ESTIMATION OF MONTHLY REFERENCE EVAPOTRANSPIRATION (ETO) FOR AREAS WITH IN ADEQUATE METEOROLOGICAL DATA IN ETHIOPIA

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ABSTRACT

Often long-term measured meteorological data are not available or in adequate in water resources development areas such as dam and irrigation sites. Under this condition, design estimates of monthly evaporation from reservoirs and monthly evapotranspiration from crops are unreliable. Estimation of mean monthly evaporation, in this case, can be obtained using regional regression methods that relate evaporation with readily available data such as altitude.

In this paper monthly reference evapotranspiration (ETo)- altitude regression equations are developed for the country using125 stations meteorological data. ETo are calculated based on radiation (sunshine hours), temperature, relative humidity, and wind speed data. FAO-Penman Monteith formula is applied to calculate monthly ETo for 125 stations. The developed relationships are valid over the altitude range from 100 to 3000 meters above mean see level.

The developed equations can be used in areas (irrigation and dam sites) where meteorological data such as radiation (sunshine hours), temperature, relative humidity, and wind speed are not available. Mean monthly evaporation from reservoirs, ponds, and lakes are also estimated by multiplying the monthly ETo by 1.2. Estimate of monthly crop evapotranspiration is made by multiplying monthly ETo by corresponding monthly crop coefficients.

INTRODUCTION

Estimation of evaporation from reservoirs, lakes and estimation of evapotranspiration from crops are needed in a number of engineering and agronomic applications. Evaporation/evapotranspiration is estimated using different methods depending on the availability of long-record meteorological data or direct measurements using pan-evaporometer. When measurements of radiation, temperature, relative humidity, and wind speed are available, evaporation is often estimated using the Penman-Monteith formulae. When only temperature data are available evaporation may be estimated with a simpler formula of Blaney-Criddle.

In areas where there is no measured meteorological data, estimation of evaporation/ evapotranspiration become uncertain and depends on the nearby (30 km)/ far away (>300 km) stations data. The stations may have radiation, temperature, relative humidity, and wind speed or only temperature data. ETo estimated from near by station with radiation, temperature, relative humidity, and wind speed data could give reliable value. However, where only temperature data is available and the nearby stations are far away, ETo estimate becomes unreliable. In this case, ETo estimate made by regional regression method gives a better estimate. This paper gives 94 regional regression equations relating mean monthly ETo with altitude for the country covering all wet basins.

DATA

Mean monthly temperature, relative humidity, radiation (sunshine hours) and wind speed data for 125 stations have been collected. The sources of the data are from *the Integrated Development Master Plan Project of Abay [1], Baro Akobo [2], Tekeze* [2], *Mereb* [3], *Additional data were also found from FAO* [4], *BCEOM* [5], *and WAPCOS* [7]. The distribution of these meteorological data in different basins is given in Table 1.

METHOLDOLOGY

Definition of concepts

In evaporation studies, the concept of *potential evapotranspiration* attributed to Thorntwaite [7] is widely used. Potential evapotranspiration (PET) is the amount of evapotranspiration that would take place under the assumption of an ample supply of moisture at all times. Therefore, PET is an indication of optimum crop water requirements.

Table 1: Hydro-Climatic characteristics of Ethiopian wet basins and the number of meteorological stations having the measurements of temperature, relative humidity, sunshine hours and wind speed used in establishing ETo-Altitude relationships.

Major Basin	Basin catchment Area (km^2)	Mean Annual Rainfall (mm)	Annual Runoff (Bm^3)	Number of Meteorological stations
Wabi Shebele and	202 220	425	3.10	
Genale Dawa	171 042	528	5.88	23
Awash and	114 919	557	4.60	
Rift valley	52 739	904	5.64	26
Abay	204 000	1 224	52.60	26
Baro Akobo	74 152	1 419	11.81	15
Omo Ghibe	78 213	1 270	17.96	19
Tekeze and Mereb	113 932	838	8.51	16

Doorenbos and Pruitt [8] introduced the concept of reference crop evapotranspiration or in short reference evapotranspiration (ETo. They defined ETo as "*the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing completely shading and not short of water*". ETo thus can be considered as the PET of the reference crop (Ponce, [9]. In this paper the concept of ETo is used.

Methodology for estimating ETo

Most potential evapotranspiration formulas are empirical, dependent upon the known correlation between potential evapotranspiration and one or more meteorological or climatic variable such as radiation, temperature, wind speed, and vapor pressures difference. Other formulas relate evaporation to direct measurements of water losses using evaporation pan. Models of evapotranspiration and potential evapotranspiration can be grouped into (1) temperature models- e.g., Blaney-Criddle and Thornthwaite models, (2) radiation models- e.g., Priestley and Taylor model, (3) combination models – e.g. Penman, Penman-Monteith models, and (4) pan-evaporation models through direct measurement of lost water from standard pan [7, 10, 11, 12, 13, 14, 15].

