ANNEX 4. CLIMATIC ANALYSES AND RIVER FLOWS

CONTENTS

1. Climatic Analyses

1.1 Climate Classification

In accordance with the use of the National Meteorological Service Agency (NMSA), a classification of climate in the micro-catchments/study areas has been prepared according to the Koppen system and is mapped in “The Abbay River Basin Integrated Master Plan Study”. It is found to be warm temperate I and denoted as CWB. This type of climate is characterized by dry months in winter, with mean temperature of the coldest month below 18^0 C, more than 4 months with average temperature above 10^0 C and a relation between mean annual rainfall (Rf) and mean annual temperature (t): Rf >20 (t+14). This type of climate prevails in the altitude range 1,750 to 3,200 m a.m.s.l.

This climate of the micro-catchments is dominated by various interrelated factors, but the main ones are the near equatorial location and the altitude. The year is divided into three seasons:

- The main rainy season (Kremt) from mid-June to the end of September;
- A dry season (Bega) from October to February;
- A small rainy season (Belg) from March to mid-June;

The small rain, originates from the Indian Ocean and is brought by south-east winds; while the heavy rain in the wet season (Kremt) comes from the Atlantic Ocean with south-west winds.

1.2 Data Sources/Collection

The NMSA is the only responsible governmental organization for the collection and compilation of meteorological data in the country. With NMSA’s assistance, all data of some stations in and around the micro-catchments were collected for further analysis. These include:

- Monthly rainfall data of Arb Gebeya (9 years), Debre Tabor (25 years), Hamusit (16 years), Gasay (10 years) and Wereta (24 years),
- Monthly mean maximum and minimum temperatures of the above stations;
- Monthly mean relative humidity (5 years), pitch evaporation (5years), sunshine hours (13 years) and wind speed (10 years) of Gonder station only;
- Daily mean rainfall of Debre Tabor, Wereta and Merawi stations;

The other source of data is from “ The Abbay River Basin Integrated Master Plan study: Volume II, Water Resources, Phase 2, 1997”.

The writer of this report (Hydrologist) visited the sites for a short period of time to grasp some idea of the micro-catchments and their characteristics. Due to lack of time a full assessment was not able to be made.

1.3 Meteorological Data Analysis

1.3.1 Temperature

The mean annual temperature of the micro-catchments is synthesized from the maximum and minimum recorded values of Debre Tabor, Weretta and Gasay. For some stations such as Hamusit, Bahir Dar and Arb Gebeya, data was extracted from “The Abbay River Basin Integrated Master Plan study”. The synthesized mean monthly values are shown in Table 1.1. From the synthesized values, the hottest months are from February to May, whereas the coldest months are from October to January. Before the analysis was made, it was necessary to fill in missing data values by appropriate methods for all stations.

1.3.2 Temperature altitude correlation

In order to extend the scanty data from within the detailed study area, the data of all meteorological elements in and around the project areas were employed to derive the relationship between temperature and altitude. Since the correlation coefficient is 0.94, then there existed a good relationship between temperature and altitude.

Table 1.1 Mean monthly temperatures (ºC)

Stations	Elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Debre Tabor	2690	15	16.7	17.6	17.9	17.5	16.1	14.3	14.4	14.8	14.9	15	15	**15.8**
Gasay	2808	13	13.3	14.1	14.1	13.9	13.7	12.4	12.2	12.5	12.6	12.2	12.3	**13.1**
Wereta	1980	19	19.8	21.2	21.4	21.3	19.7	18.1	17.9	18.4	19	18.8	18.5	**19.4**
Bahir Dar	1770	17	18	20.4	20.9	21.3	20	18.6	18.4	18.7	18.9	17.9	16.3	**18.8**
Gorgora	1830	20	20.8	22.7	23	22.7	21	19.2	18.7	19.4	19.5	19.2	19	**20.4**
Yifag	1800	20	20.8	22.7	23	22.7	21	19.2	18.7	19.4	19.5	19.2	19	**20.4**

