by crystalline basement and uncomfortably overlain by other younger volcanics.

They outcrop in the lower part of the basin around Walga town. Their thickness is not known since they are not completely penetrated by drilling but thought to be about 400m as inferred from regional geology They contain columnar jointing and covered by top soil up to 20 m in some places. The average thickness of individual lava flow reaches up to 60m.

During drilling some minor rhyolite & trachyte, tuff and ignimbrite are encountered in this basic succession. A borehole around Walga produce water from weathered and fractured basalt of the aquifer.

High degree of weathering and fracturing is observed from geological log as well as vertical and lateral permeability's can be favored by columnar jointing and inter lava flows. Even though, the area gets about 1259mm annual rainfall, the climate favors evapotranspiration rather than infiltration. Therefore, the media gets its large amount of groundwater from regional inflow.

The water point inventory data from springs, hand dug wells and deep bore holes sunk in the basalt have yields 0.5-15 l/sec. Transmissivity values range from 0.67-200 m^2 /day .The optimum depth of the drilling for this media range from 40-100 (depending on expected yield and available recharge to the aquifer).

Table 5.1 Geological well log around Walge town in lower basalt

Depth	**Description**
0-2m	Black clay soil
2-12m	Dark gray, fine grained, fair to moderately weathered and fractured volcanic rock (basaltic in composition)
12-14m	Grayish brown, fine grained, fairly weathered and moderately fractured volcanic rock (basaltic in composition)
14-32m	Grayish dark, aphanitic, fairly weathered and moderately fractured volcanic rock (basaltic in composition)
32-44m	Grayish dark, aphanitic, fairly weathered and moderately fractured volcanic rock (basaltic in composition) SWL=-32.4m below ground level
44-56m	Grayish dark, aphanitic, fairly weathered and slightly factured volcanic rock
56-62m	Grayish dark, aphanitic, fairly weathered and fairly fractured volcanic rock with fine gravel
62-64m	Volcanic ash
64-66m	Paleosol
66-68m	Massive basalt
68-72m	Gravel formed from basalt

72-74m Volcnic ash

74-78m Highly weathered basalt

76-78m slightly weathered and moderately fractured basalt

78-88m Slightly weathered and moderately fractured basalt with gravel and clay intercalation

88-92m Highly weathered scoria

92-94m Volcanic ash

94-104m Highly weathered ignimbrite

The upper basaltic flows , alluvial covers and scoria domes

This unit consists basaltic lava flows and scoria deposits that have spread from the central volcanic complexes. This hydrostratigrapic unit covers areas around and north west of Woliso down from Senkole.

Large quantity of water is obtained from this aquifer depending on the depth of penetration. The main aquifer is encountered below 60m after massive basalt confining layer forming piziometric water level of about 2.5 m above ground surface in Weliso area. A yield of more than 10 l/s and transmissivity value of about 5.4m^2 /day is calculated for Weliso Borhole in this unit.

In addition, the upper part of Wenchi mountain has high permeability aquifer property as well the low lying alluvials are identified under this group.

Table 5.2. Geological well log of Woliso police station borehole

Depth (m)	Litho logic description
0-2	Black cotton soil (clab), SWL= +2m above ground level
2-3	Thin scoria (Wealthered)
3-6	Very slightly jointed basalt
6-12	Massive basalt
12-14	Brownish grey volcanic ash
14-16	Red clay soil (? Weathered scoria)
16-18	Fractured basalt
18-24	Volcanic ash
26-30	Slightly weathered and fractured basalt

26-30	Massive basalt
30-32	Red clay (? Weathered scoria)
32-34	Weathered and jointed basalt
34-58	Massive basalt
58-66	Scoria
66-68	Basalt
68-72	Fractured basalt
72-74	Weathered and fractured scoria
74-80	Massive basalt
80-86	Scoria
86-87	Scoria
87-90	Slightly fractured basalt
90-92	Volcanic ash
92-96	Basalt
96-98	Scoria
98-106	Scoria
106-1086	Basalt

Table 5.3.Summary of Pumping test data analysis result using using Jacob method for Woliso and Walga Boreholes

No	Locality	Well depth (m)	piziometric water level(m)	dumping water level (m)	Q (l/s)	Sc(m^2/d)	T (M^2/d)	K (m/d)
1	Woliso	108.6	+2.25	78.04	12	0.066	5.374	0.298
2	Walga	104	-32.4	54	5	0.132	8.97	0.4

5.2.2.Moderate permeability aquifer systems

1. Pyroclastics of Wenchi

The Wenchi crater lake area is covered by this unit that have erupted from the central shield volcanoes type. The unit consists of ash and tuff deposits at the top & trachy-rhyolite base.

The primary aquifers are sandy pyroclastic deposits interbedded with massive trachy-rhyolitic horizon. These aquifers are encountered after 40m and the piziometric water level are greater than 60m below ground level. The yield is about 3 l/s and high draw down is registered. But almost all the perennial streams in the basin originate from base of this unit. Also many springs emerge from this unit at the base of the mountains. It has good recharge and low evaporanspiration the top sandy soil and the recent structures give it high infiltration rate.

Therefore, ground water development in this unit is possible with reasonable penetration (150-200m) depth and proper well site selection (on fractured areas) . Multilayer aquifers are common in most part of the basin because of lava flows intercalation with the pyroclastics. In the upper Dariyan case the shallow unconfined part (37-43m) and the deep confined aquifers (91-96m) and 116-163 m of three aquifers are stricken.

Table 5.4 Geological log in Dariyan BH

Depth	Lithologic description
0-1	Redclay
1-12	Redih sticky clay
12-37	Weathered ignimbrite
37-43	Weathered ignimbrite
43-82	Weathered ignimbrite SWL=60m b.g.l
82-91	Trachytic basalt
91-96	Trachytic (high weathered)
96-116	Trachytic basalt
116-133	Volcanic ash
133-163	Trachytic

5.2.3.Low permeability aquifer systems

Trachy-Rhyolitic lava flows

This rock unit includes trachyte, rhyolite, ignimbrite, tuff, (in the upper base) with minor basic basaltic flows. They crop out southeast of Woliso up to welkite. They unconformablely overlay the lower basalt.

Pyroclastics intercalated with lava flows form the aquifer system. The thickness of this unit decreases down ward in the basin. Soil cover the plain part up to 40m cover.

Because of the pyroclastic (volcanic sand) intercalation with Lava flows, the yield can go up to 10 liter/second and transmissivities up to 0-100 m^2 /day. Large quantity water can be exploited with in a reasonable depth of 100-150m. The piziometric water level comes up to

(7-14m below ground level). This may be because of high recharge area and confining property of the Lava flows.

Table 5.5.Geological log around welkite

Depth (m)	Litho logic description
0-2m	Black cotton soil (clay)
2-9m	Highly weathered ignimbrite
9-11	Sand (fine to medium)
11-12	Weathered ignimbrite
12-15	Sand (fine to medium)
15-20	Weathered ignimbrite
20-29	Slightly weathered basalt
29-31	Clay
31-41	Slightly weathered basalt
41-48	Brown clay (?ash)
48-52	Slightly weathered basalt
52-59	Weathered basalt
59-65	Slightly weathered basalt
65-66	Fresh basalt
66-69	Dark grey clay (? Ash)

CHAPTER- 6

HYDROCHEMISTRY

6.1 General

Hydrogeochemical investigations have great importance in ground water resource potential study of a basin. It provides information about:

-The interaction between water and geological materials or the environment

-Different geochemical processes controlling ground water chemical evolution

-The origin of different water bodies (both surface and subsurface)

-Ground water flow conditions

-anthropogenic effect on water
-quality of the water and its suitability for a specific use (domestic, irrigation , industry, etc).

The main purpose of using hydrochemical investigations in this research is to discriminate the origin of different water bodies and to understand the ground water dynamics .The information is used also to establish conceptual groundwater flow model of the basin. Different methods that have been used to achieve this objective include:
-analysis of geochemical data using aquachem software for hydrochemical facies differentiation.
-Geochemical modeling to reach at a conclusive insite on possible source of some constituents and ground water geochemical evolution.

Table 6.1. Chemical Analysis result of Waters from Walga Basin

terSource	UTM N	UTM E	AL	Locality	pH	T	TDS	K+	Na+	Mg++	Ca++	HCO_{3-}	CO_3	$SO_{4=}$	Cl-	F-	NO_3=
HDW	955000	395000	2430	Dilela , HDW	7.83	24	722	5.08	34.39	15.07	30.46	201.37	0	8.17	20.92	0	0
HDW	923250	366750	1720	Rebu , HDW	8.35	23.3	348.1	7.2	132.6	3.814	8	213.5	60	12	10	0.74	2.8
HDW	920700	374700	1525	Walga T., HDW	8.46	20.2	696	14.86	117.71	35.48	12.83	271.54	33	115.27	31.91	0	0
BH	951450	381150	2100	Chitu T., BH	6.4	22.5	180.9	3.4	4.86	7.2	28	103.7	48	1	0.6	0	0
BH	961400	378400	2580	Dariyan 1, BH	6.71	19.1	160	23	9.8	12	28	54.9	24	1	0.4	0.67	11
BH	95600	38200	210	Sankole , BH	7.8	20.	214	20	16.05	45	135	118	0	28.5	0	0.7	0.8

	0	0	0		4	2										6	
BH	942800	384350	2020	Waliso PS, BH	8.13	16.2	259.6	3.5	113.25	1.44	12	164.7	72	4	1	1.36	5.28
BH	938500	392200	2040	Weranan , BH	6.91	24	89	5	55.8	24	34	70	0	3	2	0.52	1.5
BH	932600	381000	1920	Gurura , BH	8.12	21.3	296	5.47	9.43	7.05	33.27	186.11	0	12.09	7.09	0	0
BH	928389	375286	1940	Goro, BH	6.8	31.1	242	8.6	18.2	4.9	28.9	176.9	0.1	3.2	1.5	0	0
BH	915860	369097	1865	Wolkite 1, BH	7.2	23.3	241	7.6	19.4	5.2	24.2	181	0.2	1	0.8	1	0.5
C.Spring	951750	363000	2000	Gindo T, CSP	6.7	25.8	232	2.97	7.48	10.7	19.2	122	0	0	6	0.06	1.11
C. Spring	961200	378400	2580	Dariyan , CSP	7.74	20.4	212	6.65	2.76	2.19	8.42	67.12	0	14.41	8.51	0	0
C. Spring	949750	382750	2080	Chitu , CSP	6.16	22	204	3.4	63.1	0.48	15.6	115.9	60	1	5	19.6	9.24
Th. Spring	969696	376889	3090	Wonchi, TSP	7.1	32.8	1419	19.8	348.4	1.3	4.1	856.4	0.8	0.1	40.1	6.3	0
Th. Spring	943265	387830	2020	Wolisol, TSP	7.12	41.3	1079	11.9	262.3	0	1.6	732	2.7	0.1	39.2	26.6	2.3
R. Walga	947000	383550	2040	Waliso 2, WR	7.94	21.2	198	2.74	7.82	4.62	10.82	183.06	0	7.69	9.22	0	0
R. Rebu	941200	389150	1789	Waliso 3, RR	7.89	15.5	280.4	61	5	0.48	15.2	67.1	24	1	0.8	0.11	8.36
Lake	971492	4E+05	2890	Wonchi 2, L	8.23	16.2	107	9.839	18.38	2.4	11.2	120.8	0	0	8	1.02	6.16

6.2 Water sample collection and Analysis

During this study fourteen water samples were collected in the field from different water bodies. Additional five The deep circulation of the recharging water may also be related with the northwest- southeast oriented fractures that are supposed to form the youngest scoria cinder cones in the area.

The deep circulation of the recharging water may also be related with the northwest- southeast oriented fractures that are supposed to form the youngest scoria cinder cones in the area.

water samples chemical analysis data were taken from different sources of previous works in the area. Generally, analysis result of twenty water chemical date were used in this investigation.The water samples are from eight boreholes, four shallow hand dug wells ,three cold springs, two thermal springs,two rivers and a lake.

Some parameters like TDS, PH, Eh, turbidity, etc are measured both in the field and laboratory. Representative water samples were collected carefully by prescribed standard methods. The sample are collected in one liter polyethelyne plastic bottle and preserved before analysis for two days in 4^{o}c with out any treatment.

