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ADDIS ABABA UNIVERSITY
DEPARTMENT OF
EARTH SCIENCES
FACULTY OF SCIENCE

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**



**EVALUATION OF GROUND WATER RESOURCES POTENTIAL
OF THE TEJI RIVER CATHMENT
SOUTH WEST SHOA ZONE, OROMIA REGION**

ANDUALEM ESHETU
January, 2008

**EVALUATION OF GROUND WATER RESOURCES POTENTIAL
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SOUTH WEST SHOA ZONE, OROMIA REGION**

**A THESIS SUBMITTED TO
THE SCHOOL OF GRADUATE STUDIES
ADDIS ABABA UNIVERSITY**

**IN PARTIAL FULFILMENT OF THE REQUIRMENT FOR THE
DEGREE MASTERS OF SCIENCE IN HYDROGEOLOGY**

**By
ANDUALEM ESHETU
January, 2008**

DECLARATION

I the undersigned declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of material used for the thesis have been duly acknowledged.

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The Thesis has been submitted for examination with my approval as university advisor.

Seifu Kebede (Ph.D) _____

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Abstract

The groundwater potential assessment of Teji river catchment is important to the currently increasing demand of water resources for different developmental activities and its quantification is vital for the efficient and sustainable groundwater resource management. The most important parameter contributing to recharge in the area are rainfall, evapotranspiration rate, and soil types. The area has an annual rainfall of 1104mm. Quantification of potential and actual evapotranspiration of the area is made using different techniques. The results obtained from are compared and representative one is determined to the area and qualitatively described. Water balance studies of the catchment indicate that 325.39mm of water is recharged annually and the months October, November, December, January, February, March, April, and May have soil moisture deficit and the remaining months are soil moisture surplus.

The main aquifer identified in the catchment is alluvial sediment, weathered and fractured ignimbrite, and weathered and fractured basalt.

Graphical presentation using Piper, Shoeller, Stiff and Wilcox diagram have been used for the effective analyses and interpretation of data. The groundwater in the catchment is characterized by Ca-Mg-Hco₃, Ca-Na-Hco₃, Ca-Hco₃ and Na-Hco₃-cl type water. TDS, EC and PH values range 184mg/l-566mg/l, 354µs/cm-838µs/cm and 6.6-7.68 respectively. The water sample analyses made in the catchment indicate the water is suitable for domestic and agricultural purpose. Almost all the water samples analyzed are with in the limits of WHO water quality standards except bore holes drilled at Urogotade PA's (fluoride = 1.68mg/l) and Asgori town (fluoride = 2.01mg/l & iron=0.39mg/l).

Chapter one

Introduction

1.1 Background

Water is the most vital component of all living things; the need for water is strongly ascending, which is not only important for domestic purpose but also vital for the development activities in both agricultural and industrial sectors. Any developmental activity is related, either directly or indirectly with water utilization.

Similar to other areas of the world, groundwater is the major source of drinking water in Ethiopia. More than 80% of the country's drinking water supply source is from ground water. This includes more than 25 major cities in the country according to Kebede Tsehayu et al., (2004).

Groundwater is an important source in Teji river catchment. It supplies drinking water and water for domestic uses, livestock watering and, to some extent, for agricultural purposes.

Now a days the need for ground water utilization is likely to increase due to expansion of irrigated agriculture (floriculture) and different development activities within the catchment and surrounding areas.

Groundwater development and utilization proceeds without an adequate understanding of water balance or a sound knowledge of the amount of recharge. The consequences can be seen widely in the longterm fall in water level and abandoning of water wells by non sustainable exploitation of ground water (<http://wrmin.nic.in/resource/gwresource.htm>).

Although the groundwater is annually replenishable resource, its availability is non uniform in space and time. Hence, precise estimation of ground water resource is a prerequisite for planning its development and resource management.

1.2 Objective of the study

General objectives

The general objective of the study is to evaluate the ground water resource potential of the Teji catchment.

Specific objectives

- Quantification of hydrologic components.
- Recharge estimation.
- Describe the hydrogeology of the area.
- Delineate recharge and discharge zones.

-Describe the hydrochemical features of the ground water from the analysis of the water chemistry data and its lithologic and anthropogenic controls.

1.3 Methodology

-Literature review of journals and previous studies.

-Data collection of the river discharge and meteorological records.

-Georeferencing distribution of meteorological and river discharge gauging stations.

-Data collection of water samples for the analysis of hydrogeology and hydrochemistry of the area.

-Water level data collection from both shallow and deep ground water.

-Georeferencing constructed water schemes.

-Determine ground water flow direction from water table mapping.

-Observation of land-use and land-cover practices.

-Field data analyses and laboratory analyses of water samples collected.

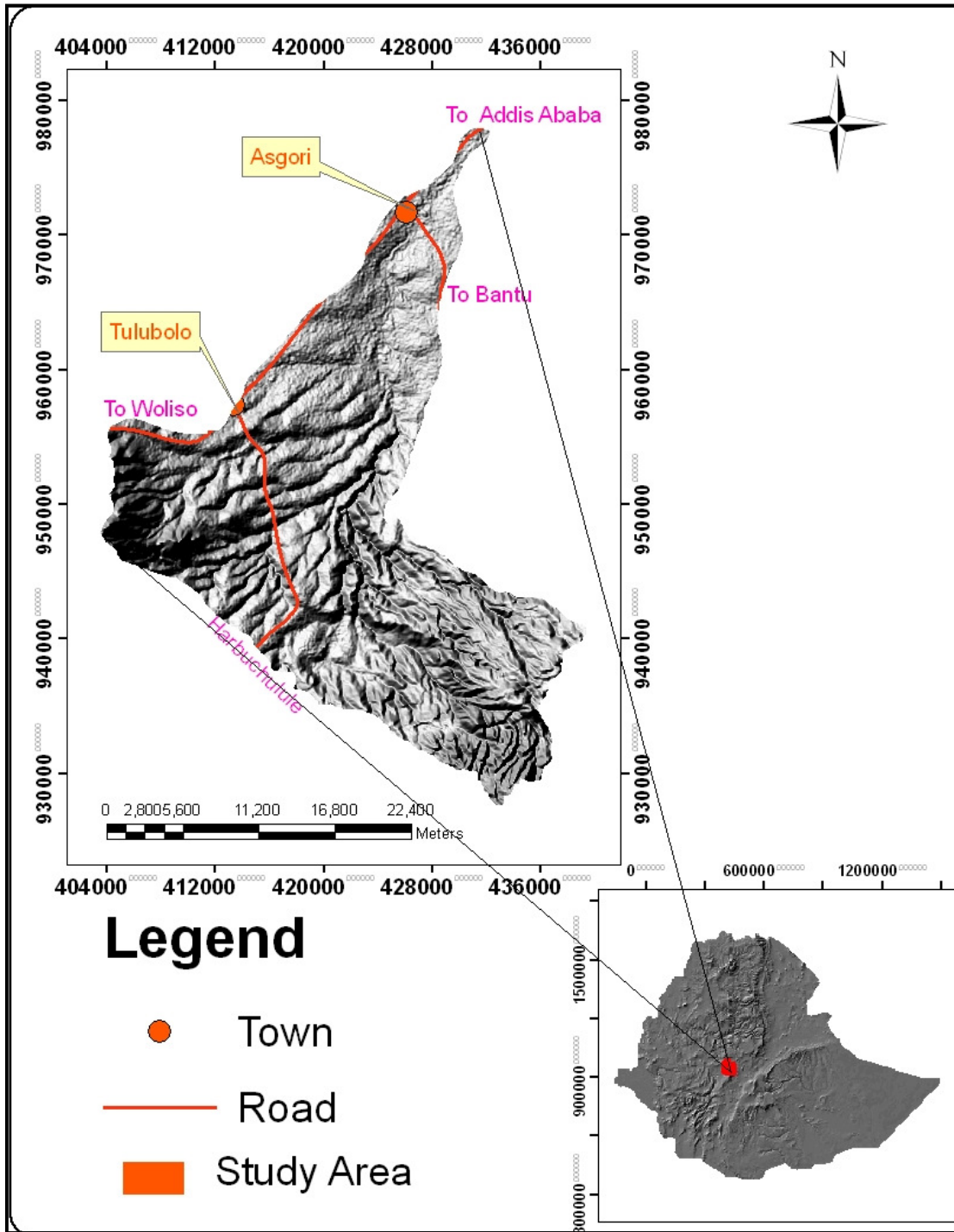
Chapter Two

Description of the study area

2.1 Location and accessibility

Teji river catchment is a tributary of Awash river basin, it drains the awash basin on its upper reach in the south west boundary. It is found in Oromia Regional State, Southwest Shewa zone, around Teji -Tulu Bolo town at a distance of about 40Kms from Addis Ababa on the main asphalt road leading Addis Ababa – Jimma. The catchment is geographically bounded between 926185 UTMN and 977839 UTMN latitude and 402592UTME and 439614UTME longitude having an aerial extent of about 700 km².

The asphalt road passes through the study area via the Teji, Asgori, Tulubolo towns and villages. Access to the different parts of the catchment, Villages and constructed water schemes is possible by two all weather roads that lead from Asgori to Bantu and Tulubolo to Harbuchulule.



2.2 Climate

The climate of the study area is classified based on elevation above mean sea level in to cool temperate (2300-3300m.a.s.l) and temperate (2040-2300m.a.s.l).The mean annual precipitation is computed to be 1104mm. The temperature, wind speed and relative humidity are variable with altitude and latitude (Tenalem Ayenew & Tamiru Alemayehu, 2001). The average minimum and maximum temperature of the study area (Table 4.6) is about 6.56^oc and 29.94^oc respectively.

The maximum and minimum relative humidity (Table 4.7) is calculated to be 83.9% and 42.2% respectively with average wind speed (Table 4.8) of 0.99m/sec minimum, and 4.4 m/sec maximum at 2m heights from the ground surface. The annual Potential evapotranspiration rate value (Table 4.9) calculated from penman combination method is 942.72mm and the annual actual potential evapo-transpiration rate (Table 4.12) calculated from water balance studies is 703.07mm. The topography of the study area (Figure2.2) ranges from 2060 – 3576 m above mean sea level.

2.3. Physiography and Drainage

The present physiographic setting of the catchment is the result of volcano-tectonic activity that forms the plateau and the rift that are later eroded and dissected by the Teji river. The study area is characterized by volcanic ridges and hills surrounding the catchment at its western and south eastern part, with flat land forms in central, eastern and northern part. Teji river catchment (Figure 2.2) has an elevation range of 2040m above sea level at mouth of Teji River and 3600m above sea level southeast of the catchment boundary.

Majority of the Teji river catchment (72.4%) has flat lying area with slope range of 0-2, 13.6% has a slope range of 2 - 3, 6.5% has a slope range of 3 - 4, 3.6% has a slope range of 4 - 5 and the remaining areas have a slope range of 5 - 8. The drainage density is an indicator of the linear scale of landform elements in a stream-eroded topography. Hydrogeological observation, integrated with drainage analysis, provide useful clues regarding broad relationships among the geological framework of a watershed, surface flow and the recharge. Drainage density is the ratio of the whole length of the hydrographic net of the given basin (L_T) to the area of the basin (A). Accordingly, the drainage density of Teji river catchment is given by;

$$D_d = L_T / A \text{ ----- (2.1)}$$

$$D_d = 154.3\text{km}/692018\text{km}^2 = \mathbf{0.223\text{Km/Km}^2}$$

The higher the drainage density corresponds with the lower the permeability of the rock and the higher the surface runoff, and the lower the drainage density the higher the permeability. The drainage density map of Teji river catchment has been made and presented in (Figure2.4) based on stream network analysis using software known as Arc GIS. Teji river catchment is tributaries of Awash river originates from the high land of Genbejo & Fuldebitu. The drainage pattern of tributaries is mainly dendritic and parallel in some parts of the area.

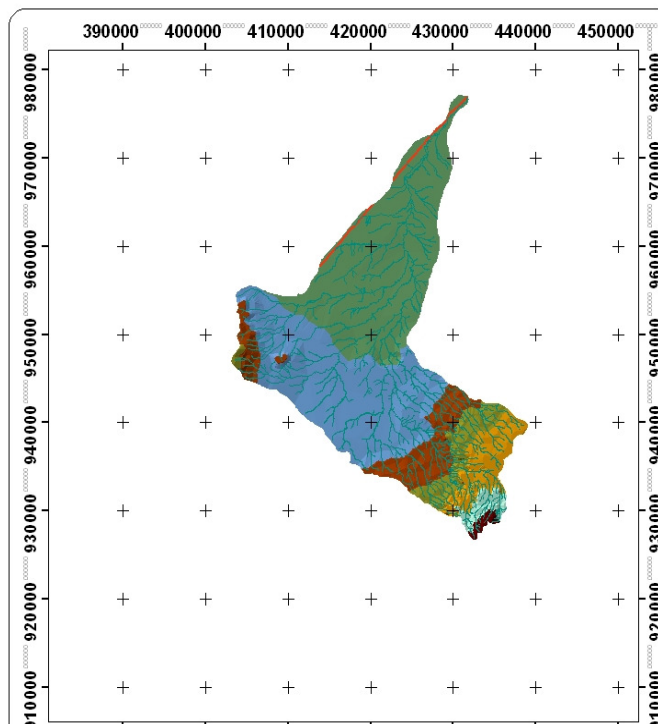


Figure 2.2 Topography and Drainage map

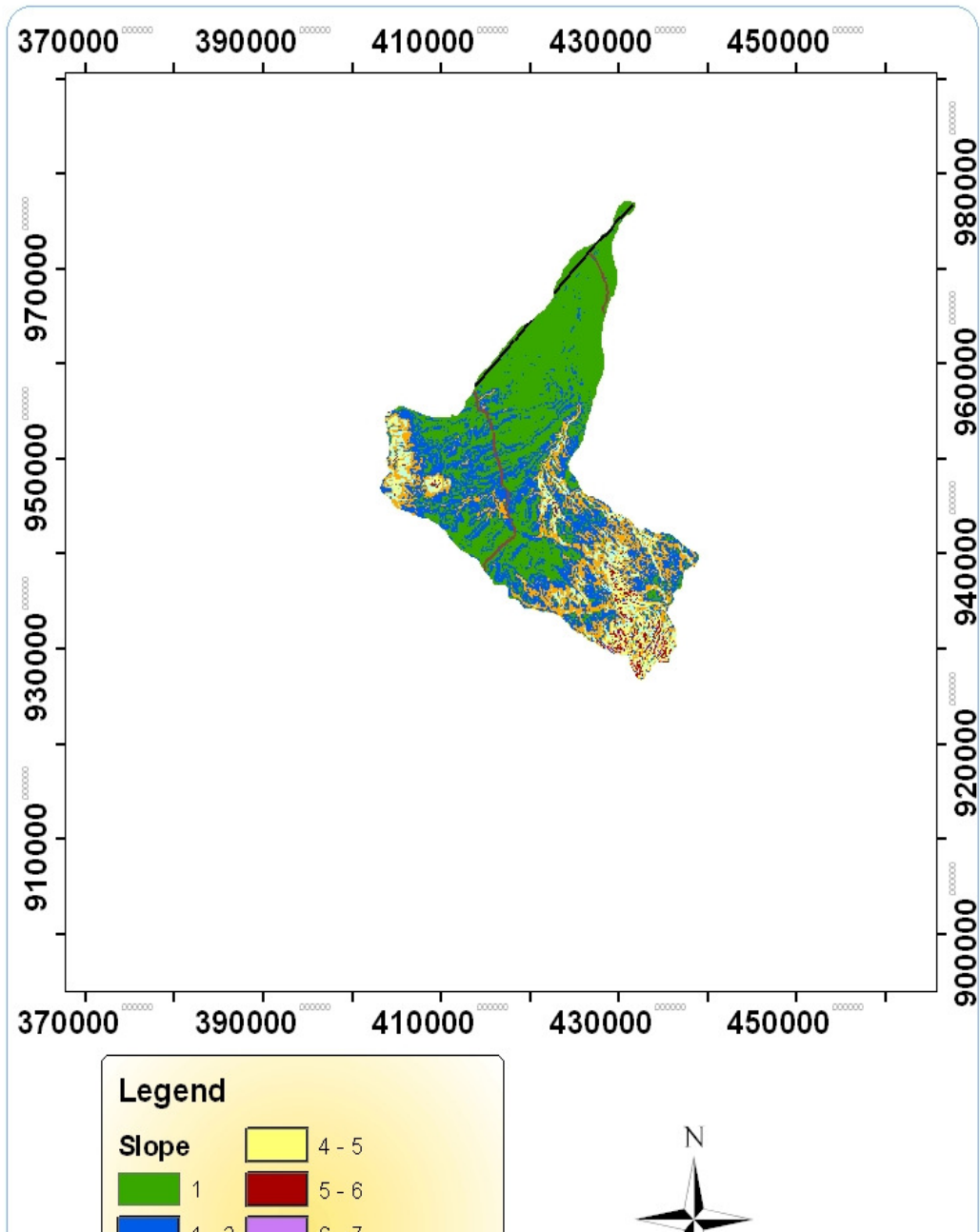
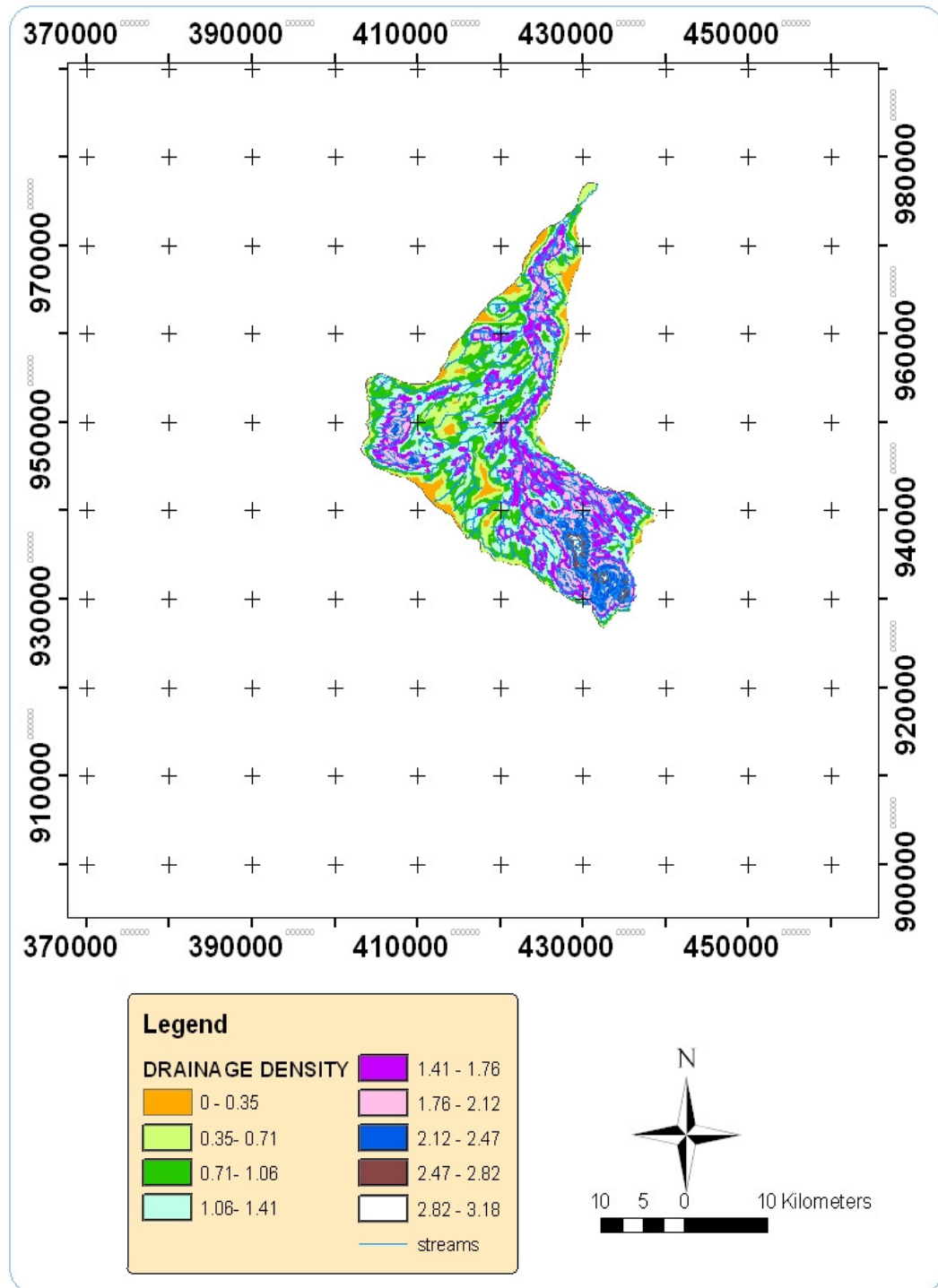


Figure 2.3 Slope map of Teji river catchment



Chapter Three

Geology

3.1. Regional Geology and Structures

The regional geological description of the study area is adapted from the report of geological map of Adaa-Becho ground water basin, presented by Ethiopian Water Works Design Supervision Enterprise. Regional geological setting of the area and its vicinity (Figure 3.1) consists of Mesozoic sedimentary succession, Tertiary and Quaternary age groups of acidic and basic volcanic rocks and Quaternary lacustrine and alluvial deposits.

3.1.1 Mesozoic Sedimentary Rocks

3.1.1.1 Adigrat Sandstone (JadS)

The Adigrat Sandstone widely known as Lower Sandstone outcrop is encountered around Ambo and Senkele situated at the northwestern part of the study area. It is fine to medium grained in texture and yellowish pink in color well sorted non- calcareous cross - bedded quartz sandstone. The sandstone in the quarry site, exhibits bedding plane that strikes N35⁰W and dipping 4⁰-5⁰ to the northeast direction. It becomes calcareous in places at the top, with development of thin beds of limestone and shale is observed. The limestone in the area is used for lime production and the sandstone is quarried for dimension/face stone/. The age of this sandstone is Permo-Triassic to lower Jurassic (Kazmin, 1979).

3.1.1.2 Abay Beds (JabB)

This unit occurs in the Abay river gorge lying between the Adigrat sandstone and the Antalo limestone. It is consisting of alternating beds of thick sandy limestone, calcareous sandstone, gypsum and variegated shale. The total thickness of the Abay beds reaches up to 580m and its age is middle Jurassic (Kazmin, 1979).

3.1.1.3 Antalo Limestone (JalL)

The Antalo limestone is exposed in the Abay river gorges and its tributaries Jemma and Muger Rivers. It is light to yellowish grey in color and massive to fossiliferous. In the Abay

gorges this unit consists of thick beds of limestone and marls (300-350m), which provided abundant marine fauna and ageing, Bathonian to lower Kimmeridgian (Kazmin, 1979). It is highly fractured and at places it becomes massive with bedding thickness up to 3m and the bedding plane is dipping 3° to 5° due southeast.

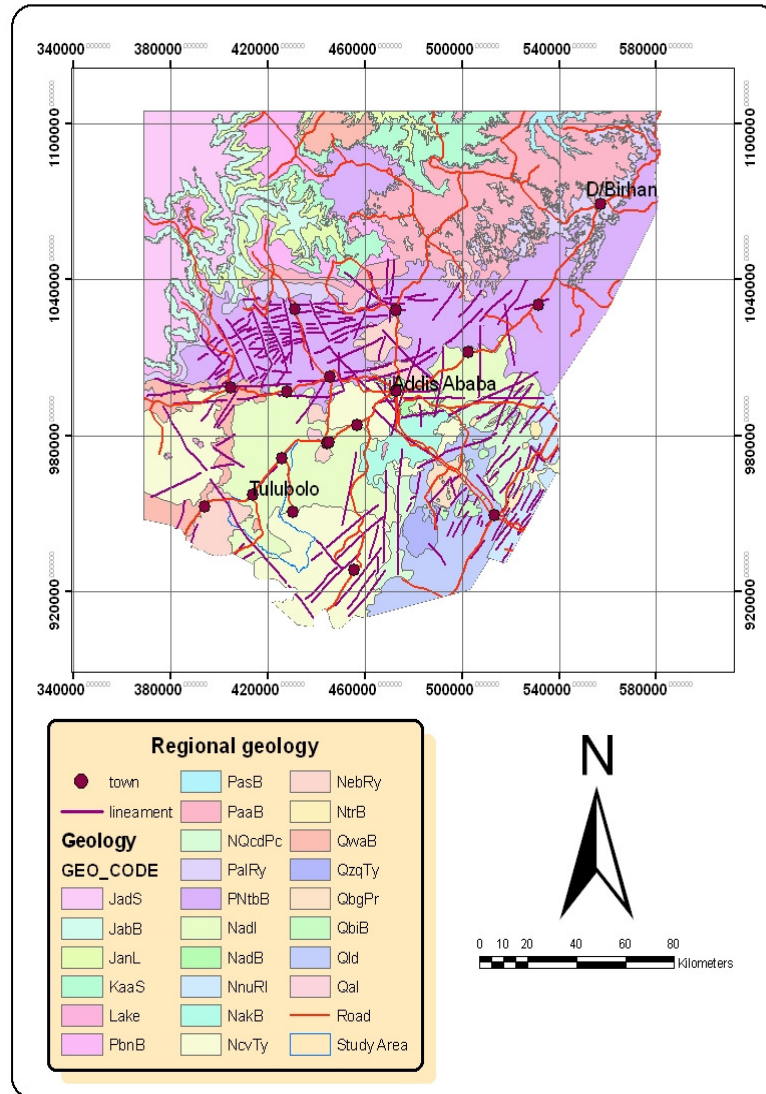


Fig.

3.1.1.4 Amba Aradam Sandstone (KaaS)

The Amba Aradam sandstone is widely known as upper sandstone is outcropped in the northern part of the area within the Abay river tributaries and conformably overlying the Antalo limestone. It is consisting of shale and marl at the bottom and quartz sand stone at the top. The sandstone is grayish to pinkish white in color and fine to coarse grained in texture. In the Abay river canyon the thickness of the unit ranges from 450 to 600m. The age of the Amba Aradam sandstone is probably of Late Cretaceous and represents a regressive facies of Cretaceous sea (Kazmin, 1975).

3.1.2. Tertiary Volcanic Rocks

3.1.2.1 Blue Nile Basalt (PbnB)

This unit is thick basaltic flows and outcrops in the Abbay gorge unconformably overlying the Mesozoic sediments. It is alkaline basalt with columnar joints of wider spacing forming vertical cliff. In hand specimen it is massive and dark in color. According to Kazmin (1975), the age of this unit is Paleocene-Oligocene (69-23 Ma).

3.1.2.2 Ashangi Basalt (PasB)

The Ashangi basalt is exposed in the northern part of the area representing the oldest fissured flood basalt next to the Blue Nile basalt volcanism in the northwestern plateau. It is strongly weathered, crushed and predominantly consisting of alkaline basalts with interbedded pyroclastics and rare rhyolites and is commonly injected by dolerite sills and dykes. According to Kazmin (1975), the age of this unit is Eocene-Oligocene (55-24 Ma).

3.1.2.3 Amba Aiba Basalt (PaaB)

This unit is exposed overlying the Blue Nile Basalt at the northern part of plateau area. It is flood basalts in thick flow with closely spaced columnar joint. In hand specimen it is aphanitic in texture and dark grey color. The age of this unit is Oligocene-Miocene (36-18 Ma).

