Surface Waters Potential of the Hantebet Basin, Tigray, Northern Ethiopia

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ABSTRACT

Ethiopia loses annually an estimated 111 billion cubic meters of water as surface runoff from its 12 major river basins. This paper quantifies the amount of monthly and annually lost rainwater through surface runoff from the Hantebet basin, which has an areal coverage of 24.4 km^2. The hydrology of the area was characterized based on land use, soil, slope, rainfall, temperature, evapotranspiration, and runoff. In order to determine the basic hydrologic parameters, meteorological data was collected from the nearby stations. The rainfall coefficient method was used to determine the monthly distribution of rainfall in the studied area and then to distinguish between rainy months and dry months. The Thornthwaite method and Thornthwaite water balance model were used for determination of the potential evapotranspiration and actual evapotranspiration, respectively, of the basin. For runoff estimation, the methods employed were the curve number and runoff coefficient.

The mean annual rainfall of the basin is 632.08 mm. The basin is characterized by two rainy seasons and three dry seasons during the year. The two rainy seasons and the three dry seasons in total have six months, respectively. The total amount of rains that comes during the rainy months is 590.61 mm. Small rains occur in the three months (March, April and September) of rainy seasons and the amount is 115.54 mm. Big rains occur in the remaining three months (June, July and August) of the rainy season with moderate and very high concentration and the total amount is 475.07 mm: 54.11 mm occurs with moderate concentration in June whereas 420.96 mm with very high concentration in July and August. The rain in the dry months is 41.46 mm. The mean annual actual evapotranspiration of the basin is 336.7 mm. The mean annual runoff is 12.74 million cubic meters. Of which 92.7 % is generated during the rainy months while 7.3 % is generated during the dry months. Among the rainy months, 79.2 % of the runoff is coming from the big rainy months and 13.5 % from small rainy months. The big rains that occur with very high concentration in July and August produce 72. 2 % the mean annual runoff of the basin.

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In the basin there are no any inland waters. The only available surface water is the runoff that is generated by the different land units of the area. This huge amount of water, which is lost annually with out being utilized, can be harvested and stored for efficient use when the rains stop, and distribute it wisely for different users.

Keywords: Curve number, dry season, evapotranspiration, rainfall coefficient, rainy season, runoff, water balance.

1. INTRODUCTION

Water is the most vital requirement for human survival. It has been described as the elixir of life, the source that sustains life on earth and the factor that governs the evolution of and functioning of the universe. The importance of water makes it synonymous to life.

Ethiopia has abundant surface water resources that can be used for different purposes. There are 12 major river/drainage basins seven of which are transboundary. The total annual runoff from these basins is estimated at about 111 billion cubic meters (Ministry of Water Resources, 2001). The major rivers carry water and sediments and drain mainly to the arid regions of neighboring countries. There are also eleven major lakes with a total area of 750, 000 ha (Ministry of Water Resources, 2001).

Although Ethiopia's water resource is large, very little of it has been developed for agriculture, hydropower, industry, water supply and other purposes. To date only about 160, 000 ha (about 4%) of the potential irrigable land has been developed. Based on available information the potential irrigable land in the country is about 3.7 million ha (Ministry of Water Resources, 2001).

Knowing the potential and availability of surface waters, currently the government of Ethiopia is undertaking a huge investment on water resource investigation and development for various uses. This would help to increase the productivity of microdams, to improve ways and means of the traditional irrigation management system, to increase potable water supply and also to increase the hydroelectric power generation of the country.

As a contribution to the national efforts, this study on the surface water potential at a small-scale will have a paramount importance to understanding the bigger picture. The Hantebet basin is one of the least studied areas in the country where shortage of water both for domestic and irrigation uses is critical. This study, therefore, documents and analyses for the first time the water potential of the Hantebet basin through detailed sampling, mapping, meteorological data analysis and estimate the surface waters potential of the area. This is expected to contribute a lot to the ongoing endeavor and alleviating the different problems occurring in the area.

2. LITERATURE REVIEW

Water is the single most important element of the environment. The availability of water largely determines the spatial pattern of the Earth's terrestrial biomes (forest, grasslands and deserts); it covers 71 % of the Earth's surface providing habitat for fresh and saltwater ecosystems; water is a major controlling element of the Earth's climate, and it is water that is largely responsible for sculpting the Earth's surface into the infinitely complex associations of erosional and depositional landforms. Water makes life on Earth possible, and, to a large extent, water makes the Earth itself.

Surface water is water that is on the Earth's surface, such as in a stream, river, lake, or reservoir. Surface water is a valuable resource which can be used for public, industrial and agricultural supply purposes. Surface water courses also provide important natural habitants and environmental and leisure resources. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation.

The geographical location of Ethiopia and its endowment with favorable climate provides a relatively higher amount of rainfall in the region. Much of the water, however, flows across the borders being carried away by the transboundary rivers to the neighboring countries. Although we can not be definite due to lack of researched data as yet, preliminary studies and professional estimates indicate that the country has an annual surface runoff of close to 111 billion cubic meters of water excluding groundwater.

Although Ethiopia's water resource is large, very little of it has been developed for agriculture, hydropower, industry, water supply and other purposes. To date only about 160, 000 ha (about 4%) of the potential irrigable land has been developed. National coverage of potable water supply stood at 26% by 1992 while coverage of sanitation services is only 7%, which is low by even the Sub-Sahran standards. There is also a wide divergence in the water supply coverage between urban (76%) and rural (18.8%) areas. If Ethiopia has to feed its fast growing population and improve the standard of living of its citizens this situation has to be changed.

3. METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

The catchment area is located in southern Tigray Regional State in North Ethiopia. Geographically it lies between 1467000 to 1476000 m N and 523000 to 530000 m E, and is estimated to have an areal coverage of 24.4 km^2 (Figure 1).