Table 1.2 Regression analysis of temperature on altitude

Nọ	Station	Altitude=x	Temp=y
1	Debre Tabor	2690	15.8
2	Gassay	2808	13.1
3	Wereta	1980	19.4
4	Bahir Dar	1770	18.8
5	Gorgora	1830	20.4
6	Yifag	1800	20.4

Output:-

Correlation coefficient------------------- **-0.94**

Constant-------------------------------------- **30.53**

Altitude coefficient-------------------------- **-0.01**

Number of observations----------------- **6**

Degrees of freedom----------------------- **5**

Regression equation:- y= 30.53 – 0.006x

1.3.3 Other meteorological elements

Data on relative humidity, wind speed, sunshine hours and pitch evaporation are available only for Debre Tabor. The maximum relative humidity occurs from June to October with mean value of 92 percent. The minimum occurs form January to May with mean value of 63 percent.

The maximum wind speed and sunshine hours takes place from February to June with average value of 1.4 m/sec and from November to May with mean value of 8.2 Ho0urs respectively.

Table 1.3:- Synthesized mean monthly temperatures(ºC) of the micro-catchments

Nọ	Stations	Catchment	Alt.(m)	Jan	Feb	Mar	apr	may	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Mean
1	Arb gebeya	Enkulal(micro)	1800	20.2	20	21.2	21.2	20.9	20.6	18.7	**18.4**	18.8	19	18.4	18.5	**19.73**
2	Debre Tabor	Baskura(micro)	2690	14	15.2	16	16.3	16	14.7	13	**13.1**	13.5	13.6	13.7	13.7	**14.4**
3	Wereta	Rib(Sub)	1980	18	19.1	20.4	20.6	20.5	19	17.5	**17.3**	17.7	18.3	18.1	17.8	**18.7**
4	Gassay	Kantay(micro)	2808	13.9	14.7	14.7	14.5	14.5	14.3	13	**12.8**	13.1	13.2	12.8	12.9	**13.7**
5	Hamusit	Gumera(sub)	2480	13.9	15	17	17.5	17.8	16.7	15.5	**15.4**	15.6	15.8	15	13.6	**15.7**
6	Gelawdewos	Enkulal(micro)	2490	15.6	15.8	16.8	16.8	16.6	16.3	14.8	**14.5**	14.9	15	14.5	14.7	**15.6**
7	Bahir Dar	Enguli(mikro)	2360	14.5	15.7	17.8	18.2	18.9	17.5	16.2	**16.1**	16.3	16.5	15.6	14.2	**16.4**
8	Gassay	Zefie(micro)	2884	13.5	13.4	14.2	14.2	14	13.8	12.5	**12.3**	12.6	12.7	12.3	12.4	**13.2**

Maximum and minimum temperature (synthesized) in ºC)

Station	Temperature	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Mean
Arb Gebeya	**Maximum**	**32.27**	30.8	31.5	31.2	30.4	29.2	26.4	25.6	**27**	28.4	28.8	29.5	**29.26**
	Minimum	**9.7**	10.6	12.4	12.7	13	13.4	12.4	12.5	**12.1**	11	9.5	8.9	**11.52**

1.4 Data Availability and Data Gaps

Out of the five micro-catchments, there are meteorological stations located at Debre Tabor, Arb Gebeya and Gassay which represent Baskura, Enkulal and Kantai/Zafie respectively. Also some stations are available outside and/or nearby the micro-catchments: these are at Wereta, Addis Zemen, Hamusit, Merawi, Adet and Sekela.

Table 1.4

No.	Stations	Sub-catchments	Micro-catchments	Elements	No. of years
1.	Debre Tabor	Rib/Gumera	Baskura	All elements	More than 10 years
2.	Arb Gebeya	Gumera	Enkulal	All elements	Less than 10 years
3.	Gassay	Rib	Kantai/Zefie		10 years
4.	Weretta	Rib	-		More than 10 years
5.	Addis Zemen	Rib	-		More than 10 years
6.	Hamusit	-	Enkulal		More than 10 years
7.	Merawi	Gilgel Ababy			More than 10 years
8.	Adet		Engule		Less than 10 years
9.	Sekela	Jema	Engule		Less than 10 years
10.	Mekane Iyesus	Wonka	Enkulal		Less than 10 years

The five micro-catchment project areas are situated in three sub-basins of the Abbay Basin and these are Rib, Gumera and Jema. The locations of the sub-catchments and their respective micro-catchments/project areas are indicated on the Maps 1 and 2 in Annex 3.

