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A detailed water budget assessment of surface and subsurface water and its environments of Wama Catchments, East Wollega zone of Oromia region, Western Ethiopia.

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NAME OF THE AUTHOR(s)

***Dr. Shayaq Ali[1]**
Lalisa Asefa Mekonin[2]

[1]Professor, Department of Earth Sciences, Wollega University, P.O Box 395, Nekemte, Ethiopia

[2]Lecturer, Department of Earth Sciences, Wollega University, P.O Box 395, Nekemte, Ethiopia

ABSTRACT

This study aims to evaluate the environmental contamination assessment of surface and subsurface water characteristic of the Wama catchment based on hydro meteorological and hydro geochemical data analysis. The study area is located in southern parts of Abay river basin, Upper part of Didessa sub basin, and bounded between $8^0$24′0″N-$9^0$0′0″N latitude and $36^0$24′0″E- $37^0$24′0″E longitude. It is characterized by highly rugged topography, dendritic drainage pattern, and tropical to sub-tropical climate condition.

Assessment of surface and groundwater of the catchment is studied based on conventional techniques, by gathering and interpreting hydro meteorological and hydro geochemical data. from long term mean monthly rainfall data, annual precipitation of the catchment is calculated as 1715 mm/ year. The PET value obtained by Penman method is estimated to be1059.1 mm/yr and used in the calculation of AET by Soil water balance. Potential evapotranspiration (PET) is estimated by using two approaches namely, Thornthwaite and Penman combination methods. Those methods gave 864.7 mm/yr and 1059.1mm/yr respectively. Thornthwaite method underestimates the value most probably because it relies on mean monthly temperature and sunshine hour.The groundwater recharge estimated from water balance method and chloride mass balance method were 481mm/year and 204mm/year respectively. The Actual Evapotranspiration (AET) was calculated using Turc method and Soil water balance method. The AET values obtained from these methods is found to be 717mm/year and 860mm/year respectively. During study the annual mean rainfall calculated by Arithmetic is 1453mm.

The study has computed evapotranspiration using Turc method and obtained 944.6mm/yr. The annual groundwater recharge estimated by applying both base flow separation and water balance technique was 196.6mm and 297.5mm respectively. Many borehole drilled around dam site with maximum depth of 92m revealed that fresh fractured and weathered trachyte basalt dominate the investigated area The fractured and weathered volcanic rocks are the main water bearing unit in the catchment. From the existing borehole data, the higher values of discharge, hydraulic conductivity and transmissivity zones are mapped at or near fractured regions.

KEYWORDS: Assessment, Geochemical, Groundwater, evaporation, Precipitation, Surface water

CITATION OF THE ARTICLE

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** Corresponding Author*

I. INTRODUCTION

The demand for groundwater in the catchment area is increasing at an alarming rate with the fast growth of population. Climatic change which affects the components of hydrologic cycle has greatly resulted in lowering of water table, which also enhance demand of water supply.In some places, the drainages may be fully controlled by the presence of minor and major structures like joints, faults and lineaments. Such zones are good and potential zones for groundwater exploration. Ground Water is important natural resource for living things to exist on the earth and it is a backbone of civilization. The resource is used for irrigation, industries, and domestic purpose. It is also one of major source, which contributed a lot to the world water demand. Ground water is precious and most widely distributed resource of earth and unlike any other mineral resource it gets in annual replenishment from meteoric precipitation. At the present one fifth of all water used in world is obtained from the ground resource (Fetter, 2001).Ground water plays important role in Ethiopia as a major source of water for domestic uses, industrial and Agricultural uses. Lack of professional and public awareness about the sustainable use of ground water resource made gaps in ground water management.

There is rising of population number in and around the catchment which in turn requires adequate quantity and quality of water. Currently, in addition to large scale irrigation of sugar cane plantation for Wama, there is newly irrigation scheme of earth dam now on construction progress nearby Wama river confluence. Despite water requirement is increasing very rapidly with the growth of human population and irrigation in the area, there is no significant research conducted to know the groundwater resources. On the basis of this concept, this study is proposed to give some detail picture on groundwater characteristics by applying meteorological and hydro geochemical methods to come up with reasonable result with respect to the potentialities of the resource.

GSE (2014) produced hydro geological and geological map of Arjo area at scale of 1:250,000. This study confirmed the presence of different rock unit (metamorphic, sedimentary, volcanic and recent deposit) in the area. The annual rainfall was estimated using arithmetic method and obtained value is 1848 mm. The geology of Nekemte area (NC 37- 9) is compiled by Solomon Gera and Mulugeta Hailemariam, 2000 (Geological Survey of Ethiopia). Detailed geologic description is forwarded by this work. The geological map of study area is presented by (GSE, 2003) at 1:250,000 scale.

II. LOCATION OF STUDY AREA

2.1 Location and Accessibility

The study area, Wama Catchement, which is the major tributary of Upper Didessa, is bounded between 36^0 24′ 0″E to 37^0 24′ 0″E longitudes and $8^0$24′0″N to 09^0 0′ 0″N latitude, and is located in the East Wollega zone of Oromia region, Western Ethiopia. It is situated at about 281km west of Addis Ababa and it includes major parts of Nekemte town which is the capital city of East Wollega Zone. The area which has a total area of 3385.5km^2 is accessible through Addis Ababa → Ambo → Nekemte asphalt road. Weather and seasonal gravel roads which connects different town of woreda are also available in the catchment.

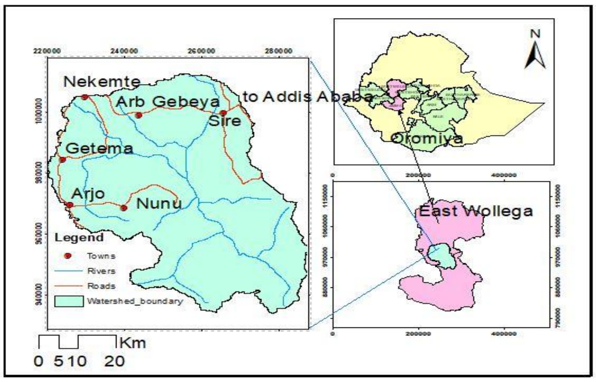

Figure 0. 1Location map of the study area

2.2 Climate

Climate of Wama catchment varies from tropical to subtropical climatic condition. The variation is largely a function of altitude and vegetation cover. The mean annual rainfall is from 1,040.6 mm/year around Agelo area to 2,480 mm/year around Dereba. The catchment is characterized by unimodal rainfall pattern and rainy season is from April to October (Figure 2.2).

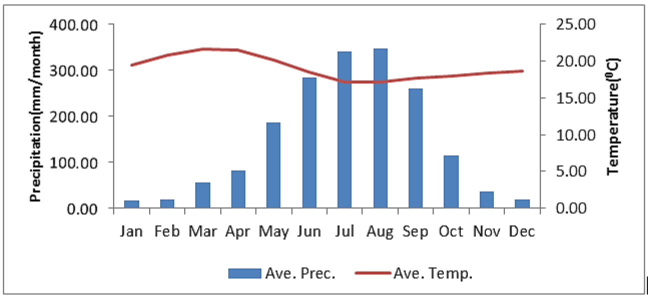

Figure 0.2 Monthly temperature and rainfall of the catchment

On the basis of rainfall distribution, climate of the study area can be categorized into two broad seasons; the dry season (winter) and the wet season (summer) with autumn and spring receiving a small amount of rain. The catchment has annual mean temperature of 19.23^{o}C. The maximum temperature was recorded in the months of March and April while minimum temperature was recorded in the month of September. Generally study area has high temperature during dry season and low temperature in rainy season.

2.3. Physiography

The present geomorphology of the area is the result of volcano-tectonic activities that occurred in the past with slight modification by recent deposition in low lying area. The catchment is known by its extensive tertiary volcanism which gave rise to the peculiar geomorphology of volcanic environments to the area. Such that it is mountainous, highly rugged and dissected topography with steep slope while the valley floor with flat to gentle slopes characterizes the lower part of the catchment particularly around Wama Adare area and adjacent to the area, Arjo Didessa. As the result a number of streams emerged from either side of the bisected plateau feed the Wama River.