3.1.2.4 Alaji Rhyolite (PaIRy)

This unit is exposed in the northern part of the area out of Teji River catchment. It is consisting of rhyolites, ignimbrites and subordinate trachytes. Obsidian bearing rhyolites are common in the area. It is grayish to pinkish brown in color. The age of this rock unit is Miocene, 33-15Ma (Kazmin, 1979)

3.1.2.5 Tarmaber Basalt (PNtbB)

The Tarmaber Basalt which is the dominant unit exposed and in the western and northern plateau parts and watershed divide of the Awash and Abbay river basins. This unit is downthrown by the regional east west running Ambo fault and overlain by thick (282m) younger ignimbrite (Lega Dadi and Melka Kunture area exploration boreholes data). It is consisting of mainly scoriaceous lava flows and at places it is columnar olivine bearing basalt as pockets within the scoriaceous components. It is highly weathered, fractured and pinkish to grayish in color. The age of this unit is Miocene, 27-5Ma.

3.1.2.6 Addis Ababa Basalt (NadB)

This unit is previously mapped by Kebede T and Taddes H. (1990) at 1:25,000 scales and the basalts area classified in to different units based on their texture and compositions. For the purpose of the present mapping scale by water works supervision enterprise they are mapped as one unit. This unit is fine to coarse-grained basalt composed of olivine and plagioclase phenocrysts. In most part of the outcropped area it is relatively thin (20m) lava flow overlying the ignimbrite. The age of the Addis Ababa basalt is 7.5-4.5 Ma (Chernet et al 1998 and Morton et al 1979).

3.1.2.7 Addis Ababa Ignimbrite (NadI)

This Ignimbrite is outcropped in most part of the plane area around Addis Ababa and the Becho plane. It is composed of welded tuff (ignimbrite) and non welded pyroclastics fall (Ash and tuff). It is grayish to white color and when welded it exhibits fiamme textures, elongated rock fragments of various color. Around the Lega dadi plane and melka kunture area the thickness of this unit reaches up to 200m (exploration drill data). In the Becho plane area it is covered by thin 5-7m thick residual soil developed from the same rock. The age of this unit is 5.11-3.26 Ma (Morton et al 1979).

3.1.2.8 Nazeret Unit (NnuRI)

This unit is mainly exposed in the southeastern part of the area mapped and forms rift floor. It consists of a sequence of welded per alkaline rhyolitic ignimbrite. The unit comprises numerous rhyolitic and trachytic domes. The ignimbrites generally show eutaxitic texture with oblate glassy fragments. Rock fragments and crystals generally broken are abundant; alkali feldspars, quartz, aegirine and amphiboles are the most common crystals. The age of this unit is 5.4 - 3.11 Ma (Morton et al 1979)

3.1.2.9 Akaki Basalt (NakB)

This unit is outcropped at Daleti, Abasamuel Dam, Akaki, Dukem area. It is coarse grained porphyritic olivine basalt. It is highly vesicular basalt and at places the vesicles were filled by carbonate minerals. It is consisting of scoria and spatter cones with associated lava flows. Both the basalt and scoria is quarried for construction around Akaki and Dukem area. The thickness of this unit around Akaki is 202m (exploration drilling data). The age of the Akaki basalt is 2.9-2.0 Ma (Chernet et al 1998 and Morton et al 1979).

3.1.2.10 Central Volcanoes Unit

3.1.2.10.1 Wechecha, Furi and Yerer Trachyte (NcvTy)

The Central Volcanoes units are mainly trachytic lavas exposed at Wechecha, Furi, Yerer, Western and Southwestern ridges of the area forming an elevated ridges or mountain picks. The Yerer trachyte is elevated about 1000 m from the surrounding plane area. The south and southern western ridges are a watershed divide between the Omo-Gibe and Awash River basins. It is grayish color fine to medium grained trachyte with subordinate ash falls and ignimbrite. The age of this unit is 10-3 Ma (Kazmin, 1979).

It is porphyritic in texture with phenocrysts of feldspar up to 1cm across. In fresh hand specimen it is grayish in color. Petrographic studies conducted by Abebe et al (1999) indicate that Trachytes of Wechecha and Furi are composed of plagioclase and sanadine phenocrysts predominating the trachyte, alkaline pyroxene and rare olivine. The groundmass varies from glassy to microcrystalline and is constituted mainly by alkali feldspar, pyroxene and amphiboles and opaque. The ages of the trachytes are different

with Wechecha 4.6-3.7 Ma, Furi 4.0-3.7 Ma (Chernet et al 1998), Yerer 3.9-3.3 Ma (Morton et al 1979).

3.1.2.10.2 Entoto ridge and Becho area Rhyolites (NebRy)

The Entoto ridge forms watersheds divide of Abay and Awash River basins. The ridge forms steep slope towards the Abay basin steep to gentle slope towards the Awash basin. In fresh hand specimen it is grayish pink and reddish brown to yellowish grey color when weathered. The rhyolites in the Becho plane forms isolated cones. Obsidian up to 10 cm across is common at the picks of the cones. Data on the ages of the rhyolites are not available; however from the cross-cutting relationship they can be younger than the adjacent ignimbrite.

3.1.2.11 Tulu Rie Basalt (NtrB)

This unit is outcropped in the southeastern part of the mapped area and forms NE trending escarpments. It is lava flow coarse grained basalt with olivine and plagioclase phenocrysts with rare clinopyroxene. The age of this rock is 2.7 to 1.44 Ma.

3.1.2.12 Chefe Donsa Unit (NQcdPc)

The Chefe Donsa volcanic rock units are outcropped at the east, north east, south and west extreme parts of Debrezeyt. They are consisting of fall deposits (ash, tuff and pumice) and poorly welded ignimbrites of rhyolitic composition. At places in the Dukem and Mojo river valleys they are observed under the lacustrine deposit. The age of this unit ranges 2.24 to 1.71 Ma (Morton et al 1979).

3.1.3 Quaternary Volcanic Rocks

3.1.3.1 Weliso Ambo Basalts (QwaB)

This unit is outcropped at the western and northern extreme parts of the mapped area. It is a lava flow composed of porphyritic basalt with large crystals of plagioclase, olivine and pyroxene, basalt breccias and minor tuff. In the area of Weliso it is scoriaceous basalt. In the Abay Master Plan report this unit is mapped as basalt lava flows connected to volcanic centers (QVCB) and its age is Pliocene to present.

3.1.3.2 Ziquala Trachyte (QzqTy)

Ziquala trachyte is isolated, well preserved cone standing about 1300m from the surrounding plane area, located in the eastern part out of the study area. It has a summit caldera 1.5 km wide and partially filled by water. The Ziquala trachyte is grayish pink in color, coarse grained and petrographically composed of anorthoclase, sanadine, minor clinopyroxene phenocrysts and glassy alkali feldspar groundmass. The age of the Ziquala trachyte is 1.28-0.85 Ma (Morton et al 1979).

3.1.3.3 Bede Gebaba Volcano Units (QbgPr)

This unit is a circular volcanic complex outcropped north of the Ziquala Mountain with maximum elevation of 400m above the surrounding plane. Its morphology dominated by the occurrence of several coalescent caldera structures. Spatter cones and basaltic lava flows belonging to younger Bishoftu Volcanic are present in the central part of the volcanic complex. The most recent products are represented by rhyolitic obsidians whose age is 0.36 Ma (Leeds University in Abebe et al 1999). Pumice and lavas show a composition ranging from rhyolites to minor trachytes. According to Gasperon et al (1993) the lava contains microphenocrysts and rare phenocrysts of sanadine and quartz as well as scattered plagioclase and clinopyroxene set in glassy to microcrystalline groundmass.

3.1.3.4 Bishoftu Volcanic Unit (QbiB)

This unit forms a NNE trending belt outcropping mainly in the central flat areas of Debrezeyt. In the Bishoftu Volcanic spatter and cinder cones with associated tabular basaltic lavas flows and phreatomagmatic deposits are distinguished. The basalt is vesicular and coarse grained with olivine phenocrysts. The phreatomagmatic deposits are mainly consisting of surges and highly fragmented deposits associated with maars and tuff ring.

3.1. 4 Quaternary Lacustrine and Alluvial sediments

3.1.4.1 Lacustrine Deposits (Qld)

The lacustrine deposit is particularly distinguished in the Adaa plain of the Lakes region. They are fine grained deposits generally brown-yellowish, thinly stratified and often contained volcanic matrix; whose thickness ranges from 5 to 8m. More thickness is

reported in the groundwater well drilling reports. In these successions volcanic layers are frequent and become predominant and coarse grained near by the maars.

3.1.4.2 Alluvial Cover (Qal)

The alluvial cover mainly outcropped above the Tertiary volcanics on the plateaus and Becho Plain and consisting of regolith, reddish brown soils, talus and alluvium with maximum thickness of about 7 m (Becho area hand dug well data).

3.2 Tectonic Structures

The geological structures in the area are normal faults, bedding and joints, block faulting, fissuring and tilting of the rocks affecting the various rock units in the area. As referred from the map four types of fault features (NW_SE, NE_SW, E_W and N_S) are recognized. The NW fault system, the oldest fault system have extended history affects all the rock type in the western escarpment. They are crustal scale served as a conduit for the extensive volcanic formation in the area and their age may go up to early Paleozoic, but becomes reactivated latter with the main tectonic event in the region. The trend of the Bede Gebaba -Weheca volcanic belt can be associated with this NW fault system.

The EW fault system, which is the upper boundary of the Ethiopian rift margin, is running approximately E-W along the Addis Ababa Ambo road. They are major fault on the western plateau part and densely affected the Tarma Ber basalt in the area.

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The NE-SW fault system runs parallel to the principal system of fissures in rift floor north east of Debrezeit and Modjo and extending to Nazeret. This fault system is densely affecting the volcanic rocks and served as a conduit to younger eruption (Tulu Rie basalt). The fault system of the rift margin exhibit step like block faults.

The NS fault system is the recent fault system, which serves as a conduit for young volcanic (Addis Ababa basalt).

AGE	SYMBOL	NAME AND DESCRIPTION
Quaternary	Qal	Alluvial deposit: Alluvial bars and swamp areas surrounded by volcanic.
	Qld	Lacustrine deposit: Thinly stratified brown-yellowish deposit with volcanic matrix.
	QbiB	Bishoftu volcanic unit: Spatter cones with basaltic lava flows and maars.
	QbgPr	Bede gebaba volcanic unit: Rhyolitic to minor trachytic lavas and pumice.
	QzqTy	Ziquala Trachyte: Per alkaline trachytes
	QwaB	Weliso Ambo basalt: Porphyritic basalt, breccias and tuff.
Neogene	NQcdPc	Chefe donsa pyroclastics: Columnar alkaline flood basalts.
	NtrB	Tulu rie basalt: Olivine basalt lava flows.
	NebRy	Entoto becho rhyolite: Obsidian reach rhyolites.
	NcvTy	Central volcanics of wechecha, Furi, Yerer, Porphyritic trachytic lavas.
	NakB	Akaki basalt: Scoria and spatter cones with associated basaltic lava flows.
	NnuRI	Nazaret unit: Welded per alkaline rhyolitic ignimbrites.
	NadB	Addis Ababa basalt: Alkaline and olivine basalt lava flows.
Paleogene	Nal	Addis Ababa Ignimbrite: Tall deposits and poorly welded pyroclastics
	PNtbB	Tarma ber basalt: Leaticular basalts with a large amount of scaraceous lava flows.
	PaIRy	Alaji Rhyolite: Rhyolites and acidic tuff.
	PaaB	Amba aiba basalt: Flood basalts in thick flows (trachy basalts & rare basic tuffs).
	PasB	Ashengi Basalt: Deeply weathered basaltic lava flows.
Mesozoic	PbnB	Blue Nile basalt: columnar alkaline flood basalts.
	KaaS	Cretaceous amba aradam sandstone: Sandstone, Siltstone, Shale & Dolomite.
	JanL	Jurassic antalo limestone: Fossiliferous limestone and maarl.
	JabB	Jurassic abay beds: Gypsum, dolomite, limestone, sandstone.
	JadS	Triassic-Jurassic adigrat sandstone: Sandstone, shale and carbonate.

Source: Geological map of Adaa-Becho groundwater basin (1:1.000.000), By Water Works Design Supervision Enterprise, 2007.

Table 3.1 Stratigraphic column of Regional Geology

3.3 Local Geology

The study area is affected by two major events of volcanic eruption namely; syn-rift and post rift .The syn-rift volcanic rocks are those associated with the formation and development of the Main Ethiopian Rift system. The main rock units are ignimbrites and rhyolites of the Neogene group. The post-rift volcanic rocks are those of the quaternary age outcropped on the plateaus and the rift system. They usually form central volcanoes and the main rock unit in the study area (Figure3.3) is quaternary basalts.

3.3.1 Tertiary Ignimbrite

This unit covers most part of the study area (Figure3.3). Rocks of this unit occurs one intercalating the other; the relatively thick deposit of unwedded tuffs and volcanic ash are most of the time blanketed by ignimbrite sheets of up to about 30 m thick in the study area. It is grayish to white color and when welded it exhibits fiamme textures, elongated rock fragments of various color. In the plane area the unit is covered by thin residual soil made of the same rock units and alluvial deposit.

3.3.2 Tertiary trachyte

Central volcanoes of trachytic formation occur along the southeast of the study area and forming an elevated ridges or mountain picks. The rocks generally are porphyritic with large euhedral phenocrysts of feldspar. It is grayish color fine to medium grained trachyte with subordinate ash falls and ignimbrite. Some of the other minerals observed in the groundmass are alkali feldspar, pyroxene and amphiboles and opaque. Jointing because of cooling of the magma and complex flow fold structure commonly occur in the rocks. According to reports of the earlier works indicated in the regional geology the age of the eruption ranges from 10-3Ma (Kazmin, 1979).

3.3.3 Tertiary Rhyolite

This unit occurs in the western part of the study area. The rhyolitic rocks overlies and/or cut through older formation of Ignimbrite. It consists of rhyolitic rocks with cryptocrystalline to fine grained brittle rocks that have reddish to white color play in fresh and almost light brownish grey to white soft material when weathered. Sometimes it is difficult to distinguish the rock from equivalent units of various tuffs (trachytic crystal tuff, andesitic crystal tuff, rhyolitic tuff, ignimbrites, etc.), perhaps, due to the effect of weathering – devitrification (Figure3.3).

3.3.4 Quaternary Basalt

Quaternary basalt flows associated with scoria cones are occurs in the southern part of the study area. This basaltic unit erupted through localized fractures and overlies the older units in areas of its occurrence. The rock consists of porphyritic and rarely aphyric olivine and pyroxene and some times plagioclase phenocrysts. The unit is more of basic, rarely andesitic, and usually scoraceous type (Figure 3.3).

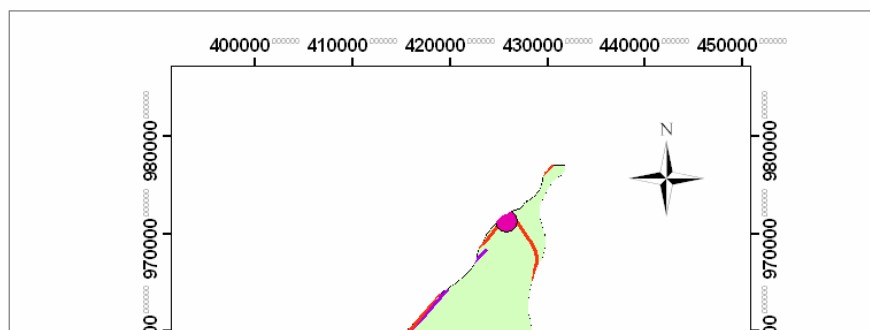


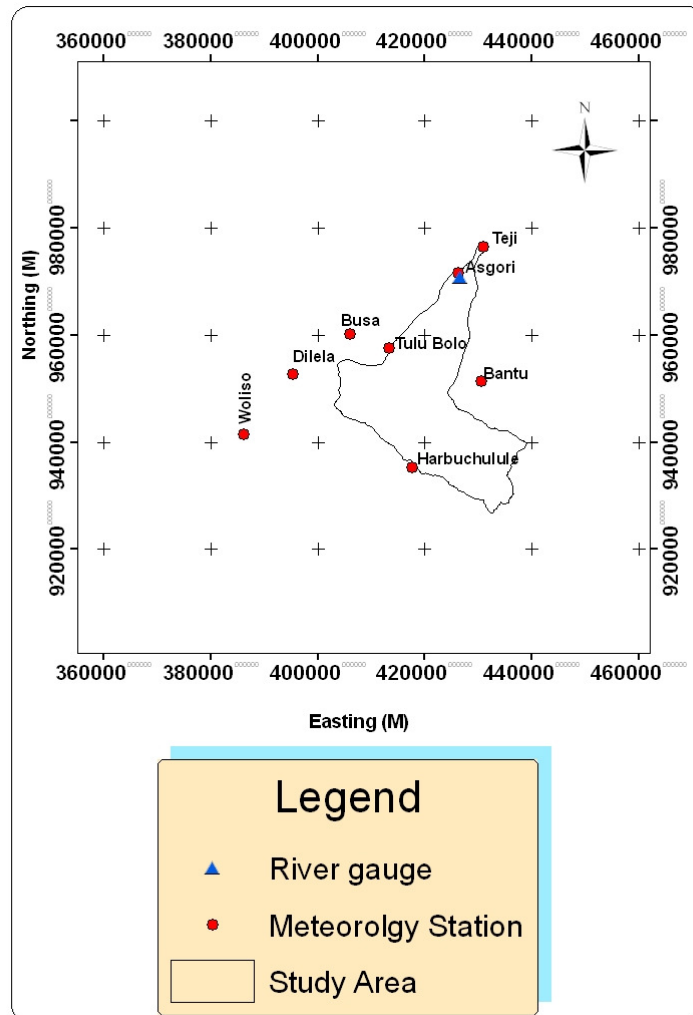
Figure 3.3 Geological map of the study area.

Chapter Four Hydrometeorology

4.1 General

Hydrometeorology data are required for the study of water resource investigation. There are seven meteorological stations distributed in different parts of the study area and surroundings. Two of the stations (Asgori & Tulubolo) have rainfall and temperature data the remaining five (Bantu, Teji, Harbuchulule, Busa and

Woliso) have elements of solar radiation (Figure 4.1).



Woliso) have elements of solar radiation (Figure 4.1).

Figure 4.1 Location Map of Meteorological & River gauge Stations.

4.2 Annual effective aerial depth of precipitation

Rainfall measurement is a point observation and may not be used as a representative value for the area under consideration. Therefore it is necessary to obtain effective uniform depth of precipitation of the catchment to get a more reliable and representative results. Aerial depth of precipitation in the catchment is estimated by simple arithmetic mean, Isohyetal method and Thiessen polygon method.

Thiessen polygon method is more reliable than arithmetic mean because the distribution of precipitation gauges in the catchment is non uniform.

4.2.1 The Arithmetic mean

Arithmetic mean method is the simplest one for evaluation of mean uniform distribution of rainfall of a basin. The rainfall stations used in the calculation are those located in the catchment and nearby gauges considered representative of the area & relatively marked with no diversity in topography to get reliable measure of aerial rainfall. Thirty years (1977-2005) rainfall data obtained from the National Meteorology Service Agency is used for the analysis.

The aerial depth of precipitation can be calculated using arithmetic mean as follows:

$$P = \frac{\sum P_i}{N} \text{-----} (4.1)$$

Where p_i = mean annual precipitation measured at i^{th} station (Table4.1).

N = number of gauging station

A = Aerial depth of precipitation

Table 4.1 Mean monthly area depth of precipitation (see Annex-1 for rainfall data).

Station	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Teji	18.92	38.66	55	82.59	70.53	121.8	222.6	217.9	94.15	26.15	5.31	6.27	959.8
Asgori	18.43	33.96	55.49	86.46	70.24	136.5	250.9	247.7	105.7	26.58	5.68	4.94	1043
Tulu-bolo	18.47	19.24	53.63	69.13	77.47	195.5	290.3	278.2	90.63	25.44	6.49	6.3	1131
Bantu	17.18	26.27	59.42	75.14	69.67	163.7	288.8	267.4	122.9	40.96	11.3	4.81	1147
Harbu chulule	21.94	45.85	69.01	93.75	81.09	168.6	217.2	211.3	115.6	19.59	5.09	5.74	1055
Mean	18.99	32.8	58.51	81.41	73.8	157.2	253.9	244.5	105.8	27.74	6.774	5.612	1067

Therefore, the annual aerial depth of precipitation is calculated to be 1067mm.

4.2.2 Thiessen polygon method

This method helps to calculate the weighted average precipitation of each station by the following formula:

$$PPT = \sum (A_i/A) * P_i, i = 1-n \text{ ----- (4.2)}$$

Where P_i = precipitation measured at i^{th} station (Table 4.2).

A_i = area of the i^{th} polygon bounded by i^{th} station (Table 4.2), A = area of the catchment.

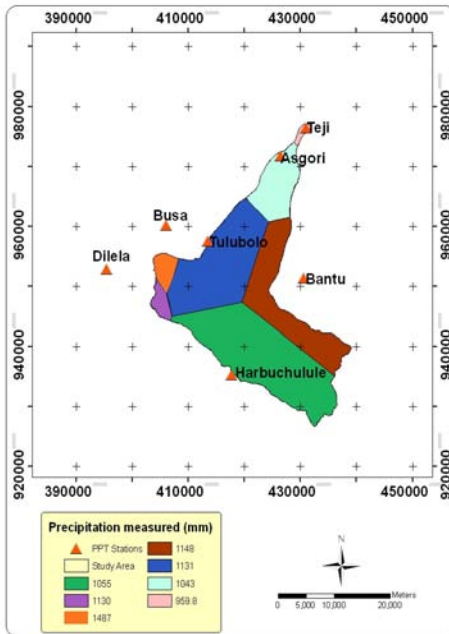


Figure 4.2 Thiessen

Table 4.2 Mean Annual depth of precipitation

Station	Area	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Teji	4.52	18.9	38.6	55	82.5	70.5	121.	222.	217.	94.1	26.1	5.31	6.27	959.8
Asgori	71.9	18.4	33.9	55.49	86.4	70.2	136.	250.	247.	105.	26.5	5.68	4.94	1043
Tulu-bolo	190.	18.4	19.2	53.63	69.1	77.4	195.	290.	278.	90.6	25.4	6.49	6.3	1131
Bantu	137.	17.1	26.2	59.42	75.1	69.6	163.	288.	267.	122.	40.9	11.3	4.81	1148
Harbuchulule	254.	21.9	45.8	69.01	93.7	81.0	168.	217.	211.	115.	19.5	5.09	5.74	1055
Busa	18.6	22.3	32.1	35.83	96.1	93.7	206.	392.	413.	153.	22.8	11.3	6.11	1487
Dilala	14.2	25.5	32.0	66.57	85.1	91.9	166.	238.	247.	131.	31.7	5.09	7.78	1130

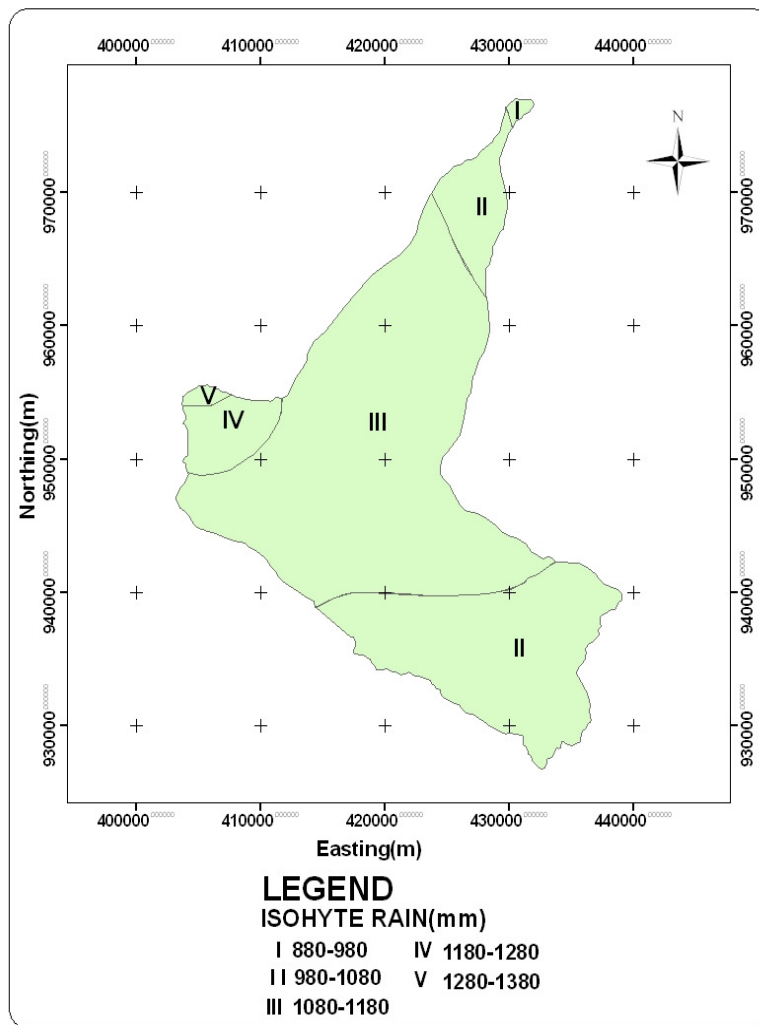
Groundwater potential Assessment of Teji River Catchment

	692.	19.7	32.6		82.3	77.1	172.	260.	250.	110.	26.5			1105.
	2	4	9	60.43	2	9	4	3	9	4	6	6.94	5.68	5
	Average annual precipitation of the catchment is 1105.5mm.													

Accordingly, aerial depth of precipitation of the catchment calculated to be 1105.5mm.

4.2.3 Isohyetal method

This method takes in to account the influence of physiographic parameters which includes elevation, slope, and distance from the coast and exposure to rain bearing winds (Shaw, 1988). Since the study area has non-uniform land and varies in topography (2040-3600 m.a.s.l), the method is more preferred to arithmetic mean. It is employed by drawing counters of equal aerial depth of precipitation.



The area rainfall (R) is calculated from the product of the inter- isohyetal area (a_i) and the corresponding mean rainfall between the isohyets (r_i) divided by the total catchment area (A).

$$R = \frac{\sum_{i=1}^N a_i \cdot r_i}{A} \text{----- (4.3)}$$

Table 4.3 Mean annual depth of precipitation obtained by isohyetal method.

Isohyet's (mm)	Estimated EUD	Net Area (km ²)	Percent of Total area	Weighted Precipitation (mm)
(A)	(B)	(C)	(D)	(B*D)
1280-1380	1330	4.09	0.59	7.85
1180-1280	1230	33.98	4.91	60.39
1080-1180	1130	424.55	61.33	693.03
980-1080	1030	226.94	32.79	337.74
880-980	930	2.62	0.38	3.53
Total		692.18	100.00	1102.54

Where, EUD is Effective Uniform Depth of Precipitation

Accordingly, the area depth of precipitation of the catchment is calculated to be 1102.54mm.

