Use of adaptable empirical equations for Potential Evapotranspiration estimation and Soil Moisture Balance approaches for estimating Actual Evapotranspiration

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ABSTRACT

Evapotranspiration is an important component of the hydrologic cycle. In this research, an attempt has been made to estimate the potential and actual evapotranspiration combining different approaches that can be easily adapted in many of the irrigation projects found in the Tigray region of Ethiopia. There is no established weather station in these project areas. Therefore, it was not possible to use more complicated equations like the Penman family to estimate the potential evapotranspiration that can be used during planning and operation of irrigation projects. Thus, as an alternative in this research, an empirical equation that uses less data input has been adapted and then calibrated with the estimated values from the Modified Penman equation.

To undertake this study three reference weather stations, having better data set of recent years, were selected. The potential evapotranspiration is estimated by the Hargreaves and Samani, as well as the Modified Penman equations. The potential evapotranspiration estimated by the two methods for the three reference stations were fitted into a straight line resulting equation with an acceptable correlation of (R^2) = 0.8**.** Therefore, in the absence of other actual measured data for the irrigation projects, the potential evapotranspiration can be estimated by the Hargreaves and Samani method and corrected with the equation developed from the calibration procedure mentioned above. Furthermore actual evapotranspiration is also calculated for the watersheds of two irrigation projects (Laelay Wukro and GumSelassa).

To undertake this exercise the landuse and soil maps of each watershed were prepared at a 1:50,000 scale and aggregated to get a combined landuse and soil for each watershed. Depending on the soil type, the available soil moisture per depth for each landuse was fixed, considering an acceptable rooting depth for the corresponding landuses. Then spreadsheets were developed to determine the monthly water balance taking into account that soil moisture storage withdrawal linearly decreases with decreasing soil moisture, i.e. as the soil becomes dry it becomes more difficult to remove water from the soil and hence less water is available for actual evapotranspiration. Accordingly, the actual evapotranspiration is found to be 627 and 442 mm year^{-1} for Laelay Wukro and GumSelassa irrigation projects respectively, which is about 44% and 32% of the potential evapotranspiration.

Keywords
Evapotranspiration, Potential evapotranspiration, Actual evapotranspiration, Hargreaves and Samani, Modified Penman

1. INTRODUCTION

Tigray is located in the northern part of Ethiopia and is solely dependent upon rainfall for agriculture and other water needs. Often here the practice is growing one crop per year and the harvests are insufficient due to less rainfall. In the past decade many micro-dam irrigation project have come up due to the effort of governmental and non-governmental organizations. This paved the way for sustainable irrigation. Design of irrigation projects demands good set of data to come up with a best and reliable design. Availability of good data sets is also equally important during project operation.

All most all irrigation projects found in the region are designed with the limited data which is available in a near by or adjacent locations. There is no any established metrological station yet in most of irrigation projects. Thus the use of empirical equation and methodologies that demand lesser data input is still paramount in project planning and operation.

More input is necessary for successful planning and operation of irrigation projects. Evapotranspiration is one of the inputs and is an important component of the hydrologic cycle. Proper irrigation operation can only be achieved with successful estimation of both potential and crop evapotranspiration.

Evapotranspiration is not easy to measure and often demands accurate device to measure physical parameters or soil water balance in lysimeters. A large number of empirical or semi-empirical equations have been developed for assessing a crop or reference evapotranspiration from meteorological data. Each method can only work for specific location or climate conditions. FAO recommends Penman method for estimation of potential evapotranspiration. But this method needs extensive data set. Thus at this moment in Tigray region it is not possible to use Penman method for planning or operation purpose. But in long term the strategy should be to establish more weather stations and develop calibration equations.

In this research an attempt has been made to estimate the potential evapotranspiration and actual evapotranspiration based on simple, less data input and adaptable techniques.

2. DESCRIPTION OF THE STUDY AREA

2.1Project Location

The selected study areas are located in Tigray region north of Ethiopia, which are about 35km to south and 45km towards North for GumSelassa and Laelay Wukro respectively. The watershed area for GumSelassa is 24.6km^2 and it is bounded geographically (UTM) 558 832 - 563832East and 1457466- 1466962North. Similarly the Laelay Wukro water shed area is 9.6km^2 and its geographical location is 566123 - 568705East and 1524978 - 1523490North.
The reference metrological stations (Adigirat and Sinkata) used for computation of potential evapotranspiration are located about 120km and 75km towards north from Mekelle. Meanwhile Mekelle Quiha is about 10km south of Mekelle.