The analysis was made in the laboratory of water resources bureau of Oromiya (Addis Ababa) between November 10, 2005 up to November 12, 2005.Accuracy of the analysis was assessed and reaction error for each sample was checked to be less than 5 % . The chemical analysis result is summarized in table 6.1.

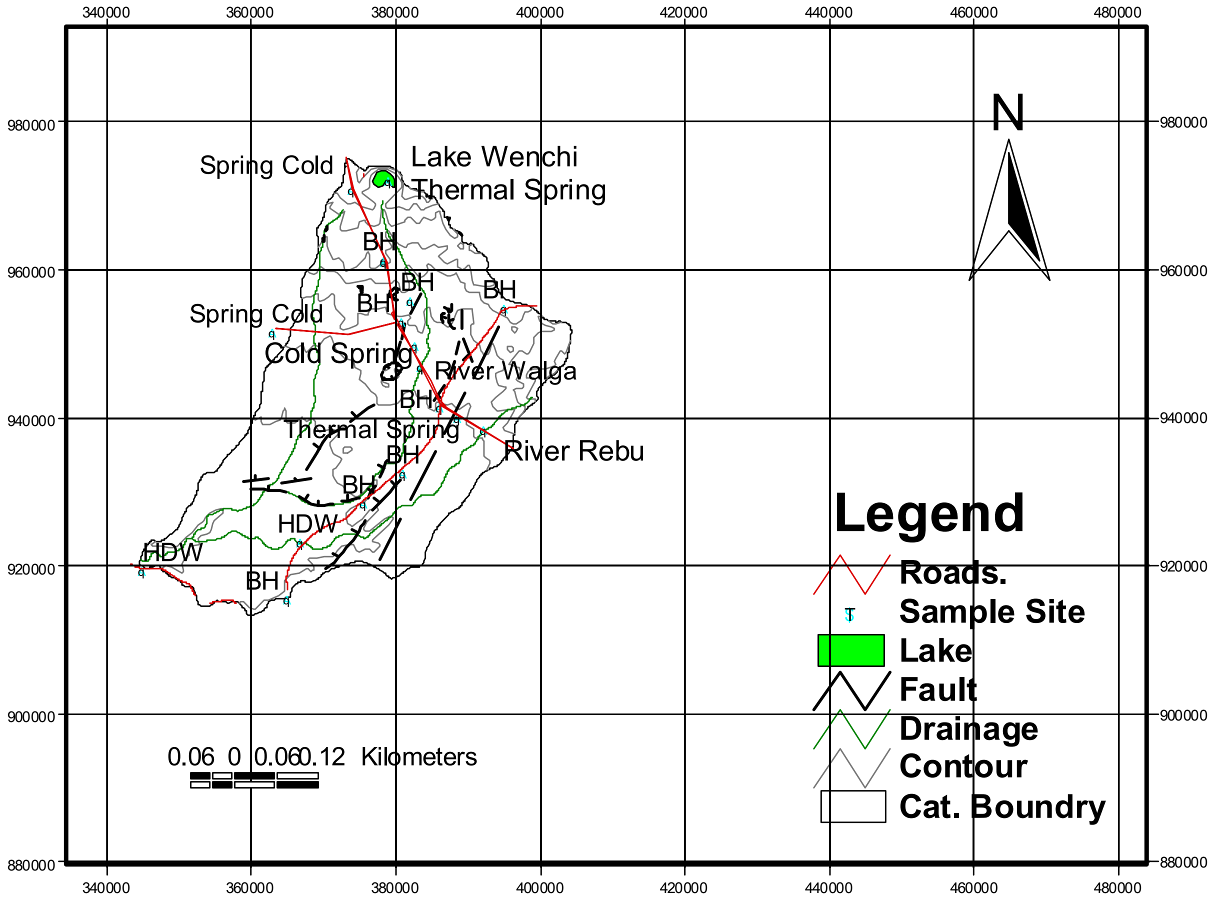


Figure 6.3.Sampling locations

6.3 Chemical data

6.3.1 Major cations and anions

The major actions and anions analyzed for the study area are K^+ Na^+, Ca^{++} ,Mg^{++}, HC3$^-$, CO$^{3\,=}$, Cl^-, and $SO^{=2}$.

Table 6.2. Major cations & anions concentration in mg/l

Source	Locality	Code	UTM N	UTM E	AL	K+	Na+	Mg++	Ca++	HCO_3^-	$CO_3^=$	$SO_4^=$	Cl-	$NO_3^=$
HDW	Dilela	KB1	955000	395000	2430	5.08	34.39	15.07	30.46	201.37	0.00	8.17	20.92	0.00
HDW	Rebu	KB2	923250	366750	1720	7.20	132.60	3.81	8.00	213.50	60.00	12.00	10.00	2.80
HDW	Walga T.	KB4	920700	374700	1525	14.86	117.71	35.48	12.83	271.54	33.00	115.27	31.91	0.00
BH	Chitu T.	KB5	951450	381150	2100	3.40	4.86	7.20	28.00	103.70	48.00	1.00	0.60	0.00
BH	Dariyan	KB6	961400	378400	2580	23.00	9.80	12.00	28.00	54.90	24.00	1.00	0.40	11.00
BH	Sankole	KB7	956000	382000	2100	20.00	16.05	45.00	135.00	118.00	0.00	28.50	0.00	0.80
BH	Waliso PS	KB8	942800	384350	2020	3.50	113.25	1.44	12.00	164.70	72.00	4.00	1.00	5.28
BH	Weranan	KB9	938500	392200	2040	5.00	55.80	24.00	34.00	70.00	0.00	3.00	2.00	1.50
BH	Gurura	KB10	932600	381000	1920	5.47	9.43	7.05	33.27	186.11	0.00	12.09	7.09	0.00
BH	Goro	KB11	928389	375286	1940	8.6	18.2	4.9	28.9	176.9	0.1	3.2	1.5	0
BH	Wolkite	KB12	915860	369097	1865	7.6	19.4	5.2	24.2	181	0.2	1	0.8	0.5
C.Spring	Gindo T	KB13	951750	363000	2000	2.97	7.48	10.70	19.20	122.00	0.00	0.00	6.00	1.11
C. Spring	Dariyan	KB14	961200	378400	2580	6.65	2.76	2.19	8.42	67.12	0.00	14.41	8.51	0.00
C. Spring	Chitu	KB15	949750	382750	2080	3.40	63.10	0.48	15.60	115.90	60.00	1.00	5.00	9.24
Th. Spring	Wonchi	KB16	969696	376889	3090	19.8	348.4	1.3	4.1	856.4	0.8	0.1	40.1	0
Th. Spring	Woliso	KB17	943265	387830	2020	11.9	262.3	0	1.6	732	2.7	0.1	39.2	2.3
River	Rebu	KB18	947000	383550	2040	2.74	7.82	4.62	10.82	183.06	0.00	7.69	9.22	0.00
River	Waliso	KB19	941200	389150	1789	61.00	5.00	0.48	15.20	67.10	24.00	1.00	0.80	8.36
Lake	Wonchi	KB20	1E+06	377438	2890	9.839	18.383	2.4	11.2	120.78	0.00	0.00	8.00	6.16

Cations

Calcium is the domination cation in all water samples ranging from 1.6 mg/e up to 220 mg/l. The higher values is for Sankole BH. This high calcium is derived from the underlying lithologies probably the ca-rich sedimentary sequence or the weathering products of plagioclase feldspar and pyroxene rich basaltic lava flows.

Another major cation is magnesium . Its value varies from nil for Woliso thermal spring to 45 mg/l(for Sankole BH). Magnesium in the area is probably derived from the weathering of the ferromagnesian minerals such as olivine , biotite , hornblende and augite.

The value of sodium varies from 276 mg/l (for Darian spring) up to about 348. 4 mg/l for the thermal water from the Wenchi spring. Sodium can be derived either from the natural processes such as weathering of plagioclase fieldspars, particularly albite,or from anthropogenic effect such as discharge of effluents (domestic, industrial ,or commercial sources) . Higher value of sodium (> 100 mg/e) is observed for the samples of thermal water and for borehole in woliso area. The high sodium concentration many be derived from the dissolution of feldspars, and by cation exchange.

Anions

Bicarbonate is the predominant major anion in all the analyzed samples. It varies from 54.9 mg/l (for Dariyan BH) to 850.4 mg/l for Wenchi thermal springs. Most bicarbonate ions in ground water are derived from the carbon dioxide from the atmosphere, carbon dioxide in the soil, and the solutions the carbonate rocks (Davis, 1966) . In the thermal springs HCO_3^- precipitation increasing during rising process to shallower depth.

Sulphate in water is generally, derived from weathering of rocks, recycling from atmosphere, or from volcanic exhalations . In the study area, the sulphate content in water is highly attributed to the weathering of rocks and volcanic exhalation or probably from lacustrine deposits in walga town area.

High chloride (20 mg/l) in the thermal springs can be from deep geothermal source. But in the case of Dilela town it could be from anthropogenic effect.

6.3.2.Minor ions

All the water samples in the area show low nitrate concentration less than 11 mg/l as NO^-_3.
The present relatively low (6.16 mg/l) NO^-_3 in the lake sample is probably because of low agricultural practice in the lake catchments (low fertilizer application) or slow oxidation of NO_2^- or rapid reduction of NO_3^- to NO_2^- or nitrogen gas and subsequent release to the atmosphere.

The maximum permissible contamination level (MPCL) for nitrate according to WHO (1984) drinking water quality standards is 50 mg/l. Such high NO_3^- and Cl^- content in water is usually derived from anthropogenic sources, utilization of nitrogen-bearing fertilizers and effluents from domestic sources mainly latrines/or septic tanks entering in to shallow unprotected springs and wells having poor well head protection

High fluoride (F^-) concentration is observed in the thermal springs and in some ground water samples. This high F^- concentration could be from acidic volcanic rock sources such as alkali amphibolites, alkali mica and accessory minerals such as apatite.

6.4 Other physiochemical and impaired organoleptice parameters

1. Total dissolved solids (TDS) and electrical conductivity

All the water samples collected from the study area have TDS values less than 1000 mg/l except the thermal springs taken from Waliso and Wenchi that have 1079 and 1419 mg/l respectively. Hence, they are all fresh waters, while the later two are brackish.

2. PH

The PH value of the samples in the study area ranges from 6.16 to 8.46. The lower value is measured for chitu cold spring water, and the highest value is for hand dug well in walga town. In natural water, PH is mostly controlled by carbon dioxide- bicarbonate- carbonate equilibrium of the system. Comparison of PH results among the samples is ploted in figure-below. Thermal waters have relatively low pH than other waters.

3. Temperature

Based on water temperature, the Collected samples can be categorized in to two groups. The cold water having template values below 25^0c and the thermal water above 25^0c .Woliso and wench thermal spring samples have temperature of 31 & 40 ^oC respectively.