Thiessen polygon and isohyets method have more or less similar values and therefore, the mean annual depth of precipitation taken to be the mean of the two values that is 1104mm.

4.3 Rainfall coefficient

Rainfall coefficient is the ratio between mean monthly rainfall and one twelfth of the annual mean of the total rainfall (Daniel 1977). Rainy and dry months in the given hydrologic year (Table 4.5) are classified based on the value of rainfall coefficient.

$$RC = P_m / (P_y/12) \text{ ----- (4.4)}$$

Where - **RC** = Rainfall coefficient

P_m = Mean monthly rainfall depth

P_y = Mean annual rainfall depth

Table 4.4 Mean monthly rainfall And Monthly rainfall coefficient.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P_m(mm)	19.5	32.3	60.8	81.4	76.3	171	258	248	109	26.9	6.95	5.62
R_c	0.21	0.35	0.66	0.89	0.83	1.86	2.81	2.69	1.18	0.29	0.08	0.06
P_y=1104												
P_y/12=92												

The months October, November, December, January, and February are dry months & the months March, April, May, June, July, August, and September are rainy months based on rainfall coefficient value classification.

Table 4.5 Classification schemes of monthly rainfall values

	Dry months	Rainy months			
		Small rains	Big rains		
			Moderate C	High C	Very high C
		R _c < 0.6	0.6 < R _c < 0.9	1 < R _c < 1.9	2 < R _c < 2.9
Months	October	March,	June, September	July, August	
	November,	April, May			
	December,				
	January				
	February				

C refers concentration

Rainy months contribute 91.74% of the total mean annual precipitation and the remaining 8.26% contributed from the dry months.

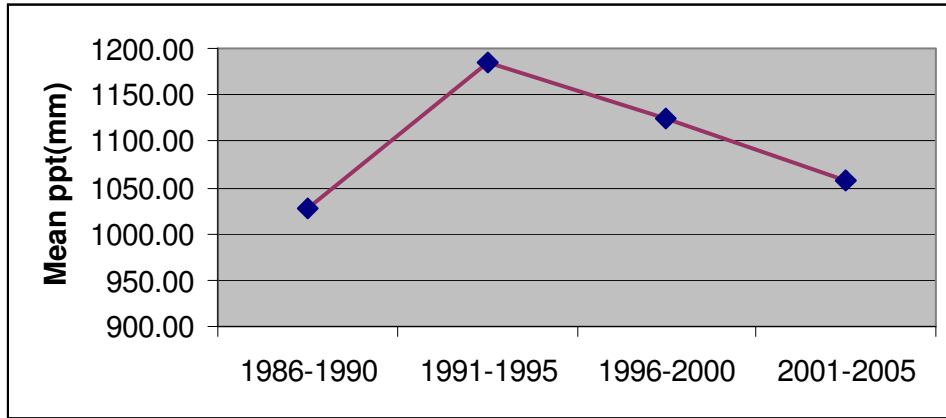


Figure 4.4 Five Years aggregate Trend of precipitation (see Annex-1 for rainfall data).

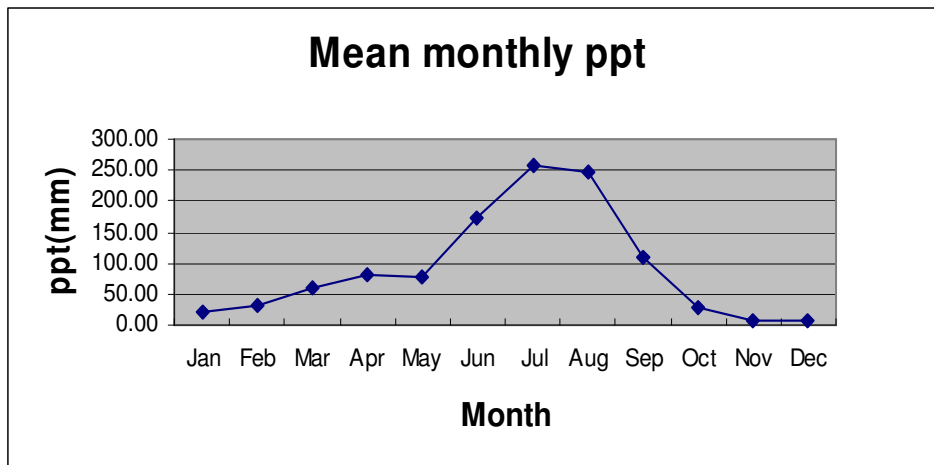


Fig 4.5 Mean Monthly Precipitations

4.4 Temperature

Air and water temperature have direct influence on evaporation by making the environment hot and favors the passage of liquid state of water to vapor state. The higher the air temperature, the more water vapor it can hold, and similarly if the temperature of evaporating water is high, it can more readily vaporized (Shaw, 1988).

Table 4.6 Mean monthly Maximum & Minimum temperature of the catchment based on eighteen years data records.

Station		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Tulu-bolo	Max	24.29	25.04	25.31	25.5	25.68	24.77	23.34	23.54	23.63	23.33	23.92	23.55
	Min	8.56	8.74	9.67	9.88	9.57	9.81	9.81	9.75	9.33	9.02	8.52	8.27
Asgori	Max	27.47	28.45	28.99	28.38	29.03	27.56	24.96	24.77	25.48	25.79	26.53	26.81
	Min	7.13	7.52	9.02	10.23	9.41	9.74	10.72	10.98	9.88	6.04	4.6	4.97
	Av.Max	25.88	26.74	27.1	29.94	27.35	26.16	24.15	24.15	24.55	24.56	25.22	25.18
	Av.Min	7.84	8.13	9.34	10.05	9.49	9.77	10.26	10.36	9.6	7.53	6.56	6.62
	Mean	16.86	17.43	18.22	19.99	18.42	17.96	17.2	17.25	17.07	16.04	15.89	15.9

The mean annual minimum temperature of the catchment is 8.8^oc and the mean annual maximum temperature is 25.92^oc. The mean annual temperature of the study area is 17.35^oc.

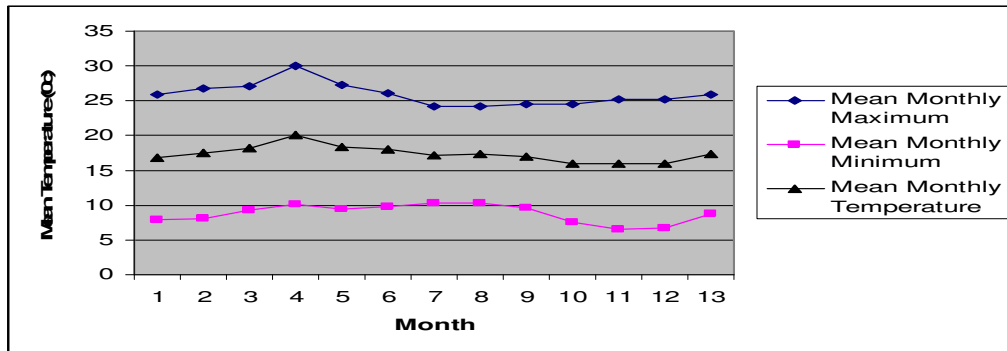


Figure 4.6 Mean Monthly Temperature of the Study Area.

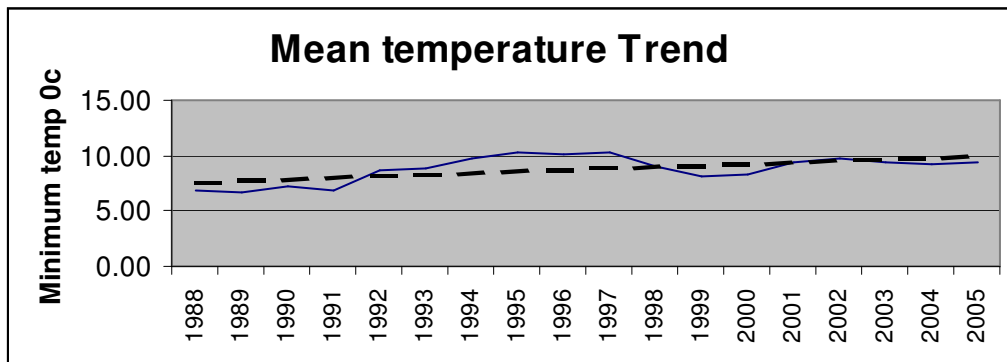


Fig 4.7 Mean annual Temperature of the study area.

4.5 Relative Humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature ed/ea represents as a percentage (Shaw, 1985).

As air humidity increases, its ability to absorb water vapor decreases and evaporation rate slows down. For evaporation to take place there must be a difference in humidity (Tenalem Ayenew and Tamiru Alemayehu, 2001; Fetter C.W, 1994).

Table 4.7. Monthly mean relative humidity (%)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Average	47.2	42.2	48.9	52.9	61.8	78.2	83.2	83.9	73.9	57.9	45.4	44.6

The maximum and minimum relative humidity is found in August (83.9%) and February (42.2%), respectively. The highest humidity values are found in the rainy months whereas the lowest humidity values are in the dry months.

4.6 Wind speed

Wind speed and air temperature removes water vapor molecules from the air in contact with the water holding surface enable evaporation to proceed at maximum rate governing with the existing main factor, temperature and humidity condition. The movement of air and moisture transfer depends on wind speed and turbulence.

Evaporation is greater in exposed areas that enjoy plenty of air movement than in sheltered localities where air tends to stagnant (shaw-1985).

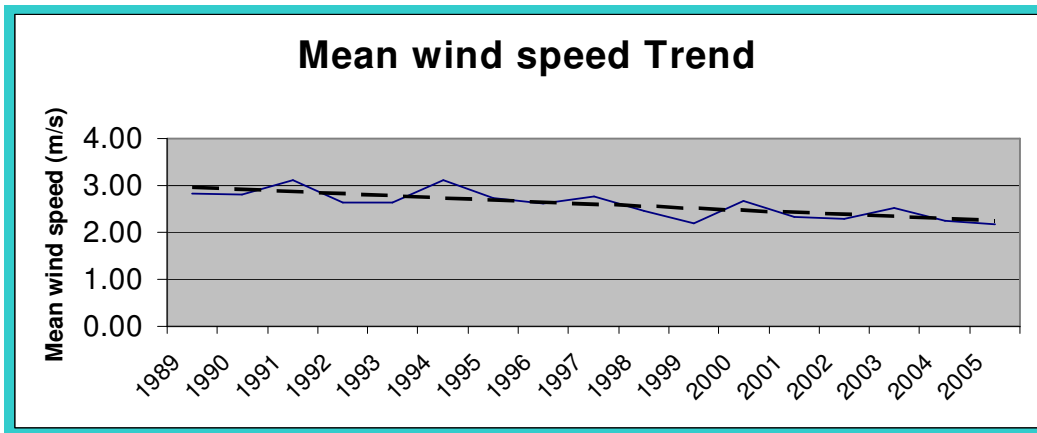


Fig 4.8 Decreasing Trend of wind speed.

Table 4.8 Mean monthly wind speed

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
M.W.S.S.A	3.97	3.85	3.13	2.85	1.92	1.16	1.04	0.99	1.20	2.71	3.92	4.44
M.W.S.S.A = Mean wind speed of the study Area												

The minimum wind speed is found relatively in the rainy season (June-September).

4.7 Evapotranspiration

Evapotranspiration is the total loss by both evaporation and transpiration from a land surface and its vegetation. Therefore, it is difficult to separate the effects of evaporation and transpiration over land areas. Evapotranspiration is difficult to measure directly from an appreciable area under natural condition and it is necessary to calculate evaporation and evapotranspiration using different conventional method and available hydro meteorological data.

4.7.1 Potential evapotranspiration (PET)

Potential Evapotranspiration is evapotranspiration from vegetal cover if sufficient water is supplied to obtain optimum growth or the maximum amount of vapor which might be transferred under existing meteorological condition, water is not the limiting factor.

Potential evapotranspiration can be calculated with various method based on the available meteorological data.

4.7.1.1 Penman or combination Approach

This method is used to quantify the PET of the study area.

Table 4.9 Mean monthly PET obtained from penman method

ELEMENTS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	(ANN UM)
T (^o C)	16.86	17.43	18.22	19.99	18.42	17.96	17.2	17.25	17.07	16.04	15.89	15.9	
n(Hrs)	8.8	7.6	8	6.9	7.9	5.6	3.8	4.1	5.7	8.9	9.8	9	
N (Hrs)	11.7	11.8	12	12.2	12.4	12.5	12.4	12.3	12.1	11.9	11.7	11.6	
n/N	0.752	0.644	0.667	0.566	0.637	0.448	0.306	0.333	0.471	0.748	0.838	0.776	
H (%)	47.2	42.2	48.9	52.9	61.8	78.2	83.2	83.9	73.9	57.9	45.4	44.6	
U1 (m/s)	3.97	3.85	3.12	2.85	1.92	1.16	1.03	0.98	1.07	2.7	3.9	4.4	
U2 (miles/h)	8.88	8.61	6.98	6.38	4.3	2.6	2.3	2.19	2.39	6.04	8.73	9.84	
$\Delta\gamma$	1.86	1.91	1.99	2.19	2.01	1.97	1.89	1.9	1.88	1.79	1.78	1.78	
R _a (mm/day)	13	14	14.9	15	14.9	14.6	14.7	14.9	14.9	14.3	13.3	12.7	
e _a (mmHg)	14.45	14.95	15.68	17.4	15.87	15.44	14.74	14.79	14.62	13.72	13.59	13.6	
e _d	6.82	6.31	7.67	9.2	9.81	12.07	12.26	12.41	10.8	7.94	6.17	6.07	
E _{at}	1.57	1.77	1.6	1.62	1.15	0.62	0.45	0.43	0.7	1.13	1.53	1.58	
R _o	38.97	44	53.4	61.5	62.53	66.2	64.94	66.56	64.89	47.21	37.83	34.15	
RI (1-r)	6.11	5.87	6.41	5.75	6.2	4.79	3.86	4.1	5.05	6.69	6.78	6.11	
fa(n/N) = 0.16+ 0.62n/N	0.63	0.56	0.57	0.51	0.56	0.44	0.35	0.37	0.45	0.62	0.68	0.64	
σTa^4 (mm/d ay)	0.63	0.56	0.57	0.51	0.55	0.44	0.35	0.37	0.45	0.62	0.68	0.64	
H _r	3.11	3.12	3.75	3.52	3.89	3.21	2.64	2.82	3.32	3.91	3.44	2.95	
PET (mm/day)	2.57	2.66	3.03	2.92	2.98	2.34	1.88	2	2.41	2.91	2.75	2.46	
PET (mm/month)	79.75	77.08	93.92	87.69	92.46	70.07	58.4	61.97	72.33	90.27	82.59	76.2	942.7

PET = Potential Evapotranspiration

e_a = the saturated vapor pressure at air temperature, T_a

$$PET = [(\Delta/\gamma)H_T + E_{at}]/(\Delta/\gamma) + 1$$

e_d = the saturated vapor pressure at the dew point, T_d , $e_a - e_d$ = the saturation deficit

$$H_T = R_i (1-r) - R_0$$

Δ =the slope of the curve of saturated vapor pressure plotted against temperature

$$R_i (1-r) = 0.75R_a * f_a (n/N)$$

γ =hygrometric constant (0.27mmHg/⁰F), R_i = incoming radiation, R_0 = outgoing radiation

$$f_a (n/N) = 0.16 + 0.62n/N$$

R_a = the solar radiation (fixed by latitude and season)

$$R_0 = \sigma T_a^4 (0.47 - 0.075\sqrt{e_d} (0.17 + 0.83n/N))$$

.. σT_a^4 = the theoretical black body radiation at T_a

$$E_{at} = 0.35(0.5 + u_2/100)(e_a - e_d) = f(u)(e_a - e_d)$$

σ = the Stephan Boltzman Constant, = $5.67 * 10^{-8} \text{Wm}^{-2}/\text{K}^4$

r = albedo

u_2 = mean wind speed at 2m above the surface, miles/day

E_a = energy for evaporation based on the air humidity and air temperature

T_a = mean air temperature for a month, °C

n = bright sunshine over the same period, h/day, H_T = the available heat

N = mean daily duration of maximum possible sunshine hours (South Latitudes)

4.7.1.2 Thornthwaite Approach

The method requires only air temperature as an index of energy available and adjusted hours of day light for evaporation, so the values tend to be under estimated. An estimate of PET calculated on a monthly basis is given by:

$$PET_m = 16N_m (10\check{T}_m/I)^a \text{-----} (4.5)$$

$$I = \sum i_m = \sum (\check{T}_m/5)^{1.5} \text{-----}(4.6)$$

Where $a = 6.7 * 10^{-7} I^3 - 7.7 * 10^{-5} I^2 + 1.8 * 10^{-2} I + 0.49 \text{-----} (4.7)$

Groundwater potential Assessment of Teji River Catchment

N_m = (day light factors) is obtained by dividing the possible sunshine hours for the appropriate latitude by 12 (it is the monthly adjustment factor related to hours of daylight)

m = months in a year 1,2,3 ---12,

Groundwater potential Assessment of Teji River Catchment

\bar{T}_m = monthly mean temperature, °C,

I = the heat index for the year

Table 4.10 Mean monthly PET obtained from Thornthwaite method

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
$T^{\circ}C$	16.86	17.44	18.25	18.50	18.43	17.97	17.21	17.26	17.08	16.04	15.89	15.90	
N (Hrs)	11.7	11.8	12	12.2	12.4	12.5	12.4	12.3	12.1	11.9	11.7	11.6	
T_m	16.86	17.44	18.25	18.50	18.43	17.97	17.21	17.26	17.08	16.04	15.89	15.90	
Nm	0.975	0.983	1.000	1.017	1.033	1.042	1.033	1.025	1.008	0.992	0.975	0.967	
i_m	6.193	6.514	6.972	7.116	7.074	6.814	6.385	6.414	6.313	5.748	5.666	5.671	76.88
I	76.88												
a	1.682												
PET (mm)	58.46	62.39	68.47	71.23	71.92	69.52	64.11	63.92	61.77	54.69	52.90	52.51	751.91

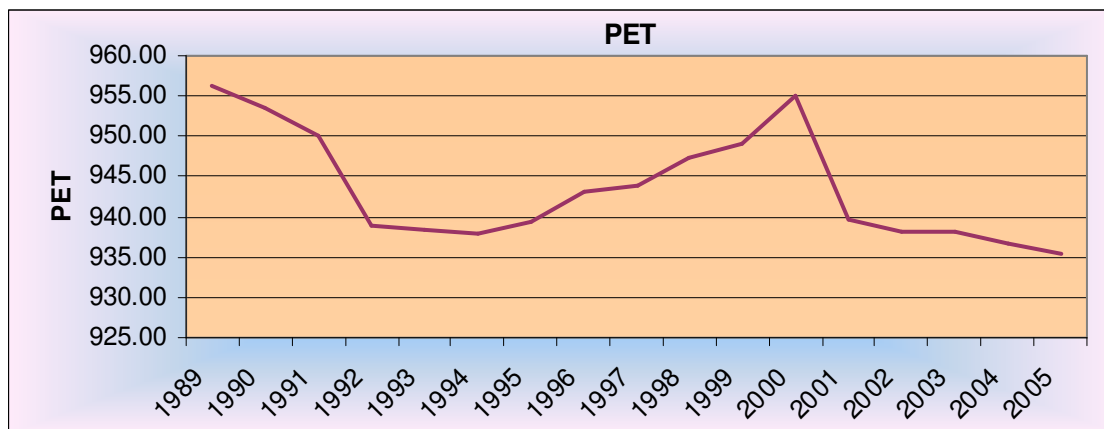


Figure 4.9 Decreasing trend of PET obtained from penman method

Trend and relationship of some of the hydrometeorological elements.

Temporal trend of some of the hydrometeorological parameters that have relationship with each other presented as follows;

- Mean minimum temperature shows a slight increasing trend.
- Mean wind speed shows decreasing trend.
- Potential evapotranspiration shows a decreasing trend.

It could be said that, the decreasing trend of potential evapotranspiration in Teji river catchment is mainly affected by wind speed.

4.7.2 Actual evapotranspiration

Actual evapotranspiration is the amount of evapotranspiration that occurs under field conditions. The actual evapotranspiration rate equals to potential evapotranspiration rate when there is abundant moisture in the soil. Always actual evapotranspiration is less or equal to potential evapotranspiration. When the vegetation is unable to abstract water from the soil, then the actual evapotranspiration becomes less than potential.

4.7.2.1 AET from PET

Actual evapotranspiration over catchments is obtained first calculating the PET and then modifying the result by accounting for the actual soil moisture content. The relationship between AET and PET depends up on the soil moisture content. When the soil is saturated, i.e. when it is at its field capacity, PET = AET (Shaw, 1984).

The value of AET obtained from measurements of PET is about **703.07mm/year**.

4.7.2.2 Turc method

$$AET = P / [0.9 + (P/L)^2]^{1/2} \text{-----(4.8)}$$

$$L = 300 + 25T + 0.05T^3 \text{----- (4.9)}$$

Where p=mean annual precipitation

T=mean air temperature (°c)

AET=756.16mm

4.7.2.3 Crowe and Thornthwaite (1971)

This method applies the following formula:

$$AET = (T-10)/9 \text{----- (4.10)}$$

Table 4.11 AET obtained from Crowe and Thornthwaite

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T,°F	569.9	589	615.8	675.7	622.6	607	581.4	583	576.96	542.1	537.1	537.4
AET	62.2	64.3	67.3	74	68	66.3	63.5	63.6	62.9	59.1	58.6	58.6

AET=768.4mm

4.7.2.4 Soil Water balance

This method helps to quantify the annual actual evapotranspiration of the area on the basis of the potential evapotranspiration already computed by using empirical and physical formula.

Table 4.12 Estimating AET by soil water balance method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
PPT	19.74	32.69	60.43	82.32	77.19	172.39	260.29	250.91	110.35	26.56	6.94	5.68	1105.49
PET (mm/month)	79.75	77.08	93.92	87.69	92.46	70.07	58.40	61.97	72.33	90.27	82.59	76.20	942.72
PPT - PET	-60.01	-44.39	-33.49	-5.37	-15.27	102.32	201.89	188.94	38.02	-	-75.65	-70.52	162.77
ACC. POT.WL	-	-	-	-	-					-	-	-	
	269.89	314.28	347.77	353.13	368.40					63.71	139.36	209.88	
SM	45.9	36.3	30.5	29.6	27.3	129.62	190	190	190	135.9	91.3	63.0	
ΔSM	-17.14	-9.64	-5.80	-0.83	-2.32	102.32	60.38	0.00	0.00	-	54.10	-44.60	-28.27
AET	36.88	42.33	66.23	83.15	79.51	70.07	58.4	61.97	72.33	80.66	51.54	33.95	703.07
D	42.87	34.75	27.69	4.54	12.95	0.00	0.00	0.00	0.00	9.61	31.05	42.25	239.65
S	0	0	0	0	0	0	141.51	188.94	38.02	0	0	0	368.48
TARO	10.49	5.25	2.62	1.31	0.66	0.33	141.51	259.70	167.87	83.93	41.97	20.98	
RO	5.25	2.62	1.31	0.66	0.33	0.16	70.76	129.85	83.93	41.97	20.98	10.49	357.82
DETENTION	5.25	2.62	1.31	0.66	0.33	0.16	70.76	129.85	83.93	41.97	20.98	10.49	

AWCR = 190mm

Where

PPT-average monthly rainfall values (mm) are listed in row 1 of table 4.12

PET-potential evapotranspiration values, mm.

PPT-PET= the difference between rainfall and potential evapotranspiration. Positive values are showing additions of moisture to the soil while the negative values are showing the monthly demand of moisture by the vegetation which is not satisfied by the monthly rainfall.

ACC.POT.WL= the accumulated potential water loss. The summation begins with October, the first month of the dry season, until and including May which obtains a value of -368.4mm.

S_M =soil moisture .The soil moisture content during the dry months is calculated using accumulated potential water loss by the following formula;

$$S_M = W \cdot \exp(-L_{aw}/W) \text{----- (4.11)}$$

S_m =soil moisture during month M (mm).

L_{aw} =accumulated potential water loss at month M (mm).

W =available water capacity of the root zone (mm).

Soil moisture values for each wet month are obtained by adding the excess of rainfall of the current month to the soil moisture of the month before. This sum may not exceed the soil moisture capacity, an eventually excess is booked as surplus (row 9).

$$\Delta S_M = S_M - S_{(M-1)} \text{----- (4.12)}$$

ΔS_M =difference in soil moisture between month M and month M-1 (mm).

AET= Actual evapotranspiration. For the wet months the actual evapotranspiration equals the potential evapotranspiration, because it is assumed that all the rain which falls is available for the plants.

For the dry month, the actual evapotranspiration is the sum of the monthly rainfall and the monthly amount of water extracted from the soil.

$$AET_M = R_M + \Delta S_M \text{----- (4.13)}$$

AET_M =actual evapotranspiration during month M (mm).

R_M = average rain of month M (mm).

ΔS_M =difference in soil moisture between month M and month M-1 (mm).

D =soil moisture deficit. The monthly soil moisture deficit is the difference between the monthly potential evapotranspiration and the monthly actual evapotranspiration and its value listed in row (8).

TARO= total available for runoff. It starts at the first month of the water surplus period which is July in the study area, but its value for the superceding months could be obtained by adding the surplus of the month and the detained amount of water in the month before because this detained water is thought to be readily available for run off for the coming month. These values are listed in row 10 of table 4.12.

Based on the bold assumptions of Thornthwaite and Mather, 1957, 50% of the surplus water that is available for run off in any month actually runs off, the rest 50% of the

surplus is detained in the subsoil, groundwater and channels of the catchments and is available for runoff during the next month.

AWCR=available water capacity of the root zone. Available water capacity for combination of soil texture and vegetation,(From the table developed by Thornthwaite and Mather 1957.) calculated as follows; during field observation 80% of the Land cover is moderately deep rooted plants grown on clay loam & 20% of the Land cover is deep rooted plants grown on fine sandy loam. AWCR= 80% (200mm) + 20% (150mm) =190mm.

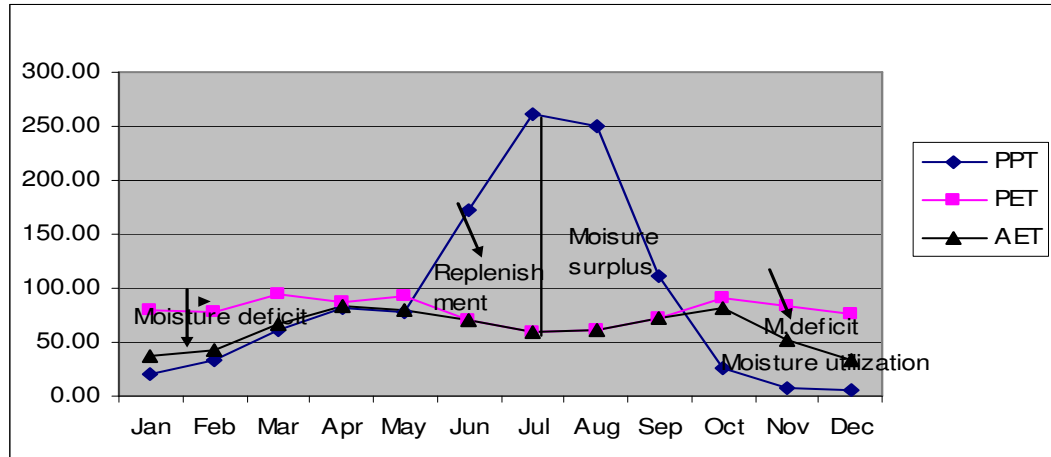


Figure 4.10 Monthly water balance of Teji river catchment based on thirty years rainfall data records.