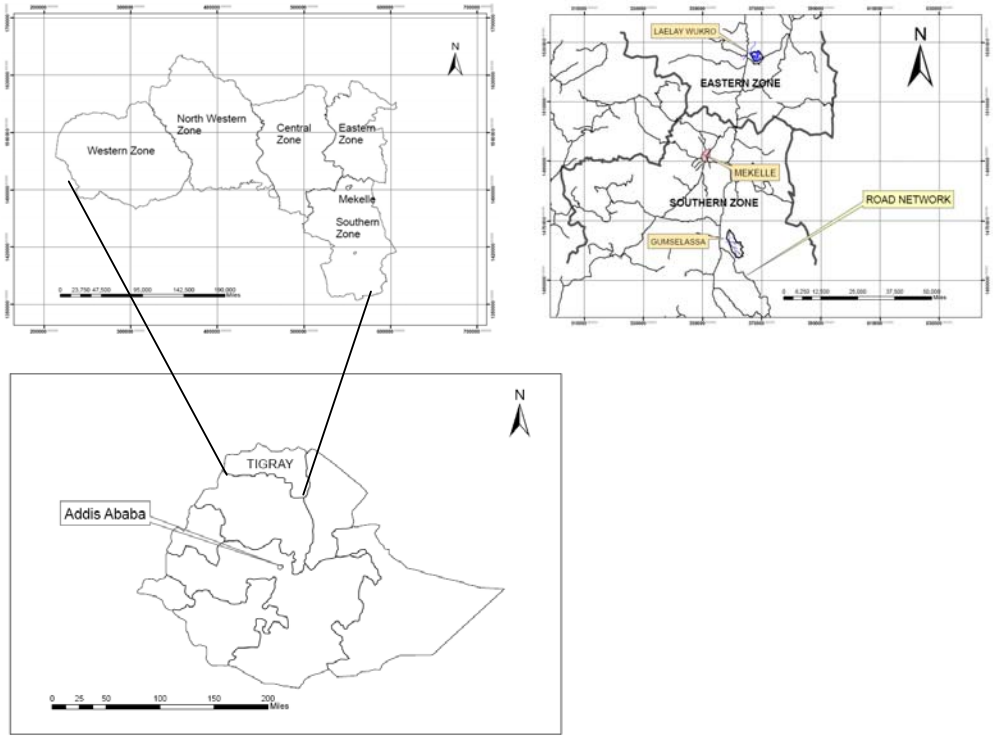

Fig 2.1 Location of the study area

3. METHODOLOGY

3.1 Data collection

Primary data has been collected during the fieldwork and relevant secondary data also collected from different offices found in the region. Existing topographic maps and aerial photos of 1:50000 scale were also used as base maps to prepare drainage, land use, soil and slope maps. The mentioned thematic maps are produced using Arcview 3.3 and ILWIS 3.3 academic software's.

Both project areas consist of weather stations that can measure rainfall and temperature with greater accuracy. Rainfall and temperature data are sufficient to estimate potential evapotranspiration by Hargreaves and Samani, where as for the Penman additional data were also collected from other three stations that will be explained in the later discussions.

3.2 Data Processing

In order to determine the particle size distribution of soils found in both watersheds, extensive soil sampling were taken that would describe the different types of soils. Accordingly the collected samples 17 in number for GumSelassa and 11 for Laelay Wukro were analyzed in the Geotechnical and soil physics laboratories of Mekelle University to identify both engineering and physical properties of soils. The United States Department of Agriculture (USDA) soil texture classification was used as basis for classification. The textural classification, the field capacity and welting point obtained from sample analysis were the fundamental inputs used to fix the water holding capacity of all soils found in both watersheds.

The land use is defined based on detailed analysis of aerial photos and complementary field verification. Based on each land use type root zone depths were estimated to determine the maximum water holding capacity of each soil in the active root zone. The maximum water holding capacity of each soil is used for the computation of actual evapotranspiration.

In this research, Hargreaves and Samani has been adapted to estimate potential Evapotranspiration, that uses less data input and then calibrated with the estimated values from the Penman equation. For this exercise three reference weather stations (Mekelle Quiha, Adigirat, and Sinkata) having better set of data are selected for the estimation of potential evapotranspiration by both methods. A calibration equation was then developed that can be used for other projects.

The Hargreaves and Samani empirical equation is given by:

$$ET_o = 0.0023(T_{mean} + 17.8)(T_{\max} - T_{\min})^{0.5} R_a \qquad (3.1)$$

Where ET_o- reference Evapotranspiration (mm month^{-1})
T_{mean} - mean monthly temperature (^{o}C)
T_{max} – mean monthly maximum temperature (^{o}C)
T_{min}- mean monthly minimum temperature (^{o}C)
R_a – extraterrestrial radiation (mm day^{-1})

Similarly the Penman method to estimate ET_o is given by:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (3.2)$$

Where ET_o- reference evapotranspiration (mm day^{-1})
R_n – net radiation at the crop surface (MJm^{-2}day^{-1})
G – soil heat flux density (MJm^{-2}day^{-1})
T_{mean}- mean monthly temperature (^{o}C)
u_2 – wind speed at 2m height (ms^{-1})
e_s – saturation vapour pressure (kPa)
e_a – actual vapour pressure (kPa)
(e_s- e_a) - saturation vapour pressure deficit (kPa)
Δ – slope vapour pressure curve (kPa^{o}C^{-1})
γ - psychrometric constant (kPa^{o}C^{-1})

Based on the corrected potential evapotranspiration an actual evapotranspiration is also calculated for the watersheds of two irrigation projects. The required parameters to determine actual evapotranspiration using this model are mean monthly rainfall, mean monthly potential evapotranspiration, water holding capacity of the dominant soil type and monthly soil moisture storage. The landuse and soil maps of each watershed were aggregated to get a combined landuse and soil for each watershed. Depending on the soil type, the available soil moisture per depth for each landuse was fixed, considering an acceptable rooting depth for the corresponding landuses. Then spreadsheets were developed to determine the monthly water balance taking into account that soil moisture (Equation 3.3) storage withdrawal linearly decreases with decreasing soil moisture, i.e. as the soil becomes dry it becomes more difficult

to remove water from the soil and hence less water is available for actual evapotranspiration. The actual evapotranspiration of the total watershed is determined by adding the weighted actual evapotranspiration for a single unit having a specific landuse and soil.