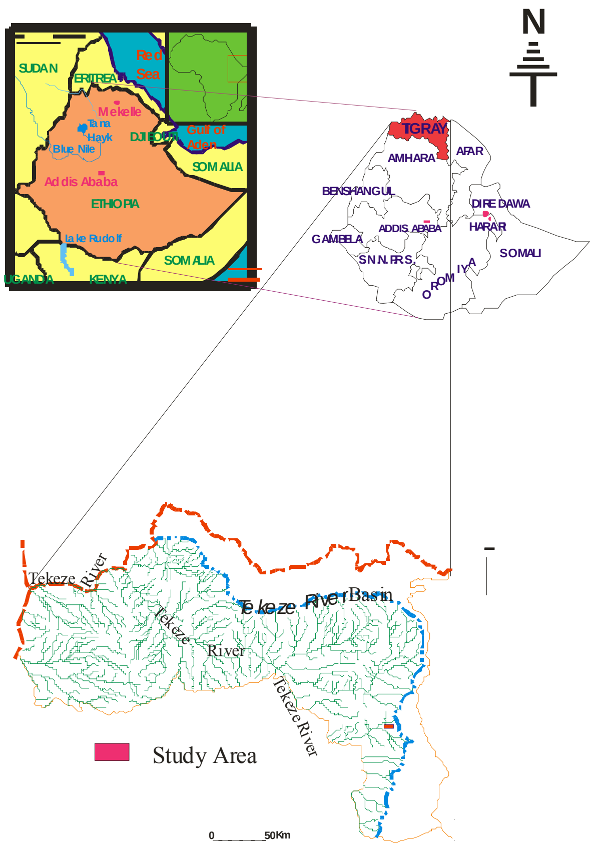

Figure 1. Location of the study area.

3.1.2 Physiography

The basin consists of vast depressed areas that extend from northeast to southwest bounded by adjacent highlands. Altitude ranges from 2000 m above sea level on the lowland to mountain peaks greater than 2600 m above sea level. The average elevation of the basin is 2330 m above sea level with peaks reaching 2660 m above sea level.

3.1.3 Geology

The major lithological units in the studied area are dolerite, shale, limestone, siltstone and thick alluvial deposits (Figure 2). Stratigraphically, the limestone is found at the base overlying by shale and then followed by siltstone. Overlying these successions, the igneous intrusions of dolerite as a sill and dike are exposed on the top parts of hills and plateaus. Alluviums are found having different thickness overlying all these successions in the lowlands.

The limestone is exposed in the northern part of the studied area overlying the shale unit. The average exposed thickness of this unit is 8 m. It has a greenish gray fresh color and gray weathered color. It is characterized by the presence of circular dissolution/karstic features on the surface and long fractural opening in the river cut exposures. In the area, limestone is highly weathered and fractured with wide ranges of openings. In some places the limestone unit is highly fossilifereous, and texturally it is fine grained. It covers 12 % of the total area.

The shale is exposed in the east and northeast hills of the studied area occupying 13.4 % the total area of the basin. It is also exposed in the lowlands along the river beds. In some other places of the lowlands, as it was observed in the hand dug wells, it is found covered by thick alluvial sediments. It consists of intercalations of limestone, siltstone, mudstone, lime and marl. It has a variegated color, and is highly weathered and fractured.

Siltstone is largely exposed on the western sides of studied area and also found as intercalation with shale unit on the eastern side. It has a whitish fresh color and light gray weathered color. It is characterized by the presence of fractures with different orientations and is highly altered where in the contact with the doleritic sill. It occupies 0.5 % of the total area. Most of the dolerites occur as sills and dykes occupying the hills and mountains of the area. It covers 45.2 % of the total area.

The alluvial deposit occurs in the valley bottom bounded by adjacent highlands. It covers large area of the basin and lies on top of the shale units. Alluvial deposits in the area are composed of very fine to coarse-grained materials, ranging from clay size to boulders of different rocks and dolerites. In some areas, it has sandy material in the deeper part, which bears groundwater. Generally, it has up to 7 m thickness as exposed in river cuts and hand dug wells. It covers 28.9 % of the total area.

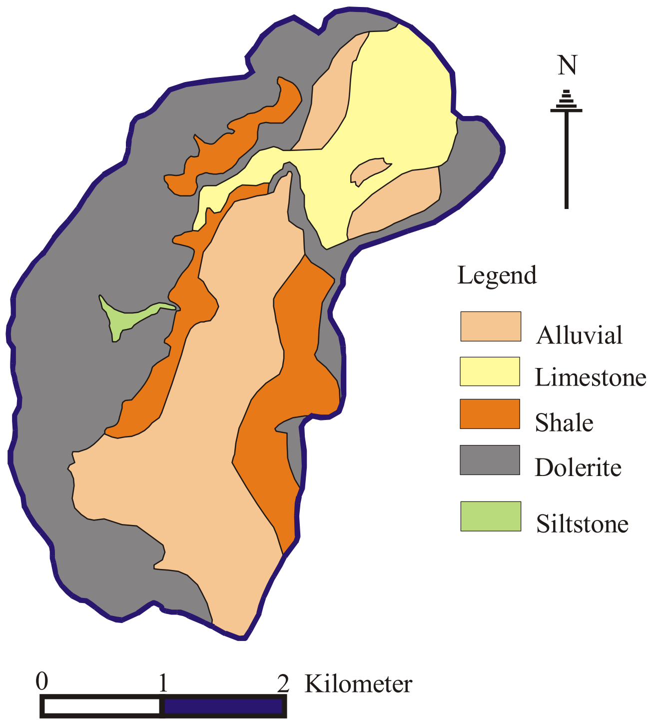

Figure 2. Geological map of the Hantebet basin.

3.1.4 Drainage

The studied area is drained by a perennial river, the Hantebet' river. It originates from the northern highlands and flows towards the southern flatlands and finally joins the Tekeze River, which is the main tributary of Atbarah River. There are in addition many small intermittent and a few perennial meandering rivers that drain the area. These streams originate from the surrounding highlands. The streams are dense at areas of higher slopes and sparse where the slope is relatively flat. The lengths of the longest and shortest streams are 7145.5 m and 89.8 m, respectively. Most of the longer streams are found on flat plain of alluvia deposits whereas the shorter ones are on the flunk of the mountain covered by mostly dolerite intrusions. Most of the steep well-drained areas usually have numerous small tributaries whereas the gentle slopes and plain areas have long streams in places where the soils are deep and permeable. In general, the studied area has a dendritic drainage pattern (Figure 3). The main sources of supply for the streams are precipitation during the rainy seasons and to a lesser extent the shallow perched aquifers during the dry seasons. The basin has no any other inland waters such as lakes and ponds.

