Water Balance and Groundwater Quality of Koraro Area, Tigray, Northern Ethiopia

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ABSTRACT

Achieving the Millennium Development Goals (MDG) has been given a paramount importance by both Regional and Federal Governments in Ethiopia. In this direction some stations in Hawzen Woreda, Tigray Regional state, extremely poor, have been selected as model areas to test the achievement of the MDG. This paper focuses Koraro Tabia (or Station), one of the millennium villages where shortage and bad quality water is a challenge. Water balance and the hydro chemical characteristics of groundwater have been investigated in order to assess the water potential and quality in the area. Hydrometeorological information has been used to calculate water balance parameters and the recharge amount. Accordingly, the mean annual rainfall, actual evapotranspiration, bare land evaporation, runoff and groundwater recharge was found to be 548.5 mm, 431.3 mm, 372 mm, 71.33mm and 56.7mm respectively. Twelve water samples were collected from hand dug wells and springs located in different lithologies and were tested for major anions, cations, and some trace metals in Ethiopian Geological Surveys Central Geological Laboratory. Mean electrical conductivity of water samples from different sources varies significantly. The mean electrical conductivity for the hand dug wells is found to be 5170 µS/cm and that of springs is 209 µS/cm. Piper diagram revealed that groundwater in the hand dug wells is of sodium sulfate type and spring water are calcium bicarbonate type. The results indicate that groundwater from the hand dug wells is of very poor quality with high salinity and sulfate content and does not fit for human consumption. Therefore, it is recommended to avoid water for drinking purpose from hand dug wells constructed in shale dominated areas and in the alluvial deposits underlain by shale. Moreover, groundwater recharge is also insufficient in the area due to the impervious shale unit. Hence, an adaptive management method is suggested for efficient use of water and a mechanism to isolate the bad quality water while trying to construct water supply scheme for drinking in the area.

Key words: Groundwater, Water balance, Water quality, Koraro, Ethiopia.

1. INTRODUCTION

Global fresh water demand is alarmingly increasing with increase in population and civilization. As industrial, agricultural and domestic pollution threaten existing supplies water will become increasingly precious resource.

Ethiopia surface water and groundwater resources have been regarded as high giving a name to the country as the water tower of east Africa (Said, 1993). This is factually true when considering half of the country, particularly the western and south western parts of the country. The endowment can be used for productive purpose that can transform the countries socio economy (Selashi, 2007). Unfortunately its uneven distribution in space and time coupled with poor management and development of the resource lead the country to a repeated famine resulting from drought (FAO, 2005).

The Tigray Regional State is situated in the northern part of Ethiopia, where drought and subsequent famine was common in the past. The study site, Koraro tabia which is found in the Tekeze basin, is characterized by intermittent rivers which are dry 8 to 9 months with arid and semi arid climatic condition. Koraro town is one of the millennium villages which are established in the year 2005. Surrounded by an arid landscape and set on eroded soil, the Millennium Village of Koraro, with a population of 55,000 faces an enormous challenge (Ngigi, 2009). Water availability for domestic use and irrigation was a major obstacle to development, in spite of two rivers running through the cluster of villages. The limited accessible water sources were unsafe for human consumption because of contamination. Sixty percent of the hand-dug wells were contaminated. The closest river was 2 to 4 km away from most homesteads. The flow of the streams was seasonal and communities had to rely on groundwater, accessed by scooping sand or digging holes in the dry riverbed. This traditional source often yields unsafe water due to contamination associated with poor sanitation (Ngigi, 2009).

The water supply for domestic use is entirely dependent on groundwater. Both the cattle and human population get water from the available groundwater resource which is not studied systematically. Moreover, the community has complained about the taste of water from the existing hand dug wells. These issues are addressed in this paper in terms of quantity and quality of groundwater, recharge from hydrological perspective, and suggest suitable viable options. To meet this objective a systematic study was carried out in the study area to 1) estimate available groundwater recharge using water balance method; 2) make a systematic hydrogeochemical investigation and 3) assess the water quality for drinking and irrigation purposes.

2. DESCRIPTION OF THE STUDY AREA

2.1 Location and Accessibility

The study area is located in the eastern zone of Tigray Regional State within Tekeze Basin (Figure 1). It is situated some 27 km south west of Hawzen town and covers an area of 58.9 km^2. The UTM location is between 1530000m-1537000m N to 527000m-533000m E. The area is accessed through dry weather road which runs from Hawzen through Megab westward.