$$SM_i = SM_{i-1} - \left[abs(P_i - ETo_i)\ x\ (\frac{SM_{i-1}}{TAM}) \right] \qquad (3.3)$$

Where SM_i = Monthly soil moisture (mm depth^{-1})
SM_{i-1}= Soil moisture previous month (mm depth^{-1})
abs = absolute value
P_i = Monthly precipitation (mm month^{-1})
ETo_i = Monthly potential evapotranspiration (mm month^{-1})
TAM = Available soil moisture for given soil type (mm depth^{-1})

$$ETac(watershed) = \frac{\sum_i^n ETac\ x\ A_i}{\sum_i^n A_i} \qquad (3.4)$$

Where *ETac* (watershed) = actual potential evapotranspiration of total watershed
$ETac_i$ = actual potential evapotranspiration of single unit with specific soil and landuse
A_i = area of a single unit with specific soil and landuse

4. RESULTS AND DISCUSSION

4.1 Soils

The soils of GumSelassa watershed is dominated with clay and fine textured soils; where as Laelay Wukro is mainly composed of silty clay loam and silt loam. Permeability test carried on clay soils are found to be between 1.12 x 10^{-7}ms^{-1} to 8.9 x 10^{-9}ms^{-1}.Soil maps prepared for both watersheds is shown in Fig.4.1 and Fig 4.2.

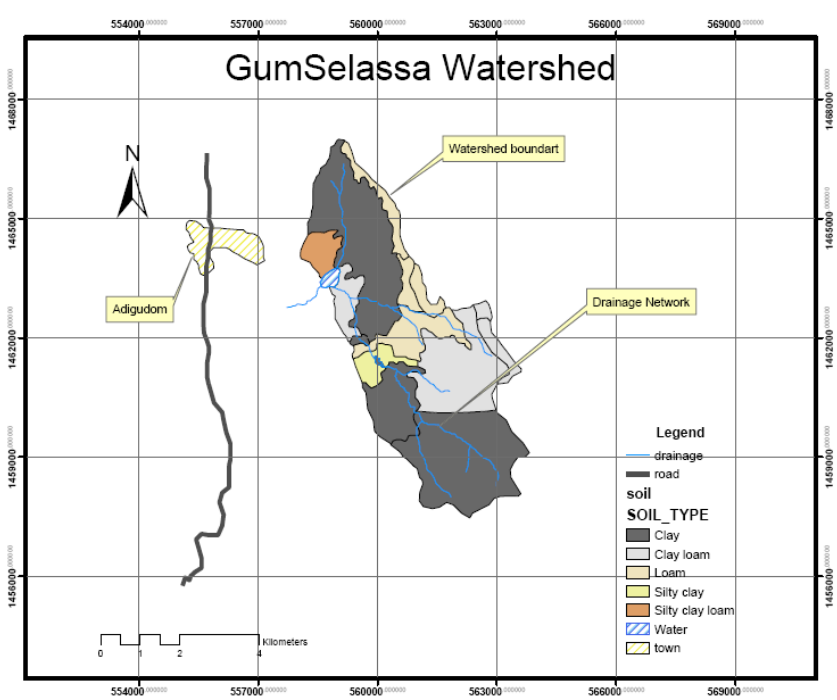

Fig 4.1 GumSelassa soil map

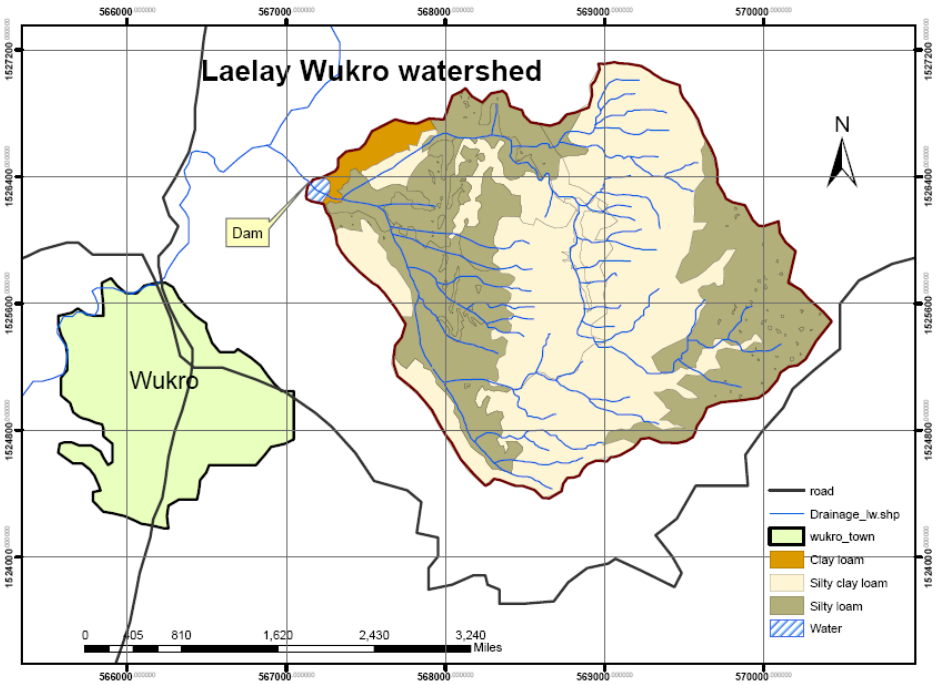

Fig 4.2 Laelay Wukro soil map

4.2 Landuse

The watershed area of GumSelassa is dominated with cultivable land, constituting about 92%.Unlike GumSelassa, Laelay Wukro watershed is composed of cultivated land (40.4%), Bush land (38.9%) and area closure (17.3%).