Generally study area is rugged terrain with deeply cut and dissected morphology with undulating topography and flat plain with variable slopes. The elevation of the study area is varies from around 1,300 m.a.s.l. to more than 3,100 m.a.s.l.

In general study area consists of the following land forms:

- ✓ Mountainous volcanic plateau with uneven surface.
- ✓ Low plateau with moderate to high relief hills and flat top ridge.
- ✓ Plains occupied by recent deposits and undulating land forms.

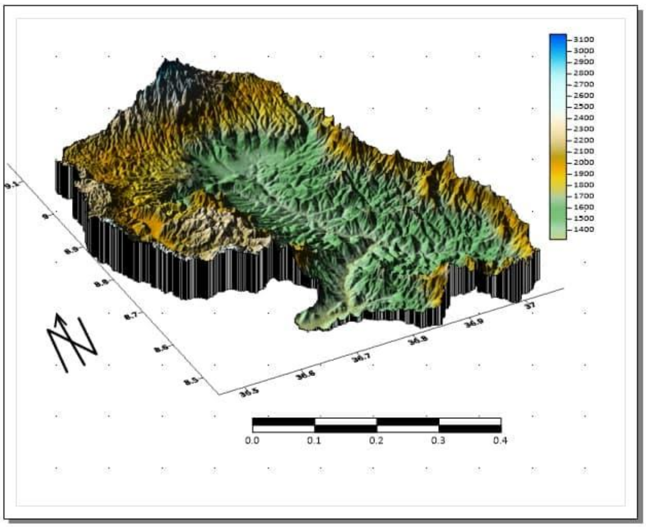

Figure 0.3 Physiographic map of the study area

2.4. Drainage

Drainage is a reflection of slope, relief, geology, geomorphology and structures. It is the spatial arrangement of streams and is, in general, very characteristic of rock structure and litho logy (Singhal and Gupta, 2010).From the northern, Negeso and Indris, and another river from the southern are some of the major tributaries which drain to the southwest and form Wama River, following the regional topography.

Wama catchment is extensive drainage system arising from mountain Komto, Getema-Arjo highlands, Mote, Atnango and Komarigde. The streams networks of study area commonly show dense dendritic drainage pattern in the upstream areas and sub parallel pattern in the down course indicating homogeneous and mountainous relief with more dissected nature. Tributaries feeding Wama River have flow in three major trends: NE-SW, N-S, and NW -SE. Drainage is relatively denser in northern and northwestern part of the catchment area.

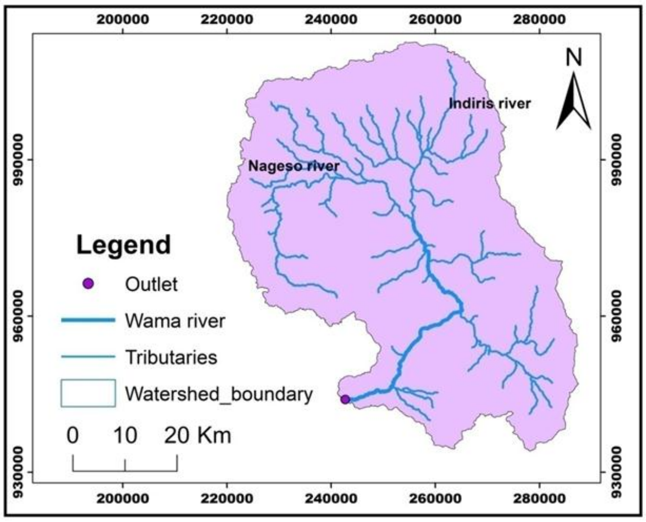

Figure 0.4 Drainage map of study area

2.5. Soil

Soil reflects the basic climatic conditions of the area, as well as the regional and site specific geological and geomorphological characteristics. Soil type distribution and characteristics depends on variation in geology, topographic setting, slope gradient, climatic conditions, land use land cover and agricultural practices**.** Soils derived from coarse grained rocks inherit a coarse texture, whereas those derived from fine grained rocks are characterized by a fine texture. This indicates that soils resemble their origin.

The hydrology of the soil is dependent on every attributes of soil properties. Soil stores rainwater in its pores before it infiltrates to greater depths and recharges the aquifer system. Water stored in thin soils evaporated directly before feeding the aquifer. Soil water that is stored in thick layers either join saturated zone or absorbed by vegetation roots and then transpires to atmosphere. The ability of soil to store and transport water is controlled by soil texture, soil structure and soil moisture content. Therefore, amount of evapotranspiration is different for every soil type.

Deeper soil has a larger soil moisture reserve than thinner soil, which can supply more water to evaporate. Hence, soil has sound role in determining hydrogeology of the area. According to the soil map adopted from food and agricultural organization, study area is covered by two types of soil texture called loam and clay. Along the river flood plains (i.e., Wama and its main tributaries Indiris, and Nageso), clay is the dominant texture. The left parts of the catchment are covered by loam.

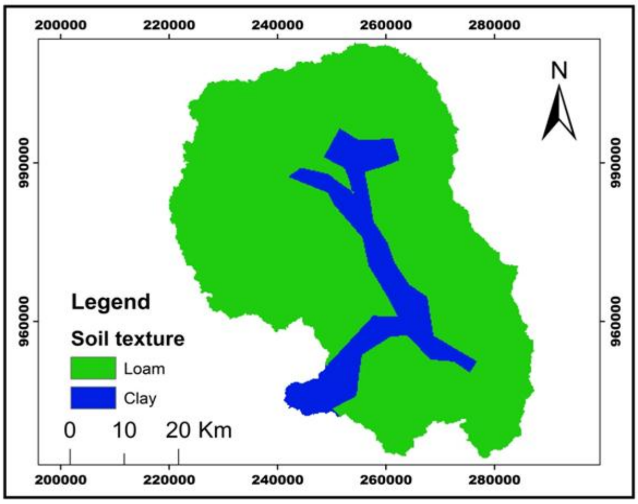

Figure 0.5 Soil map the study area

2.6. Land use/Land cover (LULC)

Majority of the catchment is generally used for agricultural purpose, including perennial and seasonal crops plantation, residence and grazing land. The major farming system prevailed around the catchment is the mixed farming system of annual and perennial crop production and livestock husbandry. Major crops grown include maize, sorghum, teff, coffee, barley, peas and bean. All crops are grown under rain fed conditions, mostly in one main season (May to October). The Arjo-Didessa and Wama irrigation for sugar factory is under perennial crop cover which is dominated by sugar cane plantation. The irrigation uses high amount of water from Wama River throughout the year except the rainy months. Farmers commonly use fertilizers of different types (DIAP and UREA) from farm to farm. Herbicide, Insecticides & fungicides are also another popular chemical applied to the crops.

Vegetation cover play important role in minimizing water loss through surface run off and increasing infiltration of water to soil and to ground water table. Major natural vegetation's found in the catchment are bushy wood land, shrubs, open woodland, natural forest, coffee, forest plantation, woodland and Elephant grasses. Riverine trees and vegetation's are also dominant along the course of main rivers; Indris, Nageso and Wama. The catchment was highly vegetated area in the past but recently because of increased farmland arose from population pressure, the species and types of vegetation's are decreased. Moreover, the high demand of wood for fire, charcoal and construction material has highly intensified the deforestation.

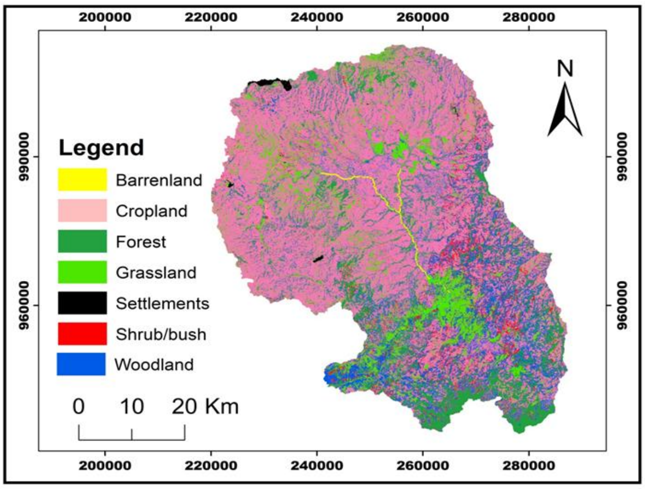

Figure 0.6 Land use/Land cover map of the study area

III. METHODS & MATERIALS

Hydrometeorology is a science which links hydrology and meteorology. It studies the hydrological cycle which involve processes in the atmosphere and at the earth's surface (Shaw, 1994). The most useful hydro meteorological elements are precipitation, wind speed, evapotranspiration, sunshine hours, humidity, and air temperature. The main objectives of analyzing hydro meteorological data is to determine evapotranspiration whose result is further used to calculate water balance of the catchment which in turn help for developing and managing its water resource through determining recharge.