Among these methods FAO expert consultation held in May 1990 in Rome recommended the Penman-Monteith method to estimate reference crop evapotranspiration ETo. Following is the description of the FAO Penman-Monteith as given in FAO [16].

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where:

ET_o = reference crop evaporation (mm/day)

R_n = net radiation are crop surface ($MJ/m^2/d$)

G = soil heat flux ($MJ/m^2/d$)

T = average temperature (°C)

U_2 = windspeed measured at 2 m height (m/s)

$(e_s - e_a)$ = vapor pressure deficit (kpa)

Δ = slope of vapor pressure curve (kPa/°C)

γ = hygrometric constant (kPa/°C)

G = 0.4 ($T_{\text{month n mean temperature}}$ °C - $T_{\text{month n-1 mean temperature}}$ °C)

900 = conversion factor

When measured radiation data are not available, the net radiation is determined as follows

$$R_n = (1-\alpha)(0.35 + 0.61\frac{n}{N})S_o - (0.9\frac{n}{N} + 0.1)(0.34 - 0.14\sqrt{e_d})\ \sigma T^d \quad (2)$$

Where:

R_n = net radiation (($MJ\ m^2\ day^{-1}$)

α = albedo from Table 3.1

n/N = ratio of actual to possible hours of sunshine

S_0 = mean solar radiation from cloudless sky for a given location ($MJ\ m^2\ day^{-1}$)

e_a = saturated vapor pressure at dew temperature (kPa)

e_s = saturated vapor pressure at ambient air temperature (kPa)
σ = the Stefan Boltzmann constant = 4.903×10^{-9} M J m^{-2} day^{-1} K^{-4}
T = the absolute mean air temperature of the evaporating surface in degrees Kelvin (°C + 273)

R_n can be expressed as an equivalent depth of evaporated water in mm by dividing R_n by $\rho_w \lambda$, where ρ_w (kg/m^3) and λ (MJ/kg).

The saturation vapor pressure is determined according to Teten's formula:

$$e_s = 611 \exp\left(17.27 \frac{T}{237.3 + T}\right) \qquad (3)$$

Where
T = the ambient air temperature (°C)
e_s = Saturation vapor pressure (Pa)

ETo-Altitude relationships

Monthly ET_o–altitude relationships are established using regression technique. Linear, exponential and logarithmic forms of equations were tried to fit to the data.

$$Y = aX + b,\ Y = aX^b, \text{ and } Y = a \text{ in } (X) + b \qquad (4)$$

Where:
Y = mean monthly ETo [mm/day]
X = altitude [m]
a and b are parameters to be estimated from monthly ET_o–altitude data for a given basin.

ET_o–altitude relationships are looked into each basin. The validity of a monthly ET_o–altitude regression equation is checked based on its coefficient of determination (R-square). Parameter significance are checked with t-test. The equations are considered to be valid if R-square is greater than 0.5 and t-values for each parameter are greater than 1.96.

RESULTS

In total eighty-four monthly ET_o–altitude regression equations were developed for eight wet basins of Ethiopia. Table 2 through Table 7 give the developed ET_o–altitude regersssion equations for the Tekeze and Mereb basins, for the Awash and Rift Valley basins, for the Abay basin except Dedisa and Dabus watersheds, for the Dedisa and Dabus watersheds, for the Wabi Shebelle and Geneale Dawa basins, and for the Omo Gibe basin respectively. Most of the relationships are linear. Occasionally, exponential or logarithmic relationship fits better a given month evaporation data.

Table 2: Tekeze and Mereb basins monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	t-value	
			Coeff.	Cons.
January	$Y = -0.0007X + 5.3209$	0.71	24.71	-6.21
February	$Y = -0.0009X + 6.2027$	0.75	24.74	-6.40
March	$Y = -0.0009X + 6.8341$	0.70	23.96	-5.77
April	$Y = -0.0009X + 7.319$	0.68	22.68	-5.39
May	$Y = -0.0007X + 6.8455$	0.64	23.72	-4.39
June	$Y = -0.0007X + 6.618$	0.62	21.87	-4.27
July	$Y = -0.8656\ \text{Ln}(X) + 10.681$	0.63	19.34	-4.29
August	$Y = -0.5021\ \text{Ln}(X) + 7.3998$	0.65	21.92	-3.14
September	$Y = -0.0005X + 5.1666$	0.60	23.87	-3.89
October	$Y = -0.0007X + 6.1164$	0.76	24.89	-6.06
November	$Y = -0.0008X + 5.6512$	0.89	38.61	-10.83
December	$Y = -0.0008X + 5.204$	0.90	39.30	-10.86