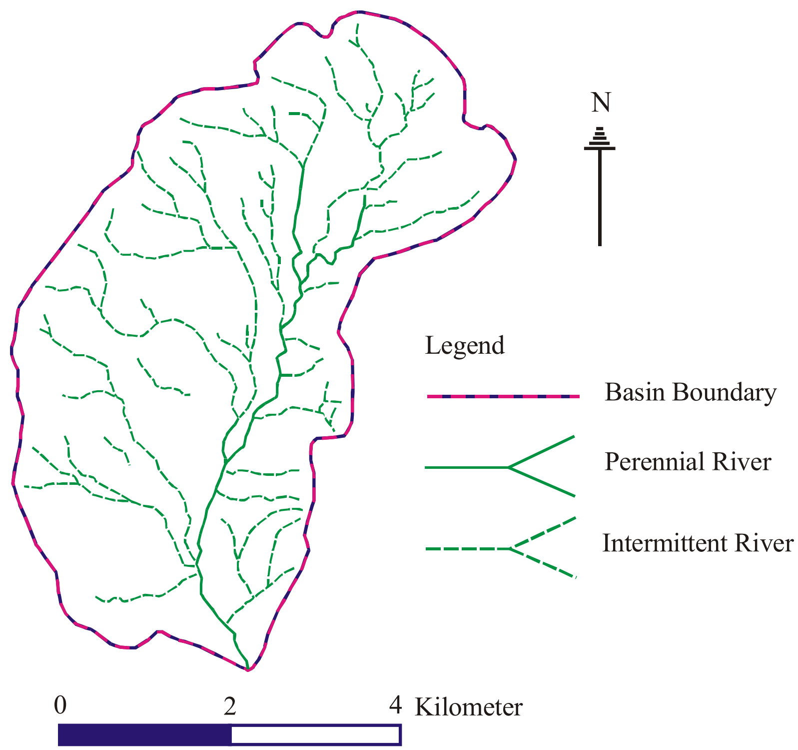

Figure 3. Drainage map of the study area.

3.1.5 Vegetation

The basin consists of poor and widely scattered acacia species, which indicate the past vegetation cover of the area. Some other trees like eucalyptus and cactus are also found. The largest part of the study area is cultivated with crops and cereals like maize, sorghum and wheat using small scale irrigation. Some parts of the studied area form hills and ridges and is covered by scattered eucalyptus trees and cactus.

3.2 Data Collection

Extensive work was carried out by collecting pertinent primary data of the area in the field and secondary data from different offices. The topographic map with a scale of 1:25,000 was used as a base map. Geological and drainage map of the area were prepared using this as a base map.

The hydrology of the basin was characterized by slope, land use, soil, rainfall, temperature, evapotranspiration, and runoff. In order to determine the basic hydrologic parameters, meteorological data was collected from nearby stations. Data for land use, soil, geology, root depth and slope were collected in the field with the help of GPS. Using ArcView 3.2 and CorelDRAW 9 software's, various thematic maps such as geological, drainage, land use, soil, and runoff were produced.

Due to lack of meteorological stations in the basin, data from two nearby meteorological stations were used for this study. These are the first class Mekelle Airport meteorological station, which is 45 km away from the study area, and the fourth class Dengolat meteorological station, which is about 8 km from the study area. Both of them are owned by the National Meteorological Service Agency.

For the analysis, rainfall data was collected from Dengolat station. The remaining climatic data such as temperature, wind speed, humidity and sunshine hours were taken from Mekelle Airport meteorological station, and temperature adjustment was done accordingly so that the data are reliable to represent the study area.

3.3 Data Processing

For the determination of particle size distributions of the different soils in the study area 15 soil samples were taken from five different depths of soil profile and on the surface. Grain size analysis was carried out in the Department of Civil Engineering, Mekelle University, and the soil classification was done on the basis of USDA soil texture classification system.

Textural classification was then used to estimate the maximum water holding capacity. Major land uses in the area were defined and the average depth of the root zone was measured in the field. Taking an active root zone of certain depth, the maximum soil water holding capacity up to the active root zone was estimated. This value of soil water holding capacity was used in the determination of the actual evapotranspiration.

The rainfall coefficient method (Daniel, 1974) was used to determine the monthly distribution of rainfall in the studied area and then to distinguish between rainy months and dry months. This method involved the calculation of "rainfall coefficient" for each month at the station, the coefficient being the ratio between the mean monthly rainfall and one-twelfth of the annual mean (the latter referred to as "rainfall module").

In this study, the Thornthwaite method (Thornthwaite and Mather, 1957) was used to estimate the potential evapotranspiration of the basin. This method uses air temperature as an index of
the energy available for evapotranspiration, assuming that air temperature is correlated with the integrated effects of net radiation and other controls of evapotranspiration, and that the available energy is shared in fixed proportion between heating the atmosphere and evapotranspiration. There is no correction for different vegetation types.

The Thornthwaite's empirical equation is:

$$E_t = 1.6\left[\frac{10T_n}{J}\right]^a \qquad (1)$$

where
E_t = Potential evapotranspiration in centimeter per month.
T_n = Mean monthly air temperature (ºC).
n = 1,2,3,......12 is the number of the considered months.
J = Annual heat index and it is given by the equation:

$$J = \sum_{n=1}^{12} j \qquad (2)$$

j = is the monthly heat index and it is expressed as:

$$j = \left(\frac{T_n}{5}\right)^{1.514} \qquad (3)$$

$$a = 0.49 + 0.0179J - 0.0000771J^2 + 0.000000675J^3 \qquad (4)$$

The computed monthly potential evapotranspiration in Eq. 1 is for a standard month with 360 hours of daylight. It must be corrected for the varying length of day with latitude using the appropriate correction factor.

For the evaluation of the actual evapotranspiration the Thornthwaite water balance model (Leopold and Dunne, 1978) was utilized. The required parameters to determine actual evapotranspiration using this model are mean monthly precipitation, mean monthly potential evapotranspiration, water holding capacity of the dominant soil type and monthly soil moisture storage.

The actual evapotranspiration, AET, for the dominant soil types and the respective land use in the area was weighted according to the proportion of the area it represents, and the weighted AET was calculated as

$$AET_W = \sum_{i=1}^{5} \frac{(AET_i)a_i}{A} \qquad (5)$$

where
AET_w is weighted actual evapotranspiration:
AET_i *is* actual evapotranspiration of the dominant soil types:
a_i is area of each soil coverage: and,
A is total area of soil coverage.

For runoff estimation, the curve number and runoff coefficient methods were used.

The curve number method is based on the potential maximum retention (S) of the watershed, which is determined by wetness of the watershed that is antecedent moisture condition (AMC) and physical characteristics of the watershed. The curve number method calculations are shown below:

$$S = \frac{25400 - 254}{CN} \qquad (6)$$

$$Q = \frac{(P - 0.2S)^2}{P - 0.8S} \qquad (7)$$

where
S is maximum potential retention of the watershed, mm:
CN is Curve number:
Q is runoff of depth (mm):

P is rainfall (mm): and,
$I = 0.2S$ which is initial abstraction rainfall by soil and vegetation.

The volume of runoff from the catchment was also computed by using the runoff coefficient method, which employed the following formula.

$$Q = K.P.A \quad (8)$$

where
Q is runoff, m^3:
K is a constant also called runoff coefficient depends up on the imperviousness of the drainage area:
P is precipitation (mm): and,
A is area of the basin (m^2).