6.5 Hydro chemical facies Differentiation

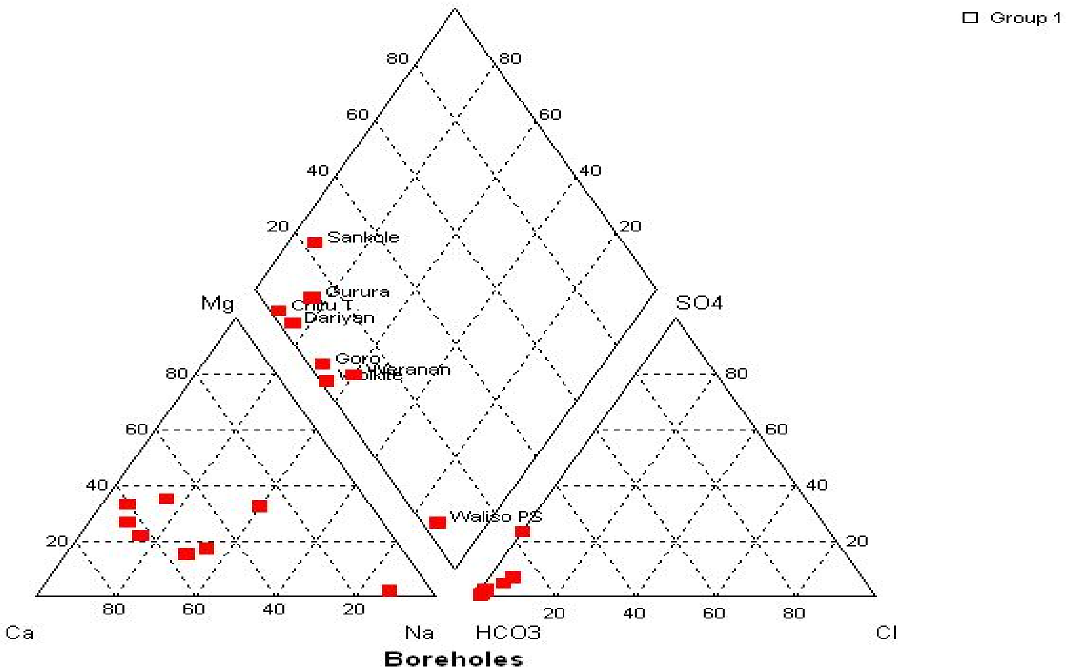
6.5.1 Classification and presentation of analytical results

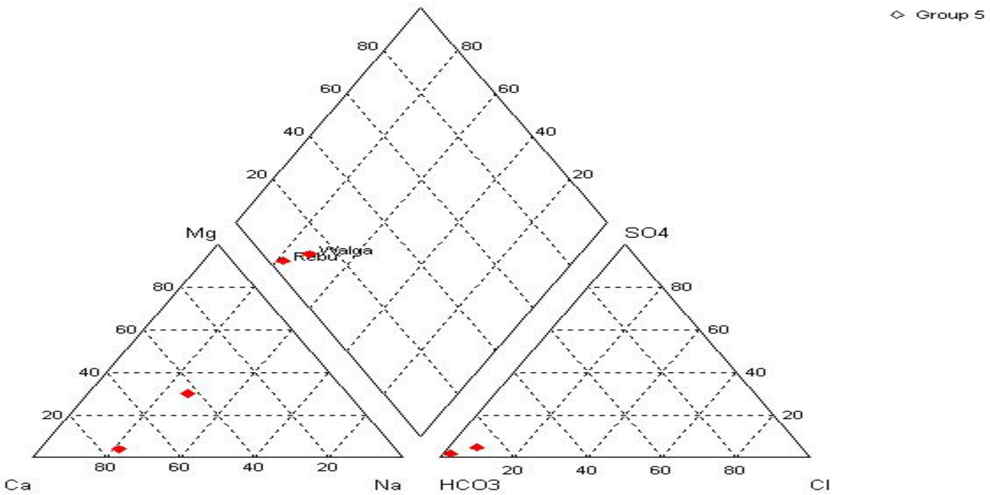
Graphical and statistical Cluster classifications are used considering mainly the major cations (Ca^{2+} , Mg^{2+} ,and Na^+ + K^+) and major anions (HCO_3^-, $CO3^{-2}$, d- and $SO4^{-2}$)

A) Piper tri-linear diagram

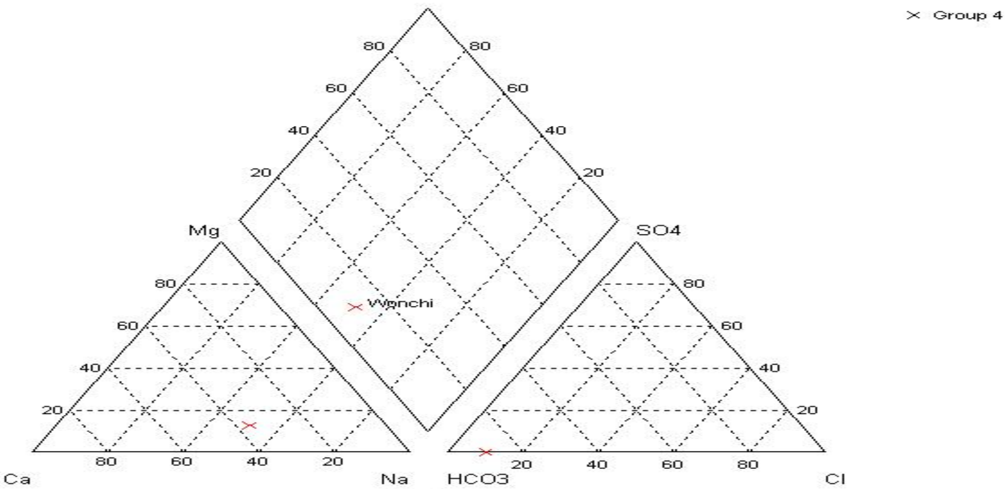
Classification based on the graphic method is done by piper tri- linear diagram. For water samples of the study area the results are plotted as shown in Fig 6- 2.According to this classification, thee water types are identified based on their similar plotting position

Figure 6.4. Piper diagram of different waters

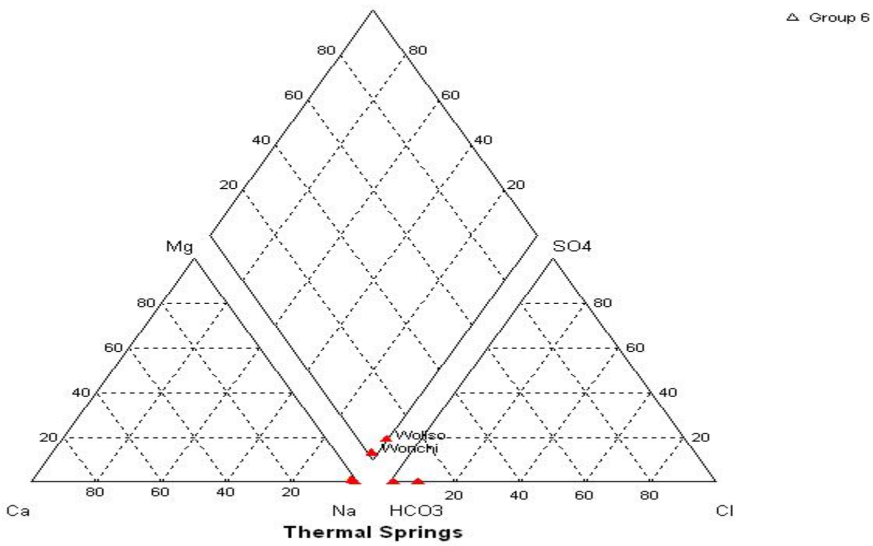


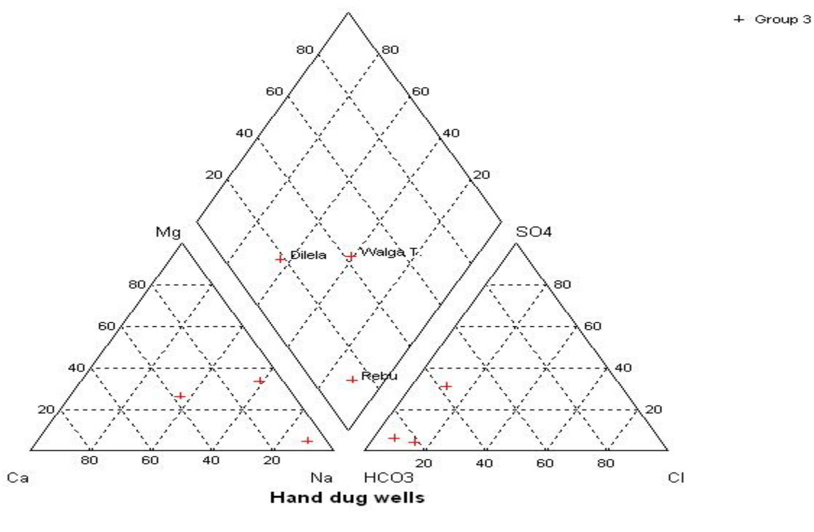

Group 5
Mg
SO4
Ca
Na
HCO3
Cl
Walga
Rebu

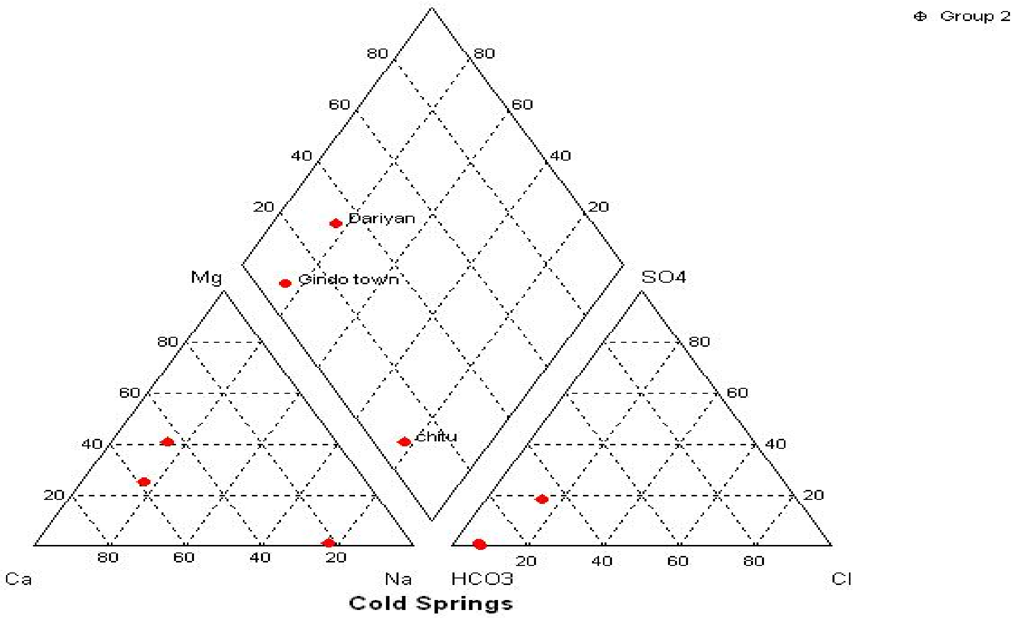
Rivers


Group 4
Mg
SO4
Ca
Na
HCO3
Cl
Wonchi

Lake


Group 6
Mg
SO4
Ca
Na
HCO3
Cl
Woliso
Wonchi
Thermal Springs


Group 3
Mg
SO4
Dilela
Walga T.
Rebu
Ca
Na
HCO3
Cl
Hand dug wells



The relative percentage concentration of each ion meq/l & the water types for the different water bodies are summarized in table 6.3.The waters can be categorized in to three groups :

Group-I. **Ca+Mg-HCO_3** low temperature and low TDS type waters of Dilela HDW, Welkite BH,Chitu BH, Darian BH , Sankole BH , Rebu river , Gindo c-spring ,Dariyan c-spring , Goro BH and Gurura BH from volcanic plateau,

Group- II. **Na+K –HCO_3** type low temperature of Lake Wenchi, Chitu spring , Woliso ps BH ,Rebu HDW , Werane BH and Walga town BH and Walga River from volcanic plateau,

Group-III . **Na+K–HCO_3 type** – low temperature and high TDS themal springs of Woliso and Wenchi which lie along Ambo – Butajira fault line.The percent meq/l concentration of the major ions in each water sample which are used for the ploting is summarized in table 6.3.

The water samples that lie under group –I of piper plot are often regarded as recharge area waters, which are at their early stage of geochemical evolution or may be a characteristics of rapidly circulation ground water which have not undergone a pronounced water rock interaction.

Some high TDS Na-rich G-II and G-III , waters on the piper plot show undergoing possible geochemical evolution like hydrolysis of silicate minerals by Ca-Mg-HCO_3 type water increasing the concentrating of Na^+ ,K^+ , Mg $^{2+}$ and HCO_3^- but the enrichment of Ca^{2+} is limited by earlier saturation and precipitation of carbonate.