For the analysis of various components of hydrologic cycle long term meteorological data have been obtained from Ethiopian National Meteorological Agency (ENMA). Totally there are 14metrological stations within and in the vicinity of the study area. Among them, 6 stations are principal station while remaining are ordinary stations. More information about meteorological data and meteorological stations location.

IV. HYDROMETEOROLOGY

4.1 Sunshine

The length of Sunshine hour and intensity varies depending on altitude, cloud, vegetation and variation of seasons which are responsible for absorption, scattering and reflection of incoming solar radiation. Sunshine hour has direct relationship with evapotranspiration. In the study area there are seven stations with available sunshine hour record. The data shows seasonal variation in relation to weather condition. The computed value increases from minimum (3.11) in July to the maximum (8.22) in December (Table 4.1). During rainy season atmosphere is usually unclear because of fog and cloud cover so that only little time is available for sunshine to reach surface. As a result, study area get high sunshine hour in dry season when sky is clear and become low in extreme rainy (Kiremt) months. The area has mean monthly sunshine hour value of 6.37.

Table 0.1 Long term mean monthly sunshine hours of the study area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	7.48	7.85	7.5	7.49	7.08	6.2	4.7	4.9	6.63	7.7	7.69	7.53	6.7

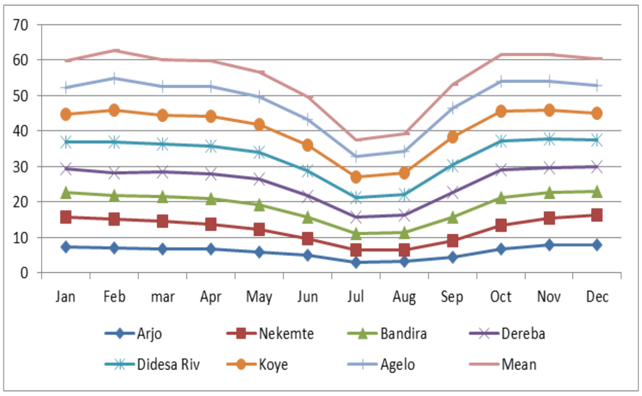

Figure 0.1 Mean monthly sunshine hour for available stations in the study area

4.2 Wind speed

Wind speed is about the fastness and slowness of the air movements controlled by pressure. The movement of air and moisture transfer depends on wind speed and turbulence. The decrease in wind speed results in a decrease in the rate of evaporation because the saturated vapor above the surface could not be removed instantaneously.

The wind speed data measured at height of 2 m above the ground level obtained from six stations (Arjo, Bandira and Dereba, Koye, Agelo and Didessa River) show spatial variation. Higher wind speed is recorded in Arjo and Dereba while Koye show low wind speed record relative to them. This variation is directly linked with the topographic altitude of the stations as Arjo and Dereba are highly elevated area of the catchment and tend to have high speedy wind than the others. The wind speeds in the catchment become high at the beginning of the spring season rain.

This is a usual phenomenon in western region of the country at the early start of rainy season. During this time, moisture carrying wind from different direction commonly the westerly trade wind blows highly toward the study area to bring the spring rainfall. It is these months when catchment experience its maximum wind speed. But it slowly decreases as spring ends and close to summer rain. In general, the mean monthly wind speed of the area varies from 0.88 m/s in November to 1.26 m/s in April with average value of 1.07 m/s. The mean monthly wind speed of available stations.

Table 0.2 Long term mean monthly wind speed (m/s) at 2 m above ground of the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Arjo	1.38	1.57	1.67	1.79	1.72	1.59	1.59	1.49	1.26	1.15	1.1	1.15	1.45
Didesa River	1.44	1.56	1.65	1.74	1.63	1.3	1.15	1.1	1.17	1.4	1.43	1.42	1.41
Bandira	1.38	1.48	1.56	1.67	1.6	1.3	1.2	1.1	1.16	1.4	1.45	1.4	1.39
Dereba	1.53	1.59	1.62	1.61	1.55	1.35	1.2	1.13	1.2	1.5	1.6	1.57	1.45
Koye	1.32	1.42	1.5	1.5	1.4	1.2	1.07	1.02	1.08	1.26	1.3	1.29	1.28
Agelo	1.67	1.76	1.77	1.68	1.53	1.3	1.16	1.12	1.21	1.49	1.6	1.64	1.49
Mean	1.45	1.56	1.62	1.67	1.57	1.34	1.23	1.16	1.18	1.36	1.4	1.41	1.41

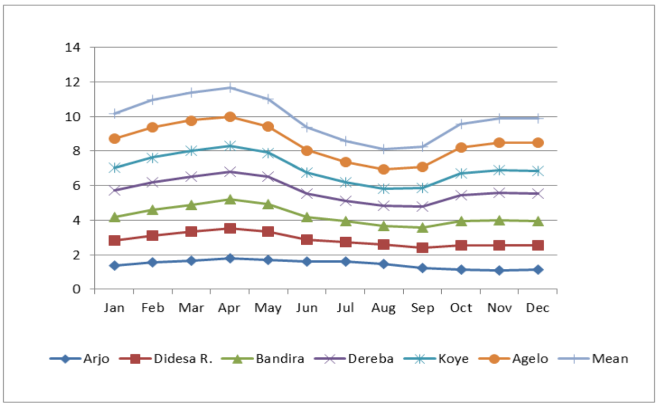

Figure 0.2 Mean monthly wind speed.

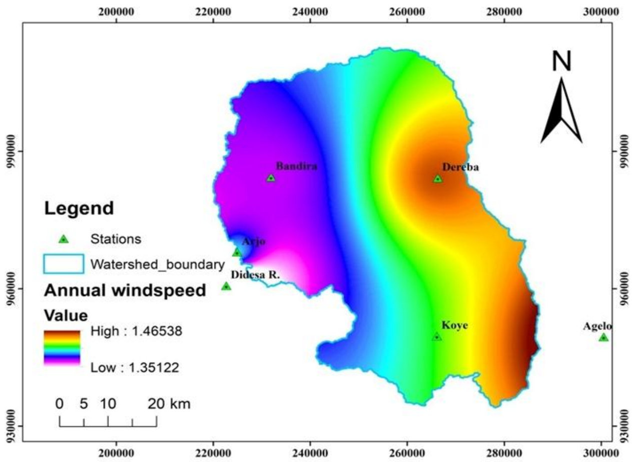

Figure 0.3 Annual wind speed (m/s) map

4.3 Temperature

Temperature governs the rate at which water molecules leave evaporating surface and enter the overlying air as water vapor. It is one of the hydro meteorological variables that actively affect water resource. Area with high temperature has low amount of water for recharge than area with less temperature because water lost to vapor rapidly before percolation.

The water stored in a surface pond as well as in soil (unsaturated) zone gradually feed the groundwater system but high temperature lead to evaporation at rate higher than recharge. In high temperature condition, vegetation absorbs more amount of water through root zone and provides much water for transpiration. Therefore, temperature determines how much water can be available for groundwater recharge. This indicates temperature affect groundwater resource by lowering recharge which in turn lowers groundwater potential. The Diga dam, which is mentioned above in the statement of problem can exemplify this concept.

In study area, there are 10 metrological stations with available temperature records. Temperature varies spatially and increases with a general trend of decreasing with altitude. The mean monthly temperature is computed as average of the daily temperature of all the days in the month. As can be seen from (Figure 4.3), high temperature is in the months of March and April while minimum temperature is in the month of July, August and September. The annual mean temperature spatially varies from 16.5^{o} C to 20.9^{o} C at Arjo and Bandira respectively with the catchments annual mean of 19.23^{o} C. From the ground truth, the maximum temperature is expected around Didessa river valley. However, due to lack of well recorded time series temperature data for Didessa station, Bandira was considered as area of highest mean annual temperature.