4. RESULTS AND DISCUSSION

4.1 Slope

The study area has been classified into six slope classes: 0 -15 % (flatland), 15 -30 % (gentle), 30 – 45 (intermediate), 45 – 60 % (slightly steep), 60 – 75 % (steep) and 75-90 % (very steep).

Steep slopes mostly characterized the northern, western and eastern parts of the study area. On the contrary, the southern and central parts of the study area are characterized by flatland and gentle slopes.

4.2 Soils

The soils in the basin are light sandy and highly plastic clay soils, which seem to have different distributions (Figure 4). Substantial area of the cultivated land is dominantly covered by fine sandy loam soil with a presence of clay loam and clay soils in very limited areas. A considerable area of the upper part of the studied area has sandy clay soil in which no activity is practiced on the hillsides.

Other than these, some part of the homesteads and wood land of the catchment's area has mainly of sandy loam soil. Within this area agriculture is practiced to some extent.

Table 1. Area coverage of the different soil types.

Soil type	Area coverage (km^2)	Area coverage (%)
Fine sandy loam	10.33	42.40
Clay	0.42	1.72
Sandy clay	8.59	35.23
Sandy loam	4.02	16.50
Clay loam	1.02	4.18
Total	24.38	100

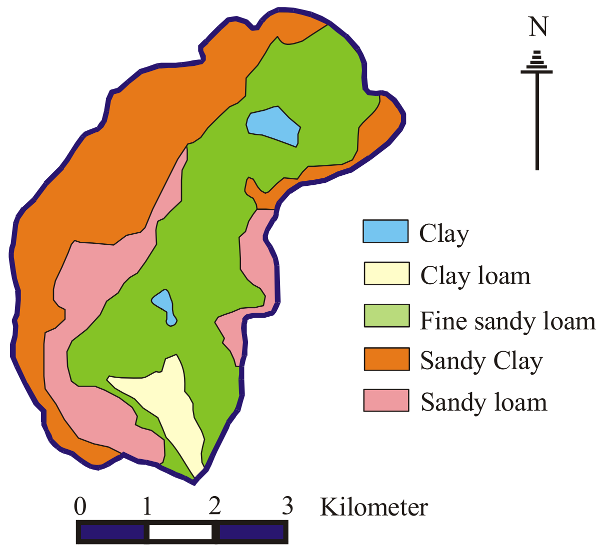

Figure 4. Soil map of Hantebet catchment.

4.3 Land Use

Six major land use types were identified from the present land use during the field assessment made on the basin. These are cultivated land, grazing land, dense woodland, homestead, sparse woodland and bare land (Figure 5). Of these, cultivated land constitutes 10.16 km² (41.68 %), which is the largest portion of the total area. The agricultural practice is largely undertaken in the slope range 0 -15 %. The major agricultural crops produced in the area are wheat, teff, sorghum, maize, and barely.

Grazing land constitutes 1.66 km² (6.81 %) of the total area. Forestland covers 1.36 km² (5.61 %) of the total area of the catchment. This area which is named as “forest land” (both scattered and densely forested area) includes areas, which are covered with very scattered acacia trees, bushes, cactus and eucalyptus trees.

The rest of the land use types cover homestead, 2.67 km² (10.94 %), and bare land, 8.52 km² (34.96 %), which is the second largest portion of the total area next to cultivated land.

Table 2. Land use type with their area proportion and slope range.

Major land use types	Total area (km²)	Area proportion (%)	Slope range
Cultivated land	10.16	41.68	0-15%
Grazing land	1.66	6.81	0-15%
Densely forested area	0.22	0.92	15-30%
Scattered forested area	1.14	4.69	15-30%
Home stead	2.67	10.94	15-30%
Bare land	8.52	34.96	0-30%
Total	24.38	100	

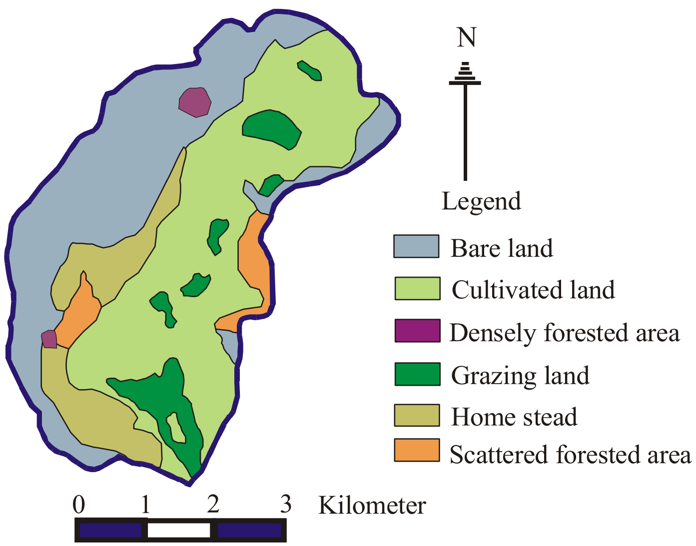

Figure 5. Land use map of Hantebet basin.

4.4 Rainfall

4.4.1 Seasonality of Rainfall

The areal pattern of the seasonality of rainfall in the study area was determined by analyzing mean monthly rainfall data for one station in the basin. To compare the monthly distribution of rainfall at this station, the method employed here was adapted from a study of precipitation data for the Awash River Basin (Daniel, 1974). This involved the calculation of "rainfall coefficient" for each month at the station, the coefficient being the ratio between the mean monthly rainfall and one-twelfth of the annual mean (the latter referred to as "rainfall module"). To distinguish between a "rainy" month and a "dry" month in the Awash Basin study, a month is designated "rainy" when the monthly rainfall coefficient reaches 0.6 (60 % of the rainfall module), and distinctly rainy when it exceeds 0.8. Extremely rainy months have a coefficient of more than 1 (that is, the rainfall exceeds the module value) (Daniel, 1974).

In this study, a month was designated "rainy" if the rainfall coefficient is 0.6 or over, as in the Awash Basin study. The term "small rains" is employed to refer to those months with a rainfall coefficient of 0.6 to 0.9; and the term "big rains" to those months where the coefficient is 1.0 and above. The "big" rainy months are further classified into three groups: those with "moderate concentration" of rainfall (coefficient of 1.0 to 1.9); those with "high concentration" of rainfall (coefficient of 2.0 to 2.9); and those with "very high concentration" of rainfall (coefficient of 3.0 and above). This scheme of classification is presented in Table 3.

Table 3. Classification scheme of monthly rainfall values.