Source	Locality	Code	UTM N	UTM E	AL	Na+ + K+	Mg++	CA++	HCO_{3-}	$CO_{3=}$	HCO3- + CO3=	$SO_{4=}$	Cl-
HDW	Dilela	KB1	955000	395000	2430	46.35	17.73	35.92	201.37	0.00	87.35	3.55	9.1
HDW	Rebu	KB2	923250	366750	1720	92.20	2.51	5.29	213.50	60.00	92.57	4.05	3.38
HDW	Walga T.	KB4	920700	374700	1525	73.29	19.62	7.09	271.54	33.00	67.46	25.50	7.04
BH	Chitu T.	KB5	951450	381150	2100	18.99	16.60	64.41	103.70	48.00	98.96	0.65	0.39
BH	Dariyan	KB6	961400	378400	2580	45.05	16.46	38.49	54.90	24.00	98.23	1.25	0.52
BH	Sankole	KB7	956000	382000	2100	16.70	20.80	62.5	118.00	0.00	80.27	19.73	0
BH	Waliso PS	KB8	942800	384350	2020	89.66	1.11	9.23	164.70	72.00	97.80	1.65	0.55
BH	Weranan	KB9	938500	392200	2040	51.06	20.37	28.57	70.00	0.00	93.30	4.00	2.7
BH	Gurura	KB10	932600	381000	1920	26.98	12.77	60.25	186.11	0.00	90.80	5.70	3.5
BH	Goro	KB11	928389	375286	1940	44.8	8.09	47.11	176.9	0.1	97.28	1.9	0.82
BH	Wolkite	KB12	915860	369097	1865	47.87	9.22	42.91	181	0.2	99.00	0.55	0.45
C.Spring	Gindo T	KB13	951750	363000	2000	25.90	26.50	47.6	122.00	0.00	95.30	0.00	4.7
C. Spring	Dariyan	KB14	961200	378400	2580	47.05	10.95	42	67.12	0.00	68.04	19.01	12.95
C. Spring	Chitu	KB15	949750	382750	2080	78.00	3.10	18.9	115.90	60.00	96.65	0.60	2.75
Th. Spring	Wonchi	KB16	969696	376889	3090	98.55	0.35	1.1	856.4	0.8	95.50	0.01	4.49
Th. Spring	Woliso	KB17	943265	387830	2020	99.42	0	0.58	732	2.7	94.93	0.01	5.06
River	Rebu	KB18	947000	383550	2040	40.60	17.80	41.6	183.06	0.00	91.54	3.85	4.61
River	Waliso	KB19	941200	389150	1789	80.51	0.59	18.9	67.10	24.00	98.06	1.94	0.86
Lake	Wonchi	KB20	971492	377438	2890	67.5	5.7	26.8	120.78	0.00	95.00	0.00	5

Table 6.3. Percentage concentration meq/l of major ions & water type

6.5 Water quality

In a water resources potential evaluation of a basin quality of the water is as important as quantity.Therefore, determination of quality of natural water for certain use according to certain standards set by different organization such as WHO for specific water uses is required

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6.5.1 Drinking water quality

Both characterstics of water that cause adverse physiological effect on a body, and those that have aesthetic characteristics areanalysed for the samples of the study area. For adverse physiological effect F^- & NO_3^- have been analyzed & for aesthetic water quality copper, manganese, sulphate, odor, taste, etc .Except TDS greater than 1000 mg/l for the thermal springs & high F up to 19 mg/l for some waters ,the concentrations of the other chemicals are with in the limit range of recommended & MPCL set by WHO (1984).

6.5.2 Agricultural water quality

Different factors affect Agricultural water quality which include crop type, climate, soil type, and amount of irrigation water use, Davis (1966). Boron content, Sodium hazard, and Salinity are analysed for adverse physiological effects and EC & SAR analysis indicate exellent value for all the waters except Walga HDW and the thermal sprigs which is permissible salinity range as summarized in table .

Table 6.4.The water quality evaluation for irrigation based on SAR and EC are as follows Todd (1980 and references there in)

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

Water class	Excellent	Good	Permissible	Doubtful	Unsuitable
EC (µs/cm)	<250	250- 750	750- 2000	2000- 3000	>3000

In order to evaluate water quality for irrigation from Salinity and Sodium hazard point of view for the study area, the parameters have been measured and calculated as shown in table 5-2. Accordingly, all water samples show low Sodium hazard; and they are all below 10, which is of an excellent quality. But from salinity point of view, the quality varies from excellent to bad (from low to very high salinity hazard). Surface water such as Lake Dandi and Wanchi have an excellent quality both from sodium hazard and salinity point of view.

Source	Locality	Alkalinit	SAR
HDW	Dilela	311.00	3.4
HDW	Rebu	472.40	0.5
HDW	Walga T.	912.00	1.11
BH	Chitu T.	249.36	0.73
BH	Dariyan	280.24	0.44
BH	Sankole	448.00	0.87
BH	Waliso PS	571.00	8.23
BH	Weranan	187.00	2.1
BH	Gurura	256.00	0.75
BH	Goro	256	0.72
BH	Wolkite	334	0.93
C.Spring	Gindo T	223.70	0.24
C. Spring	Dariyan	110.00	0.22
C. Spring	Chitu	278.00	4.29
Th. Spring	Woliso	1511	57.1
River	Rebu	111.00	0.34
River	Walga	478.70	0.5
Lake	Wonchi	171.00	1.3

Table 6.5. SAR and EC values for surface and groundwater in Ambo area

6.6. Fluoride

6.6.1. Flouride distribution in Woliso area

The spatial distribution & problem related to the occurance of high fluoride inWoliso area has not yet been investigated .This investigation also highlightes the occurance of high fluoride in Woliso area & tries to draw attention for the future to the problem related to this.

The area being in the Yerer-Tullu Wellel volcnotectonic structures and related to the MER in its genesis makes it to share some characterstics of the rift in occurence of fluoride. The occurrence of Fluoride, in Ethiopia, is often linked with volcanic activity, geothermal activity and granite rocks. Thermal high pH waters can be expected to have especially high F concentrations (Redda, 2002).High fluoride concentrations are exclusively confined to the active seismic zones & recent acidic central volcanic complexes.(Tenalem Ayenew,2004)

A map is constructed with out any buffering from the collected water samples to show the distribution of fluoride in the basin.From the map, high fluoride occurance is observed in Woliso area.This occurance is concentrated along Ambo –Butajira line which is the recent volcano-tectonic structure in the area.This is confirmed by the thermal spring sampled along this line from woliso town having fluoride concentration up to 26 mg/l.

6.6.2.Water quality standards with respect to fluoride.

Drinking water

Fluoride taken with water gets distributed rapidly throughout the body and is retained mainly in the skeleton and teeth. Proper dose reduces the solubility of enamel against acidic conditions where by providing protection against dental caries.Consumption of high dose of fluoride is toxic to man pathological changes include haemorrhagic gastro – enteritis, toxic nephritis and various degree of injury to liver and heart muscles. Long – term consumption of water containing fluoride with 1mg/l leads to such mottling in patients with long standing renal disease (Tamiru Alemayehu, 2000 and the references there in).

Table 6.6 standards and criteria of fluoride concentration (mg/l) for drinking water (After Bouwer, 1989).

US public health service, 1992		**Us Environmental protection Agency 1975**	**German, F.R, 1975**	**Us 1972 National Academy of science**	**D/76/464 EEC**	**Uk 1989**	**WHO 1993**
Distributed Maximum limited (DMAL)	Absolute maximum Limit (AMAL)	Maximum permissible concentration (MPC)	Infirm		Maximum Allowable concentration (MAC)	Maximum Value (mr	Gride level (GL)
0.6 – 0.9	0.8 – 1.7	1.4 – 2.4	1.5	1.4– 2.4	1.5	1.5	1.5

However, maximum fluoride levels are given in relation to annual average daily maximum air temperature, because ingestion water increases with temperature. The following range is recommended by the US public health service 1962.

Temperature (0C)	**Upper limit mg/l**	**Optimum value mg/l**	**Lower limit mg/l**
26.3 32.5	0.8	`0.7	0.6
21.5-26.2	1.0	0.8	0.7
17.7-21.4	1.2	0.9	0.7
14.7- 17.6	1.3	1.0	0.8
21.1-14.6	1.5	1.1	0.8
10.0-12.0	1.7	1.2	0.9

Source: Harvey, 1982

Agricultural purpose

Irrigation water

The concentration limit of fluoride in irrigation water is not clearly stated yet. But high fluoride content in local soils and plants reflect the dietary intake of this element

Livestock watering

US water quality criteria (NAS, NAE, L72) has recommended 2.0 mg/l as maximum concentration level for water to be used for livestock watering by.

Industrial use

For industries whose products are consumable by human beings , most of the upper limits do not exceed the limits set for drinking water by human. Some additional concentration limits by the American water works association for selected industries are presented in table 6.7.

Table.6.7.Fluoride concentration limits for industries (after Todd, 1980, and Hem 1992).

Type of industry	**Ranges in recommended limits concentrations of F- (mg/l)**
Brewing	1.0
Carbonate beverage	0.2-1.0
Drinking	1.4-2.4
Food canning and freezing	1.0
Food equipment, washing	1.0
Food processing, general	1.0
Canned, dried, frozen fruits and vegetable	1
Soft-drinks bottling	Not to exceed the human consumption limit.

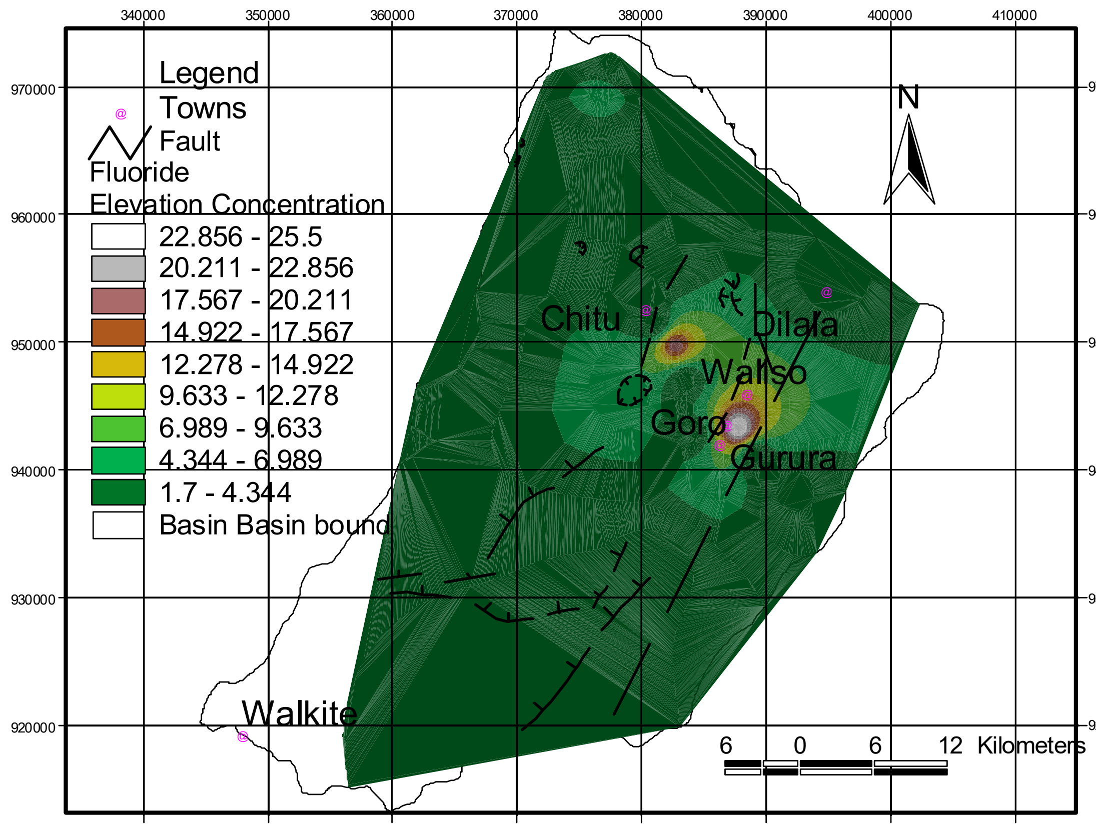


Figure 6.3. Flouride map of Walga Basin

CHAPTER - 7

WATER RESOURCE EVALUATION

7.1. Ground water and surface water interaction

To understand the interaction between surface & groundwater different physical,chemical & biological investigation methods can be applied.But here in the case of Walga river basin analysis of different hydrometological, hydrogeological & geomorphological physical parameters is made.

Walga river flows down from high lands of Wenchi (~3000m.a.s.l.) to lower Walga town area of the basin gauging station(~1500m). The river drains in low, moderate & high permeability aquifer systems. The basin has high rain fall during summer & dry time during winter. During long dry winter time, as observed from hand dug wells, the bottom of the stream channel is always above the local water table in the basin.

Therefore, the high amount of rain fall in the Walga basin during summer saturates the subsurface formations leading to the flow of Walga river without losing its initial volume of discharge rather making it a gaining down stream. On the contrary, during long dry winter time, water table starts to decline gradually below the bed of the river channel and the stream will start to feed the ground water acting as losing stream. This condition creates a continuous interaction of surface water and ground water in the basin. The lake also feeds the ground water through its bed.