Table 1.5 Micro-catchments and some characteristics

No	Micro-catchment	Average	Area (km^2)	Length (km)	Average Slope
1.	Baskura	2310	104.72	8	0.05
2.	Engule	2335	239.9	14	0.04
3.	Enkulal	2390	176.1	8	0.013
4.	Kantai	2770	110.1	12	0.05
5.	Zefie	2520	134.5	12	0.04

The Debre Tabor meteorological station is the only station with long-term data which can represent Baskura project area. For Kantai, Zefie and Enkulal mirco-catchments, Arb Gebeya and Gasay stations are available with ten years data only. There is no station available to represent the Jema sub-catchment.

2. Rainfall Analysis

2.1 Rainfall Analysis

Before any rainfall data is utilized, analysis is to be performed. Discontinuity of monthly values existed in all the six stations. These missed data were replaced by data filling techniques. The test for consistency and homogeneity of the data and also stability of mean and variance values were performed by using F-test and t-test.

2.2 Filling the Missing Rainfall Data

Arb Gebeya, Debre Tabor, Hamusit, Gasay, Wereta and Merawi stations with monthly rainfall of 9, 20, 16, 10, 24 and 2 years data were available from NMSA. Unfortunately, the available data shows discontinuity and there existed lots of missing data which hindered proper statistical analysis. Therefore, for all stations the monthly missing values were replaced by station year method. Since the available monthly rainfall data for Merawi station is only for 2 years, it was rejected for further analysis.

2.3 Data Quality Tests

Data quality tests were made using Student t-test and Fisher F-test. Homogeneity and stationary tests were performed on data for Debre Tabor, Wereta and Gasay. Critical levels of significance ($\propto$ = 5%) and Markov auto-correlation order one [r(1)] were all in an acceptable range.

Table 1.6 :- Debre Tabor rainfall homogeniety & stationary tests (t-test and F-test)

Group-1

No	Year	Rain(mm)
1	1985	1139.6
2	1986	1566.6
3	1987	1194
4	1988	1618.2
5	1989	1302.7
6	1992	1250.7
7	1993	1575.9
8	1994	1794.5
9	1995	1258.3

Group-2

No	Year	Rain(mm)
1	1996	1480.1
2	1997	1998.4
3	1998	1482.9
4	1999	1617.5
5	2000	1645.6
6	2001	1470.9
7	2002	1100.7
8	2003	1315.7
9	2004	1198.1

t-test value = 0.287797

F-test value = 0.690919

From the above result, the Debre Tabor rainfall satisfies both tests & is acceptable.

2.4 Probability Analysis

2.4.1 Empirical probability

For hydro-meteorological practice, the Weibel method was chosen to deal with measure of chance or likelihood based on the sample data. It interprets the past data in terms of future probabilities of occurrence.

2.4.2 Theoretical probability analysis

This is based on a mathematical model to fit the empirically plotted points for extrapolation purpose.

Table 1.7 Regression Analysis of Rainfall and Altitude

Station	Rain = y	Altitude (m) = x	LogY	LogX
Arb gebeya	842.7	1800	2.925673	3.2552725
Debretabor	1445	2690	3.159868	3.4297523
Wereta	1381.3	1980	3.140288	3.2966652
Hamusit	1646.4	2480	3.216535	3.3944517
Merawi	1064.9	1720	3.027309	3.2355284
Yifag	1007.1	1800	3.003073	3.2552725

Output:

Correlation. Coefficient -----------	0.822408	0.8187082
Constant---------------------------------	633.3355	
Altitude Coefficient---------------------	0.619064	
No of observations(n)----------------	6	
Degrees of freedom------------------	5	