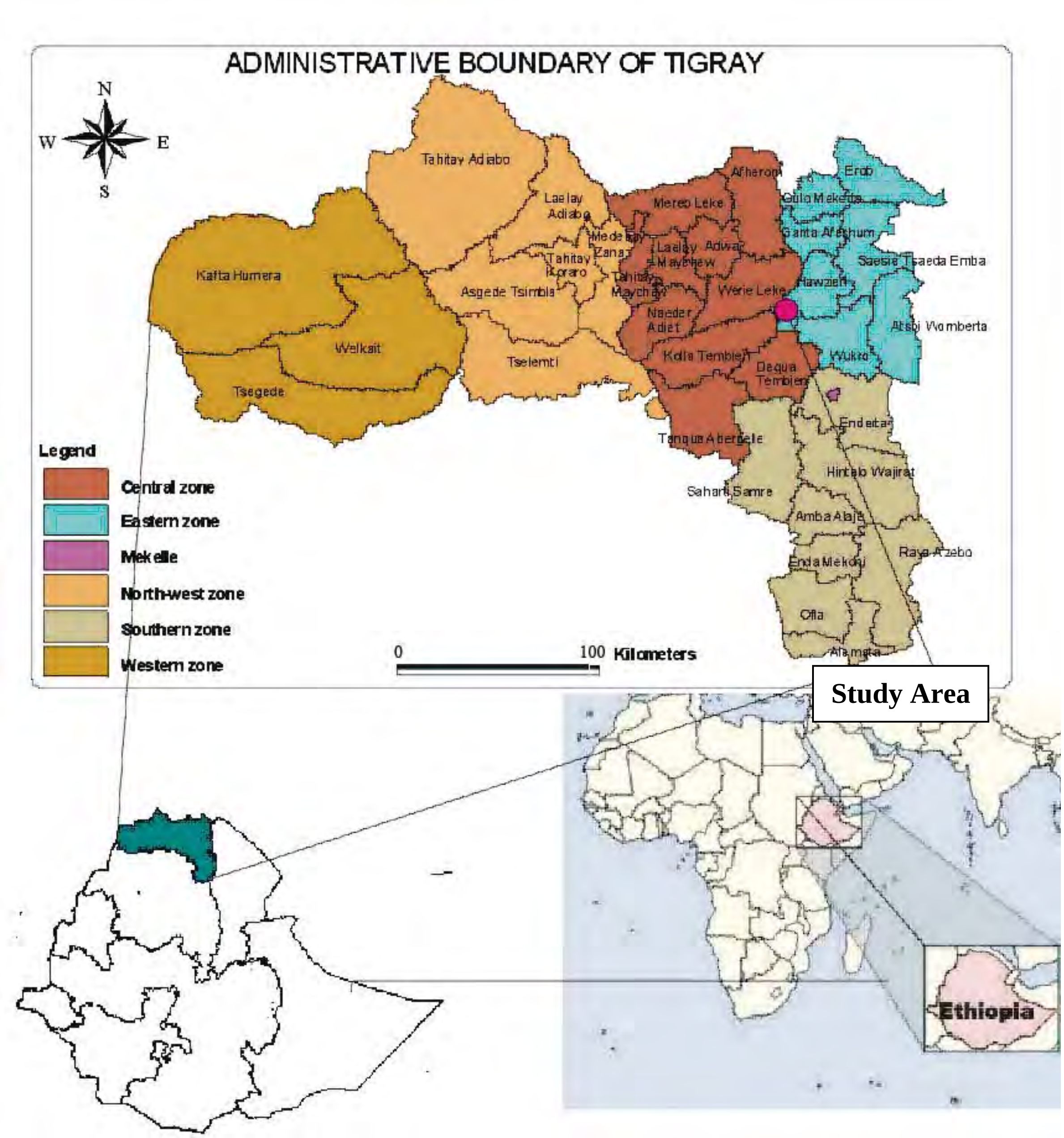

Figure 1. Location map of the study area (filled circle represents a study area).

2.2. Topography, Drainage, Land use and Land Cover

Topography expresses the physical features of a surface area including relative elevation and position of natural features. The area is characterized by a highly elevated land mainly composed of sandstone in southeast and east, and a relatively flat and lower elevation portion in the west and northwest (Figure 2). The highest and lowest elevation of the area is 2300m above sea level (a.s.l) and 1600m a.s.l, respectively (Figure 3). The catchments area has been categorized into three classes based on slope: area with gentle slope accounts for 40.2%, that of moderately steep (intermediate slope) 43% and steep slope 16.7%. The gentle slope land mostly dominate central part of the study area while, the steep and moderately steep slopes dominate the eastern and some part of the western area.

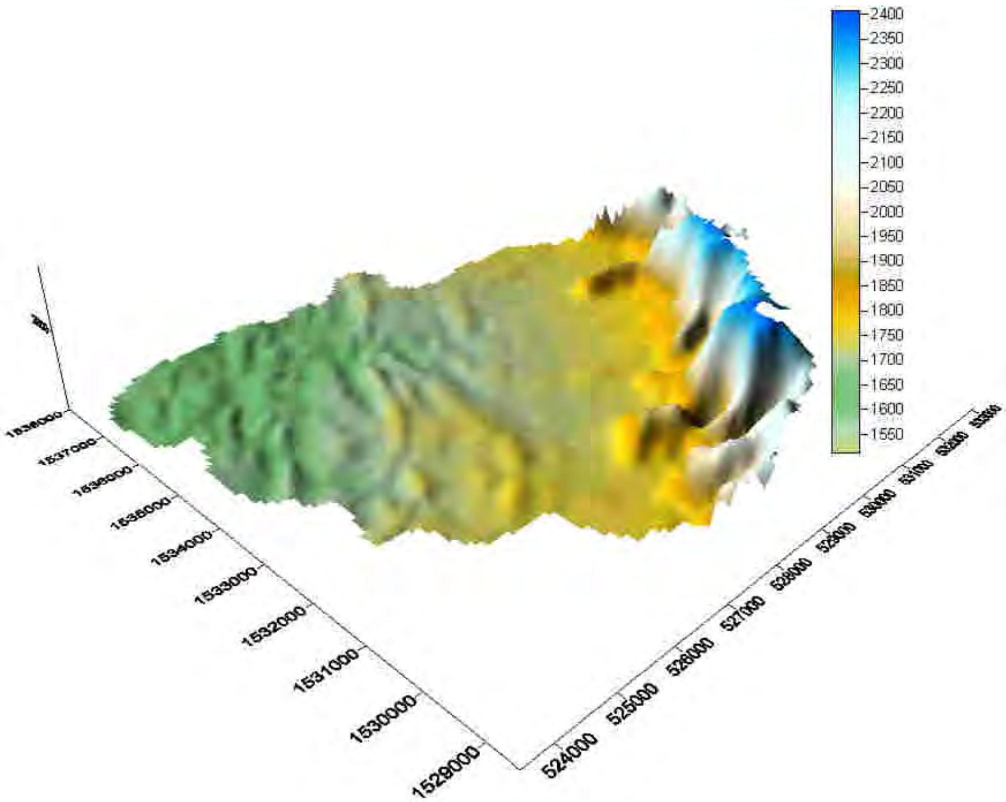

Figure 2. Digital Elevation Model of the study area.