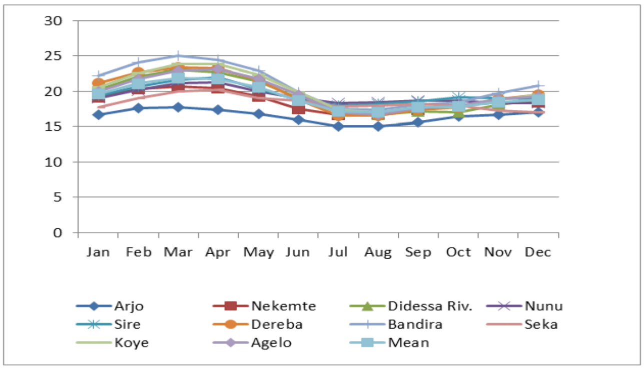

Figure 0.4 Mean monthly temperatures

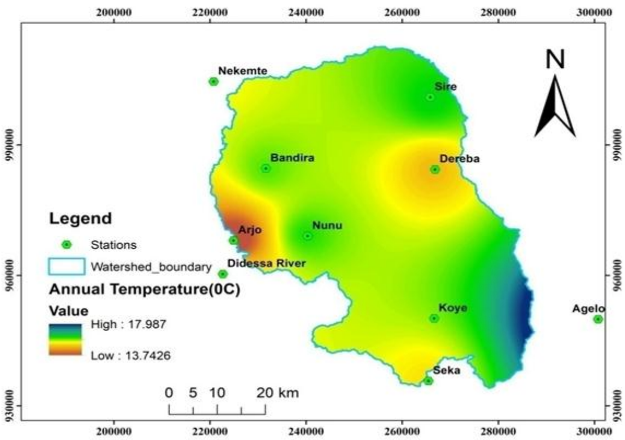

Figure 0.5 Annual temperatures (^{0}C)

4.4 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 (Shaw, 1994). Higher values indicate that the air is nearer to saturation point, and lower values shows that the air consists less water vapour in the atmosphere. It is expressed as the percentage of the ratio of actual to saturation vapor pressure. Evaporation takes place more rapidly in dry air than in air with a high humidity. Study area has seven relative humidity recording station at Nekemte, Arjo, Bandira, Koye, Agelo and Dereba and Didessa River. The annual relative humidity computed for the catchment is 66.9%. The little spatial variation in humidity between different stations is linked with altitude and exposure to moist wind.

As the general, relative humidity of the catchment reaches its peak value in the summer during cloudy weather condition and become low in dry months.As relative humidity approaches 100% evaporation ceases. Mean monthly relative humidity of the study area is given in (table 4.4). It is estimated from the Metrology station in the area and nearer to the area.

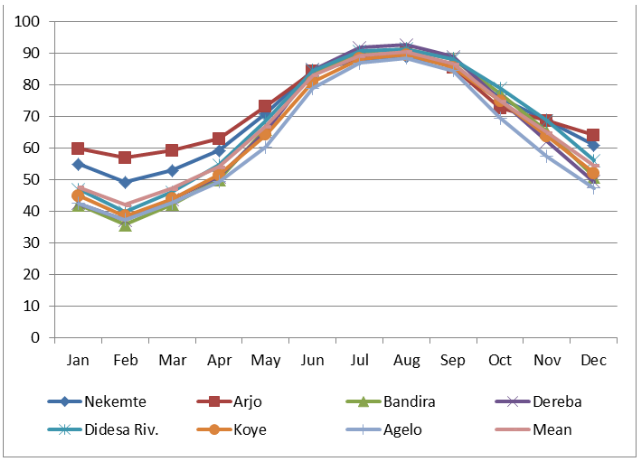

Figure 0.6 Mean monthly relative humidity

Table 0.3 Long term mean monthly relative humidity (%) of the study area.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean (%)	47.7	42.2	47.3	54.1	67	83.1	89.3	90.5	86.7	74.9	65	54.5	66.9

4.5 Rainfall

Seasonal and spatial variation of precipitation has significant effect in hydrology in the case it is a decisive factor for the river flow, groundwater dynamics and groundwater recharge. It is known that distribution and intensity of rainfall in Ethiopia is influenced by oscillation of the surface position of the Inter-Tropical Convergence zone.

In its fluctuation between north and south of the equator, ITCZ crosses over Ethiopia twice a year and this movement from one place to other gives rise to slight difference in the wind flow arrangements over the country with the onset and withdrawal of winds from north and south (Alemayehu, 2006). When ITCZ migrate to northern Ethiopia, the whole southwestern highland is under the influence of Equatorial Westerlies from South Atlantic Ocean (Kebede, 2004). During this period, Wama catchment receives most of its annual rainfall up to more than 75% when south westerly wind bring rains from the Atlantic Ocean. When ITCZ migrate to Southern Ethiopia, Wama catchment gets its remaining Belg/Spring rainfall (March–May) from southerly wind of Indian Ocean.

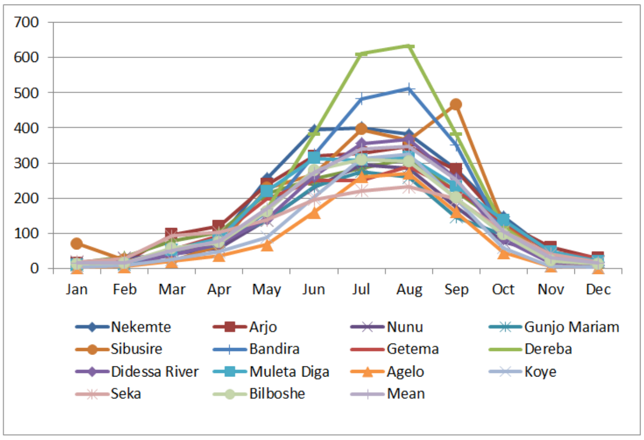

Figure 0.7 Mean monthly precipitation of the study area.

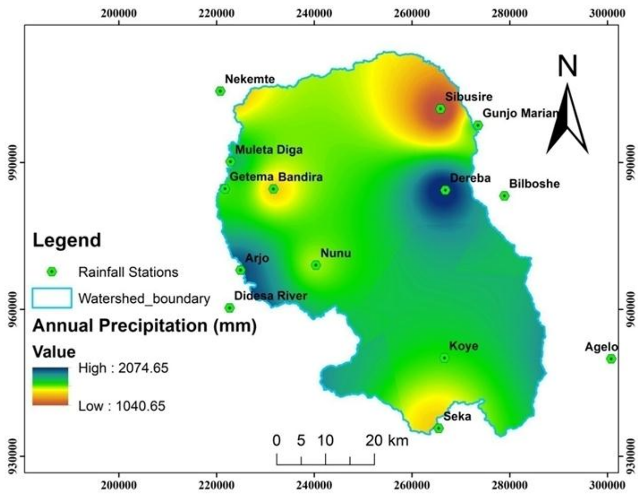

Figure 0.8 Annual precipitations (mm)

4.5.1 Determining aerial depth of rainfall

Precipitation can be defined as the total amount of water falling from the atmosphere in the form of rain, snow, sleet, mist and etc. The rainfall measured by a rain gauge is a point observation which gives depth of rainfall only at a particular geographic point where it is set up, not the aerial rainfall that can represent the whole Area of interest. Thus some method of obtaining effective depth of rainfall should be implemented. In this work, aerial depth of rainfall of study area was obtained by the following three methods.

A) Arithmetic method
B) Thiessen polygon method
C) Isohyetal method

4.5.1 .1 Arithmetic method

Arithmetic mean is the simplest method of computing aerial depth of rainfall and more reliable for relatively flat area where gauging stations are closely and evenly spaced. It is computed by dividing the sum of the rainfall measured at all gauging stations located only within study area in which the variation of individual gauge record from the mean is not too large (Wilson, 1983). By taking this into account stations within and very nearby study area were averaged to get annual depth of rainfall and obtained value is 1693mm**.**

$$Pa = \frac{P1+P2+P3+\cdots+Pn}{n}$$

Where, Pa is average depth of precipitation
P1P2…..Pn are rainfall recorded at each station 1, 2, .etc. and 'n' is the number of rain gauge Stations in the area of interest.