7.2. Ground water Recharge estimation

For the sustainable development & management of groundwater resources,the amount of recharge received by an aquifer is by far the most important figure required .Yet due to the complexity of processes involved & the large varaity of satuations encountered,it is the least well-known quantity in hydrogeology .Unfortunately , it can not be measured directly on any reseonable spatial scale that is why so many methods & techniques have been brought to bear on the analysis of ground water recharge.The methods can be categorized to: direct measurements,water balance methods (including hydrograph methods),Darcian methods & Tracer methods.

As the central core of this thesis is estimating the amount of recharge in the basin which plays a great role in determining different developmental activities related with ground water potential utilization,With the available data,the most common & reliable balance methods are used for the estimation of annual ground water recharge of the Walga basin.

7.2.1 Base flow separation method

For Walga river, since only monthly discharge is reliably found the base flow separation is made from this data,accordingly, the amount of base flow obtained is 2.7mm=48.36 Mcm of the total 452.969 mcm per year overland flow and the annual runoff is 226.45 mm =404.609Mcm per year .

7.2.2. Water balance method of the basin

The water balance represents the hydrogological gains and losses of a given system (reservoir column of soil, aquifer, river basin, etc) over a specific period (Tenalem Ayenew and Tamiru Alemayehu, 2001).For natural catchment, measurement of the precipitation and river discharge may be made satisfactorily with some degree of precision. But the measurement of ground water movements into or out of the drainage area can not be made easily.

In this study of water balance, the catchmet (basin) in assumed as a close basin, based on the detailed field observation around the water divide from Awash & Blue Nile. This condition made the evaluation relatively simple in avoiding the subsurface and surface movement of water across the defined watershed boundary. Therefore, water balance of the basin is represented by the general equation:

Inflow= outflow + change in storage

Here, the inflow includes precipitation and ground water inflow where as the out flow includes surface runoff, ground water out flow, evaporanspiration and change in strong. The general water balance equation is;

$$P + Gi = AET + SRO + R + Go + \Delta s$$

Where;

Gi= ground water inflow
Go= ground water out flow
Δs= change in storage

But change in storage in annual case is almost negligible and is assumed to be zero.

Ground water inflow is assumed to be equal to ground water out flow. Then finally, the study area will have a water balance equation of:

$$P=AET+SRO+R$$

P= precipitation (1259.912mm) annually

AET= annual actual evapotranspiration (853.05 mm),lake evaporation averaged with in the area.

SRO= annual surface run off (226.45m)

R=P- AET-SRO= 174.42mm

Therefore, the amount of recharge in Walga basin is calculated as 174.42mm. Of this amount of recharge 1.6 % leaves the basin in the form of base flow. The above result shows that recharge, AET and SRO are 13.8 %, 68.30 % and 17.9 % respectively of the total rain fall which indicated that the topography of the basin is good for ground water percolation.

Table 6.8 Result of Water Balance Method

Catchment area (Km2)	Base flow(mm)	Net Gw Recharge(mm)
1786.75	2.7	171.72

7.3.Lake Water Balance

Water balance method is used to compute annual net groundwater flux for Wenchi Lake by using only the surface inflow to the lake & surface out flow from the lake .And also G_i is groundwater inflow, and G_o is groundwater outflow are taen to be equal for there is no visible change in lake level.Therefore,the equation used for water budget approach is:

$\Delta V = P + Q_i + G_i - E - G_{o\,-}\ Q\ i$

Where: ΔV is net change in lake volume=0

P -is direct precipitation on the lake=5.04mcm

E -is lake evaporation=1641.3mm (Area of the lake=4km2)=6.565mcm

Q_{o-} is surface-water outflow & direct pumping=0

$Q_{i\,-}$is surface water inflow and storm water=1,886,445 m3/yr=1.89mcm

Thus,from the above equation,

$0=5.04+1.89+ G_i-6.565 - G_o -0$

$0 =0.365+ G_i - G_o$

Thus Go=Gi + 0.365 mcm

The above lake water balance indicates that the lake feeds the groundwater of the basin through its bed.

CHAPTER -8

GROUND WATER RECHARGE, DISCHARGE AND CONCEPTUAL GROUND WATER FLOW MODELING

8.1. Ground water recharge & discharge

The high land mountain ridge areas of Wenchi & Dilela and their surroundings are the main recharge areas for the in the basin. Walga river & the other perennial streams in the basin start from these topographically elevated areas .The main recharge type in this area is direct recharge from precipitation.

Discharge areas are those areas, which are mostly at the foot of mountainous area which are manifested by the presence of springs at the contact of the elevated and the low land areas.. Areas starting from Senkole down wards to Weliso & Walga, can be considered discharge zones by the presence of shallow ground water depth up to 6m & abundance of semi- artesian type springs. Presence of many springs at different elevations as a contact spring indicates that there is a shallow ground water circulation in addition to the regional flow of groundwater.

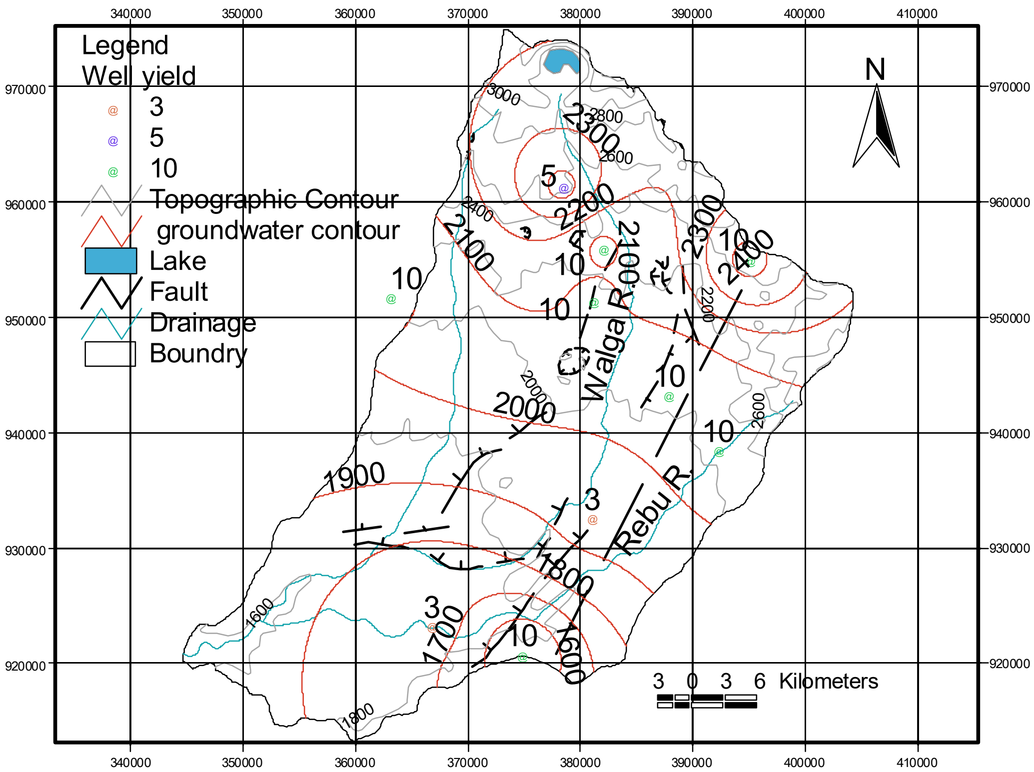


Figure 8.1 Well yield Map in Walga Basin

8.2. Water points

Characterization of the aquifer systems in the hydrogeologic basin is supported by inventory data of distribution & type of the water points like springs ,bore holes and hand dug wells used as Water supply sources for different purposes .

8.2.1 Bore holes

Both shallow(≤ 60m) and deep bore holes are found in the study area .The deep bore holes are commonly for water supply for big towns like Woliso while the shallow ones are for villages & small rural towns.

Some lateral variations in well yield with in the same aquifer syster is observed. This can be both hydrogeological or technical during the well design. Otherwise the data is very reliable for the categorization of the aquifers in as discussed in the above section.

The water table data of these bore holes can not be used for local ground water table estimation as they are largely affected by the confining property of the interbeded aquifer system giving them semi –artesian piziometric water levels. But the information is very important to in other hydraulic & storage property of the aquifers, & in evaluation of both the local and regional ground water potential of the basin.Generally there are greater than 15 bore holes in the basin almost all of them in the high permeable aquifer systems except that of Dariyan

Plate 8.1.Artisian Well in Waliso town Borehole

8.2..2 Hand dug wells

Most hand dug wells are located in the high permeability aquifer system striking through the thick soils & upper highly weathering products of the rock units. Commonly their presence indicates shallow local ground water circulation in this area.

Almost all the publicly owned ones are equipped with Afredave Indian Mark-II hand pumps. Their depth range from 2-24m and the static water level ranges from 1.5-23m.Generally there are more about 31 hand dug wells in the area used for community water supply purposes.

8.2.3 springs

The hydrogeological variations in the basin can be deduced from the presence of different types of springs. Wenchi mountain has higher number of low yield gravity cold springs that indicate low permeability underlying rock in the units the steep topographic feature favoring high runoff resulting in the out pouring of the precipitated water before it percolation to significant depth. Even if still there are big springs that are the sources of perennial streams that emerge from this unit, the presence of number of these springs in this area is also attributed to big local precipitation recharge & low relatively low evapotranspiration. There are greater than 30 such springs in this hydrostratigraphic unit used both for community water supply and irrigation.

The low land permeable areas are characterized by relatively low number of high discharge hydrostatic gravity cold springs indicating shallow ground water depth. Most of these springs are located in low areas and along river banks supplying the perennial streams.

Non-gravity thermal springs associated with deep volcano-tectonic thermal induced activities are also common in the Wenchi and Woliso areas. This springs are concentrated along the Northeast-Southwest trending Ambo Butajira fault line.They are used as Medicinal waters & recreational activities in the Swimming pool.These springs are very helpful in understanding the in local aquifer stratigraphic succession & deep ground water circulation in addition to the geothermal gradient in the area..

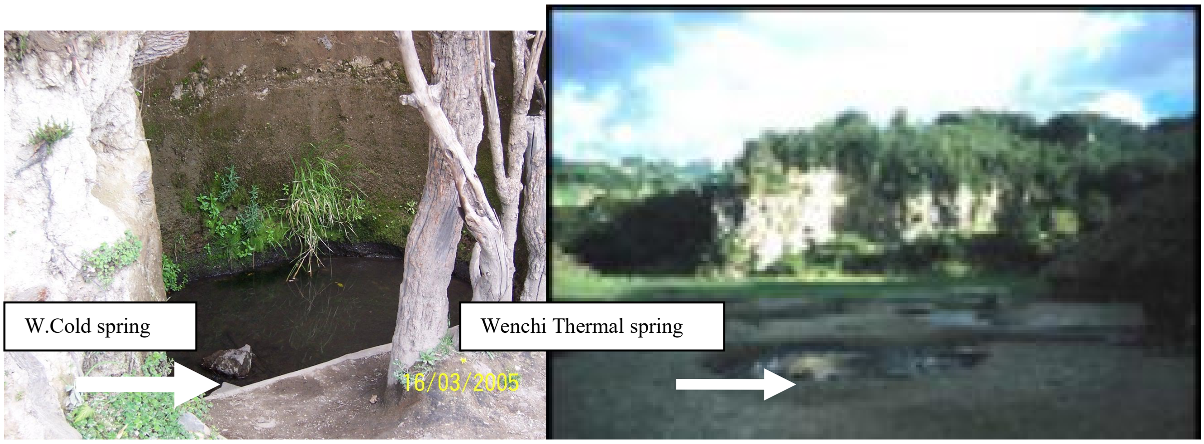


Plate 8.2.a) Cold Gravity spring in Wenchi peak, b) Hot Spring in Wenchi Crater rim

8.3.Groundwater flow direction & resource Potential

In the study area, regional ground water flow follows regional geomorphology & structures while in the case of local ground water flow topographic effect has the biggest effect.The local unconfined flows are directed down from topographic highland recharge areas of Wench & Dilela to low lying discharge areas of Woliso & Walga. The water table data of hand dug wells & the discharging of many springs following the topography (figure 5.1) show hydrostatic head loss while the ground water flows from high recharge to discharge areas. Accordingly, local flows have general south west directions of flow towards the Ghibe river with some local variation within sub-catchment

The regional ground water in depth flows Southeast following the younger Volcano-tectonic Structures in the area in addition to the general topography of the area.(Hydrogeological Map of Ethiopia,1988).