Designation	Rainfall Coefficient
Dry month	Less than 0.6
Rainy month	0.6 and over
Small rains	0.6 to 0.9
Big rains	1.0 and over
Moderate concentration	1.0 to 1.9
High concentration	2.0 to 2.9
Very high concentration	3.0 and over

Source: Daniel, 1974.

On the basis of the above classification, as depicted in Table 4, the basin is characterized by two rainy seasons during the year; that is, at this station the rainy months are separated into more than one group of rainy months by dry months. This also means that there are three dry seasons during the year.

The two rainy seasons in total have six months: March, April, June, July, August, and September. The first rainy season occurs during the months of March and April. The rains are small rains, and account for 12.34 % of the average annual rainfall of the basin. The second rainy seasons occurs from June to September. The small rain is in September, and this accounts for 5.93 % of the average annual rainfall of the basin. The big rains occur from June to August. The big rain in June occurs with moderate concentration whereas in July and August it occurs with very high concentration in both months. The big rain in June accounts for 8.56 % of the average annual rainfall of the basin. The big rains in July and August account for 66. 60 % of the average annual rainfall of the basin.

The basin is characterized by three dry seasons. The first dry season starts in January and ends in February. The second is in May, and the third is from October to December. The amount of rainfall that occurs during these six months of dry seasons in total accounts for 6.57 % of the average annual rainfall of the basin. The basin has not experienced high concentration of rainfall.

4.4.2 Mean Annual Rainfall

The rainfall data of the study area was taken from Dengolat metrological station which is 8 km from our target area. The data was collected from the last 13 years records (1992-2004), and the mean is tabulated and presented in the Table 5. Accordingly, the mean annual rainfall of the study area is 632.07 mm. The mean monthly rainfall averaged over the thirteen-year period of records for the Dengolat station is shown in Figure 6.

Table 4. Rainfall coefficient at the Dengolat station.

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainfall coefficient values	0.05	0.1	0.76	0.72	0.43	1.03	3.92	4.08	0.71	0.09	0.08	0.03
Season	Dry	Dry	Rainy	Rainy	Dry	Rainy	Rainy	Rainy	Rainy	Dry	Dry	Dry
Amount	-	-	Small	Small	-	Big	Big	Big	Small	-	-	-
Concentration	-	-	-	-	-	Moderate	Very High	Very High	-	-	-	-

Table 5. Mean monthly rainfall at Dengolat station (mm).

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean monthly rainfall (mm)	2.71	5.38	40.04	37.98	22.79	54.11	206.22	214.79	37.47	4.79	4.42	1.37	632.07

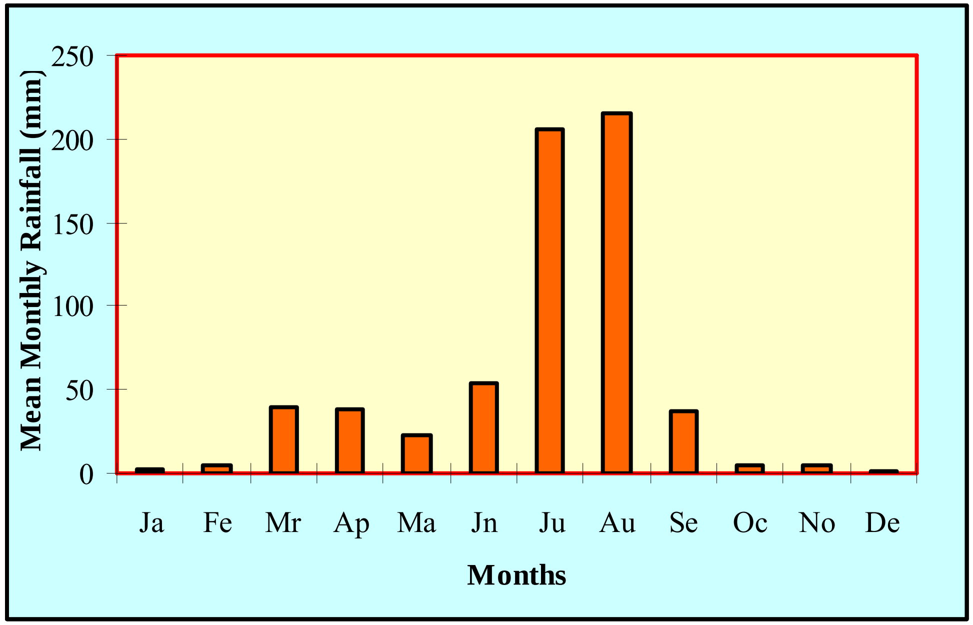

Figure 6. Mean monthly rainfall at Dengolat station.

4.5 Temperature

In the study area, as in all other places of Ethiopia, the altitude of the sun is always high, making solar radiation intense. The variation in the amount of solar radiation received daily is small throughout the year. Temperature is high during the day and is considerably reduced at night causing the daily range of temperature to be large. But in the case of monthly averages, variation is minimal and the annual range of temperature is small. This holds true in both the highlands and lowlands. Slight seasonal variations in the angle of the sun's rays and the length of the day are primary controls on temperature, resulting in a yearly temperature range that is less than the daily range.

Temperature data were taken from the Mekelle Airport meteorological station for the same year (1992-2004). Since the target area is about 45 km far from Mekelle, the data was extrapolated to the study site (Hantebet basin) by allowing an increment of 0.6 ºC for 100 m depression and the average temperature drops about 6 ºC per 1000 m altitude (Table 6 and Figure 7). The mean annual minimum temperature of the study area is 11.15 ºC and the mean annual maximum temperature is 23.39 ºC .The mean annual air temperature of the area is 17.3 ºC.

Table 6. Extrapolated mean temperature from Mekelle Airport station (ºC).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
M.M.Max.Temp	22.1	23.4	24.2	24.9	26.1	26	22.3	22.2	23.5	22.8	21.7	21.5
M.M.Mini.Temp	8.9	9.6	11.3	12.7	13.3	12.8	12.4	12.3	11.1	10.6	9.7	9.1
M.M.Temp	15.5	16.5	17.8	18.8	19.7	19.4	17.4	17.3	17.3	16.7	15.7	15.3

Where
M.M.Max.Temp is mean monthly maximum temperature;
M.M.Mini.Temp is mean monthly minimum temperature; and,
M.M.Temp is mean monthly air temperature.

From this extrapolated mean temperature data analysis, the minimum air temperature is 15.3 ºC in December and the maximum air temperature is19.7 ºC in May. The annual range of temperature is 4.4 ºC.