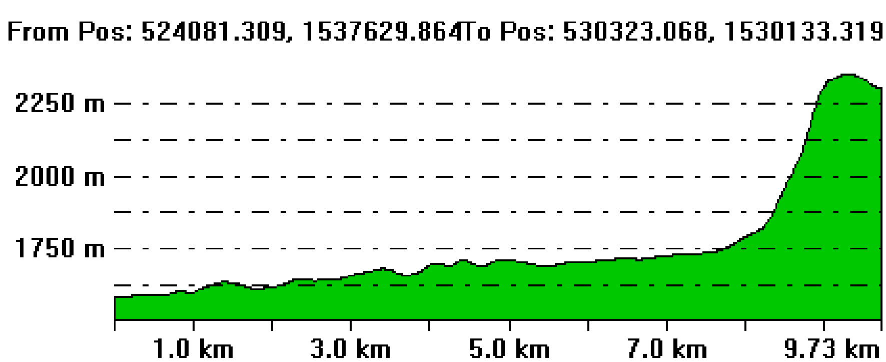

Figure 3. West - East topographic cross section of the study area.

The area portrays a dendritic drainage pattern with drainage density of 3 km/km^2 (Figure 4). The seasonal stream named as Tewulah has tributaries such as Tenseka, Dagbatat, Af Tsebib.

Land use is the manner in which human beings employ the land and resources. The land use and land cover of the area is grouped in to four divisions, namely cultivated about 43 %, Bushes and shrubs about 39%, bare land about 16% and settlement 2%.

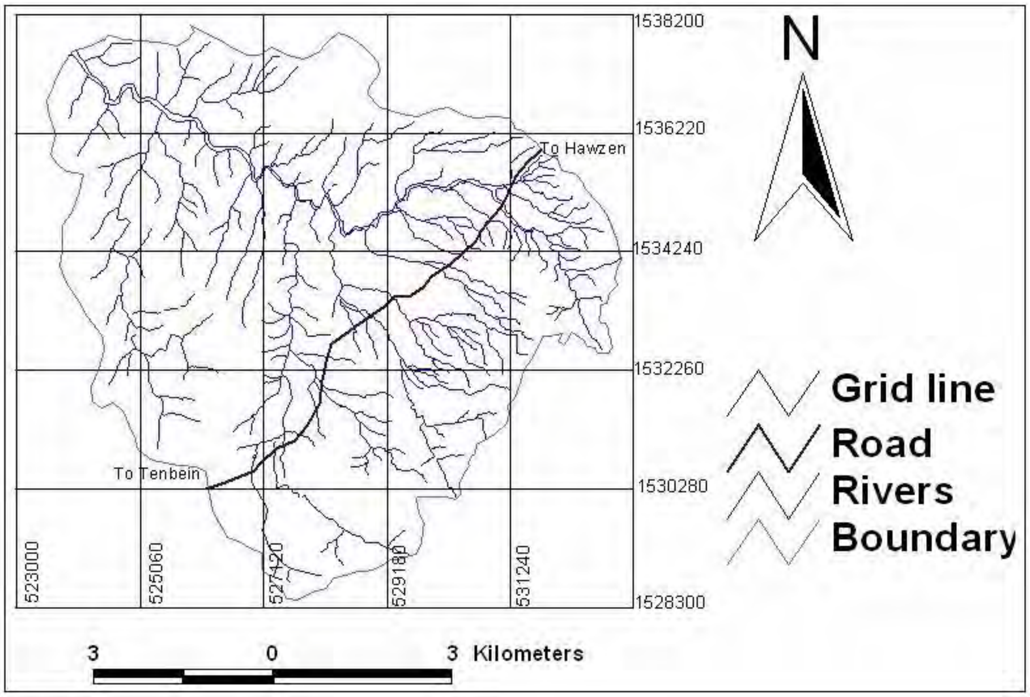

Figure 4. Drainage pattern of the study area.

2.3 Geological and Hydrogeological setting

The major lithological units in the study area are metavolcanics, tillites, sandstones and recent deposits (alluvial and colluvial). Stratigraphicaly, metavolcanic rocks are found at the base overlain by Edegarbi tillites and enticho sandstones. Moreover recent quaternary deposits with variable thickness are found overlying all these successions in the lowlands (Figure 5).

2.3.1 Metavolcanic rocks

The metvolcanic rocks cover most of the western half of the study area (41% of the surface area). The rocks are characterized by mafic composition with foliations, joints and fractures. These structural features facilitate recharge to the groundwater system in the area. The hydrogeological significance of this rock is mainly concentrated on areas which are highly weathered and with dense fracturing.

2.3.2 Tillites

The glacial deposit in the area is characterized by fine materials ranging from clay to silt with imbedded boulders. They are found in contact with the metavolcanics as small patches. This deposit accounts for 4% of the mapped area in the northeastern and southwestern parts. Because of the nature of the depositional environment the rocks are poorly sorted. Its significance as aquifer is low because of its low permeability but act as an aquitard as evidenced by the contact springs.

2.3.3 Sandstones

This Formation is mostly found at the mountainous area overlying the glacial deposit or the metavolcanics. Sandstone accounts for 20% of the mapped area and are found mainly on the eastern part of the area. Sandstones are characterized by reddish colure and cliff formation. The grain size ranges from fine to medium and are highly compacted. The sandstones are highly fractured and in some cases with a primary porosity. Most of the springs in the area emerge at the contact of the sandstone with the underlying tillite or metavolcanic rocks. Hydrogeologically the sandstones are the main recharge area for the springs developed for water supply in Koraro tabia.

2.3.4 Recent Deposits (Quaternary Deposits)

This unit occupied flat to gentle land and the deposits are transported from the surrounding hills by gravity and fluvial processes. Alluvial deposits are restricted to low lying areas close to river course. The sediments are made of clay and silt and, quartz rich sand with variable thickness. This unit covers most part of the central area with coverage of 35%. In some instances these deposits are found overlying layered thin siltstone, clay stone, thick mudstone intercalated with gypsum. The mudstones are largely exposed in the southwestern part of the study area which is around the newly established Koraro town. Hydrogeologically both the location and the lithology favors for groundwater resource development using shallow wells. Consequently, most of the hand dug wells are located in this area.

The Koraro village lies on glacial sediments which consist of mudstones and shales with some granite boulders exposed at places (Plate 1). And it is surrounded by rocks of metamorphic varieties towards the north and northwest; there are erosion remnants of sandstones on south and south east of the village.