Table 3: Awas and Rift Valley basins monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	t-value	
			Coeff.	Cons.
January	$Y = -0.0006X + 4.8328$	0.71	28.06	-5.48
February	$Y = -0.0005X + 5.1702$	0.70	33.79	-5.75
March	$Y = -0.0006X + 5.5959$	0.72	33.81	-6.46
April	$Y = -0.0008X + 5.7231$	0.76	32.08	-7.58
May	$Y = 35.054X^{-0.286}$	0.73	23.09	-6.20
June	$Y = -0.0023X + 8.1067$	0.72	13.95	-7.01
July	$Y = -0.002X + 6.8319$	0.75	16.46	-7.90
August	$Y = -0.0014X + 5.8871$	0.84	23.77	-10.14
September	$Y = -0.0012X + 5.7409$	0.80	23.29	-8.85
October	$Y = 28.698X - 0.2662$	0.76	22.62	-5.65
November	$Y = 14.348X - 0.1728$	0.75	30.86	-5.42
December	$Y = -0.0005X + 4.8254$	0.70	28.05	-5.53

Table 4: Abay basin except Dedisa and Dabus watersheds monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	t-value	
			Coeff.	Cons.
January	$Y = -0.0007X + 5.4389$	0.64	14.88	-4.72
February	$Y = -0.0008X + 6.1292$	0.56	12.73	-3.87
March	$Y = -0.0010X + 6.9370$	0.61	12.18	-4.14
April	$Y = -0.0012X + 7.4885$	0.69	13.45	-5.16
May	$Y = -0.0008X + 6.3138$	0.69	15.60	-4.70
June	$Y = -0.0006X + 5.1495$	0.76	16.57	-4.75
July	$Y = -0.0006X + 3.7716$	0.79	18.91	-5.09
August	$Y = -0.0001X + 2.8461$	0.70	37.73	-2.32
September	$Y = -0.0006X + 4.6550$	0.59	13.57	-3.83
October	$Y = -0.0008X + 5.7701$	0.72	15.30	-4.87
November	$Y = -0.0009X + 5.9514$	0.61	10.60	-3.72
December	$Y = -0.0006X + 5.0342$	0.77	15.09	-4.31

Table 5: Dedisa and Dabus watersheds (tributary of Abay river) monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	*t*-value	
			Coeff.	Cons.
January	$Y = -0.0005X + 4.9403$	0.45	12.23	-2.22
February	$Y = -0.0006X + 5.6164$	0.54	15.39	-3.07
March	$Y = -0.0006X + 5.6967$	0.82	30.32	-6.02
April	$Y = -0.0008X + 6.2272$	0.48	11.39	-2.55
May	$Y = -0.0006X + 4.7427$	0.55	13.91	-2.94
June	$Y = -0.0008X + 4.5708$	0.62	11.14	-3.35
July	$Y = -0.0006X + 3.8977$	0.76	18.14	-5.05
August	$Y = -0.0002X + 2.9166$	0.81	46.07	-4.61
September	$Y = -0.0003X + 3.9142$	0.66	22.58	-3.43
October	$Y = -0.0005X + 4.5854$	0.59	16.72	-3.16
November	$Y = -0.0007X + 4.9180$	0.58	12.33	-3.13
December	$Y = -0.0006X + 4.9761$	0.68	17.08	-3.56

Table 6: Wabe Shebelle and Geneale Dawa basins monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	*t* - value	
			Coeff.	Cons.
January	$Y = 20.324X^{-0.2219}$	0.71	-6.17	23.14
February	$Y = 22.152X^{-0.2261}$	0.75	-6.25	23.18
March	$Y = 25.49X^{-0.2400}$	0.84	-9.08	31.42
April	$Y = -0.0007X + 5.3951$	0.77	-8.62	32.31
May	$Y = -0.0007X + 5.3468$	0.79	-8.82	30.67
June	$Y = -0.0009X + 5.5797$	0.77	-8.30	24.09
July	$Y = 48.563X^{-0.3599}$	0.83	-11.49	28.74
August	$Y = 51.061X^{-0.3622}$	0.82	-9.91	24.93
September	$Y = 53.177X^{-0.3621}$	0.87	-10.17	25.64
October	$Y = -0.0007X + 5.1307$	0.80	-9.54	30.86
November	$Y = -0.0006X + 5.081$	0.74	-7.68	28.46
December	$Y = -0.0006X + 5.054$	0.74	-5.14	20.54