4.5.1 .2 Thiessen polygon method

This is another graphical technique which calculates station weights based on the relative areas of each measurement station in the Thiessen polygon network. The individual weights are multiplied by the station observation and the values are summed to obtain the areal average precipitation. The mean rainfall depth of the catchment is estimated by using 13 rain gauges in and around the catchment. By this method polygons are constructed over rain gauges to mark the area of influence by each gauge.

$Pa = \frac{PiAi}{A}$, Where, P_a= mean aerial depth of precipitation

Ai= Area of polygon corresponding to gauges

P_i= mean rainfall measurement at i^{th} gauge.

A= total area of the catchment.

The value obtained by this method is 1759.3mm/yr.

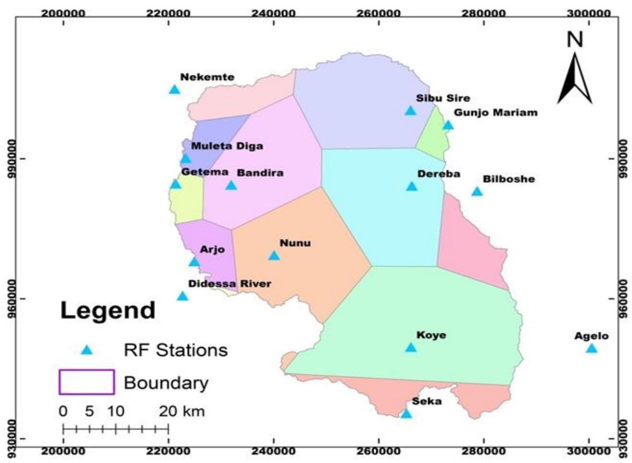

Figure 0.9 Theissen polygons and location of metrological stations

Table 0.4 Mean annual depth of precipitation obtained from Theissen polygon method.

Stations	Polygon area (Km²)	Mean Precipitation (mm)	Weighted area (%)	Weighted rainfall (mm)
Arjo	109.3	1982	0.032	64.0
Bandira	419.8	2084	0.124	258.4
Bilboshe	147.9	1547	0.044	67.6
Dereba	486.5	2481	0.144	356.6
Didessa River	4.8	1615	0.001	2.3
Getema	59.3	1597.5	0.018	28.0
Gunjo Mariam	43.0	1354.2	0.013	17.2
MuletaDiga	90.6	1759.5	0.027	47.1
Koye	839.1	1276	0.248	316.3
Nekemte	120.0	2089	0.035	74.0
Nunu	482.1	1409	0.142	200.6
Seka	148.8	1392	0.044	61.2
Sibu Sire	434.2	2074.6	0.128	266.1
Total	3385.5		1.000	1759.3

4.5.1 .3 Isohyetal method

The method is employed by preparing an Isohyetal map by drawing contours of equal precipitation using ArcGIS 10.3. In this method, the area between two successive isohyets is multiplied by the average rainfall value of the two adjacent isohyets. The method has advantage in that, the stations do not necessarily need to be equally spaced and also it takes into account the influence of physiographic parameters like distance from the coast, slope, elevation and exposure to rain bearing wind (Shaw, 1994). Therefore, the result produced by this method is believed to be more accurate than the preceding two. By this method, value of computed rainfall depth is 1692mm as given below.

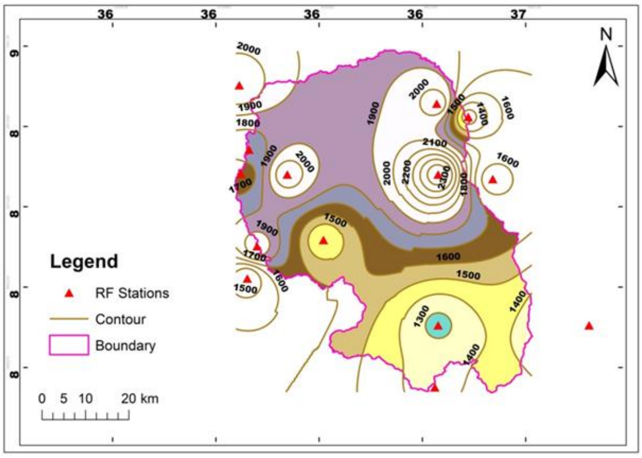

Figure 0.10 Isohytal rainfall depth map of the study area

Table 4.5 Mean annual depth of precipitation obtained from Isohyetal method

Isohyetal range	Precipitation (mm)	Enclosed area (Km²)	Enclosed area (%)	Weighted Rainfall(mm)
<1400	1350	359.8	0.106	143.5
1400-1500	1450	442.4	0.131	189.5
1500-1600	1550	314.9	0.093	144.2
1600-1700	1650	427.9	0.126	208.5
1700-1800	1750	505.7	0.149	268.9
1800-1900	1850	3.7	0.001	2.1
1900-2000	1950	971.3	0.287	530.8
>2000	1900	364.3	0.108	204.4
Total		3385.5		**1692**

Generally, the result obtained using above three methods is slightly similar and very satisfactory with respect to the annual rainfall expected for Wama catchment from the previous work. According to Alemayehu (2006), Southwestern Ethiopia is the region of heaviest rainfall in the country with mean annual rainfall of about 2500 mm, and it is over 2800 mm in Ilu Ababora and parts of Arjo in Wollega.

In this work, because the difference between results obtained from them is not significant, the average value of Arthimetic, Theissen and Isohyetal methods (i.e., 1715mm) is considered as annual rainfall of the catchment and is used for further analysis.

4.6 Temporal variability of Rainfall

It is apparent that rainfall is not uniform throughout the year. Some months are rainy month some are extremely rainy and others are dry. In the catchment, months in the given hydrologic year can be partitioned in to rainy and dry month based on the values of rainfall coefficients.

Rainfall coefficient is the ratio between mean monthly rainfall depth and one twelfth of the mean yearly rainfall (Gemechu, 1977). On the basis of this value the distribution of rain fall in the year can be analyzed as follows.

$$\mathbf{RC} = \frac{\mathbf{12Pm}}{\mathbf{Pa}}$$

Where RC = rainfall coefficient (unit less)
Pa = mean annual rainfall depth
Pm = mean monthly rainfall depth

Based on this value months in a year can be considered as:-

Dry month when RC <0.6
Rainy month when RC ≥0.6

Table 0.6 Classification of rainfall based on rain fall coefficient

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pm	14.5	16.9	51.5	77.2	170	271.4	339.3	346.8	252	105.2	31.6	15.6	1693
Rc	0.10	0.12	0.37	0.55	1.23	1.93	2.38	2.43	1.79	0.76	0.23	0.11	

On the basis of the rainfall coefficient values, months in a water year are classified as:

i) Dry month: November, December, January, February, March and April

ii) Small rainy month: October.

iii) Big rainy month: May, June, July, August and September. The following table gives abroad classification of months of water year (After Gemechu, 1977)

Table 0.7 Monthly rainfall scheme

Dry month		Rainy month		
	Small rain		Big rain	
		Moderate concentration	Higher concentration	Very high concentration
Rc< 0.6	**0.6≤ Rc ≤0.9**	1≤Rc≤1.9	2≤ Rc≤ 2.9	Rc ≥ 3
Nov	**Oct**	May	Jul	
Dec		Jun	Aug	
Jan		Sep		
Feb, Mar and Apr				

Accordingly, rainy month has about 87.6% contribution for total mean annual rainfall whereas dry month contribute only 12.4% for study area.

4.7 Evapotranspiration

Evapotranspiration is the conversion of water molecules to vapor by evaporation (open water body/bare land) and transpiration (plants) away from the watershed surface to the atmosphere (Axon, 1982). It is the additive value of both evaporation and transpiration. The process happens when the water molecules have absorbed enough energy to escape from the surface tension that holds them in the liquid or solid state. Since it is difficult to separately measure both, they treated together as evapotranspiration. The term thus includes evaporation of liquid water from rivers and lakes, ice and snow surface, bare soil and vegetative surface; evaporation from and within the leaves of plants (transpiration). Evapotranspiration is controlled by Metrological conditions, the type of vegetation, and the supply of water. It is a primary process affecting hydrological cycle.