Generally,the basin has good groundwater potential both for shllow & deep groundwater resources development.The higher groundwater concentration is in Woliso area in the high permeability basaltic lava flows .Intercalation basalt with pyroclastics ,multiple aquifer system developed giving a semi-artisian wells.The basalt forms the main aquifer in the area having yields up to 12l/s.The well depth goes 100-150m b.g.l.

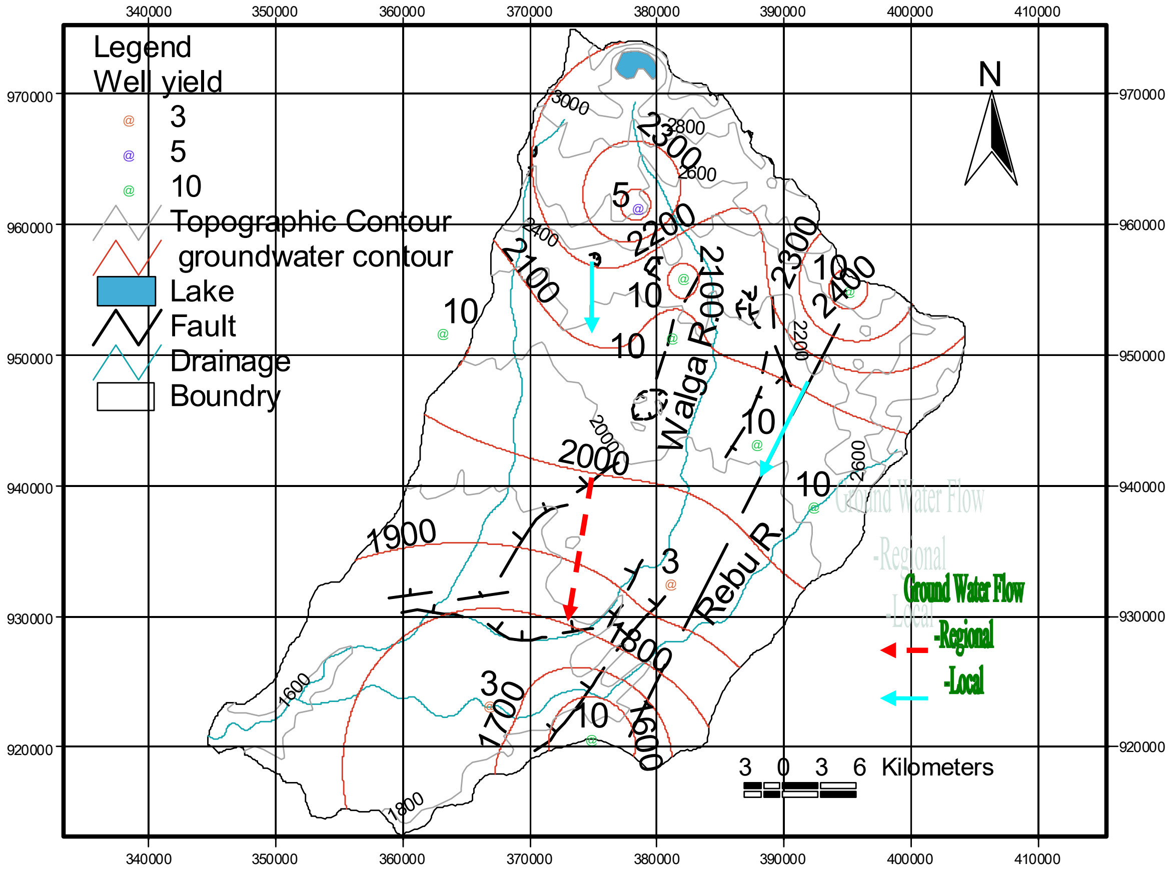


Figure 9.2.Ground Water flow direction

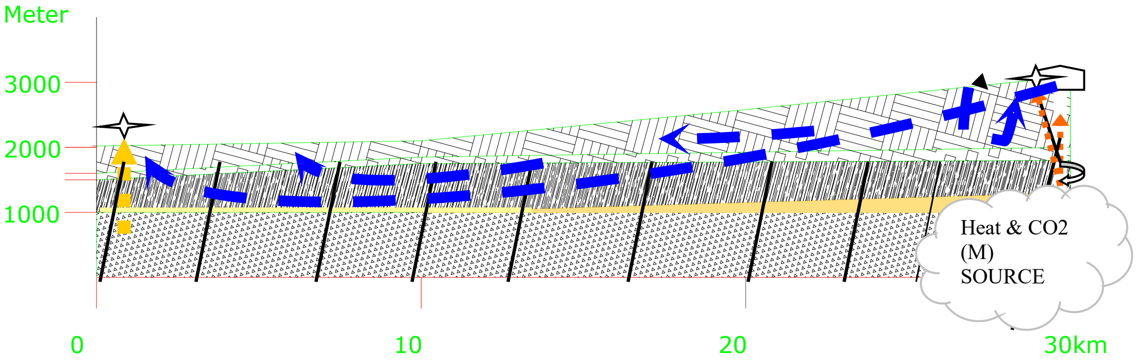
8.4.Conceptual groundwater flow modelling

From geological, structural, hydrogeological, and hydrogeochemical investigations in Walga basin a simplified relationships among the recharging meteoric water in Wanchi area, the existing hydrostructures that control the thermal and/or mineral water, and their mode of discharge in a nearly east-west trending structures are constructed in a simplified sketch or model in figure 9.3.

The ground water recharge starts at high altitude of Wenchi area which has high permeabilty unwelded tuff cover& circulates deep the volcanic structure in the area.Reduction in density caused by heating rises up the water through the available fractures as a result of this rising CO_2 is released and of travertine and silica sinter could be deposited . Major residence in acid volcanic rocks, open system hydrolysis of silicate minerals, lowering of pH by addition of CO_2 from metamorphic decarbonation of the underlying Mesozoic sediments or from direct CO_2 input form deeper sources along the fault zone. Due to these geochemical & thermal processes ,the low TDS , high PH & cold Ca-HCO_3 type recharged water could end as high TDS,low PH thermal water.

The deep circulation of the recharging water may also be related with the northwest-southeast oriented fractures that are supposed to form the youngest scoria cinder cones in the area.Finally, the outflowing of the thermal water in Woliso area is favored by the transversally oriented fractures to the supposed groundwater flow direction called Ambo-Butajira line ,which is the younger volcanotectonic structure in the area.

Isotope techniques, particularly oxygen isotope and carbon isotopes used for CO2 source verification indicated both decarbonation & magmatic origin CO2 in thermal water.(Seifu Kebede,2002).



CO2 from decarbonation

Magma tic CO2

Quaternary Volcanics

Oligocene volcanics

Mesozoic sand & Limestone

Late Miocene volcanics

Precambrian basement

Thermal Spring of Woliso & Wenchi (CO2 rich & high TDS)

Regional, Schematic ground water flow path

Figure 9.3.Conceptual groundwater flow pattern of Walga Basin(SE-NW section)

CHAPTER- 9

CONCLUSION & RECOMMENDATION

9.1.CONCLUSION

The study area is located in Ghibe drainage basin, and it forms a triple-junction for three regional drainage basins: the Ghibe basin in which it is found, the Awash basin on Northeastern , and the Blue Nile basin on the Northwest. The catchment has a dendritic and parallel drainage pattern with a forth order stream network.

The area has a mean total rainfall of 1259.921mm/year with annual Actual Evapotranspiration (AET) of 853.05mm. The annual groundwater recharge to the shallow aquifer is 174.42mm, which is only about 13.8 % of the total annual rainfall it receives.

Geomorphologial setting of Walga area facilitates the local ground water flow by draining the high land ground water recharge from the top of Wench mountains to low areas in the basin .It also controls the flow of sreams in their up stream parts that most streams follow the topography in its up stream side in the basin.

The regional and probably deeper groundwater flows & promotes groundwater system of the basin is strongly influenced by the NNE-SSW extnsional structures in the area .This can be evidenced by existence of the presence of thermals springs in the basin aligned along Ambo-Butajira fault line.

The streams that drain the basin including Walga are largely affected by these structures in their downstream sides.Figure 3.2.

The type & distribution of different lithological units with their weathering products as well as their stratigraphc sequence has gien as the advantage to get laterally & vertically different aquifr systems & a number of aquifer layers & impermeable bed within reasonable & succussive depths respectively.For example the interbeded basalts with the pyroclastics in

Woliso area has basalt as the main aquifer& pyrocalastics intercalations as impermeable layers.

In Walga basin precipitation varies with altitude with a correlation coefficient of 0.42 .Generally precipitation increases with increasing altitude. According to the data records, perception in the basin shows temporal variation of 5- month rainy season and six month dry season. Maximum and minimum annual rainfall from spatial point of view is 1642 mm and 901 mm respectively. The basin gets its maximum rainfall in the month of Augest and its minimum rainfall in the month of December.

Due to high topographic difference, large difference between minimum & maximum data values,& non uniform guage distribution variation in the basin, isotheral method was employed to determine annual depth of precipitation in the basin. Accordingly, 1259.912 mm is the annual rainfall depth of the area.

Evaporation from open water body is computed using penman combined method of estimation of evaporation from free water body or open water body. According to this method of computation, 1641.3 mm/year is the amount of water that can evaporate from lake Wenchi.

PET determined using Penman method gives maximum 103 mm/ month in the month of January which is the windy month in the basin and the annual value of potential evapotranspiration is calculated as 1641.3.In the months of June, July Augusts and September actual evaotanspiration equals potenial weva transpiration.

Long term measured values of Walga river discharge are the main data in providing information about the catchments characteristics and nature of the river. Walga river shows variation in rate of discharge as it flows from high land area to the low land area .The condition of increasing recharge as it flows along its channel down stream makes it gaining one from base flow .All; the tributaries also show the sme characterstics.

Annual total discharge of walga river from long term daily flow is recorded as 452.969 million cubic meter(mcm) at its end point of the study area this low discharge may also probably be because of high irrigation diversions in the upstream for irrigation purposes which observed in decreasing flow with out any interruption of the flow . But the rate of decreasing is increases in recent years due to the the almost total diversion of the river water for irrigation both in modern & traditional ways. .The basin has a total volume of 48.36 mcm and 226.45 annual water discharge as a base flow and direct run off respectively .

The only inflow or the main recharge to the basin is precipitation.The inflow and out flow of groundwater can be or not equal, but for the time of this evaluation they are assumed to be equal. The change in storage annually is assumed negligible since there is no abstraction of significant water .Therefore, the amount of recharge in the basin is 174.42 mm annually, which is 13.8% of the total rainfall. Of this amount of recharge less than two percent leave the basin in the form of base flow. The above result shows that recharge, AET and SRO are 13.8 % 68.3 % and 17.9 % respectively of the total rain fall which indicated that the topography of the basin is good for ground water percolation.

Water balance method is used to compute annual net groundwater flux for Wenchi Lake by using surface & subsurfaceinflow to the lake & outflow from the lake . And the result indicates that the lake feeds the groundwater of the basin through its bed.

Pump test results from different boreholes show great variation in transmissivity and well yield due to differences in aquifer characteristics. According to the analysis of these wells transitivity is very high in scoraceous basalticlac flow & top part of the uconfined pyroclastic deposits of Wenchi with in a range of 1-100 m^2/d transmissivity.The yield of the wells can go greater than 10 litter per second having an aquifer type of leaky with multilayer hydrosratigraphic units of basalt & ash intercalation resulting in semi artisian wells in Woliso area.Areas covered by pyroclastis at the lower part of Wench have moderater transitivity ranging from 1m^2 /d to 50m^2/d & well yield up to 5l/s..The aquifers have moderate hydraulic conductivity . Other type of aquifer in the basin is Trachytic aquifer commonly found in the southeastern part from Woliso to Welkite having low permeability & productivity with low yields of about 31/s.

The distribution of many contact cold & fresh springs with in the basin indicate the presence of shallow ,low residented groundwater system .At the sme time the high TDS ,thermal hard waters show deep regional cirulaion systems in the basin.Therefore,both shallow &

deepgound watr circulations are present in the basin.Groundwater flow is influeced both topography I the shallow & geologic structures in deep circulation case.