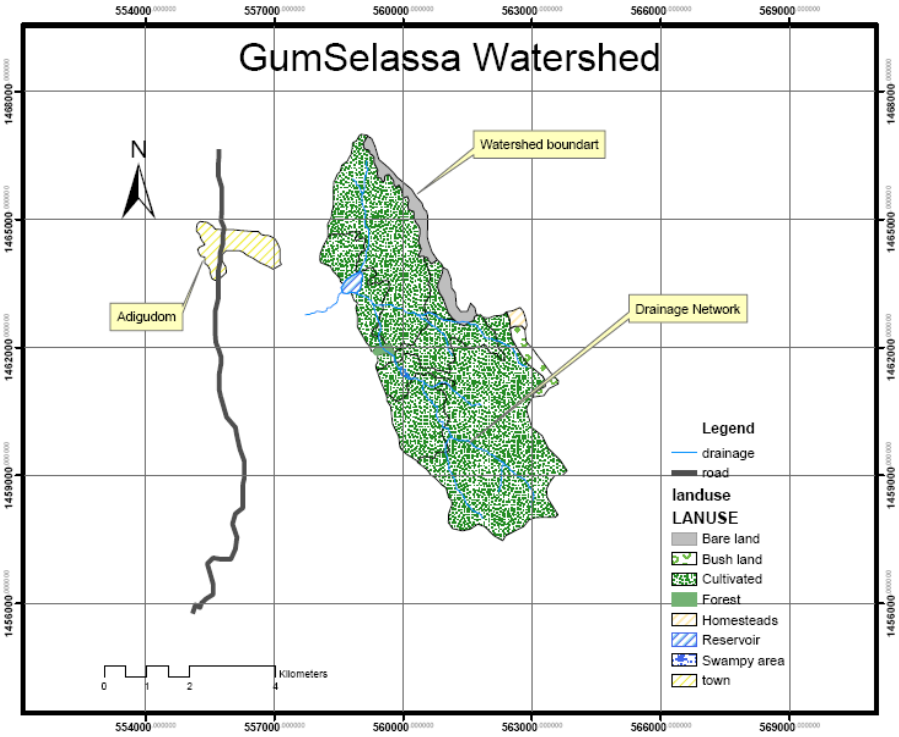

Fig 4.3 GumSelassa landuse map

Table 4.1 Landuse distribution of Laelay Wukro watershed

Landuse type	Area coverage (%)	Remark
Cultivated land	40.4	
Bush land	38.9	
Area closure	17.3	A combination of grass land and small trees which is protected from grazing and tree cutting
Forest	0.8	
Grazing land	1.8	
Homesteads	0.7	

4.3 Slopes

Slope maps of both watersheds were also prepared with ILWIS 3.3 Academic. Watershed of Laelay Wukro is dominated with steep slopes compared to GumSelassa. The mean slopes are 25.7% and 3.2% for Laelay Wukro and GumSelassa respectively.

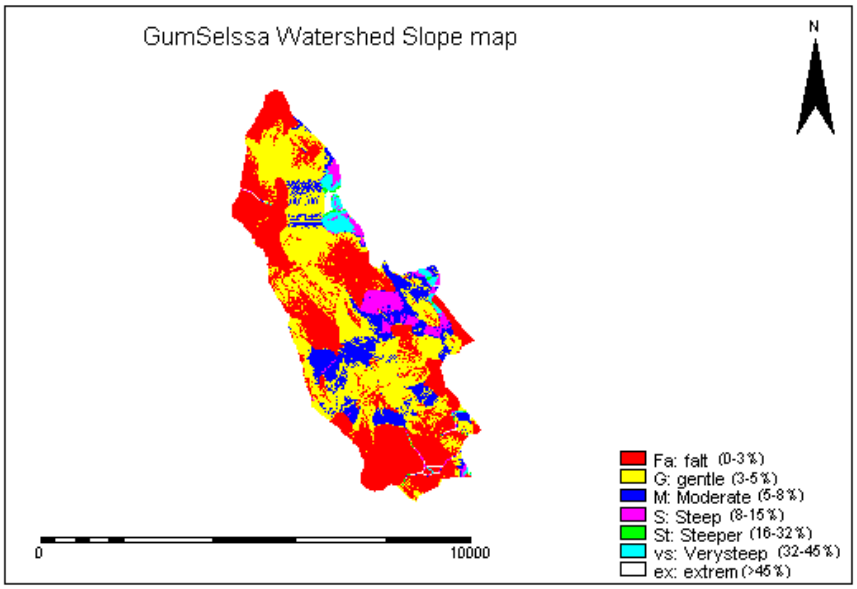

Fig 4.4 GumSelassa slope map

4.4 Rainfall

Rainfall used for the computation of actual potential evapotranspiration is measured at 5min interval with tipping bucket rain gage. The total annual rainfall measured in GumSelassa is 538.2mm and 702.8mm for Laelay Wukro. Monthly rainfall computed for both stations is shown below. The daily rainfall distribution is also shown in Fig 4.5 and Fig 4.6. The figures depicts that about 92-93% of the annual rainfall occurs during the months of June, July, August and September.