4.8 Runoff

The water which moves in defined channels or all the water that moves over the land surface in undefined channel is known as runoff. Rainfall intensity and infiltration capacity of the soil is one of the factors that influence runoff process. If the rainfall intensity is lower than the infiltration equilibrium capacity, but less than the initial infiltration capacity, at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water remain on the land surface. Surface runoff or overland flow is the water that doesn't infiltrate and forms flow as a thin sheet across the land surface. Teji river catchment is sub-catchment of Awash basin. The river has a gauging station at Asgori town at a GPS location of (426682E, 970976N). The mouth of Teji river catchment is near to Teji town some distance down stream from the gauging

station and the discharge at it's mouth is calculated by drainage-area ratio. Extrapolation of discharge rate to the mouth of Teji River is made because of having similar climate, topography and land use land cover.

Drainage area ratio is calculated by the following formula:

$$Q_{TRC} = (A_{TRC}/A_G) Q_G \text{----- (4.14)}$$

Where, Q_{TRC} is the discharge in m^3/sec of Teji river catchment.

Q_G is the discharge in m^3/sec at the gauging station.

A_{TRC} is the drainage area of Teji river catchment.

A_G is the drainage area at the gauging station.

The 27 years river discharge data collected from the Ministry of Water Resource is used in the total runoff analysis of the catchment.

Teji River Catchment discharges 184.25 mm of water annually as runoff.

The drainage map of Teji river catchment (Figure2.2) is characterized by mainly of dendritic type except a few streams that drain southwest-northeast at the center have parallel drainage pattern.

4.8.1 Base flow separation

The separation of Teji river catchment (Figure4.11) has been made using a computer code known as Time-Plot, developed by Gabriel Parodi, which uses daily flow values and an attenuation coefficient that is controlled by the slope, land-use and land cover conditions of a watershed possessing a value in the range of 0.9-0.995. The direct runoff determined from this base flow separation process is used as an input for the computation of water balance. The method shows that about 59% (108.71mm) of the flow is contributed from base flow & 41% (75.54mm) from surface runoff out off the total mean annual flow.

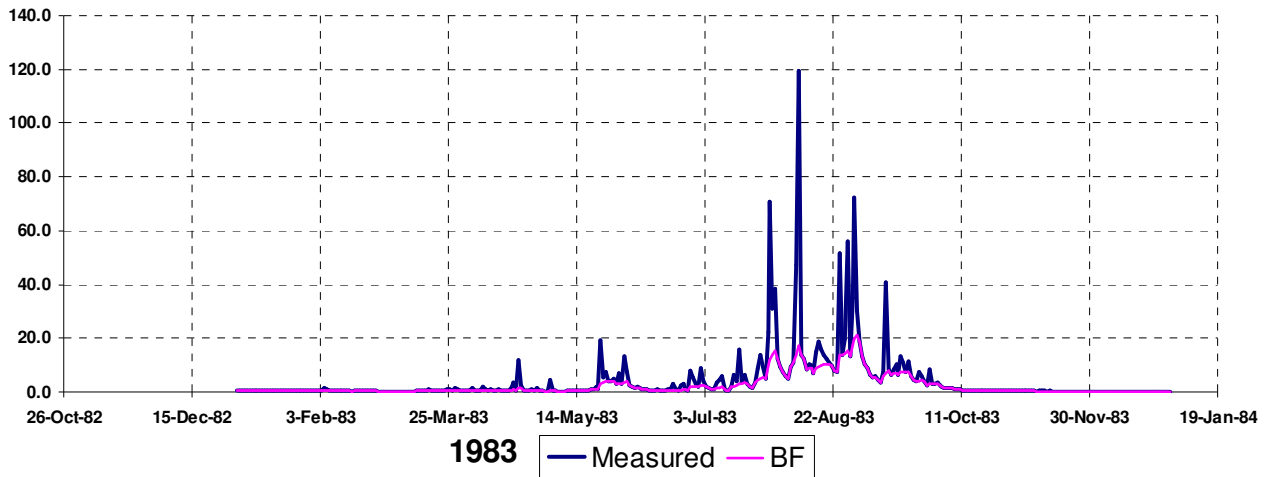


Figure 4.11 Hydrograph base flow separation.

4.8.2 Rainfall river discharge relationship

The highest peak in the river discharge corresponds to the highest rainfall in the months of July and August. In the hydrograph (figure 4.12) the months of June have relatively high rainfall amount than the months of September having equal amount of river discharge. At the beginning of the rainfall (June), rainfall is being interrupted by vegetation or soaked into the ground and making up soil moisture deficit. At the months of September the soil is at its field capacity most of the rainfall amount contribute to the river flow in addition to base flow from groundwater stored in the previous months.

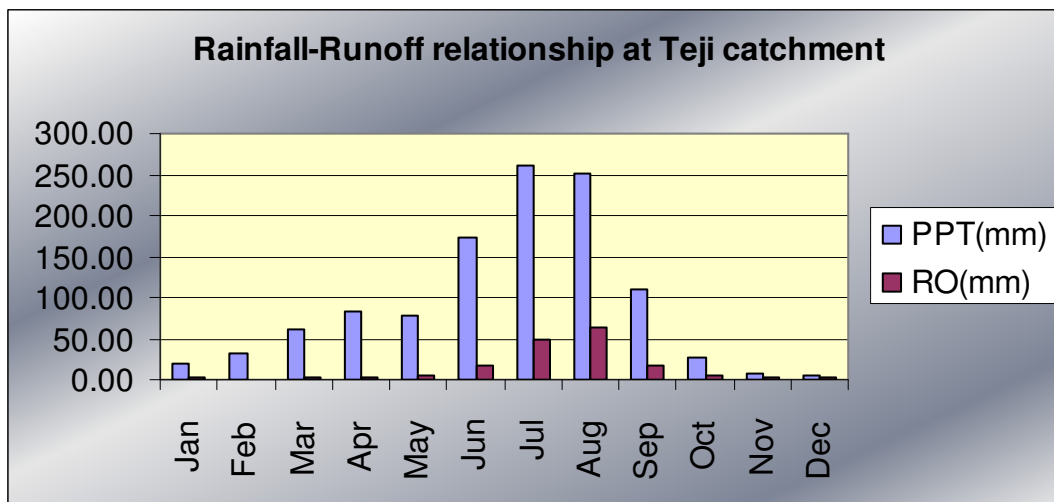


Figure 4.12 Rainfall-Runoff relationships at Teji river catchment.

4.9 Groundwater recharge estimation

Groundwater recharge is the downward flow of water reaching the water table, forming an addition to the ground water reservoir (Devries and Simmers, 2002). A number of methods have been formulated for estimation of ground water recharge, such as through direct measurement, Darcian approaches, tracer techniques, isotope dating, chloride mass balance equation, analysis of base flow hydrographs, and spring discharges, water table fluctuation, numerical modeling, water budgeting etc. Groundwater recharge in the Teji river catchment mainly occurs as vertical percolation of rainfall.

4.9.1 Base flow separation method

Base flow separation of the Teji river catchment has been made using software known as Time-plot by considering surface characteristics of the basin in addition to daily river flow data as an input. Accordingly, Teji River has base flow amount of 108.71 mm of the total 184.25mm per annum and the annual runoff 75.54mm per year.

4.9.2 Water balance method

The basic hydrological principles states that a balance must exist between the quantity of water supplied to the basin (inputs) and the amount leaving the basin (outputs) and the change in groundwater storage. In the study area the balance is made with the assumption of closed basin because the catchment is delineated based on watershed divide as data (topographic map sheet) obtained from the Ethiopian mapping Authority. The type of aquifer (confined and unconfined) that exists in the catchment assumed to be negligible or no under flow, no recharge from other catchments. The basic equation for the groundwater balance during a hydrological year may be stated as:

Groundwater Inflow (Inputs) =Groundwater Outflow (outputs) ± change in Groundwater Storage.

Inflow includes precipitation and groundwater inflow and the outflow includes surface runoff, groundwater outflow, evapotranspiration and change in storage.

This can be expressed as:

$$P+Gi= AET+SRO+R+GO\pm\Delta SG \text{-----} (4.15)$$

Where, p=precipitation, Gi=groundwater inflow, AET=actual evapotranspiration, R= Recharge, SRO=surface runoff, Go= groundwater outflow, Groundwater inflow is assumed to be equal to groundwater outflow, ΔSG =change in groundwater storage, that means the net gain or loss of water from the aquifer due to changes in the inflow or outflow component. On annual basis change in storage is assumed to be zero for an aquifer under steady state condition because the assumption is made that the inflow and outflow amount are in balance. The water balance equation of the catchment becomes:

$$P=AET+SRO+R \text{----- (4.16)}$$

$$R=P-AET-SRO \text{----- (4.17)}$$

Where P=1104mm, AET= 703.07mm, SRO= 75.54mm

$$R=1104\text{mm}-703.07\text{mm}-75.54\text{mm}$$

$$R=\underline{\underline{325.39\text{mm}}}$$

Chapter Five

Hydrogeology

5.1 General

Ground water circulation and storage in the volcanic rocks depend on the type of porosity and permeability formed during and after the rock formation. Water bearing potential of volcanic rocks varies because of its difference in mineralogy, texture, and structure. All the rock structures possessing a primary porosity may not have necessarily permeability; that is the pores must be interconnected during the formation of the rocks to have primary permeability, but later connection by means of weathering and fracturing may result secondary permeability. The groundwater flow and storage in volcanic rocks are governed by the following features;

- Vertical permeability due to primary and secondary fractures.
- Horizontal permeability due to horizons containing openings due to the lava flow and gas expansion during solidification.
- Occurrence of impervious horizons and dykes.

The main controlling factors for fractured and porous volcanic rocks to serve as ground water circulation are;

- Type, frequency and distribution of the fractures;
- Degree of the fractures and pore interconnection;
- Thickness of the lava flow;
- Occurrences of cementing material and their hydraulic characteristics;
- Constitution of the soil cover;
- The depth of the lava flow;

5.2. Hydrostratigraphic units

The main hydrogeologic unit of the study area is extrusive volcanic rock, pyroclastic and alluvial deposit. These rock units are subjected to varying degree of secondary activities such as weathering, erosion, and deposition. Some of the relatively hard formation has undergone fracturing, faulting and jointing.

5.2.1 Alluvial sediments

This formation mainly occur along the river valleys and northern plain areas of the catchment, however, it is thinner and sometimes missing in the recharging area and it gets thicker and thicker in the central & north east part of the study area. They are composed of clay, silt, sand, gravel and rock fragment deposits. The thickness of alluvial deposits varies from place to place depending on the topographic variation in the area. The shallow wells drilled at kobo & Simbiro-chirecha village have a thickness of 33 meters and 24 meters alluvial sediments respectively. This unit is underlain by tuff in most places and by scoria in the wells drilled at Areda-Leka peasant associations.

5.2.2 Weathered and fractured Ignimbrite /welded tuff

This rock unit covers majority of the study area. Welded tuffs have medium to low primary porosity and very low permeability. The groundwater circulation and storage capacity of welded tuff depends on the secondary porosity and permeability developed through fracturing and weathering processes. The degree of weathering and fracturing is not uniform through out the study area. The welded tuff in most part of the study area especially in the flat laying areas of northern, north eastern parts and along river valleys are deeply weathered and covered by soil having different thicknesses. The secondary fractures are mainly the result of weathering and tectonic activity affected the formation in different manner.

5.2.3 Fractured and Weathered basalt

Basaltic lava flows underly the ignimbrite in most part of the study area. Basically, high water storage and transmitting capacity of basaltic lava flows is due to joints caused by cooling, lava tubes, vesicles that are interconnected, tree moulds, fractures caused by buckling of partly congealed lava (aa lava surface) and voids left between successive

flows. Groundwater movement and storage depends upon secondary weathering and fracturing. This rock unit forms wells to depth of 60-70meters. Eventhough it's aerial extent is limited, basaltic lava flow associated with scoria cones of quaternary age outcropped in the southern part of study area. This rock unit has good infiltration capacity to the underlying formation due to its primary and secondary permeability. Scoraceous basaltic lava flows (Tarmaber formation) forms the deepest aquifer in the study area. This unit is exposed in the West, northern plateau part and watershed divide of Abay and Awash basin out of the study area. But as the borehole test drilled by water works design supervision enterprise at Asgori town the rock outcropped at depth of 225meters below ground surface. This unit is highly weathered and fractured and forms the main water bearing formation in the Teji river catchment.

5.2.4 Rhyolite and Trachyte

This rock unit mostly considered as impervious rocks but its water storage and transmitting capacity dependent upon secondary porosity and permeability. Rhyolite outcrops in the western boundary of the catchment which forms elevated land. It is weathered and affected by the NW-SE trending lineaments which modify the limited primary porosity and permeability of the rhyolitic lava flows. In places where the rhyolitic lava flows are highly weathered and fractured, the infiltrated water through fractures feeds the aquifer that lie in the flat –laying area. In areas where weathering and fractures are less the precipitated water lost as runoff.

Trachytic lava flows that outcrop on the steeper slopes are slightly weathered and are covered with thin or no soil layer and the precipitated water on this unit are mostly lost as runoff rather than vertical infiltration. As it was observed during the field visit trachytic lava flows cover the foothills and moderately dipping topography which has columnar joints in some places and fractured vertically with varying fracture openings that may probably extend to the bottom of the flow. The hydraulic characteristic of trachytic lava flow strongly changed in areas of intensive weathering and fractures developed. On the other hand, minor fractures have local permeability.

5.3 Recharge and Discharge area

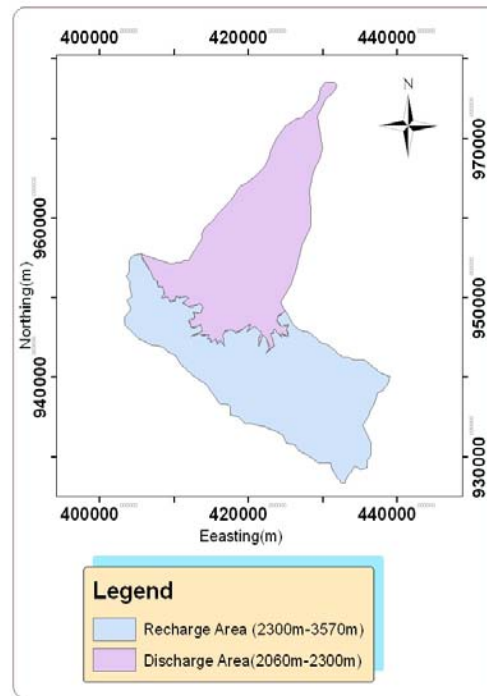
Groundwater recharge can be defined as the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. Groundwater discharge can be defined as the removal of water from the saturated zone across the water-table surface, together with the associated flow toward the water-table within the saturated zone (freeze & cherry, 1979).

Recharge areas are usually in topographical high places; discharge areas are located in topographic lows. In the recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close or at the land surface in discharge areas (Fetter, 1994). A water table contour map can often be used to locate groundwater recharge and discharge areas. The water table vector lines (Figure 5.2) tend to diverge from recharge areas and converge toward discharge areas. This convergence will not occur if the discharge zone is large.

The occurrence of vegetation and surface water can sometimes be used to locate discharge areas. Groundwater is discharged in the form of springs, lakes, seeps or stream. The presence of vegetation common to wet soils may be indicative of discharge areas.

Groundwater as it moves through a flow system undergoes a geochemical evolution that is salinity (as measured by total dissolved solids) generally increases along the flow path. Water from recharge areas is usually relatively fresh; water from discharge areas is often relatively saline.

In the study area flow line vector converges in the north east and center and the divergence of flow line is observed in the west, southwest, south, southeast. Groundwater discharged from the Teji aquifer system by flow to tributaries and the main Teji river, and evapotranspire in the wetlands close to Teji river. In general the recharge area (Figure 5.1) of the catchment lies in the west, southwest, south, southeast. Conversely discharge area lies in the central and northeast of the catchment.



Figure

5.4 Groundwater flow

Groundwater is an important source of water; it may provide the base flow for rivers, or act as an underground reservoir from which water can be pumped at a location where water can be drained. The ground water flow direction (Figure 5.2) of the area is dominated by southwest-northeast. Usually groundwater travels very slowly; one hundred meters per year is a typical average horizontal velocity and one meter per year is a typical vertical velocity (UNESCO, 2004).

Groundwater flows from a higher to a lower groundwater head. Regional groundwater flow system is affected by topography. The uniform water table produces a single flow system. The hilly topography produces numerous subsystems within the major flow system. Water that enters the flow system in a given recharge area may be discharged in the nearest topographic low or it may be transmitted to the regional discharge area in the bottom of the major valley (Toth, 1966). Regional flow systems only develop in areas where local relief is negligible. The geology of the area also affects the regional flow system; the existence of high permeability conduit thus promotes the possibility of regional system even in areas of pronounced local relief.

In general geological heterogeneity can have a profound effect on regional groundwater flow;

- It can affect the interrelationship between local and regional system
- It can affect the surficial pattern of recharge and discharge areas
- It can affect the quantities of flow that are discharged through the systems

The ground water flow map of the study area is presented in (Figure 5.2).It is prepared by utilization of wells tapping shallow ground water (unconfined aquifer). This map is produced based on 22 boreholes and 10 shallow wells water level data.

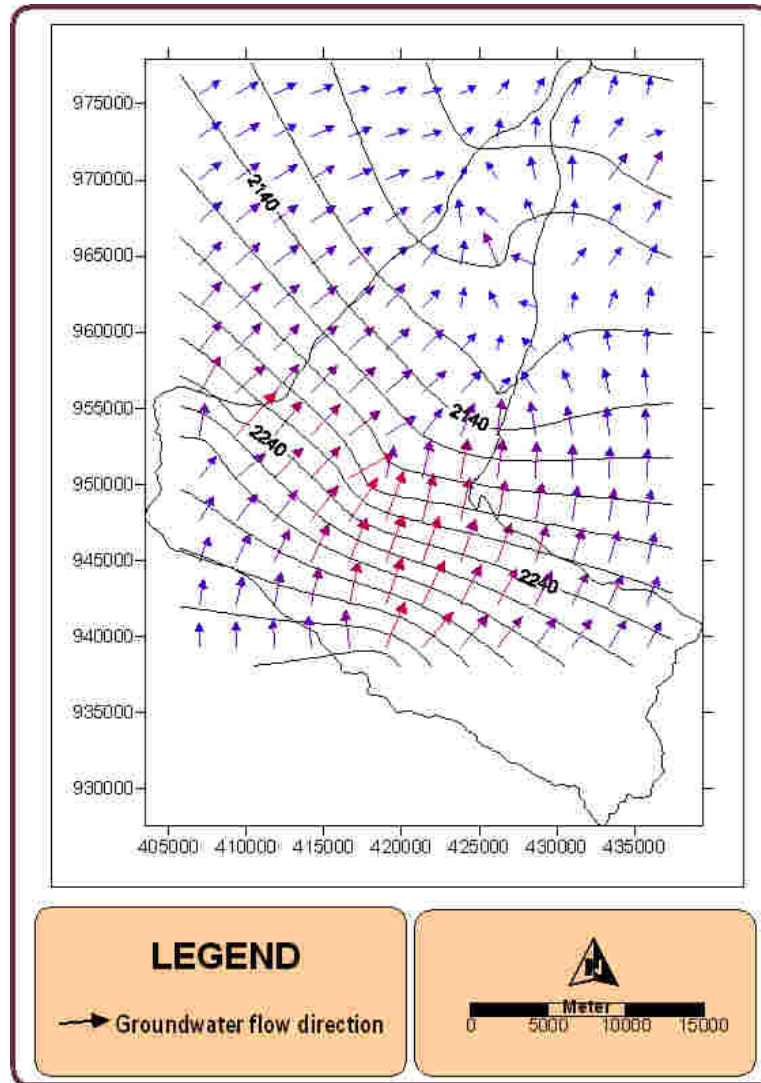


Figure 5.2 Groundwater flow map of the study area.

5.5 Surface water groundwater interaction

Rivers interact with groundwater in three ways; gaining, losing, or they do both, gaining in some reaches or losing in other reaches. Gaining streams receive water from the ground-water system, whereas losing streams lose water to the ground-water system. For ground water to discharge to a stream channel, the altitude of the water table in the vicinity of the stream must be higher than the altitude of the stream-water surface. Conversely, for surface water to seep to ground water, the altitude of the water table in the vicinity of the stream must be lower than the altitude of the stream surface. Some losing streams are separated from the saturated ground-water system by an unsaturated zone or can be connected to the groundwater system by continuous saturated zone. The water table elevation and stream bed elevation (Table 5.1) in the upper reach of Teji river (at Areda Ieka PA's) and down reach (at Asgori) indicates the stream is gaining at both location. Chemistry is also an indication of groundwater and surface water interaction. The water sample analyzed from groundwater at Uragotede and Tolebelekes rural village (groundwater elevation 2215m & 2385m) have similar water chemistry (Ca-Na-Hco₃) with the water sample analyzed from the river at stream bed elevation of 2122m, that indicates the river is gaining from the groundwater.

Groundwater and surface water interactions can be affected by natural processes and human activities.

Table (5.1) Groundwater table and stream bed elevations at some selected reaches.

Measurement Location		Stream bed elevation	Groundwater table
E	N	(m.a.s.l)	(m.a.s.l)
424000	952736	2122	2133
427126	971361	2072	2082

5.6 Groundwater sources

5.6.1 Boreholes

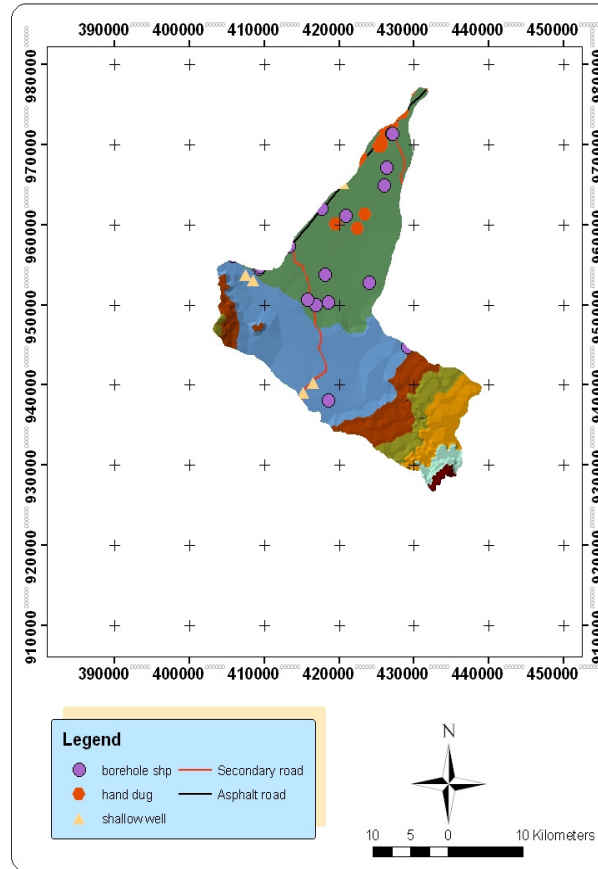
Teji river catchment and its surrounding have 19 deep bore holes and 13 shallow bore holes inventoried during the field trip. Wells drilled beyond a depth of 60m are considered as deep boreholes and those drilled upto 60m are considered as shallow wells. The deepest borehole has a depth of 308m at a place known as Asgori, also this well gives the highest yield of the catchment (>35l/sec). Three of the boreholes are fitted with submersible pump and the remaining wells are fitted with Indian mark II and Afridev hand pumps.

The main aquifers of the boreholes are alluvial sediment, Weathered and fractured ignimbrite, Weathered and fractured basalt. The thickness, weathering and fracturing of the aquifer formation varies from place to place and have variable yields. The static water level and the well yields within the range of 4.29m-40m and 0.5l/sec-35l/sec respectively.

5.6.2 Hand dug wells

Most of the hand-dug wells (37) inventoried during the field visit lies in the north east of the catchment. The abstraction of the wells is carried out mainly with pulley system but there are some wells fitted with hand pumps. The static water level and the depth of the well range between 3.5m-24m, 9m-26m respectively.

The main aquifer formation for the dug well is alluvium and weathered ignimbrite.



Fi

5.7 Aquifer characteristic

An aquifer is defined as a saturated permeable geologic unit that is permeable enough to yield economic quantities of water to wells (Kruzevan G.P., 1994).

Based on observation of the geological log and pumping test data two types of aquifers are (confined and unconfined) identified in the catchment. Hydrogeological field observations such as the degree of fracturing to the rock units, the thickness of the formations, the grain size, rounding and sorting, the clay proportions, the type and degree of cementation and the extent of weathering are some of the significant field observations which provided indirect evidence as to whether a rock unit is likely to be an aquifer of poor, low, moderate or high productivity. The field observation supported by lithological logging and pumping test data of the existing well drilled in the catchment. Accordingly, the main aquifer identified in the catchment is alluvial sediment, weathered and fractured ignimbrite and weathered and fractured basalt.

5.7.1 Alluvial sediment

This aquifer formation forms the shallow aquifer system in the catchment along the river banks and north plain area. The shallow wells drilled at kobo & Simbiro-chirecha village have a thickness of 33meters and 24 meters alluvial sediments respectively. The thickness of alluvial deposits varies from place to place depending on the topographic variation in the area.

5.7.2 Weathered and fractured ignimbrite

This aquifer formation covers majority of the study area. The permeability of this unit depends on the permeability developed by fracturing and weathering due to secondary processes. The productivity of the boreholes tapping this aquifer formation varies depending on the difference in the degree of weathering and fracturing. Bore holes that tap this aquifer formation (drilled at Asgori town, Bebeli debegna rural village) yield 5.5 & 3.98 liter per second respectively. These aquifer formations are considered to be of moderate productivity.

Table5.2 Representative well of moderate productivity.

	Asgori well	Bebeli debegna well
Depth(meter)	90m	124m
SWL-	4.29m	0.5m above ground level(artesian well)
DWL-	7.51m	30.7m
YEILD-	5.5 l/sec	3.98 l/sec
	0-2 clay	0-4 Black clay
	2-12 Weathered rock fragment	4-6 Slightly weathered vesicular basalt
	12-18 Weathered ash	6-16 Weathered & slightly fractured ignimbrite
	18-19 Clay	16-34 Highly weathered Ignimbrite
	19-32 Tuff	34-36 Highly weathered trachybasalt
	32-34 Ignimbrite	36-62 Weathered & fractured Ignimbrite
	34-58 Tuff	62-64 Weathered ash
	58-59 Clay	64-74 Slightly weathered & fractured Ignimbrite
	59-82 Ignimbrite	74-78 Slightly weathered trachyte
	82-83 Clay	78-88 Highly weathered scoria
	83-90 Ignimbrite	88-90 Weathered & fractured Ignimbrite
		90-92 Slightly weathered scoria
		92-96 Slightly weathered Ignimbrite

96-100 Highly weathered scoria

100-118 Slightly weathered &
fractured Ignimbrite

118-124 Highly weathered
Ignimbrite

Source for lithological logs: Oromia Water Works Construction Enterprise, 2005.