Inventories on ground water level also show shallow aquifer strikes at depths of 10-150m depending o the aquifer systenm in the basin flow is mostly influenced by topography and orientation of bedded or layered rock away from the basin or to ward the basin. In this case there is no such layered rock formation dipping away from the basin as being seen from handdug wells and the presence of successive springs from high land area to the low land leading to the low land leading to the accumulation water in the lacustrine to be very high.

In classification of the water chemical samples using piper diagam ,all the cold water samples from the volcanic plateau fall in the following three groups:

Group-I. **Ca+Mg-HCO_3-** low temperature and low TDS type waters of Dilela HDW, Welkite BH,Chitu BH, Darian BH , Sankole BH , Rebu river , Gindo c-spring , Dariyan c-spring , Goro BH and Gurura BH from volcanic plateau,

Group- II. **Na+K –HCO_3-** low temperature type of Lake Wenchi, Chitu spring , Woliso ps BH ,Rebu HDW , Werane BH and Walga town BH and Walga River from volcanic plateau,

Group-III . **Na+K–HCO_3 type -** low temperature and high TDS type themal springs of Woliso and Wenchi which lie along Ambo – Butajira fault line.The Percent meq/l concentration of the major ions in each water sample which are used for the ploting is summarized in table 6.3.

The above result shows that the basins ground water recharge is rapid, groundwater circulation is shallow and the waters are characterized by low TDS,low temperature,Na+Mg-CO3 type in case of group –I i.e generally characterstics of reacharge area waters.Group-II shows discharge area or slightely evol;ved waters where as grup –II is associated with deep circulating regional ground water.

There exist multi-layer aquifer systems in the area. The predominant aquifer, particularly for soft/or cold water is the weathered and /or fractured basaltic lava flow followed by alluvial sediments along some streams. Ash dominated pyroclastic deposits form the main confining layer around Woliso area, but in Wanchi area the pyroclastic deposit (unwelded tuff) forms the dominant permeable units due to its coarser grain size at the source.Generally, high ground water potential is concentrated in Woliso area in the basaltic flow high permeability aquifer system.

Relatively less fractured or weathered lava flows of basaltic & trachytic nature cause the emergence of some springs.Based on their origin two categories of springs can be identified in the area: the non- gravity (thermal) springs and the gravity (cold) springs.

The favorable geological, structural and geographical conditions of Wanchi high lands cause them to be recharge areas both for thermal and cold groundwater; where as the gentle slope of land stretched in Woliso area forms the main ground water discharging area.

The thermal water is a structurally controlled; the nearly east-west oriented fault in Ambo-Butajira line forms the main discharging conduits for the thermal water.

The presence calcite precipitation deposits in Woliso Walga Hotel area shows their thermal origin as well as the original high temperature of the thermal water as compared to the currently observed/or measured on the surface. The main source of heat supply for the thermal water should be a magmatic body in Wanchi area. For the deep circulation of meteoric water to come in contact with such magmatic body and subsequently discharged to the surface, there should be a fault. The implication of this condition is that the fault along which thethe thermal springs allign is also of a deep origin allowing deep groundwater circulation in the area.

The dominant groundwater in the study area is bicarbonates of calcium and magnesium. For the thermal water and those waters sources that show some geochemical evolution like in some deep boreholes & low land basin muoth, sodium is also the dominant cation. High nitrate,sulphate and chloride concentrations present in areas of anthropogenically affected sources . In comparison to the cold groundwater, thermal waters show low pH value; where as, surface water shows higher pH value.Temperature & lithology are the dominant controlling factors for the physicochemical characters of groundwater in the area.

The thermal waters in Woliso & Wenchi area are subsaturated with respect to calcium carbonate (calcite);which could be verified in the area from the precipitation of this mineral around thermal springs as well as in some water distribution systems .

In Walga basin ground water recharge is rapid, groundwater circulation is shallow and the waters are characterized by low TDS.The geological structures plays a major role in favoring the existence of regional and probably deeper groundwater flows & promotes the presence of thermal springs & geochemical evolution of the high TDS thermal groundwaters of the basin. The CO_2 gas from depth promotes acid hydrolysis of the volcanic cover results in geochemically evolved high TDS,low pH and high HCO_3^- of thermal springs.

Generally,the basin has good groundwater potential both for shllow & deep groundwater resources development.The higher groundwater concentration is in Woliso area in the high permeability basaltic lava flows .Intercalation basalt with pyroclastics ,multiple aquifer system developed giving a semi-artisian wells.The basalt forms the main aquifer in the area having yields up to 12l/s.The well depth goes 100-150m b.g.l.

Therefore ,as the groundwater potential of the area is high ,the resource can be developed for water supply purposes particularly drinking ,to reduce the load surfacewater & the recent observed problem of Woliso town water supply because of competitive water use between irrigation & domestic needs.

9.2.RECOMMENDATION

The effect of land use /land cover change on lake water storage ,quality & lake ecotoene because of direct entrance of eroded soils & agricultural products from elevated and rugged lake catchment should be studied & land use policies practiced in the region.

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In order to evaluate the basin full, distribution of bore holes are not uniform and even the drilled ones have no proper drilling and pump test data. Therefore, additional test boreholes which can also be used as a productive well for the required purpose are recommended .

Continuous follow up and recording of other non-recorded meteorological parameters are important to make comprehensive water balance study .There for the river guaging at different stations (at least two) and lake level fluctuation measurements arerecommended.

The detailed water demand calculations should be done in the area to fully utilize the water resources potential of the area & for sustainable water resources development & management with sound ecological balance. For this purpose managing & making available sufficient water point inventory data like borehole number ,pumping test & other relevant data are important in the future by the local water development & management organizations.

Oromia Water, Mines & Energy Resource Development Bureau should make a close follow up & should consider the water quality standard during drilling of water supply wells on fluoride & some contaminants such as NO_3^- & Cl observed in some water sources.

The regional Water resources & irrigation development Bureaus should devise the integrated basin development approach with particular emphasis on the ground water resources potential utilization specially for drinking water supply to alleviate the competitive demand on the surface water use.

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ANNEXES

Annex-1.Summary of long-term mean monthly value of metrological data for the study area

No	Parameters	stations	Altitu.	UTM	months													Annual
				East	North	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sep	Oct	No	Dec	
1	**Rain fall**	Woliso	2000	388100	945100	15	30	60	77	111	168	252	278	167	41	11	13	1223
2		Welkite	1550	369600	913800	18	34	66	82	106	165	248	257	152	58	16	10	1212
3		Dilela	2400	395400	952800	18	31	70	68	99	157	255	261	174	71	8	9	1221
4		Daryan	2590	961200	378400	35	41	98	122	148	254	319	350	180	64	15	15	1641
5		Haro Doyo	2590	972050	379000	23	17	69	87	85	198	340	348	167	75	32	10	1451
6		Chitu	2100	951450	381150	25	28	68	79	100	194	313	342	165	31	8	15	1368
7		Ameya/Gindo	1970	362400	947000	25	33	71	85	125	151	256	275	177	68	15	13	1294
8		Gibe farm	1290	343900	910200	14	28	43	51	81	139	219	182	85	39	12	8	901
	Total					173	242	545	651	855	1426	2202	2293	1267	447	117	93	8116
	Av.					21.625	30.25	68.125	81.375	106.88	178.25	275.25	286.625	158.37	55.875	14.625	11.625	1288.88
1	**Sunshin Hour**	Woliso	2000	388100	945100	8.83	10.08	8.03	6.91	7.89	6.81	5.59	3.7	4.15	5.69	8.86	9.8	7.195
1	**Relative humidity**	Woliso	2000	388100	945100	37.6	28	41.6	38.8	48.2	66	76.6	75.6	66.35	44.6	28.8	37.4	49.13
	at 1200 (%)																	
1	**Pan evap.** (mm)	Woliso	2000	388100	945100	199.5	228.34	187.6	181.8	118.5	61..5	36.74	41.7	59.2	99.1	197	231	1641.3
1	**Wind speed** (m/s	Woliso	2000	388100	945100	3.96	4.28	3	2.94	1.28	1.18	0.9	1	0.93	2.44	3.44	3.62	2.23
1	**PET (mm)**	Woliso	2000	388100	945100	103	99	112	104	97	72	57	58	70	103	100	105	1080
1	**Temp.(^{O}C)**	Woliso	2000	388100	945100													
	Max.					26.35	28.15	27.13	27.6	27.23	23.43	21.03	23	23.68	25.58	25.13	25.58	25.32
	Min.					11.98	13.03	13.58	13.65	12.6	12.5	12.44	12.84	12.05	12.04	13	13.15	12.74
	Av.					19.165	20.59	20.355	20.625	19.915	17.965	16.735	17.92	17.865	18.81	19.065	19.365	19.03

Annex-2. Chemical Analysis result of Waters from Walga Basin

WaterSource	UTM N	UTM E	AL	Locality	pH	T	TDS	K+	Na+	Mg++	Ca++	HCO_3^-	CO_3	$SO_4^=$	Cl-	F-	$NO_3^=$
HDW	955000	395000	2430	Dilela , HDW	7.83	24	722	5.08	34.39	15.07	30.46	201.37	0	8.17	20.92	0	0
HDW	923250	366750	1720	Rebu , HDW	8.35	23.3	348.1	7.2	132.6	3.814	8	213.5	60	12	10	0.74	2.8
HDW	920700	374700	1525	Walga T., HDW	8.46	20.2	696	14.86	117.71	35.48	12.83	271.54	33	115.27	31.91	0	0
BH	951450	381150	2100	Chitu T., BH	6.4	22.5	180.9	3.4	4.86	7.2	28	103.7	48	1	0.6	0	0
BH	961400	378400	2580	Dariyan I, BH	6.71	19.1	160	23	9.8	12	28	54.9	24	1	0.4	0.67	11
BH	956000	382000	2100	Sankole , BH	7.84	20.2	214	20	16.05	45	135	118	0	28.5	0	0.76	0.8
BH	942800	384350	2020	Waliso PS, BH	8.13	16.2	259.6	3.5	113.25	1.44	12	164.7	72	4	1	1.36	5.28
BH	938500	392200	2040	Weranan , BH	6.91	24	89	5	55.8	24	34	70	0	3	2	0.52	1.5
BH	932600	381000	1920	Gurura , BH	8.12	21.3	296	5.47	9.43	7.05	33.27	186.11	0	12.09	7.09	0	0
BH	928389	375286	1940	Goro, BH	6.8	31.1	242	8.6	18.2	4.9	28.9	176.9	0.1	3.2	1.5	0	0
BH	915860	369097	1865	Wolkite I, BH	7.2	23.3	241	7.6	19.4	5.2	24.2	181	0.2	1	0.8	1	0.5
C.Spring	951750	363000	2000	Gindo T, CSP	6.7	25.8	232	2.97	7.48	10.7	19.2	122	0	0	6	0.06	1.11
C. Spring	961200	378400	2580	Dariyan , CSP	7.74	20.4	212	6.65	2.76	2.19	8.42	67.12	0	14.41	8.51	0	0
C. Spring	949750	382750	2080	Chitu , CSP	6.16	22	204	3.4	63.1	0.48	15.6	115.9	60	1	5	19.6	9.24
Th. Spring	969696	376889	3090	Wonchi, TSP	7.1	32.8	1419	19.8	348.4	1.3	4.1	856.4	0.8	0.1	40.1	6.3	0
Th. Spring	943265	387830	2020	Wolisol, TSP	7.12	41.3	1079	11.9	262.3	0	1.6	732	2.7	0.1	39.2	26.6	2.3
R. Walga	947000	383550	2040	Waliso 2, WR	7.94	21.2	198	2.74	7.82	4.62	10.82	183.06	0	7.69	9.22	0	0
R. Rebu	941200	389150	1789	Waliso 3, RR	7.89	15.5	280.4	61	5	0.48	15.2	67.1	24	1	0.8	0.11	8.36
Lake	971492	4E+05	2890	Wonchi 2, L	8.23	16.2	107	9.839	18.38	2.4	11.2	120.8	0	0	8	1.02	6.16

Annex-3. Hydrometric discharge data summary

SUMMARY OF HYDROMETRIC DISCHARGE DATA

STATION :- WALGA NEAR WOLKITE — STATION No.:- OG1010

BASIN:- WALGA — co-ordinate 8d20'n 37d36'e

DRAINAGE AREA,- 1786.75Km^2

MEAN ELEVATION, 1525 m.a.s.l.:

YEAR	*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1971	I	5.180	4.580	5.820	8.990	7.900	8.300	90.840	156.180	93.100	37.310	11.240	7.750	437.190
	II	2.740	1.350	4.370	8.200	6.120	11.200	115.900	186.000	113.800	45.100	5.750	3.140	503.670
	III	1.350	4.050	1.350	1.160	1.740	1.940	8.200	27.400	19.900	5.750	2.940	2.540	78.320
1972	I	5.180	4.580	5.820	8.990	7.900	8.300	64.220	83.360	45.470	12.260	5.050	3.370	254.500
	II	2.740	4.050	4.370	8.200	6.120	11.200	79.700	87.200	39.100	7.300	2.740	1.540	254.260
	III	1.350	1.350	1.350	1.160	1.740	1.940	47.000	13.000	7.700	2.940	1.160	1.020	81.710
1973	I	2.850	1.850	1.110	0.109	3.720	7.900	42.850	137.750	116.400	30.460	6.900	4.240	356.139
	II	1.540	0.890	0.660	0.260	2.340	4.700	53.000	168.000	129.200	33.400	3.740	2.140	399.870
	III	0.660	0.660	0.090	0.003	0.210	1.540	3.740	12.400	13.600	3.740	1.740	1.160	39.543
1974	I	3.380	2.050	4.390	3.670	4.730	11.890	79.690	197.600	124.910	22.470	6.360	5.370	466.510
	II	1.740	1.350	4.370	2.940	9.200	14.800	288.800	301.000	162.300	23.900	3.140	2.340	815.880
	III	0.890	0.560	0.560	0.470	0.390	1.740	6.500	10.700	19.100	3.740	1.940	1.540	48.130
1975	I	2.880	2.140	2.160	7.530	7.780	17.690	102.780	169.600	162.690	41.700	11.200	8.200	536.350
	II	1.160	1.740	2.100	3.920	4.490	20.500	98.200	138.000	188.400	36.700	6.080	3.560	504.850
	III	0.770	0.560	0.560	2.210	2.100	2.580	7.840	26.000	21.000	6.320	3.380	2.720	76.040
1976	I	4.250	3.150	3.550	3.910	6.430	10.620	36.580	75.170	39.640	6.010	4.760	2.850	196.920
	II	1.820	1.470	1.820	2.090	3.780	9.900	72.600	65.500	30.900	4.980	3.970	1.200	200.030
	III	1.200	1.120	1.120	1.200	1.700	1.700	4.980	13.210	5.450	1.120	1.120	0.960	34.880
1977	I	3.650	3.600	2.340	2.280	5.110	14.790	92.090	95.750	66.760	29.550	4.650	2.230	322.800
	II	1.950	2.090	1.580	2.090	4.760	18.000	235.200	56.500	46.800	79.600	9.220	0.960	458.750
	III	1.040	1.200	0.640	0.480	1.040	1.580	8.230	21.500	10.250	1.370	0.720	0.640	48.690
1978	I	1.940	1.890	2.680	1.840	3.320	10.740	116.780	168.000	53.330	43.620	4.670	3.670	412.480
	II	0.960	1.280	2.090	0.880	2.720	14.000	147.600	220.500	37.200	34.400	3.060	1.580	466.270
	III	0.640	0.480	0.560	0.480	0.720	1.200	9.220	15.200	14.400	4.980	1.370	1.200	50.450
1979	I	3.290	4.620	4.100	3.820	4.600	4.720	26.380	75.170	55.900	20.030	4.670	3.670	210.970
	II	1.700	2.240	1.820	1.700	2.890	3.780	15.600	63.500	41.400	20.500	3.060	1.580	159.770
	III	0.960	1.580	1.280	0.880	0.800	1.200	4.550	11.310	12.820	3.060	1.370	1.200	41.010

1980	I	3.290	2.700	7.840	5.050	5.140	9.080	12.090	74.770	188.900	104.760	23.120	5.050	441.790
	II	1.700	1.700	4.550	3.410	4.760	7.330	13.600	164.200	460.000	134.800	15.200	3.590	814.840
	III	0.960	0.800	2.090	1.280	1.280	1.700	1.820	3.970	14.400	15.600	3.230	1.200	48.330
1981	I	1.130	0.418	3.880	3.880	2.560	2.900	59.690	191.360	104.600	27.510	2.460	1.770	549.318
	II	0.575	0.313	2.760	2.760	1.500	2.580	82.170	197.800	66.020	27.670	1.500	0.831	741.419
	III	0.261	0.136	0.036	0.831	0.575	0.261	1.930	41.140	29.710	1.780	0.740	0.501	77.901
1982	I	2.030	1.420	1.340	2.510	6.030	6.170	48.610	133.040	48.010	29.090	4.150	3.620	286.020
	II	1.030	0.740	0.740	1.380	6.620	4.220	101.700	137.800	36.320	36.320	2.080	2.240	331.190
	III	0.433	0.501	0.370	0.433	0.831	1.380	3.770	12.850	6.620	1.780	1.030	0.740	30.738
1983	I	1.500	1.500	1.790	3.254	18.250	19.370	205.200	186.920	196.160	56.990	11.970	3.420	706.324
	II	0.655	0.740	1.260	1.640	21.440	27.670	142.800	117.500	354.950	36.320	7.880	2.410	715.265
	III	0.501	0.433	0.433	0.831	1.380	2.580	6.040	43.680	25.070	7.880	2.410	0.831	92.069
1984	I	2.110	1.780	1.320	1.000	4.040	32.920	135.550	186.920	95.220	13.380	1.410	1.110	476.760
	II	1.030	1.030	0.928	0.501	8.910	31.830	110.200	117.500	108.700	13.290	0.831	0.501	395.251
	III	0.655	0.575	0.261	0.173	0.104	4.220	25.070	43.680	10.780	0.831	0.370	0.370	87.089
1985	I	0.740	0.570	0.440	1.540	5.740	12.690	107.740	207.150	35.400	13.760	1.760	0.980	388.510
	II	0.370	0.261	0.313	1.780	3.560	7.240	222.600	267.600	29.020	10.390	1.260	0.501	544.895
	III	0.261	0.136	0.136	0.313	1.030	1.030	4.220	21.440	7.240	1.260	0.433	0.261	37.760
1986	I	0.870	0.890	1.260	3.930	3.610	27.800	96.230	90.720	65.160	10.270	1.860	1.000	303.600
	II	0.433	0.740	0.831	4.460	2.080	46.310	80.950	163.600	58.680	8.220	1.640	0.477	368.421
	III	0.261	0.313	0.214	0.173	0.928	1.260	10.780	19.200	7.880	1.500	0.370	0.313	43.192
1987	I	1.010	0.961	5.030	6.701	6.904	22.790	43.614	122.260	70.600	44.600	4.844	0.700	330.014
	II	0.433	0.740	4.220	7.240	8.560	14.650	27.000	68.200	48.100	92.290	3.770	0.370	275.573
	III	0.313	0.313	1.260	0.831	0.740	3.560	7.880	25.070	14.650	3.990	0.655	0.173	59.435
1988	I	0.552	0.744	0.563	1.134	1.391	5.855	115.740	195.330	141.940	44.600	4.844	1.266	513.959
	II	0.261	0.501	0.370	1.500	0.928	8.560	346.690	240.000	189.800	92.290	3.770	0.740	885.410
	III	0.173	0.104	0.104	0.104	0.370	0.501	2.950	16.590	22.620	3.990	0.655	0.214	48.375
1989	I	0.668	0.674	1.074	5.790	4.185	7.651	72.741	121.540	68.140	12.490	1.628	1.266	297.847
	II	0.501	0.370	0.740	3.990	3.350	4.960	151.300	249.000	77.350	13.290	1.640	0.740	507.231
	III	0.136	0.214	0.173	1.030	0.831	1.380	3.560	10.010	14.190	1.260	0.370	0.214	33.368
1990	I	0.360	0.468	1.431	0.528	1.126	4.360	42.270	121.540	68.140	12.490	1.628	1.266	255.607
	II	0.501	0.501	2.410	0.313	1.030	8.560	68.200	249.000	77.350	13.290	1.640	0.740	423.535
	III	0.054	0.054	0.136	0.104	0.136	0.214	2.410	10.010	14.190	1.260	0.370	0.214	29.152
1991	I	0.360	0.468	1.431	0.528	1.126	4.360	42.270	51.260	0.344	0.076	1.069	2.013	105.305
	II	0.501	0.501	2.410	0.313	1.030	8.560	68.200	110.200	0.261	0.054	1.030	2.950	196.010
	III	0.054	0.054	0.136	0.104	0.136	0.214	2.410	0.261	0.022	0.011	0.036	0.104	3.542
1992	I	1.570	2.800	1.431	0.528	1.126	9.896	59.730	246.600	121.540	28.190	2.810	0.572	476.793
	II	2.080	7.240	2.410	0.313	1.030	10.930	89.700	322.600	163.60	2.080	2.080	0.501	604.564

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	III	0.104	0.136	0.136	0.104	0.136	0.433	6.040	18.130	12.420	0.501	0.501	0.104	38.745
1993	I	1.570	2.800	1.431	0.528	10.340	57.370	162.270	220.160	154.450	44.070	7.030	1.356	663.375
	II	2.080	7.240	2.410	0.313	15.600	178.30	407.200	370.800	189.800	46.310	5.480	0.928	1226.461
	III	0.104	0.136	0.136	0.104	1.260	2.760	12.420	34.030	23.220	6.620	0.831	0.261	81.882
1994	I	0.618	0.227	0.742	1.734	1.126	6.406	162.270	220.160	154.450	44.070	151.200	82.050	825.053
	II	0.313	0.173	1.460	1.380	1.030	4.960	407.200	370.800	189.800	46.310	160.000	63.870	1247.296
	III	0.136	0.054	0.054	0.178	0.136	1.500	12.420	34.030	23.220	6.620	20.870	14.190	113.408
1995	I	0.196	0.124	0.197	3.980	10.340	6.406	28.680	116.860	54.970	6.807	0.429	0.116	229.105
	II	0.104	0.104	0.261	4.460	15.600	4.960	48.100	129.800	62.810	6.620	0.370	0.077	273.266
	III	0.036	0.022	0.022	0.054	1.260	1.500	2.410	17.090	7.240	0.370	0.077	0.022	30.103
1996	I	0.781	0.052	3.390	5.653	11.070	82.020	163.330	199.240	63.860	13.720	1.623	0.583	545.322
	II	1.030	0.077	7.560	5.480	17.091	158.200	176.400	399.400	54.700	17.090	1.030	0.370	838.428
	III	0.036	0.000	0.000	0.928	0.655	6.040	10.390	23.220	11.580	1.140	0.370	0.104	54.463
1997	I	0.427	0.139	0.364	3.224	2.453	10.549	47.733	199.240	17.744	6.385	2.168	0.216	290.642
	II	0.261	0.261	1.031	4.462	2.082	22.028	48.104	399.400	23.828	18.131	3.995	0.371	523.955
	III	0.077	0.001	0.000	0.313	0.433	1.031	3.772	23.220	2.765	0.261	0.215	0.036	32.125
1998	I	0.389	0.167	1.782	1.755	5.264	21.653	133.766	204.822	104.120	63.164	12.201	2.023	551.106
	II	0.655	1.781	2.765	6.326	11.177	63.871	431.149	322.551	108.720	149.549	7.237	2.082	1107.863
	III	0.000	0.000	0.000	0.000	0.740	1.256	6.622	26.352	14.190	6.037	2.082	0.036	57.316
1999	I	0.085	0.000	0.058	0.522	1.365	12.345	133.766	204.822	104.120	63.164	4.108	0.145	524.501
	II	0.077	0.001	0.575	6.037	2.952	36.321	431.149	322.551	108.720	149.549	4.957	0.215	1063.105
	III	0.001	0.000	0.000	0.000	0.000	0.928	6.622	26.352	14.190	6.037	0.215	0.001	54.346
2000	I	0.000	0.000	0.000	0.091	1.967	3.405	31.291	65.371	48.896	30.373	1.183	0.260	182.836
	II	0.001	0.000	0.000	0.433	2.584	3.147	46.307	72.699	53.725	25.708	1.256	2.410	208.270
	III	0.000	0.000	0.000	0.000	0.136	0.575	1.640	9.268	12.850	1.378	0.011	0.000	25.859
	I													
	II													

* I. MONTHLY RUNOFF IN MILLION M^3

II. MAXIMUM DISCHARGE IN M^3/sec

III. MINIMUM DISCHARGE IN M^3/sec