Table 4.2 Monthly rainfall, year 2007 (mm)

Project name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
GumSelassa	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197	44.6	0.0	0.0	2.2	538.2
Laelay Wukro	0.0	8.4	13.4	26.6	4.2	81.2	285.2	210.4	81.4	0.0	0.0	0.0	702.8

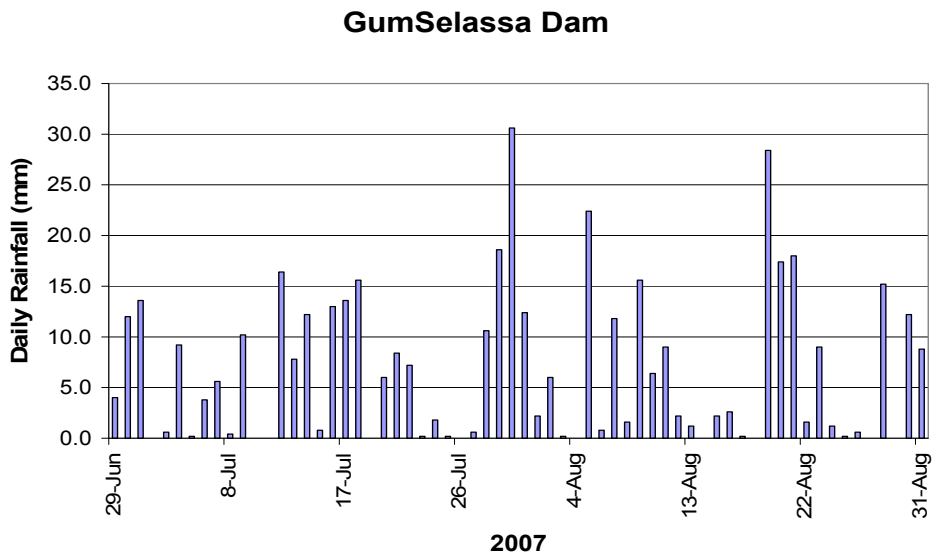

Fig 4.5 Daily rainfall (mm)

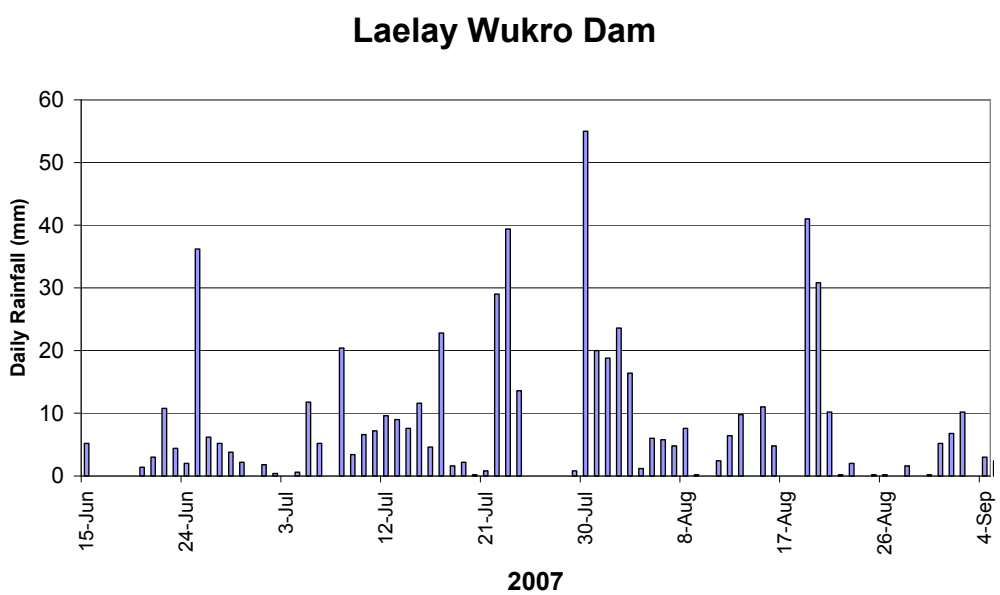

Fig 4.6 Daily rainfall (mm)

4.5 Temperature

The temperature data used for calculation of potential evapotranspiration is measured at the weather stations established at each project location. There is considerable variation of temperature between mean maximum monthly temperature and mean minimum temperature. However, there is no significant variation in monthly mean temperature.

Table 4.3 Mean monthly temperature, year 2007 (^{o}C)

Project Name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
GumSelassa	17.3	18.6	19.3	20.2	21.4	20.6	19.3	18.3	18.7	17.8	17.7	17.4
Laelay Wukro	17.4	19.7	20.9	21.8	23.2	20.6	17.5	17.4	16.9	18.6	17.5	16.2

4.6 Wind speed

The wind speed and relative humidity and sunshine hours measured at the reference stations are used for the calculation of potential evapotranspiration by the Penman method.