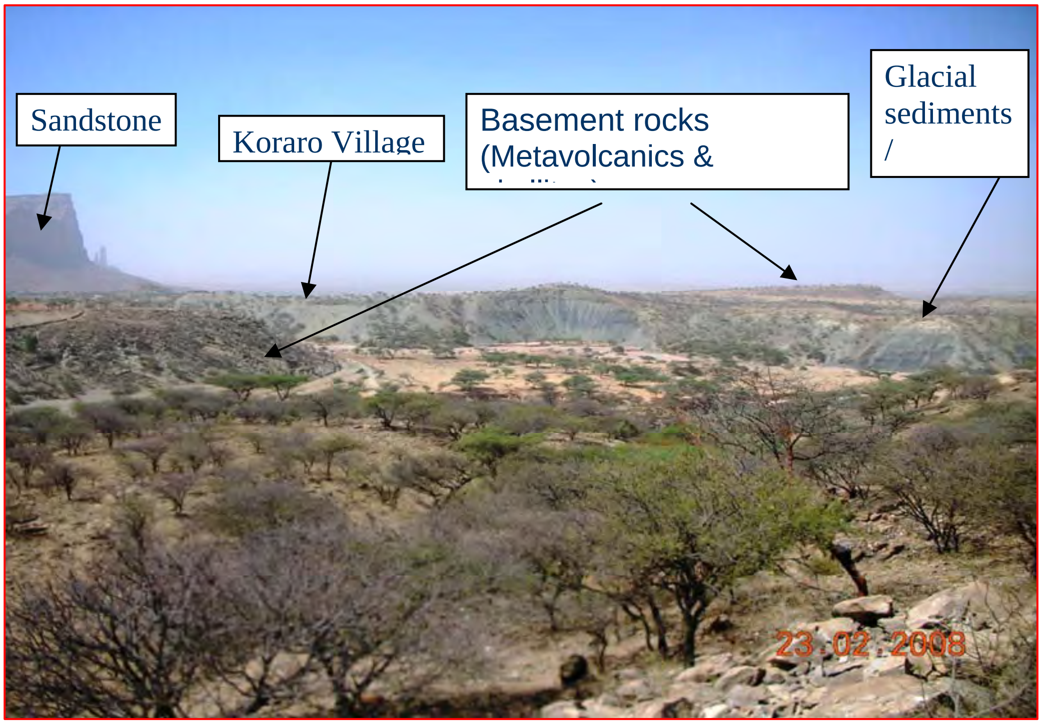

Plate 1. Photograph showing the lithologies present in and around Koraro Village.

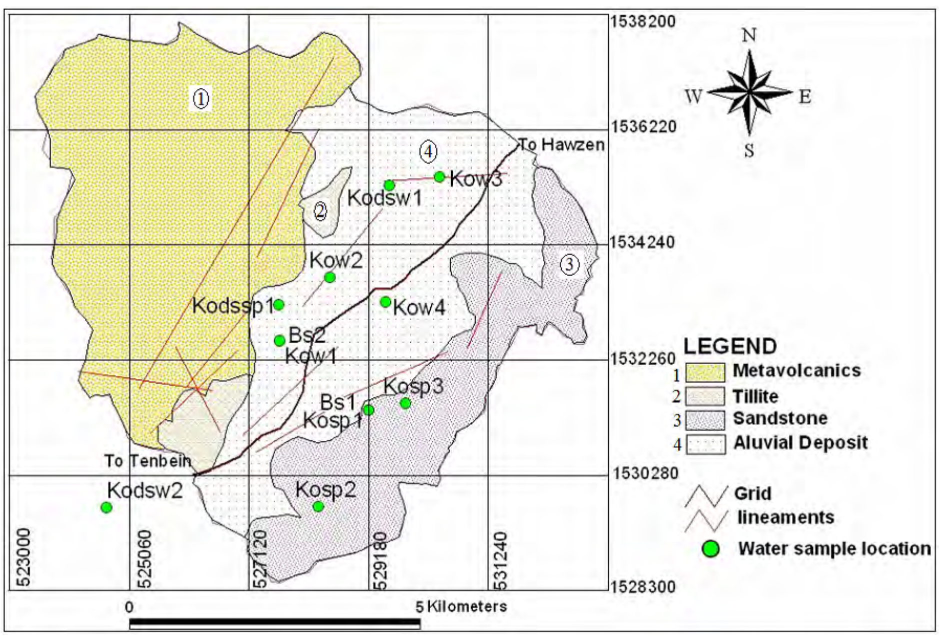

Figure 5. Geological map and water sample location.

3. METHODOLOGY

To achieve the above mentioned objective a desk work has been conducted on the available information, topographic maps, areal photographs and digital elevation model. Moreover, hydrometeorological data have been collected and analyzed to estimate groundwater recharge.

The potential evapotranspiration from vegetation covered area is estimated using Thornthwaite method where as the evaporation from bare soil is estimated by taking 20% of evaporation calculated using the Penman method. The actual evapotranspiration is calculated by applying the Thornthwaite and Mather method. The runoff is estimated using the rational method. The groundwater recharge is calculated by applying the soil moisture water balance method. Field measurement has been conducted on pH, Electrical Conductivity and Total Dissolved Solids. Twelve water samples were collected and analyzed for major ions and some trace metals at the Geological Survey laboratory, Addis Ababa. To verify accuracy of the analytical results duplicate samples were also collected from the same sample site and given to the laboratory.

The chemical data thus obtained was processed using Aquachem, ArcView and other relevant software.

4. RESULTS AND DISCUSSION

4.1 Water Balance

In order to estimate the water balance of a given hydrological basin each of the hydro-meteorological elements has been quantified. Accordingly, rainfall, actual evapotranspiration, runoff and groundwater recharge have been estimated.

4.1.1 Rainfall

In order to analyze the rainfall condition of the area sixteen years data were collected from Hawzen meteorological station (1992 – 2007). Accordingly, the total annual rainfall of the area was estimated to be 548.5mm (Table 1). The dry season are observed from September to June whereas the rainy seasons extend from June to September. A small rainy season is observed in otherwise dry season on the months of April and May.

4.1.2. Actual Evapotranspiration

In order to calculate the actual evapotranspiration, other meteorological elements such as temperature, humidity, wind speed and sunshine hours have been analyzed.