Regression Equation :-- Y = 0.62X - 55.5

2.5 Rainfall and Altitude Regression Analysis

Meteorological stations in and around the 5 micro-catchments have been considered. Their locations, mean annual rainfall, altitudes and regression outputs are shown in Table 1.8

Table 1.8 Corrected monthly rainfall values for the micro-catchments (mm) after regression analysis

Nọ	Station	Elevation	Micro-catchment	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Mean Annual
1	**Arb Gebeya**	**1800**	**Enkulal**	21.1	13.3	57.8	65.6	33.3	55.6	337.9	331.2	78.9	35.6	16.7	15.6	**1060.6**
2	**Debre Tabor**	**2690**	**Baskura**	6.4	4.8	38.6	53.1	104.6	183.5	447.5	437.9	201.2	91.8	25.8	16.1	**1612.4**
3	**Gasay**	**2808**	**Kantay**	8.4	6.7	33.5	62	103.9	184.3	484.3	422.3	194.4	102.2	33.5	38.6	**1685.6**
4	**Hamusit**	**2480**	**Gumera**	0	0	13.4	20.9	64.2	200	423.8	371.6	197	80.6	13.4	0	**1482.2**
5	**Wereta**	**1980**	**Rib**	0	0	3.6	19.4	65.5	166.1	363.7	360	164.9	57	10.9	0	**1172.2**
6	**Gelawdewos**	**2490**	**Enkulal**	28.5	18	77.9	88.4	44.9	74.9	455.3	446.3	106.3	47.9	22.5	21	**1488.4**
7	**Lij Aboja Michael**	**2360**	**Enguli**	3	2.1	13	34.6	111	250	390	335.2	191.5	75.6	13.2	6	**1407.8**
9	**Lul Michael**	**2884**	**Zefie**	8.6	6.9	34.3	63.5	106.5	188.9	496.3	432.8	199.2	104.8	34.3	39.5	**1732.7**

Rainfall values of the project area or the micro-catchments is shown on Table 1.9

Table 1.9 :- Regression Analysis of Rainfall and Altitude

Station	Rain = y	Altitude (m) = X	Log y	Log x
Arb gebeya	842.7	1800	2.925673	3.2552725
Debretabor	1445	2690	3.159868	3.4297523
Wereta	1381.3	1980	3.140288	3.2966652
Hamusit	1646.4	2480	3.216535	3.3944517
Merawi	1064.9	1720	3.027309	3.2355284
Yifag	1007.1	1800	3.003073	3.2552725

Output	Correlation coefficient-------------	0.822408	0.8187082
	Constant-----------------------------	633.3355	
	Altitude coefficient----------------	0.619064	
	Nọ of observations(n)-------------	6	
	Degrees of freedom---------------	5	

Regression eqation: Y = 0.62X - 55.5

2.6 Rainfall Reliability

From the probability analysis by Weibel formula, 80% rainfall reliability of the micro catchments is calculated and shown in Table 1.10.

Table 1.10 80% rainfall reliability of the micro-catchments

N0	Stations	Micro-catchment	80% reliability
			mm
1	Arb Gebeya	Enkulal	754
2	Debre Tabor	Baskura	1,197
3	Gassay	Kantay	1,129
4	Hamusit	Gumera sub-catchment.	1,380
5	Wereta	Ribb sub-catchment	
6	Gelawdewos	Enkulal	1,099
7	Lij Aboja Michael	Engule	1,042
8	Lul Michael	Zefie	1,282

3. River Flow Analysis

3.1 Data Availability and Quality

Hydrological data was requested from the Hydrology Department of the Ministry of Water Resources. Data was also taken from ”The Abbay River Basin and Integrated Development Master Plan Study, Volume II, Water Resources, Phase 2”. The information in the form of soft copy included flow and sediment data of the Ribb River at Addis Zemen, and the Gumera River at Gumera from the years 1960 to 1996 and 1964 to 1996 respectively. Regarding the Jema sub-catchment, no information is available. Moreover, no hydrometric data is available from the micro-catchments and project areas.