4.7 Evapotranspiration

4.7.1 Potential Evapotranspiration

In this research an attempt has been made to estimate potential evapotranspiration by two empirical methods for three reference stations in the region for three years. The potential evapotranspiration is estimated by the Hargreaves and Samani, as well as the Penman equation. The potential evapotranspiration estimated by the two methods for the three reference stations were fitted into a straight line resulting equation with an acceptable correlation of (R^2) = 0.8

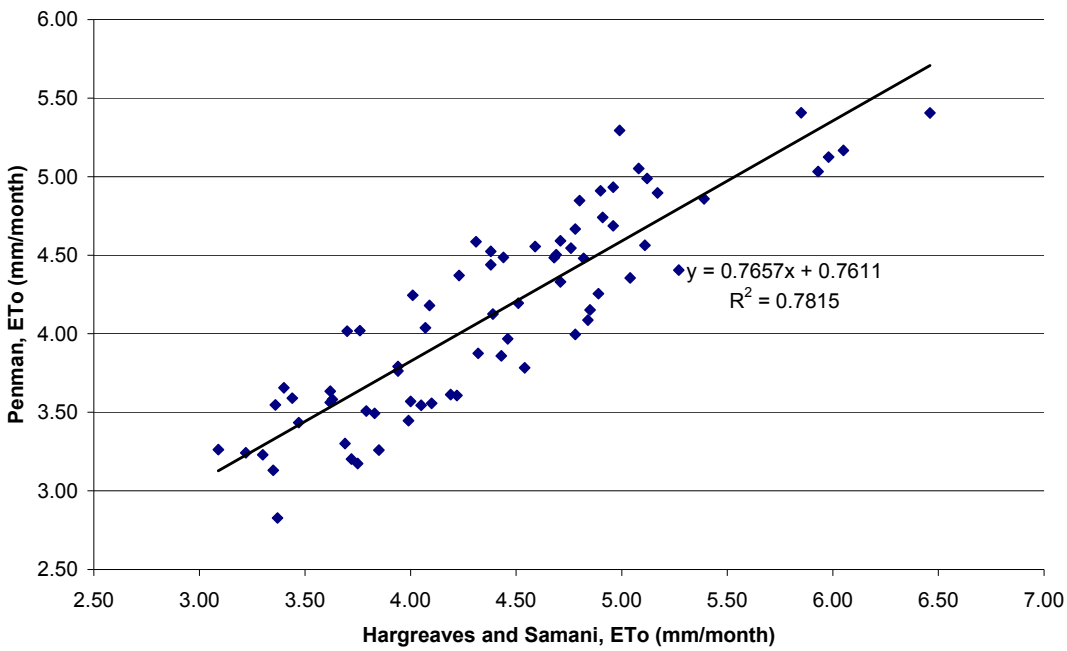

Fig 4.7 Fitting line for potential evapotranspiration by Penman and Hargreaves and Samani

The developed equation (ET_o= 0.7657ET_{oHar} + 0.7611) can be used to correct the potential evapotranspiration estimated by Hargreaves and Samani and also where necessary for planning purposes in the absence of better estimation in the project areas in the region. Tables 4.4 and 4.5 indicate the computed values before and after correction (calibration) for the research areas.

Table 4.4: Potential evapotranspiration before and after correction for GumSelassa, year 2007 (mm $month^{-1}$)

Project Name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Before	117	121	143	148	163	152	135	127	135	126	109	103	1580
After	113	114	133	135	148	139	127	121	126	120	106	102	1484

Table 4.5: Potential evapotranspiration before and after correction for Laelay Wukro, year 2007 (mm month^{-1})

Project Name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Before	160.1	151.9	134.3	146.7	132.7	127.3	110.6	124.0	120.3	147.8	153.1	181.1	1689.8
After	146.2	137.7	126.2	135.1	125.0	120.1	107.9	118.3	114.7	136.7	140.1	162.4	1570.4

The potential evapotranspiration basically depends on the amount of energy coming towards the earth's surface. Evapotranspiration is higher during an open sky compared to sky coved with clouds. Thus before adapting the corrected evapotranspiration found by calibration directly an adjustment has been also made to consider the effect of cloud during rainy seasons (June-September) by multiplying with sunshine hour ration. Considering 10hr as monthly average sunshine hour per day, the corresponding ratios used for correcting potential evapotranspiration during cloudy months are 0.73, 0.53, 0.54 and 0.78 for June, July, August and September respectively.

There is no sunshine hour record in GumSelassa and Laelay Wukro projects. For analysis, the mean sunshine hours recorded in Mekelle, 1992-2004 (Quiha Airport) which is about 25-40km from both locations have been used.

Table 4.6 Mean monthly sunshine hours, N (Hr) (mm month^{-1})

Description	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
N	9.7	9.7	9.0	9.2	10.0	**7.3**	**5.3**	**5.4**	**7.8**	9.4	9.6	9.8
Ration						**0.73**	**0.53**	**0.54**	**0.78**			

Accordingly the adjusted potential evapotranspiration that would be used for actual evapotranspiration for both projects is shown in table 4.7.