Table 7: Omo Gibe basins monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	t - value	
			Coeff.	Cons.
January	$Y = -0.0010X + 5.4424$	0.88	19.24	-4.78
February	$Y = -0.0008X + 5.3333$	0.71	20.94	-5.70
March	$Y = -0.0009X + 5.5393$	0.73	21.40	-6.32
April	$Y = -0.0007X + 5.0331$	0.69	21.65	-5.53
May	$Y = -0.0007X + 4.5584$	0.65	17.39	-4.93
June	$Y = -0.0007X + 4.1211$	0.52	12.45	-3.73
July	$Y = -0.0006X + 3.6115$	0.62	14.53	-4.79
August	$Y = -0.0005X + 3.2901$	0.56	15.18	-4.21
September	$Y = -0.0006X + 3.9205$	0.58	14.78	-4.03
October	$Y = -0.0005X + 4.1586$	0.56	19.96	-4.67
November	$Y = -0.0006X + 4.4332$	0.58	18.92	-4.38
December	$Y = -0.0006X + 4.5068$	0.62	18.71	-4.78

Table 8: Baro Akobo basins monthly reference evapotranspiration (ETo) and altitude relationships. Y = ETo (mm/day), X = altitude (m).

	Equation	R^2	t -value	
			Coeff.	Cons.
January	$Y = -0.0010X + 5.4424$	0.88	35.79	-9.63
February	$Y = -0.0009X + 5.9371$	0.80	33.68	-7.15
March	$Y = -0.0006X + 5.5812$	0.80	43.64	-6.83
April	$Y = -0.0006X + 5.7733$	0.67	30.85	-5.09
May	$Y = -0.0005X + 4.7500$	0.71	37.81	-5.69
June	$Y = -0.0004X + 4.1620$	0.65	35.01	-4.95
July	$Y = -0.0005X + 3.9859$	0.82	40.60	-7.66
August	$Y = -0.0002X + 3.4565$	0.48	39.53	-3.05
September	$Y = -0.0005X + 4.3136$	0.83	46.16	-8.08
October	$Y = -0.0006X + 4.7104$	0.88	55.32	-9.79
November	$Y = -0.0008X + 4.9346$	0.94	59.99	-14.35
December	$Y = -0.0009X + 5.0132$	0.89	41.74	-10.46

Figure 1 shows sample graphical display of ET_O-altitude relationships in the Wabi Shebelle and Genale basins.

APPLICATION

Monthly estimate of ETo has many applications. It is required for water balance calculation, to estimate crop water requirements for irrigation, to estimate reservoir evaporation, and to establish agro-ecological zonation. The actual crop water requirement is found by multiplying monthly ETo by monthly crop coefficient K_c. Evaporation from reservoirs, ponds, and lakes is estimated by multiplying the monthly ETo by 1.2.

Example: It is required to estimate annual evaporation from the Koka reservoir located in the Awash basin. At full reservoir the water level in the lake is X = 1850m. The required regression equations developed for the basin is found in Table 3. Using these equations monthly ETo are calculated. Table 9 shows the details of the calculation.

Table 9: Annual evaporation calculation for Koka reservoir.

[1]	[2]	[3]	[4]	[5]
	Developed equations	ETo Using Eq. In Col. [2] (mm/day)	ETo Col.[3]*No.days in the month (mm/month)	Evaporation Col. [4]*1.2 (mm/month)
January	$Y = -0.0006X + 4.8328$	3.84	119.1	143.0
February	$Y = -0.0005X + 5.1702$	4.35	126.0	151.2
March	$Y = -0.0006X + 5.5959$	4.61	142.8	171.3
April	$Y = -0.0008X + 5.7231$	4.40	132.1	158.5
May	$Y = 35.054X^{-0286}$	4.21	130.6	156.7
June	$Y = -0.0023X + 8.1067$	4.31	129.4	155.2
July	$Y = -0.0002X + 6.8319$	3.53	106.0	127.1
August	$Y = -0.0014X + 5.8871$	3.58	107.3	128.8
September	$Y = -0.0012X + 5.7409$	3.76	116.6	139.9
October	$Y = 28.698X^{-0.2662}$	3.99	119.8	143.8
November	$Y = 14.348X - 0.1728$	3.99	123.6	148.4
December	$Y = -0.0005X + 4.8254$	4.00	120.0	144.0
			Mean annual	**1768 mm**

CONCLUSION

Monthly mean ETo–altitude relationships have been developed for Ethiopia grouping into 6 zones. The relationships are valid over the altitudes from 100 to 3000 meter above mean see level. The developed equations can be used to estimate ET_o in areas where there are no adequate meteorological data. The actual mean monthly crop evapotranspiration is found by multiplying mean monthly ET_o by monthly crop coefficient K_c. Evaporation from reservoirs, ponds, and lakes is estimated by multiplying the monthly ET_o by 1.2.

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