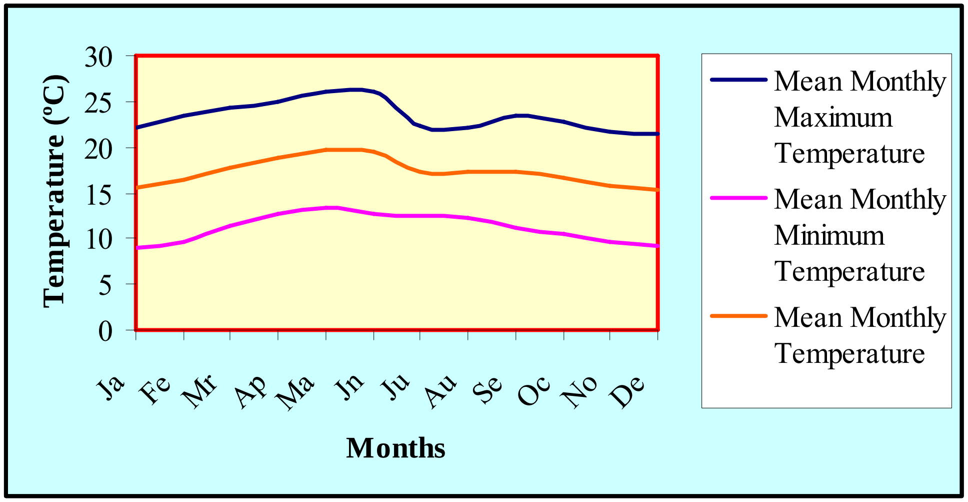

Figure 7. Extrapolated mean temperature.

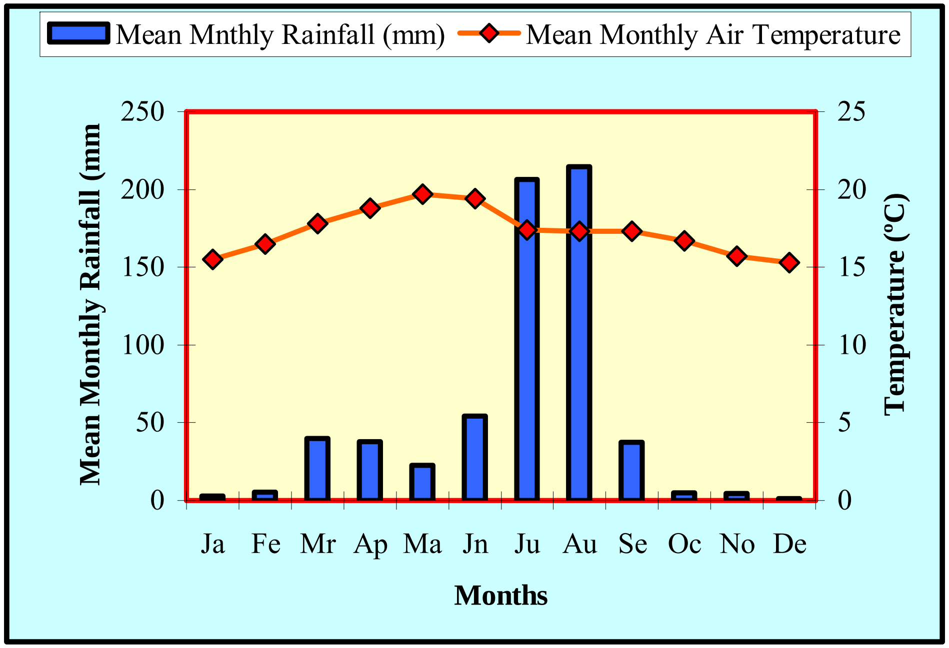

Figure 8. Temperature and rainfall relationship.

Figure 8 shows the temperature and rainfall relations over the period (1992-2004) for the basin. Even though the maximum air temperature occurs in May, high temperature values are observed during the rainy seasons. Months in the rainy seasons are warmer than months in dry seasons. The minimum temperatures as well as rainfall are also occurring almost in a similar range of months.

4.6 Wind Speed

Wind speed data was taken from Mekelle Airport meteorological station. The data was a ten years record from 1995 to 2004. The mean monthly values were computed and are given in the Table 7 below. The maximum and minimum wind speed value is obtained in February (340.4 km/d) and August (142.5 km/d), respectively. In general the highest wind speed values are found in dry months whereas the lowest occur in very highly rainy months.

4.7 Humidity

The relative humidity data (%) was taken from Mekelle Airport meteorological station. The data was recorded from 1993 to 2004. The mean monthly values were computed and are given in the Table 7 below. The maximum and minimum relative humidity value is found in August (81.61 %) and February (52.27 %), respectively. This maximum and minimum value is also within very highly rainy month and dry month, respectively. In general the highest humidity values are found in the rainy months whereas the lowest values are in dry months.

4.8 Solar Radiation

Monthly sunshine hours were collected from Mekelle Airport meteorological station. The data was recorded from 1991 to 2004. The mean monthly sunshine hours of the area are given in the Table 7. The maximum sunshine hour is recorded in December (9.79 hours) and May (9.78 hours) whereas the minimum one is in July (5.34 hours) and August (5.37 hours). Generally, the maximum sunshine hours are found in dry months whereas the minimum are in very highly rainy months.

Table 7. Mean monthly wind speed, relative humidity, and sunshine hours.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W.S(Km/d)	284.6	340.4	338.7	311.9	257.4	273.7	171.6	142.5	166.1	261.4	293.8	304.9
R.H (%)	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83
S.(Hrs)	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79

Where
W. S is Wind speed;
R.H is Relative humidity; and,
S is Sunshine hours.

4.9 Evapotranspiration

Evapotranspiration is that portion of the precipitation which returns back to the atmosphere through evaporation from a free water surface, a bare soil or interception on a vegetal cover and other objects and transpiration from plants.

In this study an attempt was made to estimate both potential evapotranspiration and actual evapotranspiration for the basin.

The Thornthwaite method (Eq. 1) was used to estimate the potential evapotranspiration of the basin. Potential evapotranspiration rates calculated for the station employed in this study is given in Table 8. Monthly variation of potential evapotranspiration at a station also indicates variation in monthly air temperatures, since potential evapotranspiration is calculated basically from temperature data. As it is depicted from Table 8, the highest monthly values of potential evapotranspiration in the basin in general come just before the onset of the rainy season; and lowest values during the rainy season, when the cloud cover reduced air temperatures and therefore potential evapotranspiration. Based on this method the mean annual potential evapotranspiration of the basin is 781.56 mm.