5.7.3 Weathered and Fractured basalt

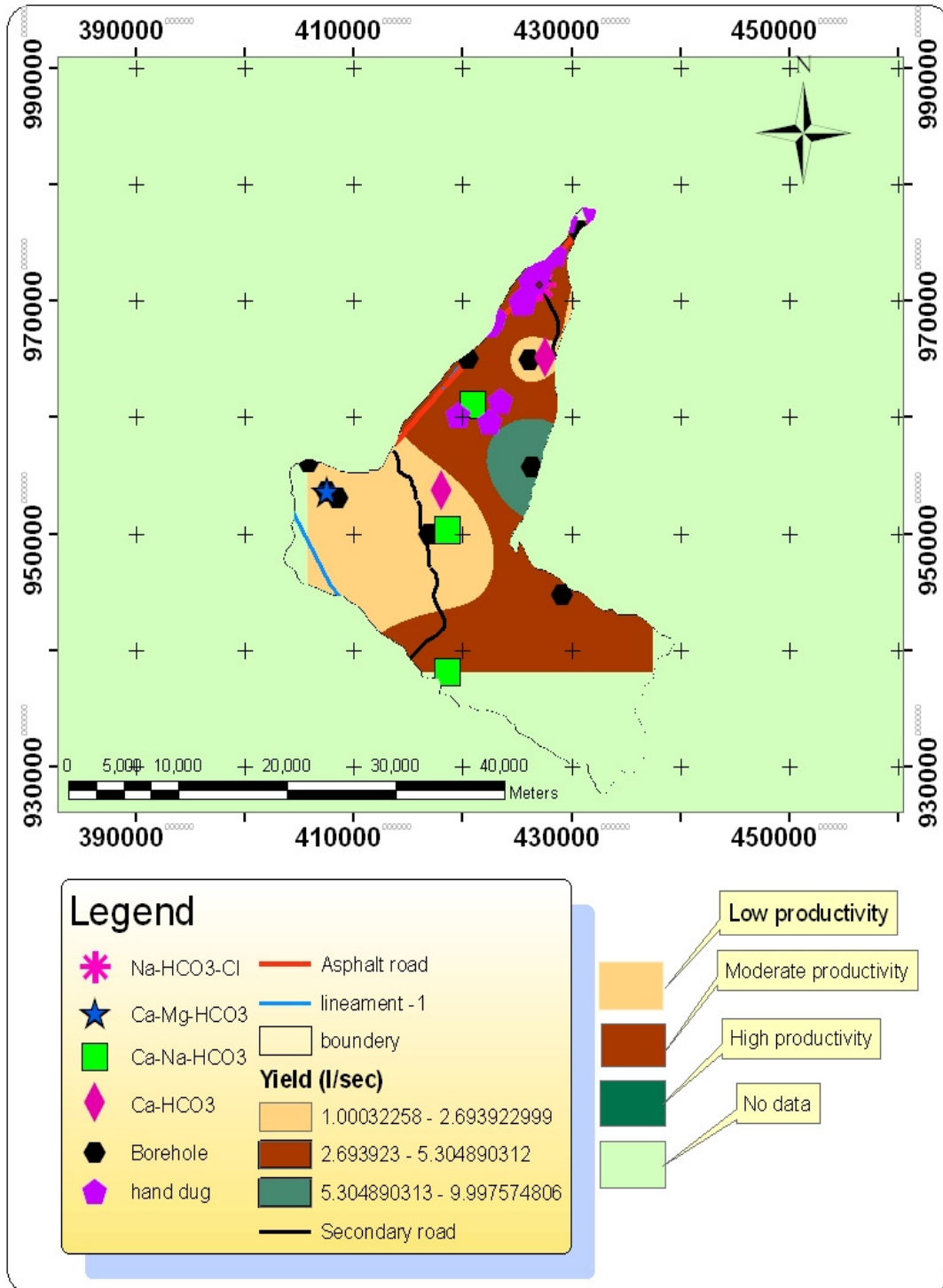
This aquifer formation is found mainly underlying the ignimbrite. This rock unit forms wells to depth of 60-70meters. There are also deep wells having basaltic lava flows overlaid by pyroclastic materials. These wells tapping basaltic aquifers overlaid by pyroclastic material yields >10 liter/sec (Example bore holes drilled at Areda leka rural village).

Groundwater movement and storage depends upon secondary weathering and fracturing. The well tapping these aquifer formations have different productivity that ranges between 1 to10 liters per second. The variation in productivity is related to degree of weathering and fracturing, and penetration of the required depth of aquifer. However, there are no wells tapping the quaternary basaltic lava flow outcropped with in limited aerial extent in the southern part of the area. This rock unit is associated with scoria cone, weathered and fractured and forming good infiltration capacity to the underlying formation. Scoraceous basaltic lava flows (Tarmaber formation) forms the deepest aquifer in the study area (Table5.3). This unit is exposed in the West, northern plateau part and watershed divide of Abay and Awash basin (figure 3.1) out of the study area. According to the test well drilled by the Water Works Design Supervision Enterprise at Asgori town the rock intersected at depth of 225meters below ground surface. According to their report the unit is highly weathered and fractured and forms the main water bearing formation in the Teji river catchment. The pumping test data of this well reveals productivity of greater than 35 liter per second. In general basaltic lava flows form high productivity aquifers. The ground water yield map of Teji river catchment has been presented in (Figure 5.2). It is prepared by utilization of well Yields in the study area.

Table 5.3 Representative Well of high productivity.

	Asgori well	Arede leka well
Depth(meter)	308m	112m
SWL-	5m	5.37m
DWL-	5.33m	50.45
YEILD-	35l/sec	10l/sec
WATER STRIKE DEPTH	19,52,103,156,225	13,96
	0-1 Black top soil	0-12 Clay
	1-24 Moderately weathered tuff	12-16 Basaltic river gravel
	24-76 Moderately weathered Ignimbrite	16-30 Weathered scoria
	76-96 Highly weathered ignimbrite	30-64 Weathered pumice
	96-136 ash	64-84 Volcanic sand
	136-154 moderately weathered basalt	84-96 Highly weathered scoria
	154-164 Massive basalt	96-112 Weathered and fractured basalt
	164-184 Highly weathered Ignimbrite	
	184-212 Moderately weathered Ignimbrite	
	212-224 Pumice	
	224-225 paleo sol	
	225-308 Scoraceuos basalt	

1. Source for Asgori well lithological log; Ethiopia Water Works Design Supervision Enterprise, 2007.
2. Source for Arede leka well lithological log; Oromia Water Works Construction Enterprise, 2005.



Fig

Chapter Six

Hydrochemistry

6.1 General

The chemical composition of surface and groundwater is controlled by many factors that include composition of precipitation, mineralogy of the water shade and aquifers, climate, and topography. These factors combine to create diverse water types that change spatially and temporally. The quality of water is also an issue due to the variations both in the natural geology and hydro geological conditions and to human impact. Water-rock interaction plays an important role in controlling water quality. The main mineral characteristics of water, especially groundwater are determined by weathering reactions taking place close to the earth's surface and there is a wide diversity of chemical composition related to the geology of the catchment or aquifer. Geochemical reaction along groundwater flow paths can lead to regional variations in water composition that involve in the direction of flow.

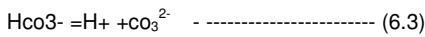
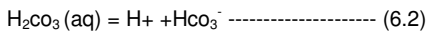
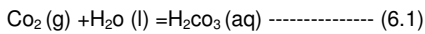
Rain water is not pure water and in some coastal areas or desert areas the chemical load of the atmospheric precipitation can be a significant contribution to the chemical character of groundwater. The chemistry of rainwater depends on such factors as the windward distance from the coast or salty lakes and soils, wind intensity, the period of rainfall within the storm, distance from cities and industrial centers. The soil zone has unique and powerful capabilities to alter the water chemistry, as infiltration occurs through this thin, biologically active zone. The type and concentration of dissolved constituents governs the usefulness of groundwater for various purposes. Therefore, it is necessary to determine the composition of groundwater before the water can be used for the intended purpose.

To understand the general chemistry variation (spatial variation) and the possible sources for variation (natural or anthropogenic), water samples (mostly from shallow or unconfined aquifer, and river) have been used for chemical analysis and physical parameters were measured on site during field work.

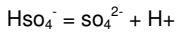
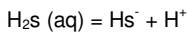
6.2 Physical parameters

6.2.1 Hydrogen ion activity (PH)

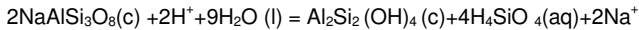
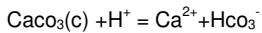
Ph is defined as the negative base-10 log of the hydrogen-ion activity in moles per liter. The hydrogen ion activity is controlled by inter-related chemical reactions that produce or consume hydrogen ions (Hem, 1971). The reaction of dissolved carbon dioxide with water, which is one of the most important in establishing pH in natural water system, is represented by the following steps;



Dissociation of acidic solutes includes; $\text{H}_2\text{PO}_4 = \text{HPO}_4^{2-} + \text{H}^+$



Many of the reaction between water and solid species consume H^+ ; for example,



The pH of water is also controlled by temperature. In the study area the pH value of Teji river (8.3-8.38) and groundwater (6.6-7.68) are mostly associated with the high bicarbonate contents of the water. The range of pH in the Teji river lies within the pH range of water not affected by pollution, which is about 6.5 to 8.5 (Hem, 1971).

The measured pH value of groundwater in the study area (Figure6.1) shows an increasing trend from southwest-north east that are the groundwater flow direction.

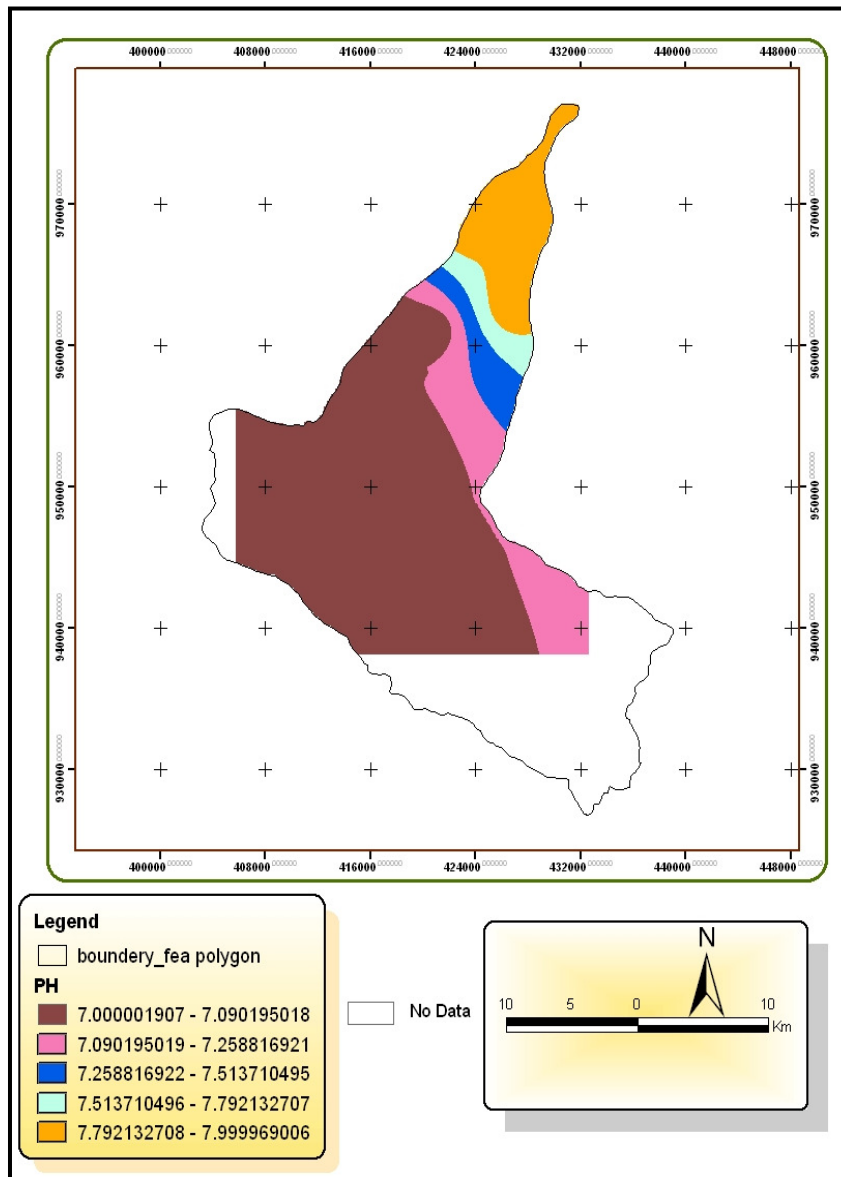


Figure 6.1 Spatial distribution of PH in the study area

6.2.2 Temperature

The temperature of the surface and sub surface waters faithfully reflects the climatic condition of the environment on which they stop or flow. Shallow groundwater are normally characterized by a temperature which is strongly influenced by the type of overlying surface environment and water coming from great depth attains higher temperatures (thermal waters). Temperature affects pH, electric conductivity, the rate of chemical reaction as well as the concentration of the reactants and the products, and

solubility of gases in the water. For most compound the value of solubility product increase with temperature.

The temperature of surface and ground water in the study area ranges between 18.5°C to 29.1°C. The spatial distribution of temperature measured at the field during the field trip indicates an increasing trend toward north east that is to discharging zone.

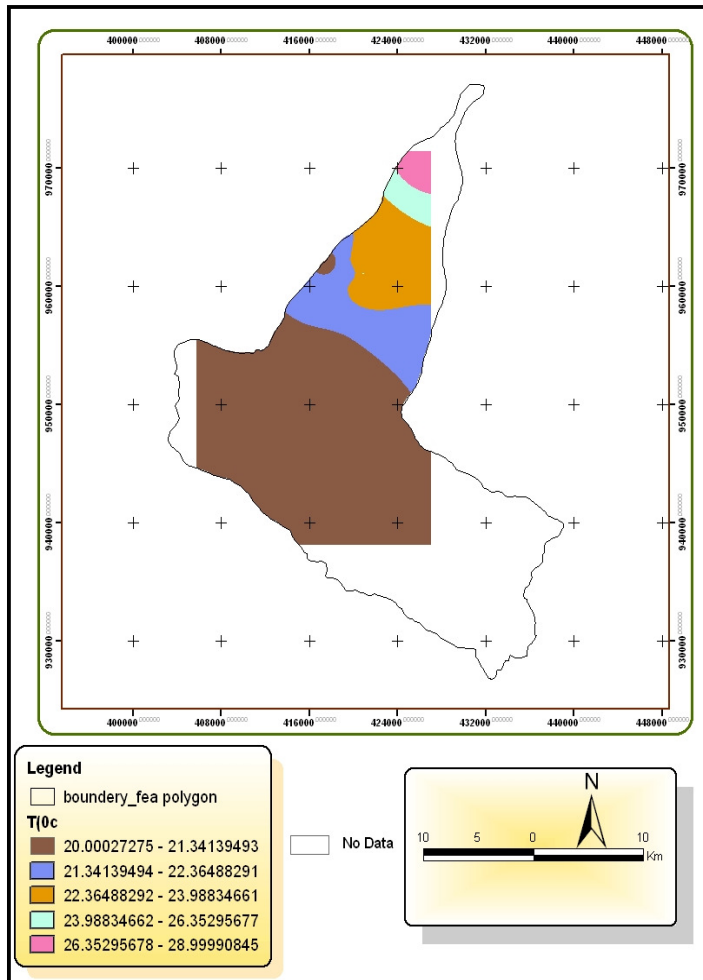


Figure 6.2. Spatial distribution of temperature

6.2.3 Total dissolved solids (TDS) and Electrical conductivity (EC)

Total dissolved solids include all the solid materials in solution, whether ionized or not. The major cation and anion are the principal ion contributing to total dissolved solids. The total concentration of dissolved ion can be used for classification of water as shown below (Devis and DeWeist, 1966).

Water type	TDS in ppm
Fresh water	0-1000
Brackish water	1000-10000
Salty water	10000-100000

Groundwater potential Assessment of Teji River Catchment

Brines

More than 100000

The TDS value of Teji river ranges between (185-220 mg/l) and ground water (242-566mg/l). Accordingly, based on the above classification both surface and groundwater in the Teji river catchment is considered to be fresh. River water has lower TDS value than groundwater because of the rapid movement of rivers causes short time contact with the geologic materials. The TDS value shows an increasing trend from the center toward discharge area (figure6.3).

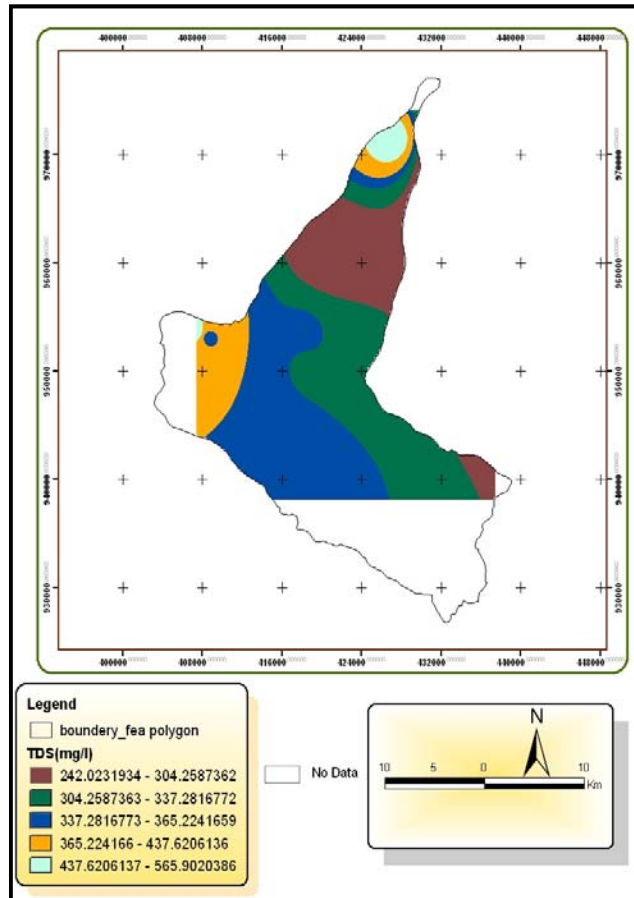


Figure 6.3 Spatial distributions of TDS in the study

area

Electrical conductance is the ability of a substance to conduct an electric current. The presence of charged ionic species in solution makes the solution conductive. As ion concentrations increases, conductance of the solution increases; therefore the conductance measurement provides an indication of ion concentration. EC is directly related to total dissolved solids value. TDS is calculated from EC by the following formula; $KA=S$ where K is specific conductance in $\mu\text{mhos/cm}$ and S is dissolved solids in mg/l , A is mostly between 0.55 and 0.75, the higher values generally being associated with water high in sulfate concentration. EC values indicate an increasing trend from the center to north east of the study area that is discharge area (figure 6.4).

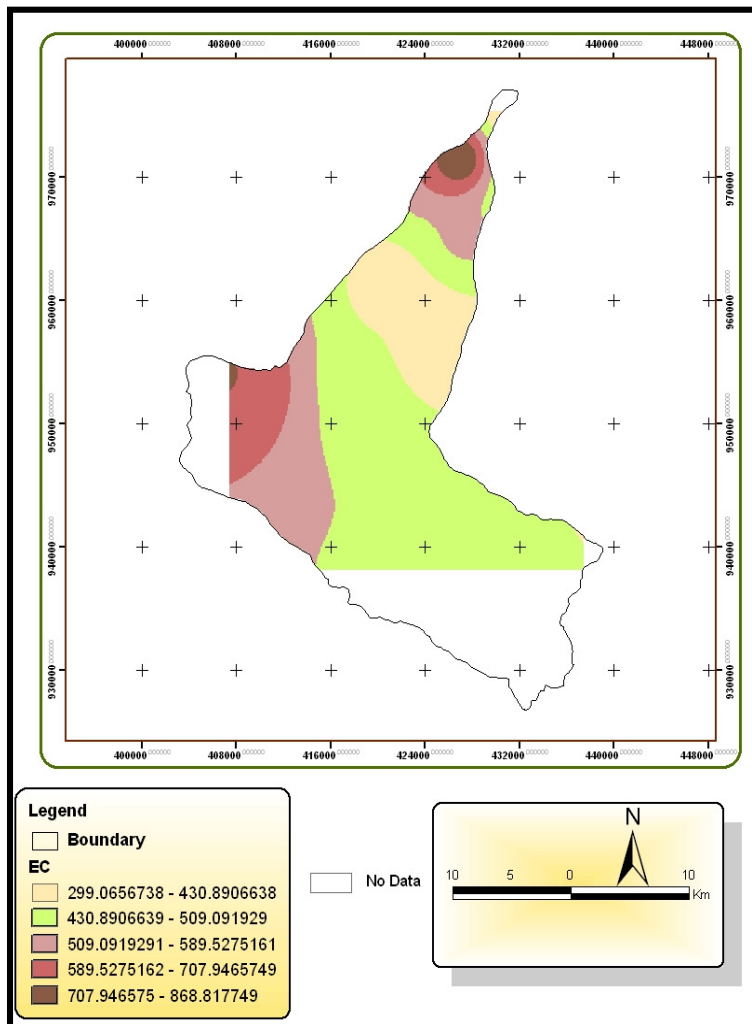


Figure 6.4 Spatial distribution of EC in the

study area

6.3 Major cations and anions

Among the major cations and anions analyzed calcium, Sodium, Potassium, Magnesium and bicarbonate ions are separately plotted to see their spatial trend.

6.3.1 Calcium (Ca²⁺)

Calcium is a major constituent of many common rock minerals. Calcium shows a decreasing trend from southwest to northeast (figure 6.5). The higher calcium can be derived from the weathering of the plagioclase feldspar and pyroxene mineral groups that are the rock forming minerals of basalt.

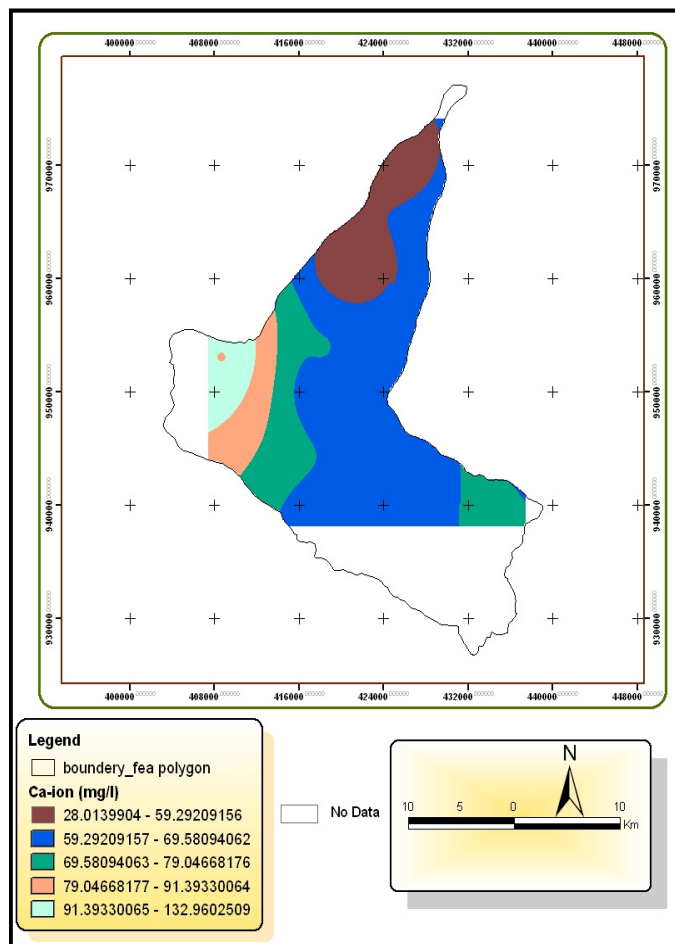


Figure 6.5 Spatial distribution of Ca ion in the study

area

6.3.2 Magnesium (Mg²⁺)

Magnesium shows a decreasing trend from south and southwest toward the discharge area.

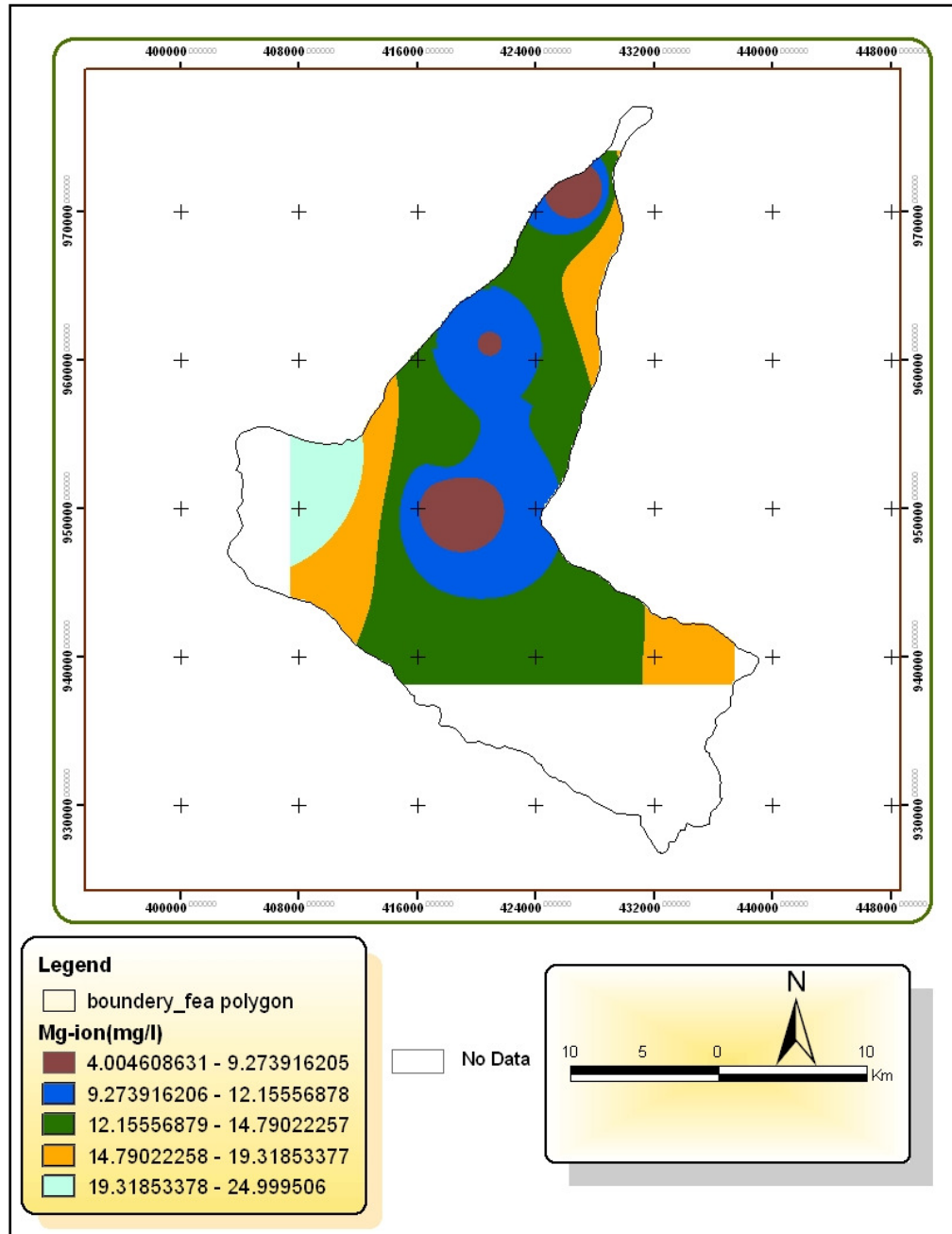


Figure 6.6 Spatial distribution of Mg²⁺.