Table 1.11 Hydrometric stations and their quality in the sub-basins

No	Subbasin/River	Station	Data availability	Station Quality
1.	Ribb	Addis Zemen	Good	Poor
2.	Ribb	Gasay	Medium	Poor
3.	Gumera	Maksegnit	Medium	Poor
4.	Gumera	Bahir Dar	Good	Medium
5.	Jema	Mouth	Nil	Unknown
6.	Jema	Insaro	Nil	Unknown
7.	Jema	Lemi	Nil	Very good

3.2 Methodology of River Flow Analysis

Surface water resource potential assessment is the main component to be determined. Since all the five micro-catchments are not gauged, the main method to be adopted is regionalization method. It is a hydrological practice to simulate flow data of ungauged catchments by considering gauged basins located within the same sub-basins with sufficient period of observations.

Therefore, the flow of the Baskura and Kantai micro-catchments is simulated by considering the long-term average flow of the Ribb River at Addis Zemen. Whereas the flow of Zefie and Enkulal is simulated by considering the long-term average flow of the Gumera River at Bahir Dar station. Since no gauged river is available in the Jema sub-basin, Koga river flow at Merawi station is utilized to simulate the flow of Enguli micro-catchment.

3.3 Regionalization Method

Flow generation of the un-gauged micro-catchments is made by considering the gauged rivers which are situated either wit in the same sub-basin or the neighbouring sub-basin. The basic criteria in applying this method is:

- ❑ Hydro-meteorological homogeneity; and
- ❑ Similarity of run-off generation of actors such as Rainfall (P), River slope(s) and drainage Area (A).

The relationship is:

$$\frac{Q_g}{A_g\, S_g\, P_g} = \frac{Q_{ug}}{A_{ug}\, S_{ug}\, P_{ug}}$$

Where,

- Qg and Qug are annual flow of gauged and ungauged rivers respectively;
- Ag, Sg and Pg are catchment area, average river slope and mean annual rainfall of gauged catchments respectively;
- Aug, Sug and Pg are catchment area, average river slope and mean annual rainfall of un-gauged catchments;

Table 1.12 Some characteristics of the rivers

No	River	Area (km²)	Rainfall (mm)	Slope
1	Rib	1,592	1679.2	0.12
2	Gumera	1,394	1623.5	0.11
3	Koga	244	1624.5	0.08
4	Baskura	105	1609.8	0.04
5	Enkulal	176	1111.4	0.02
6	Kantay	110	1675.9	0.05
7	Engule	240	1425	0.04
8	Zefie	135	1718.4	0.04

3.4 Dependable Flow

The monthly mean flows of the rivers of the micro-catchments have been synthesized by the method of regionalization. The dependable mean monthly flows are also synthesized by Weibel plotting position method of the gauged catchments.

The probability analysis of the gauged catchments are attached shown on the next page.

$$Q_{ug} = Q_g \frac{A_{ug}\, S_{ug}\, P_{ug}}{A_g\, S_{ug}\, P_g}$$

For, Baskura, $\frac{A_{ug}\, S_{ug}\, P_{ug}}{A_g\, S_{ug}\, P_2} = \frac{104.72 \times 0.04 \times 1609.8}{1592 \times 0.12 \times 1679.2} = 6743$

$Q_{Baskura} = 0.021\, Q_{Rib}$

$\therefore$ let, $\frac{A_{ug}\, S_{ug}\, P_{ug}}{A_g\, S_{ug}\, P_g} = C$

$\therefore$ for Baskura micro-catchment, C = 0.02

Based on the above Regionalized method, the synthesized flows of the rivers of the mirco-catchments are shown on Table 1.13