In managing and planning the distribution of water resources, thorough understanding of the evapotranspiration process and knowledge about the spatial and temporal rates of evapotranspiration is required. Direct measurement of evapotranspiration over an area is much more difficult and expensive and is usually impractical due to the unsecure parameters we have to take into account. Thus an array of empirical methods has been developed for estimation of evapotranspiration based on measurement of more readily measured quantities

4.8 Estimation of Potential Evapotranspiration (PET) and Actual Evapotranspiration (AET)

4.8.1 Estimation of PET

Potential evapotranspiration is the amount of water which could have evaporated if the soil had had an infinite amount of water to evaporate (Thornthwaite, 1955). There were different method of estimating potential evapotranspiration but depending on available data, the following empirical formulas were applied.

4.8.1.1 Thornthwaite method

Thornthwaite produced a formula for calculating PET based on temperature with an adjustment being made for the latitude location and number of daylight hours. The method is based upon the assumption that Potential evapotranspiration is dependent only on meteorological conditions and air temperature is an index of energy available for evapotranspiration.

However, the method devised by Thornthwaite is still useful. The necessary factors to input are: mean monthly air temperature, latitude, and a month. Latitude and month yield average monthly sun shine. The potential evapotranspiration obtained by this method is 864.7mm/yr.

$PETm = 16Nm \frac{(10Tm)^a}{I}$ (Shaw, 1988)

Nm- Monthly adjustment factor related to hours of day light

Tm- monthly mean temperature Co

I = ∑ im = ∑(Tm/5)1.5 for m=1, 2…..12 and
a = 6.7x10-7I3 – 7.7x10-5I2+1.8x10-2I+0.49

Nm – is the monthly adjustment factor related to hours of daylight and obtained by dividing the possible sunshine hours for the appropriate latitude by 12 (in this case 10°N)

Table 0.8 Mean PET of study area based on Thornthwaite method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
T (ºC)	19.6	21.1	21.9	21.8	20.6	18.7	17.15	17.1	17.7	17.9	18.4	18.8	
N	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
Nm	0.96	0.98	1	1.02	1.05	1.05	1.05	1.03	1.0	0.98	0.96	0.96	
Im	7.76	8.66	9.16	9.1	8.36	7.23	6.35	6.33	6.66	6.77	7.06	7.3	
I	90.74												
A	1.99												
PET (mm)	71.1	84	92.4	93.4	85.88	70.8	59.6	58.2	60.5	60.6	62.7	65.5	864.7 (mm/yr)

4.8.1.2 Penman combination method

The physical principle of Penman combines two approaches; the mass transfer method & energy *budget method. The basic equations are modified and rearranged to use metrological constants* (obtained from WMO tables) and measurements of variables made regularly at climatologically stations (Shaw, 1988). The method gives good estimates of PET because it takes in to account many metrological variables, such as vapor pressure, humidity, sunshine hours, net radiation, wind speed and mean temperature.

It has a form:

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

Where PET = Potential evapotranispiration

Δ/γ = is found from weighing factor Δ/γ versus temperature from (FAO, 1967) given in (Shaw, 1994) where Δ is the slope of saturated vapor pressure versus temperature and γ is the hygrometric constant with a value of 0.4859 mm Hg °C (Rami, 1996).

E_{at} = is the energy for evapotranispiration in mm/day and it takes the formula

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

e_a = the saturated vapor pressure at air temperature, T_a

e_d = the saturated vapor pressure at the dew point = $e_a * H_R/100$

$T_d = e_a - e_d$ = the saturation deficit

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

$H_T = R_I(1-r) - R_0 = 0.75R_I - R_0$ is the net heat

The procedures followed throughout the calculation are provided below and also in (Table 4.9).

From the above equation, r is the reflective coefficient (albedo) of the area based on land use land cover type. In this work, the study area is slightly dominated by agricultural land mainly seasonal crops. This agricultural land usually become bare land after the ripened crops harvested. As a result, the barren land, crop residue together with mature forest increases the reflection capacity of the area. Considering these factors, r = 0.24 is taken for study area.

R_I = incoming radiation,

R_0 =outgoing radiation,

r = albedo

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

Where, σT_a^4 =the theoretical black body radiation at T_a

T_a = mean air temperature for a month, (°C)

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

Taking account of the increased albedo for vegetation and introducing the multiplying factor 0.95 to σT_a^4 since vegetation does not radiate as a perfect black body, the following equation for H is used:

$H = 0.75R_a(0.18 + 0.55n/N) - 0.95\sigma T_a^4(0.10 + 0.9\,n/N) - (0.56 - 0.092\sqrt{e_d})$

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

$f_a(n/N) = 0.16 + 0.62n/N$ – for latitudes south of 54 and 1/2° N

But this formula takes different form depending on latitude (Shaw, 1994). In this case since study area is located at latitude south of 54 and 1/2° N.

R_a = solar radiation (fixed by latitude and season) = 10° considered for the study area, n = bright sunshine over the same period, h/day, H_T =the available heat

N = mean daily duration of maximum possible sunshine hours (North Latitudes) = 10°considered for the study area.(After M. Shaw, 1989)

This method gives reasonable estimate of PET because it takes in to account many metrological variables which govern the rate and magnitude of evapotranspiration. The annual PET of the catchment obtained by this method is 1059.1mm and this value is used for further analysis.

Table 0.9 Mean annual PET obtained from penman combination method

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
T (°C)	19.6	21.1	21.9	21.8	20.6	18.7	17.2	17.1	17.7	17.9	18.4	18.8	
N	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
Ra(mm/day)	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5	
U (mil/day)	53.7	60.7	65.5	67.6	64.4	59.1	55.8	54.76	52.08	50.47	47.24	48.32	
n/N	0.63	0.6	0.6	0.57	0.52	0.43	0.32	0.33	0.47	0.61	0.64	0.65	
H (%)	47.7	42.2	47.3	54.1	67	83.1	89.3	90.5	86.7	74.9	65	54.5	
σTa^4	14.7	15	15.2	15.2	14.9	14.6	14.2	14.2	14.4	14.4	14.5	14.6	
ea(mmHg)	17.1	18.8	19.7	19.6	18.2	16.2	14.7	14.6	15.2	15.4	16.9	16.3	
ed(mmHg)	8.16	7.94	9.32	10.6	12.2	13.5	13.1	13.2	13.2	11.5	11	8.9	
ea-ed	8.96	10.9	10.4	9	6	2.7	1.57	1.39	2	3.9	5.9	7.4	
E_{at}	3.06	3.5	3.54	3.28	2.45	1.26	0.8	0.7	0.96	1.7	2.37	2.7	
Δ/γ	2.19	2.37	2.47	2.46	2.3	2.08	1.91	1.9	1.97	1.99	2.18	2.09	
R1(1-r)	5.35	5.6	5.96	5.9	5.47	4.84	4.08	4.22	5.06	5.83	5.57	5.32	
Ro(mm/day)	2.6	2.59	2.44	2.2	1.86	1.5	1.23	1.25	1.59	2.1	2.25	2.55	
Fa(n/N)	0.55	0.53	0.53	0.51	0.48	0.43	0.36	0.37	0.45	0.54	0.56	0.56	
Ht	2.75	3.01	3.52	3.7	3.61	3.34	2.85	2.97	3.47	3.73	3.32	2.77	
PET(mm/day)	2.85	3.16	3.53	3.58	3.26	2.67	2.15	2.18	2.62	3.05	3.02	2.75	34.82
PET(mm/mon)	86.7	96.1	107	109	99.16	81.2	65.4	66.31	79.69	92.77	91.86	83.65	1059.1

From the above calculated PET by Thornthwaite and Penman combination method, the result of Penman seems to be the representative value. This is because Penman uses many inputs of metrological parameters that affect evapotranspiration whereas; Thornthwaite depends only on temperature and usually underestimate the PET. So, the value of PET used in further analysis is the one from Penman obtained from Penman method (i.e., 1059.1 mm/yr).