6.3.3 Sodium (Na⁺)

Sodium evolves from south toward northeast.

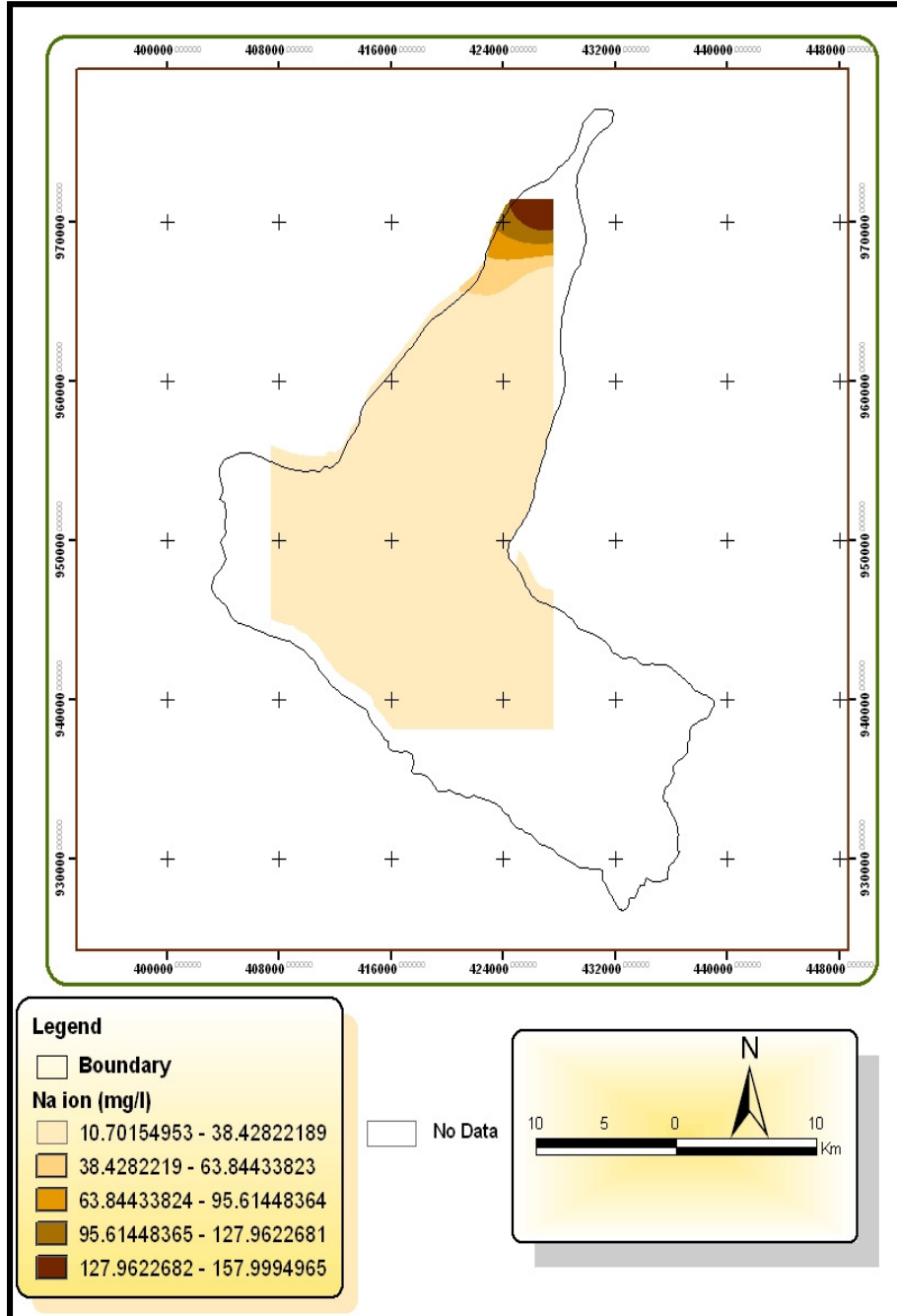


Figure 6.7 Spatial

distribution of Na⁺.

6.3.4 Potassium (K⁺)

Potassium is also increasing toward the discharge area.

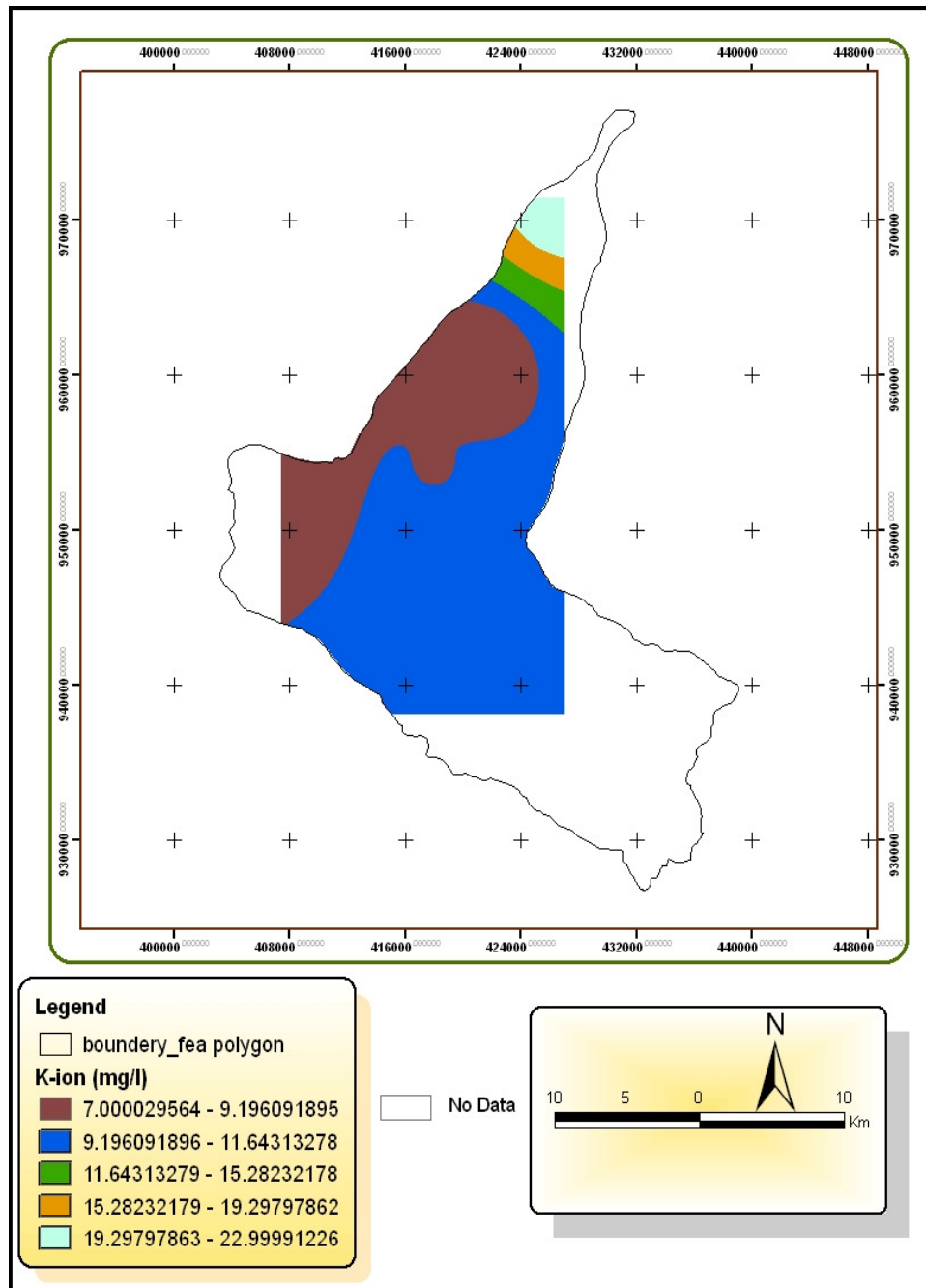
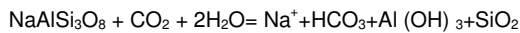


Figure 6.8 Spatial distribution of potassium ion.

In general the chemical analyses of water samples collected in the study area indicates the measured value of calcium and magnesium is large in the recharge area which is the result of weathering reaction of pyroxene and biotite along with anorthite, the calcium reach plagioclase end member. As the water moves along the groundwater flow direction that is toward the discharge area calcium and magnesium ion decreases this is because of;

(I)- Cation exchange reaction of calcium and magnesium in solution, exchange for sodium adsorbed in the aquifer solid such as clay mineral, results in an increase in sodium concentration.

(II)-The geo media along which groundwater moves become sodium bearing lithology (acidic volcanic mainly ignimbrite) example the decomposition of plagioclase feldspar results increase of sodium in natural water. The transformation reaction can be represented as:



6.3.5 Anion

In the study area the major anions is bicarbonate ion concentration, which increases from the center towards the north east. The possible source of the bicarbonate in the area is atmospheric CO₂, plant root respiration and soil zone CO₂, which produces carbonic acid and hydrogen ions that are consumed in weathering reactions with the silicate minerals. The bicarbonate ion in groundwater varies from 252.54mg/l in Simbiro-Chirecha bore hole to 570.96mg/l in Mende tofisa shallow well. Chloride ion range in the study area from 1.99mg/l to 73.48mg/l. Chloride ion generally shows an increasing trend from south to north and north east.

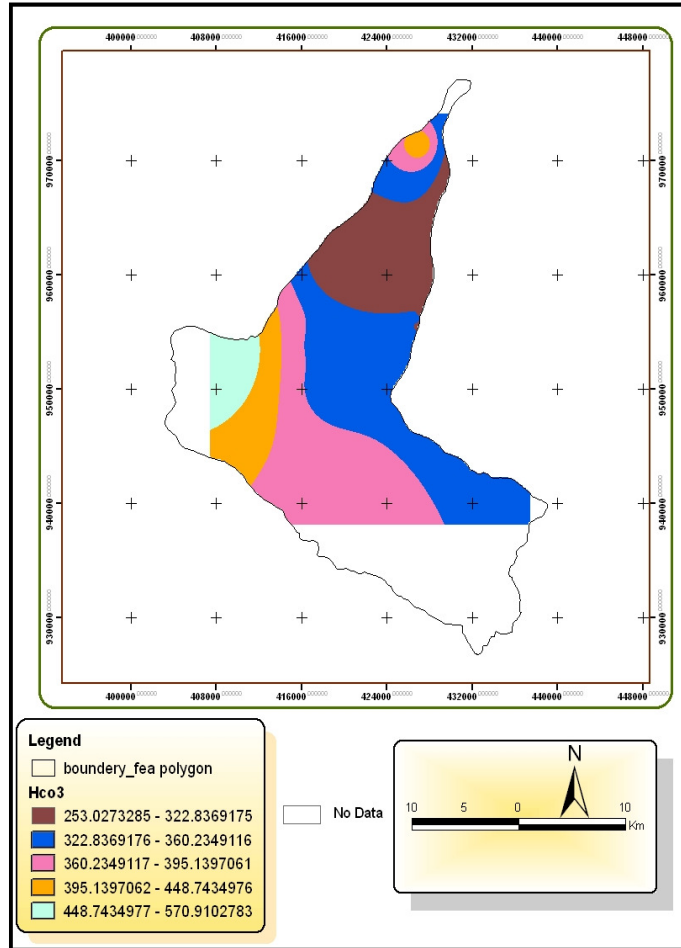


Figure 6.9 Spatial distribution of Hco3.

6.4 Minor ion

The results of the chemical analysis of the water sample collected in the study area other than major ion such as fluoride, nitrate, iron, and manganese considered as minor ions. Among the minor ion analyzed, fluoride and iron shows above the maximum permissible contaminant level set by WHO (1984) drinking water quality standard which is 1.5mg/l and 0.3mg/l respectively.

The relatively higher concentration of fluoride (1.68mg/l and 2.01mg/l) has shown at Uragotade and Asgori boreholes. In nature fluoride comes from chemical weathering products of igneous rocks, magmatic emissions, atmospheric dust from continental sources and industrial pollution (Hem, 1970). The most important sources are acidic

volcanic rocks such as tuff, pumice and obsidian and emanation from geothermal systems (Tesfaye chernet, 1982; Tesfaye chernet et al, 2001).

In the study area fluoride source may be the weathering product of acidic rocks covers majority of the catchments. Iron is also shown at higher concentration level (0.39mg/l) at Asgori borehole.

6.5 Water Type

In the study area water type classification were made based on the major cations and anions of different water sources using the following graphical method;

6.5.1 Graphical presentation

In order to show the ionic concentration of water sample analyses different graphical methods proposed, including piper, pie, bar graphs, Schoeller, stiffs, radial, scatter plot etc. But on this thesis chemical analyses report presented on piper, Schoeller & Stiff methods.

The piper diagram is the most widely used graphical form and it is quite similar to the diagram proposed by Hill (1940, 1942). The diagram displays the relative concentrations of the major cation and anion on two separate trilinear plots, together with a central diamond plot where the points from the two trilinear plots projected. The central diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water (Hill, 1940; Piper, 1944).

Accordingly, the piper plot is done for all water samples collected from borehole, hand dug and river sources and as a result the samples are classified into a variety of water types including Ca-Na-HCO₃, Ca-HCO₃, Ca-Mg-HCO₃ and Na-HCO₃-Cl type.

The schoeller diagram is presented by drawing the major cat ion & anion on the X-axis and its concentration in (meq/l) on the Y-axis see figure 6.12.

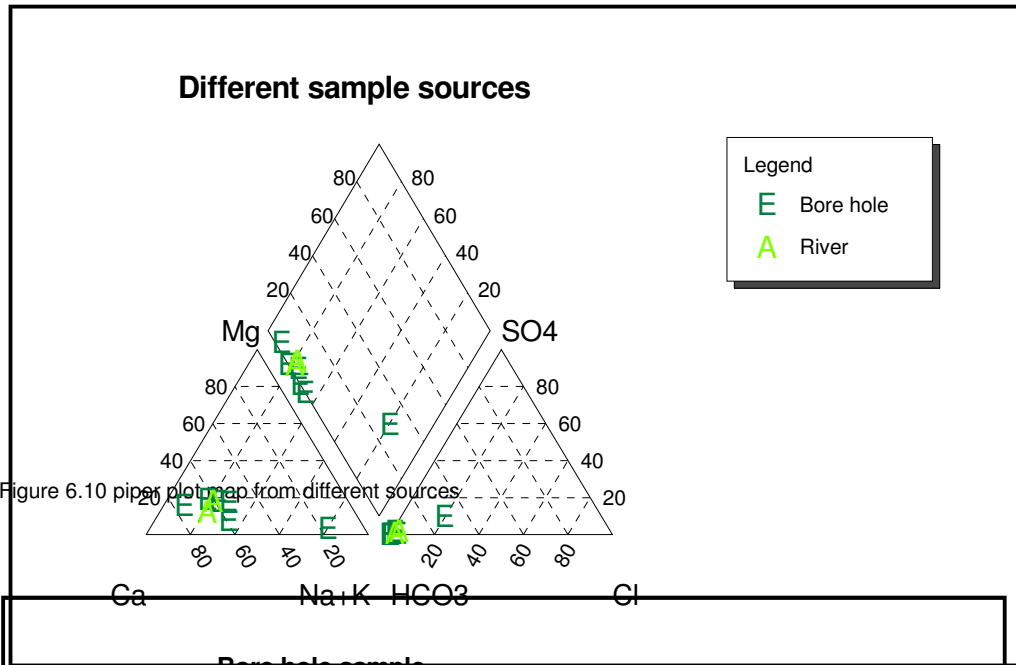


Figure 6.10 piper plot map from different sources

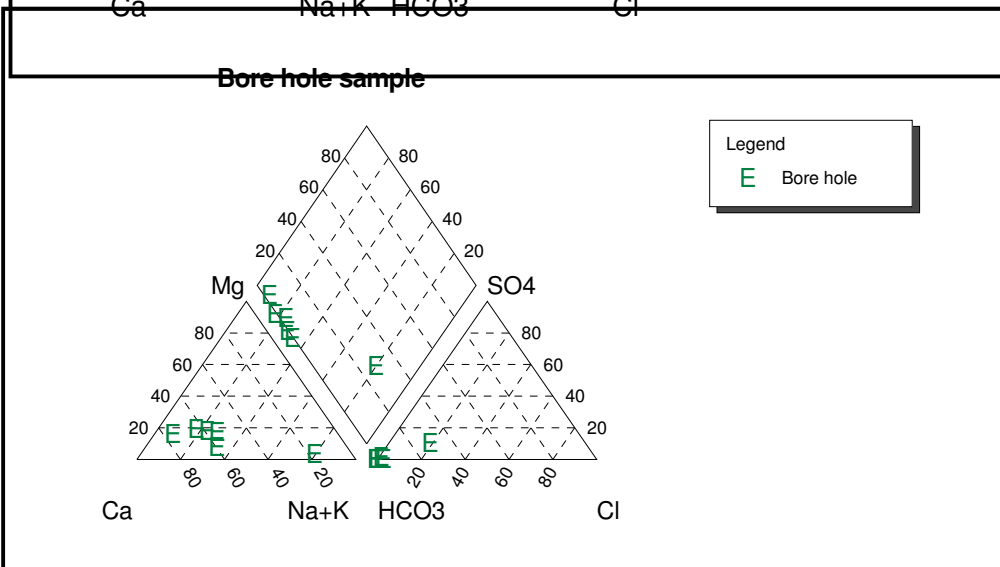


Figure 6.11 piper plots for boreholes sample.

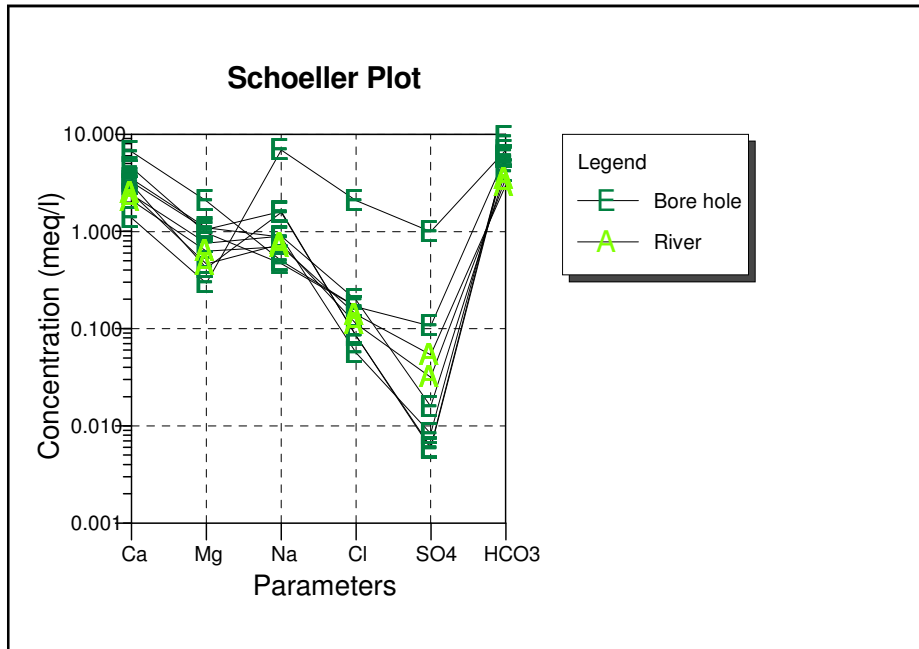
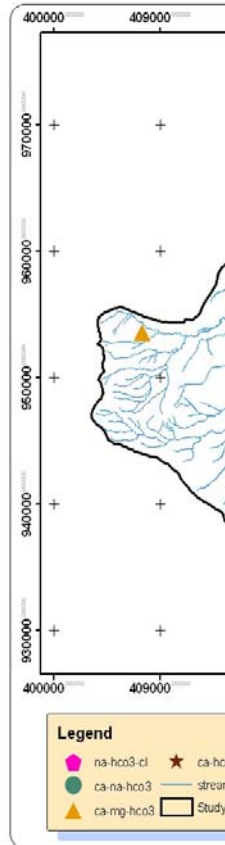


Figure 6.12 Schoeller plot for all water sample area

Figure 6.13 Location map of water type in Teji river catchment



6.6 Water quality

The quality of water varies due to variation both in the natural geological and hydro geological conditions and human impact. Water rock interaction plays an important role in controlling water quality. The main mineral characteristics of water, especially groundwater are determined by weathering reaction taking place close to the earth's surface and there is a wide diversity of chemical composition related to the geology of the catchment or aquifer. The primary purpose of water analyses is to determine the suitability of water for a proposed use. The three main classes of use are domestic, agricultural and industrial.

6.6.1. Domestic use

Based on WHO drinking water quality standard most of the water samples collected is within the permissible limit, but borehole drilled at Asgori town has fluoride (2.01mg/l) and iron (0.39mg/l) concentration above the standard set by WHO which has (<1.5mg/l) and (<0.3mg/l) respectively. The bore hole drilled at uragotade rural village also has fluoride concentration (1.68mg/l) above the maximum permissible limit set by (WHO). Those two boreholes having higher concentration in the catchments need chemical purification.

6.6.1. Agricultural use

Good Water quality permits maximum yields consistent with proper soil and water management. Water quality problem includes salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in top soils. Water used for irrigation always contains dissolved salts, but the type and the concentration of salt depend on the geologic environment, the source and movement of groundwater. The salinity of the water governs its suitability for crop irrigation. Irrigation acts as a source of salts in groundwater by adding salt to the soil and dissolving salt in the root zone. Evapotranspiration tend to concentrate salinity of groundwater. The development and maintenance of successful irrigation projects involve not only the supply of water to the land but also the control of salt in the soil. When sodium reach water is applied to the soil, some of the sodium is taken up by clay causing Base Exchange and leading to plant growth retardation. The quality of water for irrigation classified based on sodium adsorption ratio (SAR) and sodium percentage among the principal cations (%Na).

6.6.1.1. Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is defined by the following formula;

$$SAR = \frac{Na}{\sqrt{[(Ca + Mg)/2]}} \text{----- (6.4)}$$

Table 6.1 Water classification based on SAR and EC (Tenalem Ayenew and Tamiru Alemayehu, 2001)

Water class	EC in $\mu\text{s/cm}$	Alkali hazard (SAR)
Excellent	<250	Up to 10
Good	250-750	10-18
Medium	750-2250	18-26
Bad	2250-4000	>26
Very bad	>4000	

Classification of irrigation water also can be presented graphically using Wilcox diagram based on salinity hazard and sodium hazard. Accordingly both surface and subsurface water samples collected in the catchment is good for irrigation.

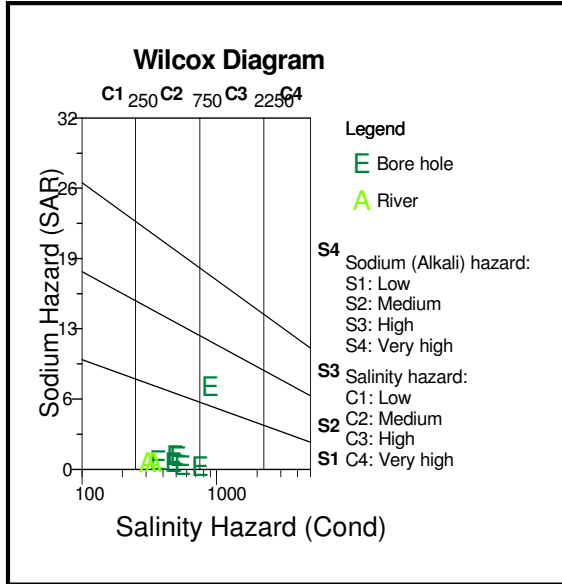


Figure 6.14 Classification of irrigation water using Wilcox Diagram

6.6.1.2. Sodium percentage among the principal cations (%Na)

The relative proportion of sodium to other cation in irrigation water is expressed by the following formula;

$$\%Na = [(Na+ K) / (Ca+Mg+Na+K)] \dots\dots\dots (6.5)$$

The classification is made based on the under mentioned water classification tables. Accordingly the water sample collected in the catchment is good for irrigation water except bore holes drilled at Asgori town.

Table 6.2 Water classification based on %Na

Water class	EC in $\mu\text{s} / \text{cm}$	%Na
Excellent	<250	<20
Good	250-750	20-40
Medium	750-2250	40-60
Bad	2250-4000	60-80
Very bad	>4000	>80

(Source- Tenalem Ayenew and Tamiru Alemayehu, 2001)

Table 6.3 classification of water resources in Teji river catchment based on %Na.

No	Water source	Location	%Na	Water quality
1	Borehole	Sodoliben	26.03	Good
2	Borehole	Sinbiro chirecha	32.19	Good

Groundwater potential Assessment of Teji River Catchment

3	Borehole	urago tede	41.34	permissible
4	Borehole	Mende tofisa	10.35	Excellent
5	Borehole	Tole belekes	37.50	Good
6	Borehole	Asgori	85.26	Unsuitable
7	hand dug well	Jato	15.01	Excellent
8	River	Teji	29.02	Good
9	River	Teji	28.60	Good

6.7 Pollution

Groundwater contamination can occur in many ways and from many sources, both natural and human induced. Ground water commonly contains one or more naturally occurring chemicals, leached from soils or rocks by percolating water, in concentration that exceed the maximum permissible drinking water quality standard set by WHO.

Dissolved solid and chloride- The presence of dissolved solids and chloride in concentration that exceeds the recommended maximum limit in WHO drinking water standards is one of the most common concern; 1000 mg/l (milligram per liter) for dissolved solids and 250 mg/l for chloride. In the study area among the water samples analyzed from borehole sources such concentration above the permissible limit is not found and therefore the catchment is free from contamination of dissolved solid and chloride.

Iron- Although not particularly toxic, iron concentration greater than WHO drinking water quality standard (0.3mg/l) can impair the taste of water, stain plumbing fixtures, glassware and laundry; and form incrustations on well screens, thereby reducing well pumping efficiency. Such concentrations are found in the catchment at the borehole drilled at Asgori town (0.39 mg/l).