Actual evapotranspiration data are not available in the stations employed in this study. Due to the almost complete lack of field instruments such as lysimeters, the Thornthwaite water balance model (Leopold and Dunne, 1978) was used to estimate the actual evapotranspiration of the

basin. Through the calculation of an average water balance, actual evapotranspiration was estimated for the dominant soil types and the respective land use in the area, and for the entire basin. For each dominant soil type and respective land use, the results are summarized and are given in Tables 9 to 11. The actual evapotranspiration for the dominant soil types and the respective land uses in the area was weighted according to the proportion of the area they represent, and the weighted actual evapotranspiration was calculated by utilizing Eq. 5 to determine the actual evapotranspiration of the basin. Accordingly, the annual actual evapotranspiration of the basin is 336.7 mm.

Table 8. Potential evapotranspiration at Hantebet basin.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
T	15.5	16.5	17.8	18.8	19.7	19.4	17.4	17.3	17.3	16.3	15.2	14.8	
J	5.46	5.99	6.72	7.29	7.82	7.64	6.49	6.44	6.44	5.89	5.30	5.09	76.57
LCF at 10º N	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96	
GPET	50.9	60	68	74.8	81.1	79	66	65	65	58.7	52	49.7	
CPET	49.35	58.80	68.00	77.04	85.16	83.74	69.30	67.60	66.30	58.11	50.44	47.71	781.56

T = Mean Monthly Air Temperature (ºC); j = Monthly Heat Index; GPET: Monthly Gross or Unadjusted Potential Evapotranspiration (mm); LCF at 10º N = Latitude Correction Factor at 10º N; CPET = Corrected or Adjusted Potential Evapotranspiration (mm).

able 9. Average monthly water balance at Hantebet, for a soil with an available water capacity of 150 mm. The soil is a fine sandy loam in areas of subsistence farming cover by cereal crops with an average rooting depth of 100 cm. All values in table are in millimeters.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
P	2.70	5.40	40.00	38.00	22.80	54.10	206.20	214.80	37.50	4.80	4.40	1.40	632.10
CPET	49.35	58.80	68.00	77.04	85.16	83.74	69.30	67.60	66.30	58.11	50.44	47.71	781.56
P-CPET	-46.65	-53.40	-28.00	-39.04	-62.36	-29.64	136.90	147.20	-28.80	-53.31	-46.04	-46.31	
Acc. Pot. WL	-221.12	-274.52	-302.52	-341.56	-403.92	-433.56			-28.80	-82.11	-128.15	-174.47	
SM	34.00	24.00	20.00	15.00	10.00	8.00	144.90	150.00	124.00	87.00	64.00	47.00	
ΔSM	-13.00	-10.00	-4.00	-5.00	-5.00	-2.00	136.90	5.10	-26.00	-37.00	-23.00	-17.00	
ET_{actual}	15.70	15.40	44.00	43.00	27.80	56.10	69.30	67.60	63.50	41.80	27.40	18.40	490.00

Table 10. Average monthly water balance at Hantebet, for a soil with an available water capacity of 250 mm. The soil is a clay loam under a pasture grass cover with an average rooting depth of 100 cm. All values in table are in millimeters.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
P	2.70	5.40	40.00	38.00	22.80	54.10	206.20	214.80	37.50	4.80	4.40	1.40	632.10
CPET	49.35	58.80	68.00	77.04	85.16	83.74	69.30	67.60	66.30	58.11	50.44	47.71	781.56
P-CPET	-46.65	-53.40	-28.00	-39.04	-62.36	-29.64	136.90	147.20	-28.80	-53.31	-46.04	-46.31	
Acc. Pot. WL	-221.12	-274.52	-302.52	-341.56	-403.92	-433.56			-28.80	-82.11	-128.15	-174.47	
SM	103.00	84.00	75.00	64.00	50.00	44.00	180.90	250.00	224.00	180.00	150.00	125.00	
ΔSM	-22.00	-19.00	-9.00	-11.00	-14.00	-6.00	136.90	69.10	-26.00	-44.00	-30.00	-25.00	

ET_{actual}	24.70	24.40	49.00	49.00	36.90	60.10	69.30	67.60	63.50	48.80	34.40	26.40	554.10

Table 11. Average monthly water balance at Hantebet, for a soil with an available water capacity of 300 mm. The soil is a sandy loam under a wood cover with an average rooting depth of 200 cm. All values in table are in millimeters.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
P	2.70	5.40	40.00	38.00	22.80	54.10	206.20	214.80	37.50	4.80	4.40	1.40	632.10
CPET	49.35	58.80	68.00	77.04	85.16	83.74	69.30	67.60	66.30	58.11	50.44	47.71	781.56
P-CPET	-46.65	-53.40	-28.00	-39.04	-62.36	-29.64	136.90	147.20	-28.80	-53.31	-46.04	-46.31	
Acc. Pot. WL	-221.12	-274.52	-302.52	-341.56	-403.92	-433.56			-28.80	-82.11	-128.15	-174.47	
SM	144.00	120.00	110.00	96.00	78.00	71.00	207.90	300.00	273.00	228.00	196.00	168.00	
ΔSM	-24.00	-24.00	-10.00	-14.00	-18.00	-7.00	136.90	92.10	-27.00	-45.00	-32.00	-28.00	
ET_{actual}	26.70	29.40	50.00	52.00	40.80	61.10	69.30	67.60	64.50	49.80	36.40	28.40	576.00

P = Mean Monthly Precipitation; CPET = Corrected Potential Evapotranspiration; P - CPET = is Difference by Subtraction; Acc. Pot. WL = Accumulated Potential Water Loss; SM = Soil Moisture; ΔSM = Change in Soil Moisture During the Month; ET_{actual} = Actual Evapotranspiration; D = Soil Moisture Deficit; S = Soil Moisture Surplus.

4.10 Runoff

Since there were no water level observations and flow measurements conducted in the basin due to lack of hydrometric station in any one of the rivers in the entire basin, it was impossible to analyze the runoff of the basin by computer models or scale models. Other methods like the unit hydrograph and flood frequency analyses were also not used because of their requirements of historical records.

Therefore, in this study, the volume of runoff was determined by two methods: curve number and runoff coefficient.

The curve number is a versatile and widely used method for runoff estimation. The mean monthly runoff of the catchments was calculated using Eq. 7 and tabulated and presented in Table 12 and Figure 9. Accordingly, the mean annual runoff of the basin is 12.74 million cubic meters.

Out of the mean annual runoff of the area, 92.7 % of the runoff is generated from rainy months whereas 7.3 % from dry months. Among the rainy months, 79.2 % of the runoff is coming from the big rainy months and 13.5 % from small rainy months. The big rains that occur with very high concentration in July and August produced 72. 2 % the mean annual runoff of the basin.