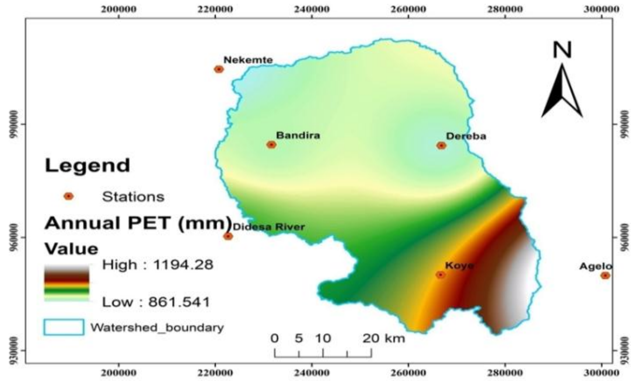

Figure 0.11 Annual PET (mm)

4.8.2 Estimation of AET

Actual evapotranspiration is the amount of water that is actually removed from the surface by evapotranspiration under the given climatic and soil moisture condition (Fetter, 2001). It is less than or equal to potential evapotranspiration.

4.8.2.1 Empirical formula to calculate AET

One of the imperial formulas to estimate Actual Evapotranspiration is formula developed by Turc, (1954). This is a widely used formula to estimate annual AET for catchment areas (Shaw, 1989). The formula takes into consideration mean annual precipitation and mean annual temperature of the catchment area.

$$AET = \frac{P}{\sqrt{0.9+(\frac{P}{L})^2}}$$

Where,P= mean annual precipitation (mm), which is 1715mm

$L= 300 + 25T + 0.05T^3$

T = is mean annual air temperature (C^0), which is 19.23 C^0

Using this method the estimated annual value of AET of the catchment is found to be **717**mm.

4.8.2.2 Soil water balance method (Thornthwaite and Mather, 1957)

This method uses monthly values of rainfall and potential evapotranspiration as input to estimate monthly actual evapotranspiration. It has been tempted to compute soil water balance of study area with the main objective of finding actual evapotranspiration. The basic assumption of this method is that when monthly rainfall is greater than or equal to the corresponding monthly potential evapotranspiration, the actual evapotranspiration equals potential evapotranspiration, if the moisture storage in the soil zone is at maximum capacity (Thornthwaite and Mather 1957, Shaw 1994). But when the moisture content in the soil is limited and vegetation unable to abstract enough water from the soil, the actual evapotranspiration becomes less than the potential evapotranspiration.

The actual evapotranspiration of the area is calculated using Thornthwaite and Mather standard soil water balance model based on the above soil and vegetation cover; precipitation and potential evapotranspiration are used as main inputs. In the model, accumulated potential water loss, which indicates the severity of water shortage, is obtained by cumulating of the negative values of the differences between monthly precipitation and potential evapotranspiration for dry season only, and the summation begins with the first month of dry season.

In such case, the soil moisture during dry month is given by

$$SM = AWC\exp\left[-\frac{(|APWL|)}{AWC}\right]$$

Where, SM: Soil moisture during the month M (mm)

APWL: Accumulated potential water loss at month M (mm).

AWC: Available water capacity of the root zone (mm)

Actual evapotranspiration is calculated depending on the relationship between AET & PET which is affected by the soil moisture content. When the soil is saturated or when there is abundant moisture in the soil, PET = AET, that means, If Pm>PETm, AET = PET

Otherwise AETm = Pm + Sm-1-Sm where 'm' stands for month, Sm-1 and Sm are soil moisture during month m-1 and m respectively. As soil moisture deficit increases, the AET become increasingly less than PET. Soil moisture deficit (SMD) is the difference between PETm and AETm. According to the assumptions of Thornthwaite and Mather (1957) 50% of the total available runoff (TARO) in any month actually runs off, the rest 50% is detained (D) in the subsoil, groundwater as well as channels of the catchment and is available for runoff during next month.

TAROm = Sm + Dm-1 where 'S' is surplus and 'D' is detention.

On the basis of above concept the actual evapotranspiration of the catchment is computed by taking into account different land use land cover and soil type of the catchment. For this work the soil in Wama catchment is classified into two major soil texture namely, loam and clay in which loam accounts for 86% of the area and the left one, clay is 14%. The areal coverage of each soil class in proportion to types of vegetation cover is determined. The result from each soil class then summed and the obtained value of actual evapotranspirationis 860 mm/year.

Where P=Precipitation; PET= Potential evapotranspiration; P-PET is difference by subtraction, APWL=Accumulated potential water loss derived by accumulating negative values in row 3; SM=Soil moisture; AET=Actual evapotranspiration; ΔSM= Change in soil moisture during the month; SMD= Soil moisture deficit; S=Soil moisture surplus;

TARO =Total available runoff; TO=Total runoff and D=Detention

The result obtained from Turc method underestimates the actual values. This might be due to the case:

- ✓ Turc empirical formulae use only temperature and precipitation which do not account for the effect of the rest hydro-meteorological, pedological and botanical (land cover) effect on the rate of actual evapotranspirartion.

- ✓ Turc method is developed for specific climatic region, which may not work effectively for a different one. Therefore, the result obtained from the soil water balance thought to represent the actual evapotranspirartion of study area and will be utilized for further analysis.

Table 0.2 AET for the area represented by clay and loam soil that accounted to 14% and 86% of total catchment respectively, with total available water capacity of 228 mm. All values in the tables are in millimeters.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P	14.5	16.9	51.5	77.2	170	271.4	339.3	346.8	252	105.2	31.6	15.6	1693
PET	86.69	96.11	107.37	108.9	99.16	81.2	65.4	66.31	79.69	92.77	91.86	83.65	1059.1
P-PET	-72.19	-79.21	-55.87	-31.7	70.84	190.2	273.9	280.49	172.31	12.43	-60.26	-68.05	
APWL	-140.	-219.5	-274.5	-306.2							-60.26	-128.31	
SM	123.3	87	68.4	59.5	228	228	228	228	228	228	175	129.8	
ΔSM	6.5	-36.3	-18.6	-8.9	168.5	0	0	0	0	0	-53	-45.2	
AET	21	53.2	70.1	86.1	99.16	81.2	65.4	66.31	79.69	92.77	84.6	60.8	860
SMD	66.09	46.01	39.31	23.9	0	0	0	0	0	0	7.86	24.65	

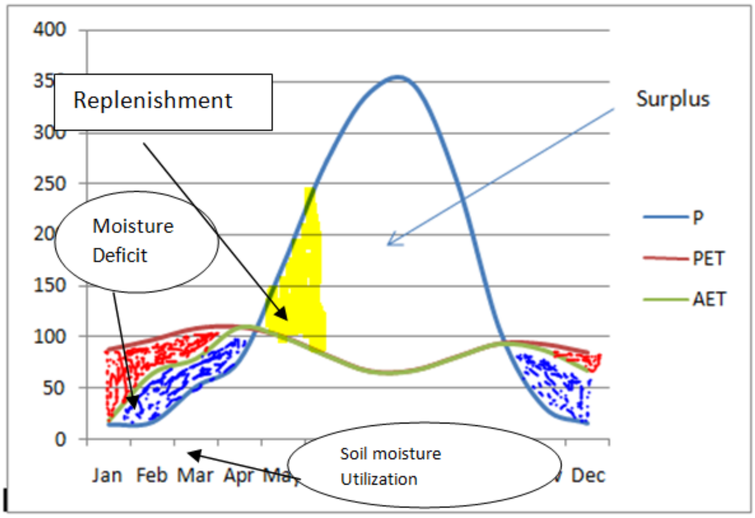

Figure 0.12 Results of monthly average water balance of the study area.

4.9. Runoff estimation

Runoff estimation using rainfall coefficient

This method estimates the runoff by multiplying the runoff coefficient to the rainfall depth of the area. The runoff coefficient is the fraction of rainfall converted into runoff (Chow, 1988)

The runoff value by rational method has its own limitations. This formula is more applicable for small catchment area (i.e., <50km²). The researcher used this method due to the fact that the catchment area is ungauged. There is no a river flow record or river discharge gauge in the Wama River.

It is given by: R = PK.

Where, R = runoff (mm)

P = rainfall depth (mm)

K = runoff coefficient (dimensionless).