Nitrate-nitrogen- Most groundwater not affected by human activity contains less than 10 mg/l nitrate-nitrogen, the maximum concentration allowed by the federal drinking water standards. Although relatively nontoxic, nitrate may be reduced by bacteria to nitrite in the intestines of newborn infants and cause the disease methemoglobinemia. Nitrate also can react with amines in the human body to form nitrosamines, carcinogenic chemicals known to induce tumors in laboratory animals and thought to be linked to human cancers. The water sample taken from Tulukorma well has nitrate concentration of 8.36 mg/l. Thus, the presence of nitrate attributed to intensive utilization of fertilizer and animal manures.

Among the agricultural activities, even though their effect of chemical effluents is not seen in the water sample analysis, the floriculture is currently being practiced in the catchment.

These farms utilized various toxic and hazardous chemicals for fungicide and insecticide that composed of mainly copper sulphate and ethyldibromide and discharge their chemical effluents by mixing with water in to an excavated pit of about 2m depth unsafely that can easily percolate and pollute the ground water on the basis of hydrogeological setting in the future.

Fluoride- Fluoride concentration in drinking water can have toxic effects in both excess and deficiency. Fluoride greater than WHO drinking water quality (<1.5 mg/l) causes dental or skeletal fluorosis and also its shortage may cause dental carries, a weakening of teeth. In the study area fluoride concentration greater than the drinking water quality standard is found to the borehole drilled in Asgori town and Uragotade rural villages 2.01 mg/l and 1.68 mg/l respectively. Fluoride is present in minerals such as Fluorite (CaF₂) and apatite [Ca₅ (Cl, F, OH) (PO₄)₃]. Its presence in the area may be related with weathering of acidic volcanic rocks underlying the catchment.

Chapter Seven

Syntheses and Conclusion

To conceptualize the ground water potential assessments of Teji River catchment that have great importance in controlling the potential of groundwater resources parameters such as; Geology and geological structures, hydrogeological, hydrological and climatological, chemical and physical parameters have been analyzed thoroughly.

The study area is mainly comprised of four lithologic unit that are; tertiary Ignimbrite which covers majority of the catchment, Trachyte and rhyolite that forms ridges and hills and watershed divide of the area in the south east and west, and quaternary basalts in the south. An alluvial deposit in the northern plain area, mainly along the river banks overlies tertiary volcanic. The weathering of this geological formation makes the development of secondary porosity which had a paramount significance in groundwater occurrence and movement.

There is one known NW-SE trending fault crossing the rhyolitic rock formation in the west which may significantly affect or disturb the rock masses outcropped very close to the structure, which means the hydraulic conductivity of the rock will be modified. In addition, the existence of this geological structure facilitates the percolation of precipitation to the subsurface.

The mean annual depth of precipitation is obtained from three different methods; the Arithmetic Mean Method yields (1076mm), Thiessen Polygon Method yields (1105.5mm) and Isohytal Method (1102.54mm). The results obtained from the Arithmetic method shows a large variation from the other two methods. This method doesn't consider topographic variation (2040m-3600m) and uneven distribution of meteorological stations. The result is obtained by calculating the mean of the two methods having low variation and as a result the area receives an annual precipitation of 1104mm.

The potential evapotranspiration is found using penman or combination methods yields (942.72mm), Thornthwaite approach yields (751.91mm). The result of the Thornthwaite

approach under estimates the actual values since this method use only temperature and will not account other hydrometeorological parameters that have a direct effect on the rate of potential evapotranspiration.

The actual evapotranspiration quantified with empirical formula developed by Turc yield (756.16mm), Crowe and Thonhwaite method yield (768.4mm) and soil water balance method yield (703.07mm). The actual evapotranspiration of Teji area taken to be 703.07mm since soil water balance method uses many parameters that have a paramount effect on the rate of actual evapotranspiration such as mean annual precipitation, potential evapotranspiration, soil moisture, field capacity of the soil, rooting depth of vegetation, temperature, wind speed and relative humidity etc.

In the Teji River catchment temporal trend of temperature shows an increasing trend, wind speed shows a decreasing trend, the potential evapotranspiration shows a decreasing trend. The decreasing trend of potential evapotranspiration in Teji river catchment is mainly affected by wind speed.

The maximum and minimum relative humidity is found in August (83.9%) and February (42.2%), respectively. Highest humidity values are found in the rainy months whereas the lowest humidity values are in the dry months. The minimum wind speed is found relatively in the rainy season (June-September). Minimum potential evapotranspiration corresponds with the maximum relative humidity and minimum wind speed and sunshine hour in the months of June- September.

The river has not gauging station at its mouth and therefore to get the actual runoff, extrapolation of the flow from the gauging station located at Asgori town is made using area ratio by considering similarity in climate, topography, and land use land cover. The separation of the river catchment in to surface runoff and subsurface runoff has been made using computer software known as Time-plot. Based on this 59% (108.71mm) of the flow is contribution of base flow and 41% (75.54mm) is from surface runoff of the total mean annual flow of 184.25mm.

Ground water recharge is calculated using water balance method yield (325.4mm). Under steady state condition discharge from the aquifer is assumed to be equal to the total recharge to the aquifer. The inflow amount calculated by water balance method and outflow amount (base flow) shows inequality in the study area. The inflow amount exceeds the out flow amount. This could happen probably;

- Teji river catchment may be recharged regionally from other catchments.
- There may be inflow of groundwater to the catchment through NW-SE trending fault line.
- There may be because of groundwater divide exceeds surface water divides.
- There may be under pass of water somewhere in the catchment not measured by the river gauging station.
- Base flow - surface runoff separation made based on individual personal point of view that may bring unrealistic results.
- There may be doubtful in the accuracy of the river discharge measurement.

The main aquifer types identified in the area are weathered and fractured Ignimbrite, weathered and fractured basalt and alluvial deposit. The productivity of the wells tapping the aquifer formation has spatial variability; this is because of variation in the degree of weathering and fracturing. The productivity of the well from Ignimbrite aquifer yield 5.5 l/sec & 3.98 l/sec at Asgori town and bebeli debegna rural village. The productivity of the well from basaltic aquifer has yield range between 1 and 10 l/sec. The test bore hole drilled at Asgori town by water works design supervision enterprise shows scoraceous basaltic lava flow is the main water bearing formation in the catchment which intersected at depth of 225m below the ground surface. The productivity of this well yield 35 l/sec.

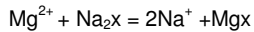
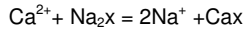
The surface and subsurface interaction of the area is observed by measuring the difference between hydraulic head of the groundwater system and elevation of stream beds and from the chemistry of groundwater and river water. Accordingly the stream gains water from groundwater bodies.

The chemical analyses of water sample indicate variation in the water type from Ca-Mg-Hco₃, Ca-Hco₃, Ca-Na-Hco₃, and Na-Hco₃-Cl. The cat ion evolutionary sequence is more variable than anion sequences because of ion exchange and other processes.

The spatial trend of major cation and anion plotted on a 2-dimensional plot shows Ca²⁺ and Mg²⁺ ion shows a decreasing trend toward the discharge area where as the concentration of K⁺ and Na⁺ shows an increasing trend. This is interpreted as;

- Cation exchange reaction

The ca²⁺ and Mg²⁺ ion in solution exchange with Na⁺ ion adsorbed in the aquifer solid which is represented by the following reaction;



- Along the flow paths rock water interaction increases and the water encounters sodium bearing lithology.

From the chemistry of the water sample analyzed in the catchment its suitability of the water for a proposed use is determined.

- Accordingly all the water sample analyzed is good for domestic use except two bore holes drilled at Asgori town (fluoride & iron) and Urago tede rural village (fluoride) having concentration above the permissible limit.
- Classification of the water sample for irrigation based on sodium adsorption ratio indicates the entire water sample is good for irrigation.
- Classification of the water sample for irrigation based on sodium percentage indicates except the water sample at Asgori town, all samples are good for irrigation. In general it could be said that the water resource in the catchment is good for domestic & irrigation purpose.

Recommendations

Based on the availability of data on the major controlling factors for groundwater potential assessment such as geology and geological structures, hydrogeology, hydrology, meteorology, and physical and chemical analyses and findings of the study the following recommendations are given;

- In order to achieve self sufficiency in food grain productions, utilization of surface water for those living nearby the river and groundwater for dwellers far away from the river should be practiced.

- Even distribution of boreholes with full penetration and pumping test analyses is required to understand the aquifer characteristics and their hydraulic parameters very well.
- Installation of observation pipes should be practiced in the future for the newly constructed boreholes which is vital for the groundwater level change assessments.
- Concerned bodies are suggested to collect reliable meteorological elements and river discharge data on daily basis for the evaluation of surface and subsurface water resources very well.
- Flower farming is recently being practiced in the catchment that have adverse effect on the quality of groundwater and surface water in the future due to uncontrolled discharge of chemical effluents and therefore care has to be taken by not to discharge their effluents to surface water bodies and unprotected storage pits.

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Annex-1 Meteorological Data

Element- Monthly Total Rain Fall

Station- Asgori

Geographic Coordinate- 426430UTME, 971756UTMN

Altitude-2078m

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1977	56	45.2	34.3	86.5	165.1	157.2	322.9	220.1	88.8	233.6	13	0	1422.7
1978	0	34.4	38.8	35	34.9	195.5	184	312.9	141.5	12	0	19.5	1008.5
1979	57	19	82.8	17.09	114.6	146.9	227.1	182.5	92	50.3	11.3	17.4	1018
1980	15.05	16.8	12.7	76.4	16.6	117.4	207.8	272	64.5	39.3	0	0	838.55
1981	0	33.3	182.1	117.7	11.4	36.4	243.2	296.6	232.4	7.2	0	0	1160.3
1982	17.8	51.7	57.6	72.2	60.6	80	154.1	286.9	35.5	34.8	26.3	8	885.5
1983	8.6	80.4	61.9	124.4	101.9	89.9	236.6	29.6	85.7	9.8	0	5.7	834.5
1984	0	0	20.9	1.3	104.3	184.4	302.7	215.6	85.4	0	0	15.3	929.9
1985	25.4	0	20.2	64.8	51.7	121.3	317.1	340.1	100.7	6.8	0	0	1048.1
1986	0	40.9	46.7	143.2	109.1	200.9	234.9	255	91	8.6	0	3.2	1133.5
1987	0	26.8	130.3	135.4	140.4	100.2	156.8	251.9	42	4.2	0	0	988
1988	3.6	45.5	2	112.8	8.9	75.4	293.3	255.9	177.4	15.7	0	0	990.5
1989	1.7	77.6	87.4	66.7	8.2	113.9	234.6	200.2	93.3	11	0	5.1	899.7
1990	0	100.5	36.7	116.4	17.4	173.1	348.3	307.2	88.5	25.2	0	0	1213.3
1991	1.6	24.9	63.7	4.8	45.1	213.6	283.1	345.6	115.7	3.5	0	2.1	1103.7
1992	53.5	54.9	19.7	120.7	60.5	135.5	308.5	339.9	114.5	70.8	0	0.8	1279.3
1993	26.3	150	0	210.6	80.9	99.5	291.8	299.5	86.6	13.9	0	4.7	1263.8
1994	0	0	60.8	88.4	90.4	162	289.1	304.8	169.2	0	14.3	0	1179
1995	0	27.2	56.8	149.3	66.7	121.8	232.2	277.4	145.1	4.5	0	30.2	1111.2
1996	82.4	0	133.2	108.7	117	189.4	218.2	353.1	186.4	10.9	64.1	0	1463.4
1997	7.8	0	30	50.5	33	141.3	256	167	49.6	52.4	25.5	0	813.1
1998	49.1	70.4	31.2	80.8	79.7	103	315.4	302.6	51.6	20.4	0	0	1104.2
1999	5.27	0	61.5	8.9	66	137.2	254.8	214.9	130.6	59.1	0	0	938.27
2000	0	0	0	106.7	63.2	111.6	238.1	167.4	143.6	1.4	8.3	0	840.3
2001	1.4	12.5	103.4	22.8	127.9	183.9	253.8	128.3	55.8	5.8	0	0	895.6
2002	20.7	41.4	48.1	40.7	52.2	97.3	258.4	252.7	93.4	0	0	20.7	925.6
2003	45.1	24.5	65.2	119.8	43.9	169.6	264.8	272	107.9	2	1.3	10.5	1126.6
2004	30.2	4.5	44.6	172	24.6	151.8	183.6	183.8	74.3	57.1	0	0	926.5
2005	25.9	2.4	76.7	52.7	140.8	149	164.2	146.8	123.2	10.5	0.6	0	892.8
Total	534.42	984.8	1609.3	2507.3	2037	3959	7275.4	7182.3	3066.2	770.8	164.7	143.2	
Mean	18.43	33.96	55.49	86.46	70.24	136.52	250.88	247.67	105.73	26.58	5.68	4.94	1042.6

Element- Monthly Total Rain Fall

Station-Bantu Liben

Geographic Coordinate- 430641UTME, 951387 UTMN

Altitude-2175m

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1977	32.3	28.7	40.9	80.2	61.9	168.2	258.2	303.6	34.9	99.4	9.2	0	1117.5
1978	0	65.4	47.7	30.5	42.5	175.9	172.4	260.9	91.2	32.5	0	25.63	944.63
1979	65.93	9.8	69.4	37.2	68.7	170.1	242.8	170	88.9	47.1	0	2.5	972.43
1980	1.8	30.2	44.9	46.7	0	225.1	264.6	255.4	63.2	9.2	0	0	941.1
1981	0	4	113.8	75.8	7.8	38.6	285.6	167.2	170.3	10	0	0	873.1
1982	12.8	71.8	27.5	32.2	23.8	74.4	221.7	187.6	38	29	23	17	758.8
1983	13	37	71	48.5	75	62	119.9	15.9	0	5	0	2	449.3
1984	0	0	5.8	3	104.3	150	161	149.9	51.2	0	0	0	625.2
1985	0	0	15.21	45.7	81	84.5	297.32	235.5	311	111.6	0	1.34	1183.2
1986	0	0	59.5	68	98.91	229	195.93	184.02	100.2	14.95	0	2.73	953.24
1987	0	18.8	133.2	66.2	245.2	142.7	177.8	217.4	111.8	2.5	0	0	1115.6
1988	7.4	29.8	3.75	87.5	7.3	171.8	302	224.5	137.9	17.06	0	0	989.01
1989	4.5	66.3	113.1	21.8	62.7	12.8	568.5	372.1	143.7	12.5	0	14.1	1392.1
1990	16.5	124	48.4	100.4	34.04	78.6	272.6	284.9	86.2	8.7	0	0	1054.3
1991	15	16.6	107.2	8.9	28.2	129.4	342.7	459.1	153	0	0	6.6	1266.7
1992	38.3	82.5	29.9	30.9	46.6	200.5	157.2	419.6	166.7	80.9	15.2	0.5	1268.8
1993	6.3	90	2.1	198.9	43.3	251.7	646.8	324.5	246.4	271.5	0	1.63	2083.1
1994	0	0	75.7	129.3	38.5	151.8	284.4	309.2	211.6	0	0.7	0	1201.2
1995	0	0	61.1	238.5	103.2	62.4	210.6	215.6	75.7	0	0	19.4	986.5
1996	25.4	0	52.7	157.7	52.2	355.1	324.5	482.4	450.4	323.7	225	0	2449.1
1997	0	0	0	40	17.4	157.9	268.7	232.5	54.4	47.7	32.2	0	850.8
1998	61	9	68.6	29.5	127	150.9	430.6	433.4	87.8	0	0	0	1397.8
1999	0	0	49.9	0	20.9	146.3	225.9	295.8	74.8	39.1	0	0	852.7
2000	0	0	6.5	123.6	86.5	150.2	257	186.2	143.1	6.5	22.4	5.7	987.7
2001	0	5.2	148.2	47.7	76.1	159.8	306.4	259.8	2.8	0	0	0	1006
2002	33.3	26.5	76.5	60.1	62.1	207.8	270.1	215.9	12.6	0	0	19.2	984.1
2003	64.2	43.3	110.6	131.5	38.6	238.3	372.9	259.4	210.6	0	0	21.3	1490.7
2004	74.6	0	39.5	160.1	43.2	333.2	302.1	280.1	77.4	18.9	0	0	1329.1
2005	25.9	2.9	100.5	78.6	323.4	268.4	434.9	351.6	167.1	0	0	0	1753.3
Total	498.23	761.8	1723.2	2179	2020.4	4747.4	8375.2	7754	3562.9	1187.8	327.7	139.63	
Mean	17.18	26.27	59.42	75.14	69.67	163.70	288.80	267.38	122.86	40.96	11.30	4.81	1147.49

Element- Monthly Total Rain Fall

Station-Tulu bolo

Geographic coordinate- 413482UTME, 957527UTMN

Altitude-2169m

Year	Jan	Feb.	March	April	May	June	July	Aug.	Sept.	oct.	Nov.	Dec.	Total
1977	70.5	0	45	48.2	87	225.8	409	351	108	178.5	85.3	0	1608.3
1978	0	62.5	60.7	34.6	113.4	143.2	222	193.9	73	0	0	25.1	928.4
1979	93.9	39	117.5	5.9	136.8	151.3	351.4	256.2	99.4	79.5	0	36.9	1367.8
1980	39.5	29.8	62	57.2	14.7	175.9	409	340	86	22.5	0	0	1236.6
1981	20	25	112	35	0	61	367	283.5	119.1	43	0	2.2	1067.8
1982	18.5	20	39	39.5	42.5	178.7	420.8	498.9	205	58.6	8.5	12.3	1542.3
1983	5	21.4	102.1	59.3	70.5	114.4	116	274.2	110.8	7.6	0	3.7	885.0
1984	3.3	2.6	24.8	5.56	65.1	35.5	247.8	228.6	91.6	0	0	6.7	711.6
1985	27.8	12.2	7.2	58.5	87.5	149.6	320.4	268.7	63	19.8	0	4.5	1019.2
1986	10.6	43.3	71.6	99.7	86.7	214.2	175	146.2	144.6	4.4	0	4.2	1000.5
1987	3.7	31.6	137	71.8	140.4	137.4	177.7	173.9	52.3	11.3	0	0	937.1
1988	2.5	18.6	0	135.9	4	205.7	339.8	157.1	58.5	4.4	0	0	926.5
1989	6	68.8	87.3	95.8	0	345.2	229	298.6	91.4	20.5	0	9.2	1251.8
1990	0	27.6	25	106.5	29	150.1	238.3	199.8	36.6	0	0	0	812.9
1991	9.2	7.2	70.8	11.2	129	160.3	192	167.4	4.1	0	0	0	751.2
1992	14.1	63.3	62.2	37.3	42.6	336.9	441.7	575	65.7	8.2	4.7	2.8	1654.5
1993	12.4	26.3	13.9	113.8	193.5	548.9	440.4	563.7	176.45	107.1	0	2.2	2198.7
1994	0	0	86.6	46.9	69	48.2	339.4	316.6	22.8	0	6.4	0	935.9
1995	0	8.3	43.1	99.7	109.2	139.8	90.1	221.6	0	3.1	0	14.7	729.6
1996	17.5	3.1	39.8	65.5	87.8	216.3	243.9	338.2	121.2	0	4.3	0	1137.6
1997	0	0	36.3	60.7	42.1	203	343.2	190	78.8	63.3	37.1	0	1054.5
1998	0	23.3	0	90.4	155.3	317	343.6	340.9	113.8	68.9	0	0	1453.2
1999	15.7	0	56	0	79.1	270.1	356.7	449	140.3	5.5	0	0	1372.4
2000	0	0	1.8	160.8	131.9	222	320.4	226.7	114.3	6.3	26.4	4.6	1215.2
2001	0.5	3.2	98.1	36.4	68.6	186.5	224	160.1	35.3	6.9	0	0	819.6
2002	46.3	9.1	41.7	60.6	43.3	124.9	236.8	241	77.2	0	0	40.6	921.5
2003	40	11.7	49.1	94.3	7.8	127.1	315.1	219.1	91.5	0	0	7.7	963.4
2004	52.5	0	10.8	92.9	44.7	270.9	330.6	185	163.8	0	0	5.2	1156.4
2005	26	0	53.9	180.9	165	208.4	177.3	203.7	83.8	18.3	15.5	0	1132.8
Total	535.5	557.9	1555.3	2004.9	2246.5	5668.3	8418.4	8068.6	2628.4	737.7	188.2	182.6	
Mean	18.47	19.24	53.63	69.13	77.47	195.49	290.29	278.23	90.63	25.44	6.49	6.3	1130.8

Element: Monthly Total Rain Fall

Station: Teji

Geographic coordinate: 430440UTME, 972917UTMN

Altitude: 2066m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	60.1	77.1	77.6	61.4	73.9	133.2	202.8	205.8	66.2	204.8	5.5	0	1168.4
1978	1.6	53.3	57.6	75.5	59.1	168.3	273.6	229.8	141.9	1.5	0	6.8	1069
1979	81.5	36.3	74.2	68.4	111.7	113.3	181.4	251.1	82.3	27.4	0	11.1	1038.7
1980	15.6	28.8	32.6	71.2	26.2	126.5	273.9	245.8	106.2	36.7	0	0	963.5
1981	0	24.8	113.5	125.4	198	60.4	239	179.3	131.1	5.3	0	0	1076.8
1982	35.5	46.7	28	77	48.3	97.8	239.2	226.1	49.9	26.7	42.9	5.6	923.7
1983	13.1	100.1	43.3	137	9.8	61.4	248.6	178.8	53.1	17.3	0	26.6	889.1
1984	0	19.8	11.6	3.7	147.2	214.8	242.1	148.8	131.9	0	0	0	919.9
1985	17.1	0	21	64.7	43.7	54.9	283.3	234.4	116.6	3.8	0	4.7	844.2
1986	17.9	18.3	62.3	144.9	105.3	180.7	197.5	188.4	76.7	6.9	0	0	998.9
1987	0.9	46.2	133.4	94.7	128.8	55.7	90.7	207.5	48.3	11.7	0	0.8	818.7
1988	7.6	71.9	10.8	156.1	4.3	120.4	249.3	289.2	226.4	26.3	0	0	1162.3
1989	0.4	92.5	49.6	72.2	6.1	71.5	245	246.6	114.1	5.8	0	17.6	921.4
1990	0	149.6	74.5	79.1	30.4	101.7	251.1	210.6	81.3	11.8	0	0	990.1
1991	0	53.1	140.3	3.1	34.7	96.9	221.7	261.8	129.3	1.8	0	18.3	961
1992	43.7	60.1	61.3	87.1	76.4	124.3	122.8	235.4	89.5	56.3	4.6	1.5	963
1993	5.1	100.3	0	149.9	100.1	92.9	234.7	288.8	97.3	22	0	2.5	1093.6
1994	0	0	34.8	36.8	28.4	197.8	185.4	241.6	128.8	0	13.3	0	866.9
1995	0	41	18.2	98.2	65.7	66.1	223.8	179.4	46.5	1.3	0	48.6	788.8
1996	53.3	2.3	99.8	95	71.9	113.2	219.3	208.3	72.5	3.6	1.9	0	941.1
1997	12.7	0	28.7	131.9	29.3	96.1	187.9	143.9	63.7	48.1	48.6	0	790.9
1998	89.8	52.4	29.7	70.6	68.2	135.7	310.2	232.1	87.2	64.4	0	0	1140.3
1999	4.9	0	44.2	5.8	45.2	97.5	242.4	218	98.2	76.5	0	0	832.7
2000	0	0	13.9	94	74.3	94.4	186.6	212.5	148.7	10.8	29.3	1.6	866.1
2001	2.3	1	95.5	14.9	164.7	182.9	214.5	120.3	64.6	3.3	7.7	0	871.7
2002	14.3	10	63.1	38	45.7	139.8	210.5	214.3	48.9	0	0	26.5	811.1
2003	29.3	21.1	80.6	153.7	48	158	229.8	267.4	84.3	0	0.2	9.6	1082
2004	20.1	6.4	22.2	129.5	28.5	163	209.2	216.9	72.6	68.5	0	0	936.9
2005	21.9	8.1	72.6	55.2	171.4	213.7	237.9	235	72.3	15.7	0	0	1103.8
Total	548.7	1121.2	1594.9	2395	2045.3	3532.9	6454.2	6317.9	2730.4	758.3	154	181.8	
Mean	18.92	38.66	55.00	82.59	70.53	121.82	222.56	217.86	94.15	26.15	5.31	6.27	959.81

Element: Monthly Total Rain Fall

Station: Busa

Geographic coordinate: 406000UTME, 960200UTMN

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1992	36.5	108.2	41	66.1	42.8	140.6	359.5	559.6	98.2	45.7	0	0.8	
1993	2.8	61.6	11.4	292.2	225.9	150.9	212.6	296	172	29.9	0	0	
1994	0	0	29.2	57.9	33.2	249.8	466.7	66.8	103.6	6.4	21.2	0	
1995	0	35.4	42.6	97.8	143.6	135.6	270.8	225.25	37.9	4.4	0	31.6	
1996	17.2	0	77.7	161.4	320.1	406.5	437.3	422.4	476	39.6	19.5	6.9	
1997	51.2	0	31.8	14	19.6	238.6	399.7	540.9	77.9	24.3	66.1	0	
1998	5.4	76.4	15.4	104	147.4	217.3	371.8	493.8	88.5	30	0	0	
1999	8.4	0	25.8	0	109.2	237.1	567.2	362.1	306.2	75.1	0	0	
2000	0	0	10.3	44.5	21	151.2	337.6	522.1	182.9	18.3	25.2	0	
2001	12	3.9	0	41.4	74.7	150.7	566.7	632.8	45.8	0.8	6.8	0	
2002	25.3	11	25	89.4	43.2	315.6	432.3	444.5	134.1	0	0	38.2	
2003	63.2	151.7	70.5	131.9	50.9	254.9	279.4	507.8	221	9.9	10	8	
2004	48.9	2	46.1	213.7	60.5	139.6	287.8	298.8	63.3	29.3	5.5	0	
2005	42.4	0	74.8	32.2	19.9	107.1	506.8	421.3	139.1	6.1	4.4	0	
Mean	22.38	32.16	35.83	96.18	93.71	206.82	392.59	413.87	153.32	22.84	11.34	6.11	1487.2

Element: Monthly Total Rain Fall

Station: Harbu chulule

Geographic coordinate: 417711UTME, 935349UTMN

Altitude: 2428m

Year	Jan	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1989	3.73	0	77.7	153.9	46.4	299.7	156.2	284.2	114.7	15.9	0	21.2	1173.6
1990	2	188	29	93.8	73	146.3	199.1	284.4	96.5	0	0	0	1112.1
1991	21.5	20.3	74.4	33.6	40	165.1	198	227.4	125.3	1	2	8.6	917.2
1992	47.6	49.4	60.7	96.2	36.4	100.7	193.2	246.8	87.8	8.5	0	6.7	934
1993	17.7	87.8	3.2	229.2	95.9	157.3	393.7	303.3	192.4	44.1	0	0	1524.6
1994	0	0	59	58.7	97	113.2	176.5	175.7	124.9	0	3	0.1	808.1
1995	0	75.1	22	131.5	151.1	194.7	142.6	10.5	79.5	0	0	20.25	827.25
1996	40.2	0	213.4	148.6	123.7	243.6	299.2	231.4	115.6	11.8	3.3	0	1430.8
1997	25	0	63	74.2	51.8	128.3	268.9	160.2	38.7	68	29.32	0	907.42
1998	71.7	25.9	84.2	63.7	114.9	128.1	179.5	247.5	183.7	37.9	0	0	1137.1
1999	2.5	0	71.2	22.7	93.7	196.9	226.2	255.8	134.5	95.9	0	0	1099.4
2000	0	0	15.3	113	74	132.7	230.8	177.1	172.9	12.2	33.9	12.5	974.4
2001	0	24	128.8	18.3	148.7	170.3	236.6	207.1	73.2	0.2	0	0	1007.2
2002	20.9	4	65	36.3	70.8	124.2	156.6	219.2	74.1	0	0	26.6	797.7