The annual runoff was also calculated using runoff coefficient method (Eq. 8), and the monthly runoff of the catchment is presented in the Table 12. Accordingly, the annual runoff of the basin was estimated to be 9.15 million cubic meters.

Since the curve method takes into account a number of hydrologic parameters than the runoff coefficient method, the calculated value of the curve method is taken as a representative of the basin.

Table 12. Monthly runoff of the basin calculated by curve matching method and runoff coefficient method.

Months	Runoff (Million Cubic Meter)	
	Curve method	Runoff coefficient method
January	0. 192	0.039
February	0.164	0.078
March	0.603	0.580
April	0.563	0.550
May	0.087	0.330
June	0.896	0.783
July	4.392	2.985
August	4.804	3.109
September	0.553	0.542
October	0.180	0.069
November	0.156	0.064
December	0.153	0.020

Total	12.743	9.149

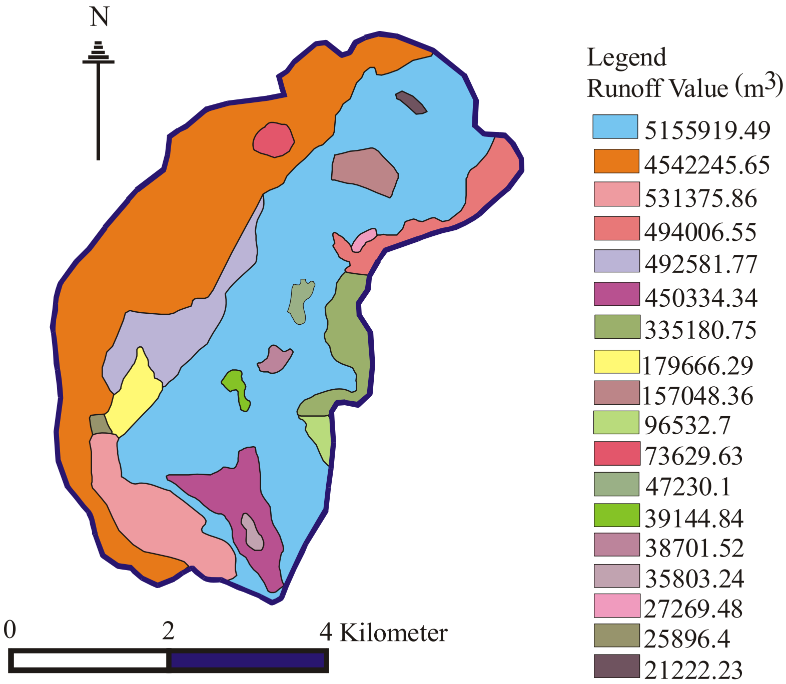

Figure 9. Runoff value of each land use.

5. CONCLUSIONS

The study area receives a mean annual rainfall of 632.08 mm. The mean annual actual evapotranspiration is 53.27 % of the mean annual rainfall of the basin. The mean annual runoff that leaves the basin is 12.74 million cubic meters, which corresponds to 522 mm. Inland waters are not available in the basin. The only available surface water is runoff that is generated by the different land units of the area. Out of 12.74 million cubic meters, 11.81 million cubic meters is generated from the six months of rainy seasons and 0.93 million cubic meters from the remaining six months of the dry seasons. Generally, this result implies that the outflow is in excess of the inflow or input, which is precipitation. This might be due to the contribution of the neighboring basins: subsurface water might flow across the surface boundaries toward the basin. To have a complete knowledge of the surface water of the basin an investigation of such kind of link should be conducted. In general, the basin has very good surface water potential, if it is harvested, that can be used for different purposes.

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7. REFERENCES

Buckle, C. 1978. Landforms in Africa: An introduction to geomorphology. England: Addison Wesley Longman Ltd.

Daniel Gamachu. 1974. Aspects of climate and water budget in Ethiopia. Addis Ababa: Addis Ababa University Press.

Davis, N.S. and Dewiest, R. J. M. 1966. Hydrogeology. New York: John Wiley and Sons, Inc.

Fetter, C.W. 1994. Applied hydrogeology. New Jersey: Prentice-Hall, Inc.

Garg, K. 1987. Irrigation engineering and hydraulic structures. India: Khanna Publishers.

Hermiyanto, B., M. Zoebisch, G. Singh, S. Ranamukhaarachchi, R. Clemente and F. Agus. "Comparing Runoff, Soil and Nutrient Losses from Three Small Watersheds in Indonesia". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript LW 04 007. Vol. VI. September, 2004.

Hillel, D. 1998. Environmental soil physics. San Diego: Academic Press.

Leopold, L. B. and Dunne, T. 1978. Water in environmental planning. San Francisco: W. H. Freeman and Company.

Ministry of Water Resources. 2001. Initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change (UNFCCC). A report submitted to the conference of parties of the UNFCCC under the GEF support Climate Change Enabling Activities Project of Ethiopia. Ethiopia, Addis Ababa.

Nata Tadesse. 1994. Hydrogeology of Jimma area. M.S. thesis, Department of Earth Science, Addis Ababa University, Addis Ababa.

Nata Tadesse 2003. Hydrogeological investigation and environmentally sound plans for the development of groundwater in the Weri River Basin, Tigray, Ethiopia. Ph.D. diss., Institutes of Applied Geology, University of Natural Resources and Applied Life Sciences (BOKU) Vienna, Vienna.

Nata Tadesse. 2004. Sustainable groundwater management: A case study in the Weri River Basin, Tigray, Ethiopia. In Proc. of the International Conference and Exhibition on Groundwater in Ethiopia, Paper No. 21. Addis Ababa, 25 -27 May.

Pereira, L. S. "Water and Agriculture: Facing Water Scarcity and Environmental Challenges". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Invited Overview Paper. Vol. VII. February 2005.

Rijo, M. and C. Arranja. “Hydraulic Performance of a Downstream Controlled Irrigation Canal Equipped with Different Offtake Types”. Agricultural Engineering International: the CIGR Ejournal. Vol.VII. Manuscript LW 04 014. March, 2005.

Sharma, R. K. and Sharma, T. K. 1990. Irrigation and drainage. India: Raju Publishing Co. Pvt. Ltd.

Smedema, L. K and Rycroft, D. W. 1983. Land drainage. London: BT Batsford Ltd.

Stephen A. Thompson. 1999. Hydrology for water management. Rotterdam: A. A. Balkema.

Thornthwaite, C.W and Mather, J.R. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. New Jersey: Publication in Climatology, Center ton, X, No3, pp. 185-204.

Tripathi, M.P. 1999. Hydrological modelling of small watershed. Ph.D. diss., Department of Agriculture and Food Engineering, Indian institute of Technology, Kharagpur.