But, K is obtained by,

$$K = \frac{A1K1 + A2K2 + A3K3 \ldots + AnKn}{A1 + A2 + A3 \ldots + A}$$

The values of runoff coefficient for different land use land cover given by Barlow were used to estimate the runoff coefficient for the study area. Accordingly, the land use land cover as stated in chapter two is grouped under four major category as given below (Table 4.11).

$$K = \frac{(1963.8*0.3+495*0.11+920*0.1+6*0.67)}{3385.5} = 0.218$$

From the above equation, by multiplying the value of runoff coefficient (i.e., 0.218) with rain fall depth (1715mm/yr), the annual runoff value of 374 mm/yr was obtained for the study area. Therefore, for water balance method calculation, the catchment's annual runoff is assumed to be 374 mm/yr. Following this approach, runoff coefficient for the entire area is estimated to be 0.218

Table 0.11 Runoff coefficient for different Land use Land cover in the study area

№	Classification of land use land cover	Area in (Km^2)	Runoff Coefficient
1	Cultivated (Intensively to moderately cultivated perennial crops and state farms)	1963.8	0.3
2	Pasture, bush land, grassland, open and dense wood land	495	0.11
3	Forest	920	0.1
4	Settlement	6	0.67

4.10 Recharge estimation

4.10.1 Water balance method

An important objective of most groundwater studies is to make a quantitative assessment of the groundwater resource. In order to bring these objectives in to effect, two water balance approaches, which have generally the same ground but presented in different forms, have been applied. The first approach is the one developed by (Thornthwaite and Mather, 1957), known as soil water balance, and 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 formulae (detail of this method was presented under soil water balance sub-topic).

The second approach is based on the general water balance equation. This equation follows basic assumptions such as:

- The surface water divide and ground water divide coincides
- The catchment is bounded by both surface and ground water divide, except at the mouth of the River where ground water escapes as base flow.
- There is no ground water inflow and outflow across the boundary
- The water balance is on annual basis and the change in storage on annual base is assumed to be zero.
- Abstraction by human is insignificant.

Based on the assumptions made the water balance equation representing the catchment is:

Inflow = Outflow + Change in storage

The inflow component of a system includes precipitation, groundwater inflow, irrigation and artificial water transport to the system and the out flow components include abstraction, groundwater out flow, direct runoff, evapotranspiration, recharge and water transfer to another systems. This water balance approach involves identifying which components of inflow and out flow can take place within the area of consideration and quantifying each one individually.

Based on the assumptions made the water balance equation representing the catchment is:

R = P – AET – Q –W

Where, P= mean annual precipitation in mm, AET = mean annual actual evapotranspiration in mm, Q = Mean annual surface runoff in mm, W= Withdrawal (insignificant) and R = mean annual ground water recharge in mm.

Thus, by using the above relation of the conventional water balance equation, the mean annual groundwater recharge of the Wama Catchment is estimated as follows:

AET = 860mm (From Soil water balance methods), Q = 374mm and P = 1715mm

Therefore, R= 1715mm - 860mm - 374mm = 481mm/year.

4.10.2 Chloride Mass Balance in Evaluation of Groundwater Recharge

This method is used for estimation of recharge to ground water by using relatively stable environmental tracers. Chloride ion do not significantly enter in to oxidation or reduction reactions; they form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, they are not significantly adsorbed on mineral surfaces, play few vital biochemical roles, and the circulation of chloride ions in the hydrologic cycle is largely trough physical processes. Chloride ions moved with the water through most soils tested with less retardation or loss than any of the other tracers' tested-including tritium that had actually been incorporated in to the water molecules. This conservative behavior should not be expected where movement is through compact clay or shale, however (Kaufman and Orlob, 1956). Chloride ions may be concluded characteristically to be retained in solution through most of the processes that tend to separate out other ions (Mairs, 1967).

The method is based on the assumption of mass between the input of atmospheric chloride and the chloride flux in the sub-surface. Ignoring the direct inputs of pollution, the fluxes for a catchment can be interpreted in terms of a mass balance equation: (Drever and Clow, 1995).

Here are assumptions for this method:

- The only source of chloride in groundwater is from precipitation falling directly on the aquifer material;
- Concentration of chloride in groundwater is by evapotranspiration within the unsaturated zone, not from recycling, dissolution of minerals containing chloride, or inflow from adjacent aquifers;
- Chloride is not retarded by adsorption nor accelerated by anion exclusion
- Chloride is conservative and its mass flux has not changed over time
- Chloride application rate is constant and known
- There is no appreciable chloride run off or run on from the sampling sites and
- Steady state conditions prevail.

In this work, samples of precipitation from three stations (WamaHagelo, NunuKumba, and Nekemte) were collected and tested its chloride concentration at Nekemte City Water Quality Analysis and the average value of chloride concentration for these stations was 1.88 mg/l. On the other hand, the averaged value of chloride ion concentration in the groundwater from 11 boreholes is 15.8mg/l.

The general equation for mean annual recharge estimation from chloride data and attributes is:

$GR = P^* [Cl^-_p]/ [Cl^-_{GW}]$

Where GR=Mean ground water recharge in mm/year, P= Mean annual precipitation depth in mm

$[Cl^-_{GW}]$ = Average concentration of chloride in ground water in mg/l, $[Cl^-_p]$=Concentration of chloride in precipitation in mg/l

In this case, P = 1715 mm/yr, Cl^-_p = 1.88 mg/l, $[Cl^-_{GW}]$ = 15.8 mg/l, GR = 204 mm/yr.

It is seen that the recharge value obtained by this method is lower than the values obtained by other methods. It has therefore the following limitations:

Only three samples of rainfall (in mid-March) were taken; it would be better if more rainfall data were collected over a year to know the variation of Cl^- with time.

It depends on the detecting limits of laboratory a slight error in detection can cause erroneous result.

The total amount of precipitation that carries the chloride ions is not retained with in the soil; however, part of it runs off leaving the catchment. And direct input of pollution is observed due to higher amount of concentration Cl^- in the falling Precipitation over the catchment.

V.CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The overall objective of this work is to assess the groundwater resource of Wama catchment. Estimation of quantitative values of water cycle components (Precipitation, surface runoff, PET, AET, ground water recharge) are tried to be performed using different approaches. From the three methods for calculation of aerial depth of precipitation, the value obtained by averaging the results of rainfall depth from the three methods (i.e., 1715mm/yr) was used for successive analysis because these results have no significant differences.

Potential evapotranspiration (PET) is estimated by using two approaches namely, Thornthwaite and Penman combination methods. Those methods gave 864.7 mm/yr and 1059.1mm/yr respectively. Thornthwaite method underestimates the value most probably because it relies on mean monthly temperature and sunshine hour. The Penman combination method on the other hand takes many parameters as input. It considers parameters like temperature, vapour deficit, sunshine hours, solar radiation and heat, and the value obtained by the method is reliable and used in the consequent analysis. Therefore, the PET obtained from Penman combination method was used in this work.

Actual evapotranispiration (AET) is obtained by adopting empirical formula of Turc and soil- water balance developed by Thornthwaite and Mather, 1957. By these methods the calculated AET were 717mm /yr and 860mm/yr.

Because the Turc method underestimates the value, the AET obtained from soil-water balance method is used in the calculation of recharge by water balance method.

The Wama River has no gauging station at the catchment mouth. This is cause for possessing the problem on obtaining the reliable runoff value. Water balance and CMB methods have their own limitations. In water balance method, run off value is obtained from rational method which has inherent errors because it is more useful for small area. Similarly, for Chloride mass balance (CMB) method, only three rainfall samples were analysed for Cl^{-}concentration. Therefore, the annual groundwater recharge value (i.e. 481mm/year), obtained from water balance method was used as representative value for the catchment.

Generally depending on transmissivity and yielding capacity observed from pumping test data in conjunction with geological and hydrometrological consideration, catchment is grouped into five potential zones. Fracture traces as manifested lineaments in land sat images are abundant in the catchment area. They have significant controls on drainage pattern, drainage density and ground water flow systems. Water flows from surrounding highland to the discharge areas following low hydraulic gradient and regional groundwater flow is generally toward the southwestern direction.

VII. REFERENCES

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