Groundwater potential Assessment of Teji River Catchment

2003	56.7	299	44.1	82.2	19.5	157.3	200.8	149.6	134.8	14.1	10	0	1168.1
2004	36.6	0	62.8	150.9	42.5	231.6	251.3	200.3	106.6	14.4	0	1.59	1098.6
2005	26.8	6	99.4	87	99.2	176.6	183.3	211.3	110	9.1	4.93	0	1013.6
Total	372.93	779.5	1173.2	1593.8	1378.6	2866.6	3692.5	3591.8	1965.2	333.1	86.45	97.54	
Mean	21.94	45.85	69.01	93.75	81.09	168.62	217.21	211.28	115.6	19.59	5.09	5.74	1054.8

Element: Monthly Total Rain Fall

Station: Dilela

Geographic coordinate: 395400UTME, 952800UTMN

year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1977	70.2	22.4	47.7	54.9	103.3	170.2	234.9	213.4	97.6	144.9	6.9	0	1166.4
1978	0	67.6	39.6	37.4	132.7	201.9	248.2	240.8	182.5	10.2	0	36.6	1197.5
1979	58.6	68.6	99.8	17.2	187.8	188.7	198.5	207.3	129.9	48.5	37.5	20.3	1262.7
1980	10.8	0	29	118.6	41.1	160	273.8	186.5	74.6	22.2	0	0	916.6
1981	0	19.8	128.6	75.1	6.2	42.3	278.2	234.8	185.4	14.2	0.2	2	986.8
1982	22.7	51.8	48.1	100.3	97.2	85.6	220.8	238.7	101.5	86.3	19.4	14.2	1086.6
1983	6	32	83.3	80.3	158.7	69	175.9	321	227.3	7	0	2.9	1163.4
1984	9.3	7.5	43.9	11.8	144.8	269.1	335.4	229.3	126.7	0	0	3.4	1181.2
1985	26	0	19.5	62.9	105.6	103.3	296	216.3	131.1	35.6	0	0	996.3
1986	8.5	39.1	78.9	67	113.4	153.9	200.7	167.7	82.4	34.2	0	1.2	947
1987	0	29.5	126.6	107.9	121.5	148	195.6	275.3	59.9	7.8	0	0	1072.1
1988	17.3	27.2	9.8	25.7	9.6	270.9	318.8	286	189.6	33.1	0	0	1188
1989	17	29.3	106.1	143.6	41.5	140.8	181.7	238.5	116.9	19.1	0	30	1064.5
1990	4	89.7	56.7	89.4	62.2	154.4	208	298.3	96.8	0	0	0	1059.5
1991	5.4	6.5	110.3	3.5	33	102.5	226	273.9	92.4	1.9	0	0	855.4
1992	87.6	58.8	79.4	58.2	41.6	171.5	194.7	306.3	136.9	46.7	4.3	0	1186
1993	6.8	121.8	4.7	208.6	169	147.1	244.5	340	315.6	36.1	0	0	1594.2
1994	0	1.7	77.8	52.2	78.2	225.9	202.8	254.9	112.8	0	3.2	0	1009.5
1995	0	73.7	34.1	204.3	139.8	52	249.4	347.7	73.3	3.6		10.2	1188.1
1996	31.5	0	152.4	155	109.9	291	238.7	298.4	122.6	6.1	11.3	0	1416.9
1997	68.6	0	41.2	67.3	57.2	171.5	238.1	176.5	85.7	103.1	20.1	0	1029.3
1998	83.8	77.4	31	114.4	133.4	257.4	266.9	287.8	151.7	54.6	0	0	1458.4
1999	9.5	0	78.3	15.4	100.5	181.3	249.9	247.2	128.3	101.5	0	0	1111.9
2000	0	0	5.1	67.4	77.9	129.5	238.3	215.6	188.9	29.6	31.6	17.6	1001.5
2001	2.2	10.7	81.8	52.5	141.2	138.1	221.1	142.1	81.1	27.1	0	0	897.9
2002	45.8	81.2	92.6	55.8	52.7	205.7	294.4	237.8	58.7	0	0	68.7	1193.4
2003	40.9	12.2	72.2	98.7	8.4	138.2	272.2	240.5	157	7.9	3.7	18.1	1070
2004	64	0.8	48.4	154.4	42.8	274.5	264.4	168.3	189.5	23.3	6.8	0.3	1237.5
2005	44.7	0	103.7	169	154	180.1	152.5	274.7	119.7	14.9	2.6	0	1215.9
	741.2	929.3	1930.6	2468.8	2665.2	4824.4	6920.4	7165.6	3816.4	919.5	147.6	225.5	

Groundwater potential Assessment of Teji River Catchment

Total													
Mean	25.56	32.04	66.57	85.13	91.9	166.36	238.63	247.09	131.6	31.71	5.09	7.78	1129.5

Element: Monthly Maximum Temperature

Station: Tulubolo

Geographic coordinate: 413482UTME, 957527UTMN

Altitude: 2169m

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1988	26.9	27.1	28.5	27.5	27.6	26	21.5	23	23.4	25.8bbb	24.9	25.8
1989	23	23.4	25.2	27.2	27	26.7	24.4	23.4	21.6	21.6	22	23.2
1990	22.9	22.1	22.6	26.8	23.6	20.5	21.2	23.6	22.3	21.4	24.5	24.8
1991	26.3	27	26.2	26.5	26.7	26.4	26.1	26.2	26.4	27.1	26	21.5
1992	26.9	27.1	26.5	27.2	27.6	26.9	26.9	27.5	26.8	27.7	26.7	27.2
1993	27.4	27.2	26.9	26.7	27.4	28.3	27.5	28.1	27.4	27.6	27.5	27.4
1994	27.1	28.3	27	27.7	28.4	28.3	26.8	26.8	27.4	26.7	26.4	25.2
1995	25.2	24.6	24.5	25	25.4	25	24.7	21.7	23.6	24	23.4	21.4
1996	21.1	21.7	22	22.4	22.5	22.9	20.7	22.7	22.5	22.7	21.6	20.7
1997	22.3	21.4	22.4	22.9	24.4	23.1	21.7	22.1	21.2	21.5	21.4	20.8
1998	21.3	21.6	23.6	22	21.4	21.2	21.1	21.6	20.3	21.6	21.3	20.5
1999	20.6	22.8	21.8	22.3	22.1	21.7	21.3	20.4	20.5	20.7	20.9	20.2
2000	19.7	21.1	22.4	20.8	22.1	21.6	19.9	20.1	20.9	20.4	20	19.8
2001	25.4	26.8	25.3	27.2	27.2	24.1	22.4	22.1	24.8	25.6	24.6	25.2
2002	25.1	27.3	27.7	27.3	28.5	25.7	24	23	23.2	14.9	25.1	25.6
2003	23.6	26.4	27.2	25.7	27	26	22.8	23.3	23.6	23.2	25.2	24.6
2004	26.7	26.8	27.9	25.8	27.6	24.4	23.5	23.7	24.7	22.1	23.9	25.6
2005	25.7	28.1	27.8	28	25.8	27.1	23.6	24.5	24.7	25.3	25.2	24.4
	437.2	450.8	455.5	459	462.3	445.9	420.1	423.8	425.3	419.9	430.6	423.9
M.M.M.T	24.29	25.04	25.31	25.50	25.68	24.77	23.34	23.54	23.63	23.33	23.92	23.55

M.M.M.T= Monthly Mean Maximum Temperature

Element: Monthly Minimum Temperature

Station: Tulubolo

Geographic coordinate: 413482UTME, 957527UTMN

Altitude: 2169m

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1988	4	5.6	5.6	5.7	7.5	6.6	5.1	5.2	5.2	5.6	6.2	6.3
1989	5.2	5.1	5.8	8.3	5.4	5.7	5.9	6	5.4	6	5.9	5.9
1990	6.2	5.9	5.9	7.3	5.3	4.9	5.5	4.6	6	6.2	6	5.9
1991	6.2	6.5	6.3	6.3	6.2	6.2	6.3	5.7	6.3	6.3	6.3	6
1992	6.3	8.1	10.1	9.5	10.2	10.6	9.9	9.8	9.5	9	9.8	9.6
1993	10	9.7	10	9.4	9.4	10.4	10.4	9.2	9.7	9.7	8.6	9
1994	9.8	7.8	9.7	9.3	9.3	10.4	10.7	10.3	10.1	13	10.6	13
1995	12.5	11.3	11.8	12.2	10	12.9	11.9	12.2	12.7	12.8	12.7	11
1996	11	10.8	10.9	10.7	10.8	11.1	11.2	12.7	12	11.8	11.8	10.6
1997	11.4	11.2	11.3	11.8	11.9	11.2	12	11.8	11.2	11.3	11.1	10.4
1998	10	10.6	11.6	11	10.9	9.9	10.6	10.9	9.8	10.8	10.7	9.2
1999	8.8	7.8	10	10.7	9.8	9.8	9.7	10.1	8.6	10.3	10.4	8
2000	7.8	8.6	8.7	9.3	9.1	9.1	9.5	8.9	9.7	9	8.6	8.1
2001	8.8	9.2	11.6	11.1	11.9	11.8	12	11.9	9.7	8.7	8.4	8.1
2002	9.8	9.4	11.2	10.9	12.2	11.9	11.7	11.4	10.6	9	6.9	10.1
2003	8.8	9.8	11	11.7	10.7	11.7	11.4	11.8	10.7	9.4	7.9	6.5
2004	10.5	9	11.4	12.5	10.5	10.6	11	11	9.6	5.8	5.5	6.7
2005	6.9	10.9	11.2	10.2	11.2	11.8	11.8	12	11.1	7.6	6	4.5
Total	154	157.3	174.1	177.9	172.3	176.6	176.6	175.5	167.9	162.3	153.4	148.9
M.M.Mi.T	8.56	8.74	9.67	9.88	9.57	9.81	9.81	9.75	9.33	9.02	8.52	8.27

M.M.Mi.T = Monthly Mean Minimum Temperature

Element: Monthly Maximum Temperature

Station: Asgori

Geographic coordinate: 426430UTME, 971756UTMN

Altitude: 2078m

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1988	30.2	30.1	31.7	29.9	31.3	30.5	25.2	24.2	25	25.8	25.6	28
1989	26.4	25.4	28.6	25.3	27.8	25.3	24.4	22.1	24.6	23.9	25.9	27.4
1990	27.3	27	27.6	27.9	28.3	26.9	24.7	23.5	25	25.1	27.8	26.9
1991	28.4	28.7	28.5	29.9	30.6	28.4	24.6	24.6	24.4	26.2	26.2	26.6
1992	26.4	26.2	29.1	28.4	28	28.7	25.9	25.7	25	25.6	26.2	26.8
1993	27.3	27.2	28.5	27.6	28.4	27.8	25.4	25.6	26.1	26.4	26.6	27.4
1994	28.7	30.9	30	28.4	28.1	25.9	24.8	24.3	24.8	24.9	25.7	25.8
1995	26.3	27.9	28	27.8	28.6	28.2	26	25.7	26	26	26.3	26.5
1996	26.4	27.7	28.4	28.3	28.3	28.7	27.6	27.3	26.8	25.1	26	26.1
1997	26.7	28.1	29.7	27.9	29.8	27.5	23.9	25.4	26.4	25.5	26.1	26.3
1998	26.5	27.9	29.6	28.8	29.5	27.2	23.5	24.7	26.2	25.3	25.3	26.2
1999	26.9	28.5	29.6	29.7	29.3	27	23.2	24.1	26	25.1	24.5	26.1
2000	27.3	29.1	27.8	27.4	27.8	27.5	23.9	23.1	24.7	25.4	26.3	26.9
2001	27.6	28.4	27	28.6	27.8	25.6	24.3	23.9	25.7	26.7	26.9	25.7
2002	26.6	28.6	28.2	29.1	30.6	27.7	26.6	25.1	26.1	28	28.1	28
2003	28.5	30.3	30	28.8	30.6	28.7	25.2	25	25.4	26.8	27.9	26.7
2004	28.7	29.5	29.7	27.6	29.8	27.6	25.6	26.2	25.2	26	28.1	27.9
2005	28.3	30.6	29.8	29.5	28	26.9	24.5	25.4	25.2	26.4	28	27.3
Total	494.	512.	521.8	510.	522.	496.	449.	445.	458.	464.	477.	482.
M.M.M.	27.4	28.4		28.3	29.0	27.5	24.9	24.7	25.4	25.7	26.5	26.8
T	7	5	28.99	8	3	6	6	7	8	9	3	1

Element: Monthly Minimum Temperature
Station: Asgori
Geographic coordinate: 426430UTME, 971756UTMN
Altitude: 2078m

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1988	6.2	9.1	6.7	9.5	7.8	9.8	11	11.3	11.4	6	2.5	2.9
1989	4.1	6.6	6.7	10	7.8	8.7	9.5	10.3	8.9	4.1	3.1	8.4
1990	5.9	7.5	9.3	10.9	8.1	9.7	11.4	11.3	10.4	7.5	6.1	4.2
1991	7.2	8.4	8.5	8.8	8.7	8.8	9.8	10.5	8.8	4.5	3.4	4.6
1992	7.5	10.8	8.1	8.4	8.6	8.5	8.8	10.9	9.3	6	4.3	6.5
1993	6.9	7.2	5.9	11.1	10.1	9.5	10.6	10.7	8.8	5.8	4.5	4.2
1994	6.8	6.6	10.1	9.9	9.9	12.8	12.5	11.9	11.2	5.8	8.1	5.9
1995	5.7	9.5	9.5	9.9	9.7	10.3	10.9	11.4	10.4	5.9	5	6.6
1996	8.5	8.8	9.9	10.1	8.6	10.2	10.4	10.4	11.1	6	6.5	6.2
1997	10.1	6.3	11.4	10.3	8.2	11.9	12.1	12.1	10.7	6.2	4.8	4.7
1998	9.3	5.9	9.8	9.3	8.8	8.1	10.2	10.1	8.5	6.4	3.2	3.2
1999	7.2	5.6	8.3	8.3	9.4	4.4	8.4	8.1	7.6	8.1	3	4.7
2000	5.2	4.5	8	12.2	11	9.7	11	10.9	9.4	4.8	3.5	1.7
2001	7	6.8	10.6	8.4	11.5	11.3	11.3	12.3	9.5	7.1	3.6	1.7
2002	7.8	7.2	9.7	12.4	11	10.5	11.6	11.2	9.7	6.1	5.2	8.7
2003	6.1	9.6	10.4	12.6	8.8	9.4	10.6	11.5	11.6	4.9	5.8	4.6
2004	8.7	7.1	8.3	11.6	9.8	11.2	11.6	11	9.7	6.7	4.7	7.2
2005	8.2	7.9	11.2	10.4	11.6	10.5	11.3	11.7	10.9	6.9	5.3	3.5
Total	128.4	135.4	162.4	184.1	169.4	175.3	193	197.6	177.9	108.8	82.6	89.5
Mean	7.13	7.52	9.02	10.23	9.41	9.74	10.72	10.98	9.88	6.04	4.6	4.97

Element: Monthly Wind speed

Station: Woliso

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1989	4.6	4.5	2.6	2.7	2.7	1.3	1.3	1.3	1.4	2.9	4.3	4.3
1990	4.7	2.2	3.3	2.5	2.1	1.3	1.3	1.2	1.3	3.7	4.2	5.8
1991	4.3	3	3.2	4.4	3.9	1.4	1.2	1.2	1.6	3.5	5.1	4.6
1992	4	3.1	3.6	2.9	2.2	1.3	1.2	1	1.5	2.4	3.9	4.6
1993	4.1	3.4	3.8	2.1	2	1.1	1	1.1	1	2.2	4.6	5.2
1994	4.6	4.3	2.7	3.8	1.7	1.2	1.1	1	1.9	4.2	4.9	6.1
1995	5.2	3.7	3.6	2.6	2.3	1.5	1.1	1	1.1	2.8	3.9	4
1996	3.5	3.9	2.8	2.5	2	1.4	1.1	1.1	1.3	3.1	4.1	4.5
1997	3.2	5.6	3.3	2.6	2	1.4	1.1	1.1	1.6	2.8	3.6	4.9
1998	3.9	2.7	3.3	3.1	1.7	1	1	1	1.1	1.7	3.9	5.2
1999	4.4	5.1	2.8	3.4	1.4	1	0.9	0.9	1	1.8	1.9	1.7
2000	5.1	5.2	4.6	2.8	1.3	1	0.9	1	0.9	2	3.3	4
2001	3.2	3.8	2.3	3.1	1.3	0.9	0.9	0.8	1.1	2.4	3.6	4.6
2002	4	3.9	2.2	3	1	0.9	0.9	0.7	0.9	2.8	3.9	3.3
2003	3.1	3.4	3.1	2.4	2.4	1.1	0.9	0.8	0.8	3.2	4.5	4.5
2004	2.7	3.9	3.1	2.1	1.8	1	0.9	0.9	0.8	2.5	3.6	3.8
2005	2.9	3.8	2.9	2.4	0.9	0.9	0.8	0.7	1.1	2	3.4	4.3
Mean	3.97	3.85	3.13	2.85	1.92	1.16	1.04	0.99	1.20	2.71	3.92	4.44

Element: Relative Humidity at 0600L.S.T

Station: Woliso

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1989	70	69	76	82	77	94	96	94	95	73	62	82
1990	68	87	81	75	86	94	93	96	94	65	60	56
1991	69	78	79	69	73	94	95	94	88	62	54	64
1992	77	85	75	76	80	93	96	96	89	80	69	74
1993	75	78	57	86	85	94	94	93	94	82	66	x
1994	x	x	x	x	85	94	94	95	87	61	71	67
1995	60	74	74	86	83	91	96	96	94	71	61	75
1996	82	59	82	82	85	97	97	98	97	71	68	70
1997	75	57	72	84	86	94	95	97	92	84	84	71
1998	80	73	78	75	87	96	97	97	96	85	53	48
1999	59	27	77	61	88	92	96	94	x	88	x	58
2000	54	43	48	64	83	90	93	94	93	83	73	63
2001	65	58	78	66	89	94	94	95	93	83	63	57
2002	76	52	76	72	88	93	91	93	91	65	50	72
2003	69	59	71	74	70	92	96	96	93	64	65	63
2004	74	56	38	81	76	90	92	95	94	72	61	66
2005	69	49	70	66	84	92	94	94	93	71	61	50
Mean	70.13	62.75	70.75	74.94	82.65	93.18	94.65	95.12	92.69	74.12	63.81	64.75

Groundwater potential Assessment of Teji River Catchment

**Element: Relative Humidity at
1200L.S.T
Station: Woliso**

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1989	42	41	45	50	45	65	79	76	71	42	39	50
1990	40	56	45	46	51	67	73	75	67	40	38	34
1991	41	47	49	35	38	67	79	77	65	38	36	38
1992	46	52	43	49	45	65	74	76	66	52	43	43
1993	47	48	30	56	59	71	77	75	68	49	41	x
1994	x	x	x	x	51	70	80	79	63	36	39	42
1995	41	47	41	56	53	65	77	77	67	46	41	47
1996	54	36	53	52	62	78	80	78	73	47	48	52
1997	49	34	43	55	52	48	85	76	62	54	52	43
1998	50	44	51	47	62	73	82	83	78	60	35	29
1999	33	15	54	30	49	65	77	75	x	59	x	35
2000	30	20	24	43	56	64	77	75	69	53	41	37
2001	41	36	47	34	56	69	76	76	64	45	34	33
2002	45	32	44	37	47	67	74	75	63	32	29	43
2003	39	33	39	50	33	65	79	77	70	34	40	39
2004	43	31	32	47	42	68	74	76	67	44	36	38
2005	41	31	39	37	53	66	72	72	69	41	36	28
Mean	42.63	37.69	42.44	45.25	50.24	66.65	77.35	76.35	67.63	45.41	39.25	39.44

Element: Relative Humidity at 1800L.S.T

Station: Woliso

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1989	35	38	48	59	49	73	84	78	77	54	43	56
1990	34	64	44	50	52	73	74	82	79	47	43	32
1991	35	46	50	35	40	64	76	78	73	42	37	38
1992	45	55	42	46	53	73	77	84	74	62	49	41
1993	43	47	26	65	65	77	78	79	82	61	47	x
1994	x	x	x	x	54	77	77	80	71	38	38	33
1995	34	41	36	62	55	67	79	81	74	52	42	44
1996	49	36	54	54	66	83	82	83	78	52	50	51
1997	44	25	40	58	57	54	77	78	64	63	58	44
1998	47	43	51	50	62	79	81	84	85	70	39	25
1999	28	x	64	32	51	67	80	77	x	73	x	36
2000	25	19	19	44	56	68	75	80	76	61	49	35
2001	34	26	54	39	62	72	76	82	75	61	36	30
2002	37	27	43	36	48	72	74	79	68	34	27	44
2003	35	29	43	48	30	66	80	81	80	45	39	38
2004	41	29	32	49	43	72	78	81	77	55	36	37
2005	38	23	38	46	52	69	76	76	72	51	35	24
Mean	37.75	36.53	42.75	48.31	52.65	70.94	77.88	80.18	75.31	54.18	41.75	38

Annex-2 Hydro chemical Data

In situ measured hydro chemical data

Source	Location	Depth	SWL	Gw level	North	East	Ph	T(0c)	EC
BH	Sodoliben	60	22.85	2179.15	953728	418098	7.25	20.5	513
BH	Urago Tad	60	22	2213	949964	416967	7.19	20	532
BH	Urago Tad	60	21.15	2225.85	950641	415757	7.1	21.2	583
BH	Urago Tad	65	27.2	2187.8	950317	418601	7.05	21.1	555
BH	Sinbiroch	62.5	32	2120	961055	420920	6.69	24.2	405
BH	Sinbiroch	24	22.5	2127.5	961061	419790	6.95	22	430
BH	Kobo	62.5	20	2132	961937	417672	6.6	21.2	400
BH	Soyama gengi	60	37	2249	956128	405805	6.93	21	554
SW	Mende Tofisa	36	5	2275	953575	407454	6.88	19.7	838
BH	Tole belekes	60	10	2373	938096	418607	7.13	21.1	542
HD	Keta	21	20	2082	968410	423501	7.6	22.8	413
HD	Koticha	16	15	2107	965072	427600	7.68	21.2	619
HD	Gorbe	18	15	2111	962881	426797	7.6	20.5	546
HD	Jigdumida	11	9	2060	977477	432585	7.65	20.5	827
HD	Jigdumida	11	8.5	2058.5	977624	432604	7.62	20.4	712
BH	Asgori	90.3	4.29	2082	971380	427045	8	29.1	765
River	At Areda Pa's			2122	956342	425366	8.52	21.8	354
River	At Teji town			2065	975368	431039	8.6	18.5	407

Groundwater potential Assessment of Teji River Catchment

Laboratory measured hydro chemical data

code	East	North	Elev	Na	K	Ca	Mg	cl	Hco3	F	So4	P04	Alka	TDS	pH	EC
BH1	41809	95372	2202	20	9.2	69.72	13.26	1.99	353.56	1.4	0.4	0.203	289.8	344	6.94	466
BH2	42092	96105	2152	20.5	6.6	47.9	9.18	5.96	252.54	1.04	0.76	0.466	207	242	6.77	358
BH3	41860	95031	2215	36	10.8	61.32	5.1	2.98	346.97	1.68	0.28	0.154	284.4	334	6.98	480
480BH	40745	95357	2280	11.5	6.7	132.7	25	5.96	570.96	0.97		0.197	468	493	6.87	733
BH5	41860	93809	2383	37	9.5	64.7	12.8	2.98	371.12	1.46	0.29	0.387	304.2	357	7.31	503
BH6	42704	97138	2086	158	23	27.72	3.58	73.48	417.2	2.01	47.8	0.54	342	566	7.91	869
HDW	42760	96507	2111	10.7	7.4	90.72	11.73	5.96	362.34	1.48	5.1	0.596	297	362	7.4	543
TR1	42536	95634	2122	16	4.3	42	7.65	4.96	180.32	0.78	2.57	0.344	163.8	185	8.38	299
TR2	43103	97536	2063	17	5.1	49.56	5.61	3.97	211.55	0.38	1.52	0.537	185.4	220	8.3	330
SW	40856	95307	2286			88	25.2		473.36	0.86	1.5	1	388	340	8.18	680
SW-1	43608	97396	2079			80	14.4		329.4	1.42	2	1	270	330	8.2	660
SW-2	43738	97106	2075			96	36.48		361.12	0.62	2	0.043	296	320	7.02	495
SW-3	43489	97082	2098			78.4	14.4		361.12		0	0.33	296	188	7.71	376
SW-4	43301	97151	2098			75.2	7.2		302.56		0	0.46	248	184	7.55	368
SW-11	43251	97006	2110			83.2	36.48		219.6	0.65	0.55	0.049	180	305	7.65	483
SW-12	43290	97001	2108			73.6	12.96		300.12		1	0.66	246	192	7.66	384
SW-13	43443	96929	2096			56	25.92		244	0.6	0	0.046	200	172	7.32	292

Annex-3

Type and Location of water points in the study area

Type	Location	East	North	Depth(M)	SWL(M)	Yield(L/s)
BH	Sodoliben	418098	953728	60	22.85	
BH	Urago Tad	416967	949964	60	22	1.23
BH	Urago Tad	415757	950641	60	21.15	
BH	Urago Tad	418601	950317	65	27.2	0.5
BH	Sinbiroch	420920	961055	62.5	32	
BH	Sinbiroch	419790	961061	24	22.5	
BH	Kobo	417672	961937	62.5	20	
BH	Soyama genji	405805	956128	60	37	1.52
SW	Mende Tofisa	407454	953575	36	5	1.7
BH	Tole belekes	418607	938096	60	10	3.8
HD	Keta	423501	968410	21	20	
HD	Koticha	427600	965072	16	15	
HD	Gorbe	426797	962881	18	15	
HD	Jigdumida	432585	977477	11	9	
HD	Jigdumida	432604	977624	11	8.5	
BH	Asgori	427117	971583	90.3	4.29	5.5
BH	Aredaleka	426311	955728	112	5.9	10
BH	Bebelidebegna			124	0.5a.g.l	3.98
SW	Tulumangura(dula)	433018	971516	50	17.9	1.2
SW	Tulumangura(Guto)	434898	970823	50	25	0.7
SW	Tulumangura(birbo)	437385	971069	38.8	10	2
SW	Tulumangura(Tulu)	436085	973969	50	13	1.3
SW	WeserbiNedo 1	432515	970061	50	21	0.5
SW	Mende Tofisa 2	408563	953076	50	15.2	1.23
SW	Jato	426097	964927	60	23.6	1.5
BH	Tegeba	429167	944712	70		2.5
BH	Teji	430636	975971			5
BH	Awash bune	420444	965014	155		5
BH	Asgori	427126	971361	308	5	35

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