4.1.2.1. Temperature and Humidity

Six years temperature data were considered (2002-2007) for Hawzen station. Accordingly, the lowest mean monthly temperature (14.5 °C) is recorded in January and the highest mean monthly temperature is recorded in May (20.6 °C) (Table 1). The moisture content of air expressed in weight per unit of volume is called the absolute humidity. Relative humidity is used to characterize the area. Looking the values tabulated below the area is mainly characterized by a dry air except July and August (Table 1)

4.1.2.2. Wind speed

Wind speed has a strong influence on the rate of evaporation, and evapotranspiration. The wind speed from the Mekelle air port meteorological station has been used to evaluate the bare soil evaporation. The 12 year data of wind has been averaged as follows (Table 1).

4.1.2.3. Sunshine hour

Sunshine hour has a direct relationship with the solar radiation received on a certain area which in return has an impact on daily evaporation. The sunshine hours as recorded from Mekelle Station has been presented in Table 1.

Table 1. Monthly meteorological elements used for water balance calculation.

Month	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***July***	***Aug***	***Sept***	***Oct***	***Nov***	***Dec***
Rainfall (mm)	4	3.7	23.4	35.9	30.7	42.6	160.6	188.3	32.3	12.9	9.7	4.4
Mean Temp (^{o}C)	14.5	17	20	20	20.6	20.2	18	17.8	17.5	17	16.8	16.3
R.H (%)	43.8	38.2	39.7	39.8	37.1	39.8	68.6	74.3	49.5	42.9	44.7	42.5
Wind speed (m/s)	3.6	4.2	5.3	3.9	3	2.3	1.9	1.7	1.8	3.1	3.5	3.7
Daily Sunshine hour	9.67	9.9	8.2	9.1	9.73	7.2	5.5	5.3	7	9.6	9.9	9.7

4.1.2.4. Evapotranspiration (ET) from vegetation covered area

For the study area, potential evapotranspiration rate was evaluated using the Thornthwaite method. The mean monthly gross potential evapotranspiration is calculated for the basin (Table 2). Monthly variation of potential evapotranspiration (PET) indicates variation in monthly air temperature. As it can be seen from the table, highest monthly value of PET in the catchment area generally come just before the onset of rainy season. Based on this method the mean annual PET of the study area is 813 mm (Table 2).

Table 2. Estimated potential evapotranspiration in the study area.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Temperature	14.5	17	20	20	20.6	20.2	18	17.8	17.5	17	16.8	16.3
PET	45	60	80	80	85	82	66	65	63	60	59	55
Latitude correction	0.94	0.97	1.00	1.04	1.07	1.08	1.08	1.05	1.02	0.98	0.95	0.93
Corrected PET	42.3	58.2	80	83.2	90.95	88.56	71.28	68.25	64.26	58.8	56.05	51.15

The actual evapotranspiration is computed from the PET, precipitation and the soil moisture availability as presented by Thorentwaite and Mather (Thorenthwaite and Mather, 1957). The soil moisture availability is calculated from accumulated potential water loss and available water capacity. The available water capacity (AWC) has been computed from the vegetation type and soil type. Accordingly, the following combination of land cover and soil type has been recognized. Sandy loam with cereal crops with area coverage of 14.51 km^2, fine sand with cereals 10.79 km^2, bush and shrub with fine sand with an area of 22.93 km^2. Each combination has AWC value of 150, 75 and 100 respectively. Accordingly, the actual evapotranspiration of each land cover and soil type combination is calculated (Table 3). Considering all the land cover type and taking the weighted mean of the actual evapotranspiration in proportion to the area coverage the actual evapotranspiration has been found to be 431.3 mm per year for the vegetation covered area.

Table 3.Estimated actual evapotranspiration for the different land use and soil type combinations.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Area coverage(Km^2)
AET for AWC of 150	15	15	31	41	35	45	70	68	61	45	33	22	481	14.51
AET for AWC of 75	7	6	24	36	31	43	70	68	59	36	22	11	412	10.79
AET for AWC 100	10	9	26	37	32	43	70	68	60	40	27	15	437	22.93

4.1.2.6 Evaporation from bare land and settlement area

The evaporation from the bare land and settlement which accounts for 18% of the surface area coverage has been calculated using Penman method (Penman, 1948). Twenty percent of the Penman evaporation has been assumed to be the evaporation rate considering the lower amount of precipitation (548.5 mm/year) and a higher rate of runoff in the area (71.33 mm/year). Accordingly the evaporation from these areas has been assumed to be 0.2 *1860 mm = 372 mm per year.

4.1.3 Runoff

Estimating runoff from rain fall measurement is very much dependent on the time scale being considered. Due to absence of flow data in the area, the volume of runoff was determined by use of runoff coefficient method. Value of runoff coefficient for different types of land use is used in the calculation of runoff coefficient for the study area. The runoff coefficient (C) of the Koraro catchments with an area of 58.9 km^2 is determined to be 0.13. Accordingly the runoff has been found out to be 4.2MCM = (71.33 mm/year).

4.1.4 Water Balance Calculation

Water balance, is the relationship between the inflow water from precipitation and the out flow of water by evapotranspiration, groundwater recharge and stream flow. In the study area, the soil moisture water balance method has been used for the estimation of the natural ground water recharge of the area. Since the calculation is made on annual bases, net change in soil moisture storage is assumed to be zero. Moreover subsurface water exchange with neighboring basins is assumed to be zero.

Hence the water balance equation for the catchments area is simplified as follows.

P = AET + E + I +Q ---------------------------- (4.1)

Where

P: mean annual Precipitation on the basin; E: Evaporation from the bare land and settlement

AET: mean annual Actual Evapotranspiration from the basin

Q: mean annual Run off from the basin

I: Infiltration (recharge)

From the above budget equation the amount of water that infiltrate in to the catchment area as a ground water accretion was calculated.

I = P-(AET + E+Q) ------------------------------- (4.2)

I = 548.7mm/yr – ((431.3mm/yr*0.82)+(372 mm/yr *0.18)+(+ 71.33mm/yr)) = 56.7 mm/yr

From the above calculation the safe yield of the basin can be assumed to be 50 percent of the total estimated recharge which is 28.35mm/year or 1.67 MCM. Therefore, 1.67 MCM of groundwater can be safely abstracted with out adversely affecting the system.