Table 1.13: 80% Dependable flow (m³/sec) of the Rivers of the Micro-catchments

No	Micro-Catchments	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Annual Mean
1	Baskura	0.005	0.004	0.003	0.003	0.005	0.03	0.34	0.74	0.34	0.07	0.03	0.02	0.13
2	Enkulal	0.03	0.014	0.014	0.01	0.014	0.06	0.71	1.58	0.87	0.32	0.1	0.05	0.32
3	Kantai	0.01	0.005	0.005	0.005	0.01	0.05	0.51	1.1	0.5	0.1	0.05	0.02	0.2
4	Engule	0.41	0.34	0.3	0.25	0.28	0.69	3.49	5.76	3.44	1.61	0.87	0.58	1.53
5	Zefie	0.06	0.04	0.03	0.02	0.04	0.13	1.57	3.65	2.01	0.75	0.22	0.12	0.72

Table 1.14:- Values of Multiplying Constant (C) For the Micro-Catchments

No	Mic.Catch.	Gauged Catchment	C
1	Baskra	Ribb	0.02
2	Enkulal	Gumera	0.016
3	Kantay	Ribb	0.029
4	Engule	Koga	0.4
5	Zefie	Gumera	0.037

Table 1.15:- Synthesized Mean Monthly Flow (m³/sec) of the Rivers of the Micro-Catchments

No	River	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual Mean
1	Baskura	0.01	0.007	0.006	0.006	0.01	0.06	0.7	1.5	0.7	0.14	0.07	0.03	0.25
2	Enkulal	0.04	0.02	0.02	0.013	0.02	0.08	1	2.21	1.22	0.45	0.14	0.07	0.45
3	Kantai	0.02	0.01	0.01	0.01	0.02	0.09	1.03	2.24	1	0.21	0.1	0.04	0.4
4	Engule	0.53	0.44	0.38	0.32	0.37	0.9	4.56	7.53	4.5	2.1	1.14	0.76	2
5	Zefie	0.08	0.054	0.04	0.03	0.05	0.18	2.2	5.12	2.82	1.05	0.31	0.16	1.01

4. Flood Analysis

Since there is no observed flood data in the micro-catchments, the daily maximum precipitation data recorded at Debre Tabor, Wereta and Merawi stations are considered for frequency analysis. The non-availability of flood data forced the author to adopt empirical methods to estimate the peak flood at different return periods. Keeping in mind the size of the micro-catchments, a design flood up to 100 years return period is selected.

4.1 Maximum Design Precipitation

The Debre Tabor, Wereta and Merawi rainfall stations are considered for the frequency analysis of maximum daily rainfall data. It is fournd that Gumble extreme value method is suitable for determining the 100 year return period precipitation value.

Table 1.16 Peak daily rainfall (P max)

No	Micro-catchment	Return Period (T)	Pmax (mm)
1.	Baskura	25 50 100	106 115 125
2.	Kantai	25 50 100	106 115 125
3.	Zefie	25 50 100	118 128 141
4.	Enkulal	25 50 100	118 128 141
5.	Engule	25 50 100	95 101 110

4.2 Flood Estimation

In the absence of actual peak flood data the design flood can be computed by:

a) Rational method
b) Creager method
c) Unit Hydrograph method

But due to time constraint, only the first method is considered.

4.3.1 Rational Method

This method is based on the concept that for storms of uniform intensity distributed over the basin, the maximum rate of run-off is equal to a certain percentage of rainfall intensity, when the entire basin is contributing at the outlet. This condition is met after a time Tc (the time of concentration) and is expressed as:

$\therefore$ Qp = 0.278 CIA

Where, Qp = Peak run-off (in m^3/sec),

C= Run-off co-efficient = 0.57

I = Rainfall intensity (mm/hr) of storm, the duration of which is equal to Tc

A = Area (km^2)

Table 1.17:- Peak flow (m^3/sec) for the project areas

No	Micro-catchment	Return Period (T)	Pmax (mm)
1.	Baskura	25 50 100	777 845 919
2.	Kantai	25 50 100	814 880 957
3.	Zefie	25 50 100	1,100 1,193 1,313
4.	Enkulal	25 50 100	1,460 1,566 1,725
5.	Engule	25 50 100	1,584 1,704 1,884