Table 4.7 Potential Evapotranspiration adjusted for cloud effect, year 2007 (mm month^{-1})

Project Name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
GumSelassa	117	121	143	148	163	111	72	69	105	126	109	103	1387
Laelay Wukro	146	138	126	135	125	57	64	90	115	137	140	162	1435

4.7.2 Actual Evapotranspiration

In order to estimate the actual evapotranspiration accurately, knowledge of periodic soil moisture status is necessary. But in the absence field records it is wise to look for an alternative method that can be used to estimate the actual potential evapotranspiration. In this research water balance sheet model (MaCabe, G.J., and Markstrom, S.L., 2007) has been deployed to estimate actual evapotranspiration with step wise and monthly based analysis.

The water balance analysis is carried out for different soil and landuse group and for the whole basin. The calculation tables are shown from table 4.8 through 4.14. The actual evapotranspiration for the whole basin is calculated by using equation (3.4) after computing the actual evapotranspiration for a single unit with a specific soil and landuse combination. Details of GumSelassa watershed and summary of Laelay Wukro watersheds are presented. Accordingly the annual actual evapotranspiration are 442 and 627 mm year^{-1} for GumSelassa and Laelay Wukro respectively.

Table 4.8 Soil water available (Clay), for cultivated land soil depth = 100cm and available moisture 225 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	10.0	4.7	1.9	0.7	0.3	0.2	147.8	225.0	164.6	72.4	37.3	20.6	
ΔSM	-10.6	-5.3	-2.8	-1.1	-0.5	-0.1			-60.4	-92.2	-35.1	-16.7	
ETac	11.5	7.3	10.3	14.3	16.1	35.7	72.0	69.0	105.0	92.2	35.1	18.9	487.4

Where **P** = Precipitation (mm $month^{-1}$), **ET_o** = Potential Evapotranspiration (mm $month^{-1}$), **Acc.ET_o** = Accumulated Potential Evapotranspiration (mm $month^{-1}$), **Abs** = Absolute (P-ET_o) (mm $month^{-1}$), **SM**= Soil Moisture (mm $month^{-1}$), **ΔSM=** Change in Soil Moisture (mm $month^{-1}$)

Table 4.9 Soil water available (Clay), for cultivated land soil depth = 100cm and available moisture 200 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	4.9	2.0	0.6	0.2	0.1	0.0	147.6	200.0	139.6	51.7	23.5	11.7	
ΔSM	-6.8	-2.9	-1.3	-0.4	-0.2	0.0			-60.4	-87.9	-28.2	-11.8	
ETac	7.7	4.9	8.8	13.6	15.8	35.6	72.0	69.0	105.0	87.9	28.2	14.1	462.6

Table 4.10 Soil water available (Clay loam, Silty clay loam, Silty clay and Loam), for cultivated land soil depth = 100cm and available moisture 150 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	0.3	0.1	0.0	0.0	0.0	0.0	147.6	150.0	89.6	14.3	3.9	1.3	
ΔSM	-1.0	-0.2	-0.1	0.0	0.0	0.0			-60.4	-75.3	-10.4	-2.6	
ETac	1.9	2.2	7.6	13.2	15.6	35.6	72.0	69.0	105.0	75.3	10.4	4.8	412.6

Table 4.11 Soil water available (Clay loam), for bush land soil depth = 150cm and available moisture 150 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	10.0	4.7	1.9	0.7	0.3	0.2	147.8	225.0	164.6	72.4	37.3	20.6	
ΔSM	-10.6	-5.3	-2.8	-1.1	-0.5	-0.1			-60.4	-92.2	-35.1	-16.7	
ETac	11.5	7.3	10.3	14.3	16.1	35.7	72.0	69.0	105.0	92.2	35.1	18.9	487.4

Table 4.12 Soil water available (Loam), for bare land soil depth = 15cm and available moisture 150 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	0.0	0.0	0.0	0.0	0.0	0.0	22.5	22.5	0.0	0.0	0.0	0.0	
ΔSM	0.0	0.0	0.0	0.0	0.0	0.0			-22.5	0.0	0.0	0.0	
ETac	0.9	2.0	7.5	13.2	15.6	35.6	72.0	69.0	67.1	0.0	0.0	2.2	285.1

Table 4.13 Soil water available (Clay), for forest land soil depth = 150cm and available moisture 200 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	25.7	14.6	7.4	3.8	1.7	1.3	148.9	275.0	214.6	116.3	70.2	44.5	
ΔSM	-18.8	-11.1	-7.2	-3.6	-2.0	-0.5			-60.4	-98.3	-46.1	-25.7	
ETac	19.7	13.1	14.7	16.8	17.6	36.1	72.0	69.0	105.0	98.3	46.1	27.9	536.3

Table 4.14 Soil water available (Clay loam), for homesteads soil depth = 15cm and available moisture 150 mm m^{-1}

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
P	0.9	2.0	7.5	13.2	15.6	35.6	219.6	197.0	44.6	0.0	0.0	2.2	538.2
ET_o	117	121	143	148	163	111	72	69	105	126	109	103	1387.0
P-ET_o	-116	-119	-136	-135	-147	-75	148	128	-60	-126	-109	-101	
Acc. ET_o	-512	-631	-767	-902	-1049	-1124			-60	-186	-295	-396	
Abs(P-ET_o)	116.1	119.0	135.5	134.8	147.4	75.4	147.6	128.0	60.4	126.0	109.0	100.8	
SM	0.0	0.0	0.0	0.0	0.0	0.0	22.5	22.5	0.0	0.0	0.0	0.0	
ΔSM	0.0	0.0	0.0	0.0	0.0	0.0			-22.5	0.0	0.0	0.0	
ETac	0.9	2.0	7.5	13.2	15.6	35.6	72.0	69.0	67.1	0.0	0.0	2.2	285.1