4.2 Hydrochemistry

4.2.1 Accuracy of chemical analysis result

A total of 12 samples including the duplicates; KOW1, KODSSP1, KOW2, KOW4, KODSW2, KOW3, BS2 from hand dug wells, KOSP1. KOSP2, KOSP3, BS1 from springs and KODSW1 from river bed were collected from the study area on 3/14/2009 (Figure 6 and Tables 4, 5 & 6).

To evaluate the accuracy of the chemical analysis results three methods were used. First the values of the blind samples are compared to their twin. The error was found to be 0.02% and 0.08%. Secondly the balance between Cations and Anions measured by the Electro Neutrality has been examined and it has shown a value of less than 5 for 75 % of the samples the average Neutrality value was found to be 4.1 %.

$$Electro \cdots Neutrality = \frac{(sumcations - sumanions)}{(sumcations + sumanions)} \cdot 100 \quad \text{...........(4.3)}$$

Third technique used to check accuracy of chemical analysis is to compare calculated conductivity with measured electrical conductivity (EC) with the following relationship (C.A.J. Appelo et.al, 1996).

$$\sum anions = \sum cations(meq / l) = EC / 100(\mu s / cm) \quad \text{................(4.4)}$$

The error ranges from 0.006 % to 0.18%. Accordingly, the chemical analysis result was found to be good so further interpretation has been conducted from the analysis result.

4.2.2 General characteristics of the water samples from the study area

The field pH for the samples ranges from 6.89 in KOSP3 to 9.14 in KODSW2 with an average pH value of 7.6.

4.2.2.1 Water samples from the hand dug wells

Out of the 12 samples seven of them were collected from the area which is covered by thin Quaternary alluvial deposits underlain by the tillite intercalated with marl and shale. These samples are collected both from existing hand dug wells and shallow wells which are dug for the purpose of this investigation (Table 4.). The major geologic materials exposed in the wells are shale and marl units overlain by alluvial deposits. The electrical conductivity (EC) of most samples is more than 3000 μS/cm which makes them to be grouped as brackish water. In general, the samples were found to be dominated by sodium, sulfate and chloride (table 4, and figure 6).

The EC value ranges from 2650 µS/cm in KODSW2 to 6970 µS/cm in KOW1 with an average of 5170 µS/cm (Table 4). Among the cations the dominant element is sodium which ranges from 530 mg/l in KODSSP1 to 1280 mg/l in KOW2 with an average concentration of 786 mg/l. The next dominant cation is calcium followed by magnesium. The range of calcium is from 5 mg/l in KODSW2 to 370 mg/l in KOW1 and that of magnesium is from 0.9 mg/l in KODSW2 to 360 mg/l in KOW1. The average concentration of Ca^{+2} was found to be 176 mg/l where as that of Mg^{+2} was found to be 167 mg/l. Potassium ranges from 3 mg/l to 14 mg/l with an average concentration of 5.2 mg/l. Iron manganese, zinc and aluminum were also measured but their concentration was found to be insignificant. Among the anions the dominant ion was found to be Sulfate which ranges from 101 mg/l in (KODSW2) to 2671 mg/l in (KOW1), with an average concentration of 1424 mg/l. The next dominant anion is bicarbonate which ranges from 305 mg/l in KOW1 to 1149 mg/l in KODSW2 with an average concentration of 732 mg/l. Chloride is the third dominant anion in the area ranging from 137 mg/l in KODSW2 to 929 mg/l in KOW1 with an average concentration of 637 mg/l. Next to chloride the dominant anion was found to be nitrate which ranges from 0.4 mg/l in KOW4 to 35 mg/l in KOW1.

4.2.2.2 Samples from springs

Four water samples were collected from springs which emerge out from the sandstone formation which make up the cliffs in the south eastern parts of the study area. The samples are namely KOSP1, KOSP2, KOSP3, and BS1 (Table 5). The EC of all the samples in this terrain are less than 300 µS/cm indicating the water to be fresh in contrast to the other groups of water. The EC ranges from 170 µS/cm in KOSP1 to 256 µS/cm in KOSP2 with an average value of 209 µS/cm. The samples were found to be calcium bicarbonate type (Table 5 and Figure 6). The dominant cation is calcium and the concentration ranges from 21 mg/l in KOSP1 to 33 mg/l in KOSP3. Next to calcium, sodium is found to be abundant ranging in value from 6 mg/l in KOSP1 to 9 mg/l in KOSP3. Among the anions bicarbonate (HCO_3) was found to be the most abundant and ranges in concentration from 61 mg/l in KOSP1 to 107 mg/l in KOSP2 with an average concentration of 83.5 mg/l. Next to bicarbonate, sulfate was found to be abundant and ranges from 14 mg/l in KOSP1 to 34 mg/l in KOSP2 with an average concentration of 22 mg/l. Next to sulfate, chloride was found to be dominant with a concentration ranging from 12 mg/l in KOSP1 to 15 mg/l in KOSP2 with an average concentration of 14 mg/l. Next to chloride the dominant anion was found to be Nitrate it ranges from 1.4 mg/l in KOSP2 to 3.5 mg/ l in KOSP1.

4.2.2.3 Water Sample collected from a river bed sand deposit

One sample has been collected from the alluvial cover in a river bed in Tewlah river. The sample is labeled as KODSW1 (Table 6). The electrical conductivity of this sample was found to be 952 mg/l. The most abundant cation was found to be Calcium with 110 mg/l next to Calcium, Sodium was found to be most abundant with 50 mg/l. The most abundant anion was found to be HCO3 with a concentration of 295 mg/l followed by sulfate with a concentration of 107 mg/l.

4.2.3 Total Hardness of the water samples

Analytical hardness is calculated using the following formula: $H = 2.5Ca + 4.1Mg$ --- (4.5)

Accordingly the hardness was found to range from 470 to 2406 in the hand dug wells and from 64.8 to 107.12 in the springs. There is a clear distinction of the water samples from the hand dug well and the springs.

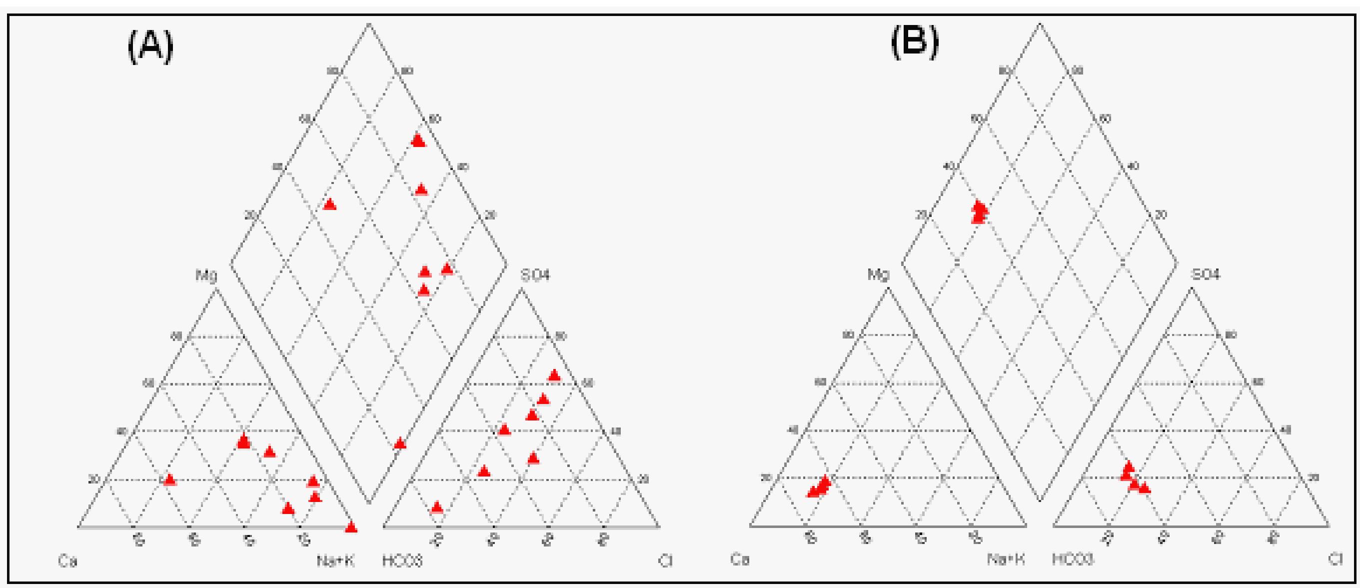

Figure 6. Piper plot for water samples A) hand dug well, B) Spring samples**.**

Sample ID	Type	UTME	UTMN	pH	EC	TDS	Na	K	Ca	Mg	F	Cl	B	HCO3	NO3	SO4	SiO2
		m	m		uS/cm	mg/l											
Bs2	Na-Mg-Ca-SO4-Cl	527646	1532585	7.68	7040	5630	830	3	380	390	1.2	944	<0.17	329	36	2666	25
Kodssp1	Na-Mg-SO4-Cl	527630	1533202	7.93	4270	3230	530	14	130	170	1.3	563	4.1	468	0.16	1311	19
Kodsw2	Na-HCO3	524675	1529716	9.14	2650	2173	575	2	5	0.9	9.5	137	0.68	1149	<0.04	101	36
Kow2	Na-SO4-Cl-HCO3	528517	1533677	7.17	6630	5058	1280	3	110	110	1.3	797	1.2	1000	14	1673	34
Kow1	Na-Mg-Ca-SO4-Cl	527646	1532585	7.71	6970	5536	810	3	370	360	1.2	929	0.77	305	35.4	2671	25
Kow3	Na-SO4-HCO3-Cl	530409	1535405	8.13	3680	2839	660	3	40	90	4.1	335	8.7	864	0.53	795	19
Kow4	Na-Cl-HCO3-SO4	529469	1533245	7.35	4950	3659	820	6.2	200	50	0.53	755	4.5	1013	0.41	749	30
Average				7.87	5170	4018	786.4	4.9	176	167	2.73	637	3.325	732.6	14.42	1424	26.9

Table 4. Chemical analysis results and water types of samples collected from hand dug wells.

Sample ID	Water Type	UTME	UTMN	pH	EC	TDS	Na	K	Ca	Mg	F	Cl	B	HCO3	NO3	SO4	SiO2
		m	m		uS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Bs1	Ca-HCO3-Cl	529160	1532221	7.16	170	144.41	6	1	21	3.4	0.14	15	<0.17	61	3.5	13	10
Kosp1	Ca-HCO3-Cl	529160	1532221	7.07	169	142.61	6	0.6	21	3	0.14	12	<0.17	62	3.5	14	10
Kosp2	Ca-HCO3-SO4	528328	1529731	7.35	239	223.02	7	2	32	4	0.23	15	<0.17	107	1.4	34	8
Kosp3	Ca-HCO3-SO4	529810	1531505	6.89	256	223.02	9	3	33	6	0.25	15	<0.17	104	2.4	28	11
Average				7.1	209	183.3	7	1.7	27	4.1	0.2	14		83.5	2.7	22	9.8

Table 5. Chemical analysis results and water types of samples collected from springs.

Sample ID	***Water Type***	***UTME***	***UTMN***	***pH***	***EC***	***TDS***	***Na***	***K***	***Ca***	***Mg***	***F***	***Cl***	***B***	***HCO3***	***NO3***	***SO4***	***SiO2***
		m	***m***		***uS/cm***	***mg/l***	***mg/l***										
Kodsw1	Ca-Na-Mg-HCO3-Cl-SO4	529537	1535253	7.64	952	713.77	50	3	110	24	1.3	83	<0.17	295	4.1	107	18

Table 6. Chemical analysis result and water type of sample collected from river bed sand.