Table 4.15 Summary of actual evapotranspiration calculation for GumSelassa Project

Landuse	Soil type	Available moisture	Assumed soil depth	Available soil moisture	Area coverage	Area ration	ETac	ETac weighted
		(mm m^{-1})	(m)	(mm depth $^{-1}$)	(m^2)	(%)	(mm $year^{-1}$)	(mm $year^{-1}$)
Cultivated land	Clay	225	1.00	225	5985742	24.3	487.4	11858.6
	Clay	200	1.00	200	8049590	32.7	462.6	15133.9
	Clay loam	150	1.00	150	891465	3.6	412.6	1495.0
	Clay loam	150	1.00	150	4003178	16.3	412.6	6713.4
	Silty clay loam	150	1.00	150	804360	3.3	412.6	1348.9
	Silty clay	150	1.00	150	751830	3.1	412.6	1260.8
	Loam	150	1.00	150	2186265	8.9	412.6	3666.4
				Subtotal	**22672430**	**92.1**		
Bush land	Clay loam	150	1.50	225	505732	2.1	487.4	1001.9
Bare land	Loam	150	0.15	22.5	1178283	4.8	285.1	1365.4
Forest	Clay	250	2.00	500	94409	0.4	536.3	205.8
Homesteads	Clay loam	150	0.15	22.5	153084	0.6	285.1	177.4

Table 4.16 Summary of actual evapotranspiration calculation for Laelay Wukro project

Land use	Soil type	Available moisture	Assumed Soil depth	Available Soil Moisture	Area Coverage	Area ration	ETac	ETac Weighted
		(mm m^{-1})	(m)	(mm depth $^{-1}$)	(m^2)	(%)	(mm $year^{-1}$)	(mm $year^{-1}$)
Cultivated land	Silt loam	250	1.0	250.0	3552416	37.0	587.8	21765.1
	Silt clay loam	250	1.0	250.0	120063	1.3	587.8	735.6
	Clay loam	250	1.0	250.0	203152	2.1	587.8	1244.7
				Subtotal	3875631	40.4		
Bush land	Silty loam	175	2.0	350.0	34466	0.4	680.0	244.3
	Silty clay loam	175	2.0	350.0	3699870	38.6	680.0	26223.8
				Subtotal	3734336	38.9		
Grazing land	Silty loam	150	1.0	150.0	169039	1.8	487.8	859.5
Forest	Silty clay loam	175	2.0	350.0	76383	0.8	680.0	541.4
Area Closure	Silty clay loam	175	1.5	262.5	1410217	14.7	623.2	9160.5
	Silty loam	175	1.5	262.5	256981	2.7	623.2	1669.3
				Subtotal	1667198	17.4		
Homesteads	Clay loam	125	0.15	18.75	71326	0.7	355.80	264.5

5. CONCLUSIONS AND RECOMMENDATIONS

Evapotranspiration is an important component of the hydrologic cycle. To accurately estimate the potential evapotranspiration good records of climatology data is necessary. The estimated potential evapotranspiration can be used during project planning and operation of irrigation projects. However in many of the developing countries this data are not available. Often designers are forced to transfer data from near by or adjacent stations.

In this research an attempt has been made to estimate potential evapotranspiration and actual evapotranspiration by after collecting field data, analysis and interpretation of data. At the same time necessary digital maps like soil map and landuse maps also prepared bases on soil laboratory test results and field GPS verifications.

On using the available meteorological data potential evapotranspiration has been estimated by two methods (Hargreaves and Samani and Penman Equation). The potential evapotranspiration estimated by the mentioned methods were fitted into straight line and resulting an equation with R^2 (0.8). Thus in the absence of better data estimation technique one can estimate potential evapotranspiration with Hargreaves and Samani and then correct the estimated value with the fitted equation.

With the corrected potential evapotranspiration by the mentioned method, actual evapotranspiration also computed for two irrigation projects in the region. Estimation of the actual evapotranspiration is done based on the field knowledge and data sampling. In order to estimate the potential evapotranspiration the water balance approach proposed by (MaCabe, G.J., and Markstrom, S.L., 2007) has been used. The actual evapotranspiration estimated by the water balance analysis is found to be 442mm $year^{-1}$ for GumSelassa and 627 mm $year^{-1}$ for Laelay Wukro. This estimated value is about 32% and 44% of the potential evapotranspiration for GumSelassa and Laelay Wukro respectively.

Both estimation and calibration of the potential evapotranspiration estimated by the Hargreaves and Samani is done with the limited data available. Further modification can be done to the equation ($ET_o = 0.7657ET_{oHar} + 0.7611$) when additional records are available in the region. Besides the technique for the estimation of the actual potential evapotranspiration is adaptable and can be checked its further applicability by installing soil moisture measuring facilities. Nevertheless the approach can be used incases of data scarcity and project planning purposes.

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