4.3 Water Quality

4.3.1 Drinking Water Quality

In general, the spring water samples have excellent quality where as the hand dug wells have very poor quality as per the World Health Organization recommendation. In the hand dug wells boron ranges from 0.68 mg/l to 8.7 mg/l which is well beyond the recommended value 0.3 mg/l MoWR (2002). Long term exposure to high boron concentration will lead to gastrointestinal irritation. Chloride is found to be more than the guideline value, 533 mg/l in most of the hand dug wells resulting in undesirable test. Sodium concentration in the hand dug well ranges from 530 mg/l to 1280 mg/l. The guideline value of MoWR is 358 mg/l. Therefore the concentration is way beyond the standard. High sodium in general results undesirable taste. Sulphate in the hand dug well ranges from 795 mg/l to 2671 mg/l this is much higher than the guideline value which is 483 mg/l. Normally high sulphate concentration results in noticeable taste.

4.3.2 Irrigation Water Quality

The concentration and composition of dissolved constituents in water determine its quality for irrigation use. The characteristics of an irrigation water that appear to be most important in determining its quality are: (1) total concentration of soluble salts (2) relative proportion of sodium to other cations (3) concentration of boron or other elements that may be toxic (United States Salinity Laboratory Staff, 1954). The effect of total dissolved solids could be safely appraised using electrical conductivity. Accordingly, water with less than 750 µs/cm is satisfactory for irrigation, waters in ranges of 750 µS/cm to 2250 µS/cm are widely used, and satisfactory crop growth is obtained under good management and favourable drainage conditions, but saline conditions will develop if leaching and drainage are inadequate. Use of waters with conductivity values > 2,250 µS/cm is the exception and very few instances can be cited where such waters have been used successfully used (United States Salinity Laboratory Staff, 1954). The conductivity of the waters in the hand dug well ranges from 2650 µS/cm to 6970 µS/cm. Therefore, the hand dug wells were found unsuitable for irrigation purpose.

Sodium occurs in almost all irrigation water. It is the most injurious of the major cations. The danger of high sodium water in irrigation agriculture is examined using sodium adsorption ratio (SAR). SAR value between 2 and 10 indicates little danger from sodium; between 7 and 18 medium hazard; highly hazardous between 11 and 26 and very highly hazardous above 26

(Fetter, 2001). Most of the hand dug wells has a SAR value greater than 11 coupled with high salinity. This make the water in most of the hand dug well to be highly hazardous.

Boron is a constituent of practically all natural waters, the concentration varying from traces to several parts per million. It is essential to plant growth, but exceedingly toxic at concentrations only slightly above optimum. In the study area, most of the hand dug wells were found to have a concentration above 1ppm indicating to be the waters highly hazardous.

4.3.3. Classification of Irrigation Waters

The irrigation water classification of samples in the US Salinity Laboratory diagram is given in the following figure (Wilcox, 1955). All the hand dug wells are found to be very high salinity and very high sodium water which renders them to be unsuitable for irrigation. The spring waters are excellent for irrigation (Figure 7).

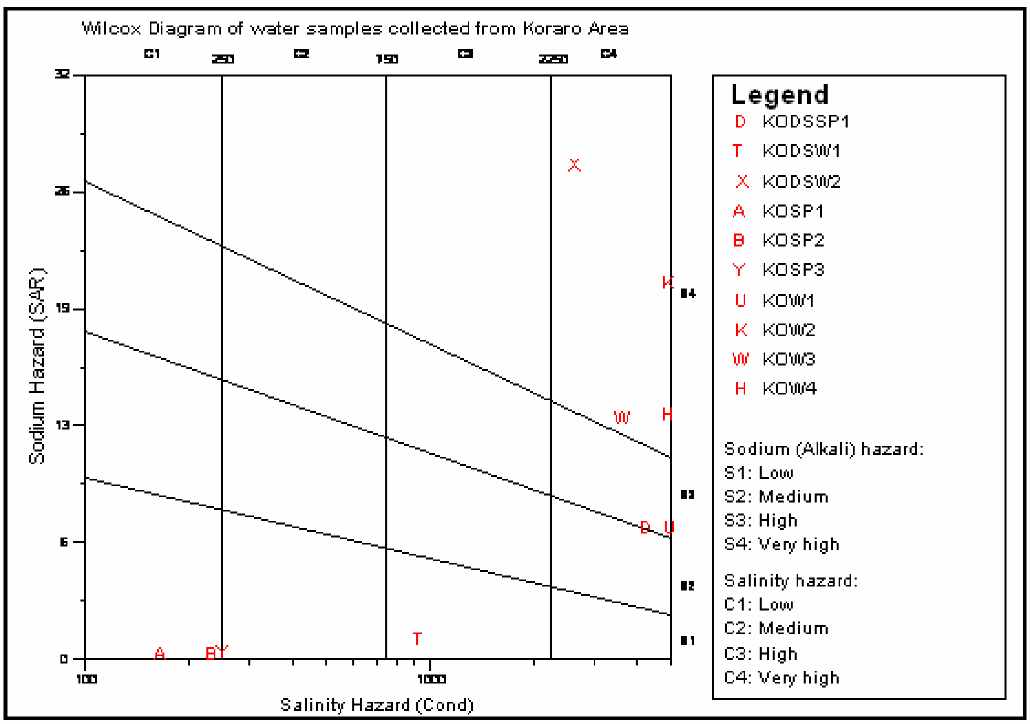

Figure 7. Wilcox diagram for irrigation water classification, Koraro area (Note: Electrical conductivity of some samples which were more than 5000 µs/cm has been reduced to 5000 µs/cm only for the purpose of plotting.

5. CONCLUSIONS

As per the finding of this work, the groundwater recharge is low. It accounts only 10% of the precipitation. This is mainly because of the high evapotranspiration rate, and low permeability of the surface materials associated with high temperature and lower humidity. The groundwater quality from the hand dug wells dug in the shale are extremely poor both for drinking and irrigation purpose where as that of springs is excellent.

The development of the Koraro village as a successful millennium village depends completely on the wise utilisation of the existing water in a more efficient way. Therefore, one should make every effort possible to increase the groundwater recharge through different artificial recharge mechanism. Moreover groundwater development should avoid the shale unit as much as possible when water is sought for drinking or irrigation. The subsurface and sand storage dam constructed is a good example of both increasing the recharge and avoiding the bad quality water.

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