DEVELOPING SIMPLIFIED REGIONAL POTENTIAL EVAPOTRANSPIRATION (PET) ESTIMATION METHOD FOR ABBAY RIVER BASIN

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ABSTRACT

Regional Potential Evapotranspiration (PET) estimation method was developed to estimate the potential evapotranspiration (reference evapotranspiration) over Abbay Basin as a function of basin maximum and minimum temperature, and modulated by site specific elevation data. The method is intended to estimate PET in largely un-gauged locations of Abbay basin. The new model was calibrated based on data from twenty three stations in the basin. Except two stations, which showed model performance (R^2) to be less than 50%, performance of the regional model is encouraging. More than 50% of the stations' performance (R^2) is above 70% and the remaining stations performance is between 60 and 70 %. Therefore, the regional model can be used to estimate monthly potential evapotranspiration at any un-gauged location in the Abbay basin provided elevation data is available. The benefit of the new model is that site specific temperature data is not required as the basin average temperature modulated by site specific altitude ensures the local potential evapotranspiration (PET) estimate. The method is simple and can be used as alternative estimation method for agricultural and water resources planning, and studying the hydrology of the Basin. Practitioners in irrigated agriculture and water resources planning can benefit from the developed regional method. The author cautions the use of the method doesn't substitute the availability of site specific data and should be used only under no or little data condition.

Keywords*: Abbay basin, FAO Penman-Monteith method, Regional PET method.*

INTRODUCTION

Water resources and agricultural engineers and practitioners often face tremendous challenges in planning and execution of water and agricultural projects due lack of data on evaporation and the climate. Less challenging, but more probable circumstances include large areas of missing data relating to one or more of the climatic variables. Due to a combination of reasons, such as vandalism, ignorance of the gauge readers and careless data transfer to the secondary storage, the quality of the data usually remains below standard for variables such as pan evaporation, sunshine, wind speed and humidity. However, parameters like temperature can be measured more accurately than others and are usually available for a longer period of time.

Over more than half a century, many research activities relating to modelling evaporation and/or evapotranspiration have taken place for climatological, agronomical, and hydrological purposes (e.g. [1,2,3,4,5,6]. Allen et al., [7] were correct when they stated that most PET methods are subject to rigorous local calibrations and have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time-consuming and costly, while evapotranspiration data are frequently needed at short notice for project planning or irrigation scheduling design. As a consequence, a considerable number of practitioners in many parts of the world seldom question the accuracy of the method for their particular location. Rather most practitioners tend to choose PET estimation method based on the type and availability of data. This kind of estimation approach may over- or under-estimate the actual values of PET significantly and often produces undesirable results in the planning and operation of water and agricultural projects. As evapotranspiration accounts more than 60 7o 70 % of the water balance component, the accuracy of the PET estimation is vital. In recognition of this, the FAO proposed that the FAO Penman-Monteith Method serves as a standard reference method for estimating and evaluating evapotranspiration methods universally [7]. However, in many parts of the world, the available meteorological data doesn't allow the proper use of this method and developing alternative methods have been the pre-occupation of water and agricultural engineers.

For regional or local PET estimation in areas with limited data, where the only available weather measurements are maximum and minimum temperature and rainfall, the usefulness of the simplified empirical methods demonstrated its benefit in earlier agricultural development in countries like the USA and India [8, 9, and 10].

The largely rural Africa, including Ethiopia, has inadequate or lack of quality data sets for various agricultural and water resources planning purposes. Lack of quality data in this context refers to lack of sufficient data sets for the Penman-Monteith method due to the limited first class stations, improper functioning of the existing ones, and recording errors. Relatively large sets of accurate temperature data are available from class 3 and class 4 stations. This is also the case to Abbay basin in Ethiopia. Therefore developing regional equation that is used to estimate PET in largely un-gauged catchments of the basin is vital for the purposes of water resources and agriculture planning and operations.

Given the nature of the data and the importance of potential evapotranspiration (PET) for regional assessments and local planning and operational purposes, the author of this paper argues that the simplified empirical methods can be based on temperature and should adequately capture the PET. Schulz and Kurz [11] and Pike [12] evaluated Hargreaves' equation against class A pan evaporation data gathered from 82 stations in southern Africa and developed coefficients applicable to derive PET in data limited areas. The research of Cahon et al. [13] supports this idea. Similar work was done in Tanzania by Moges et al. [14].

In accordance with the recommendation by the FAO mentioned above (see [7]), the Penman-Monteith equation is used as a comparison criterion for the performance of the empirical PET methods. The evaluation was done on a monthly basis using 23 class one stations that could provide observed historical data of maximum and minimum temperature, actual sunshine duration, relative humidity, and wind speed. This paper is the first of its kind which was done using actual data in Abbay basin.

DESCRIPTION OF THE STUDY AREA

The Abbay River is one of the most important tributaries of the Nile River in terms of flow contribution to the total Nile yield (about 60%) and socio-economic development of the Basin. The river originates in the western highland of Ethiopia and extends from 745' to 13 N and 3430' and 3745'E (highlighted in Fig.1).

The Basin covers an area of about 184,245 km^2 and is characterized by highly seasonal rainfall pattern, with most of the rainfall falling in four months (June to September - JJAS) with a peak in July or August (Fig. 2). The mean annual total rainfall for the 1961-1990 period amounts to 1,224 mm, of which more than 70% fell during the period June to September. The total annual PET has been estimated as 1,448 mm (calculated from an historical data set by the Penman-Monteith method), with higher values estimated for the three months of March, April and May (MAM) before the onset of the rainy season; the temperature is very high in these months.

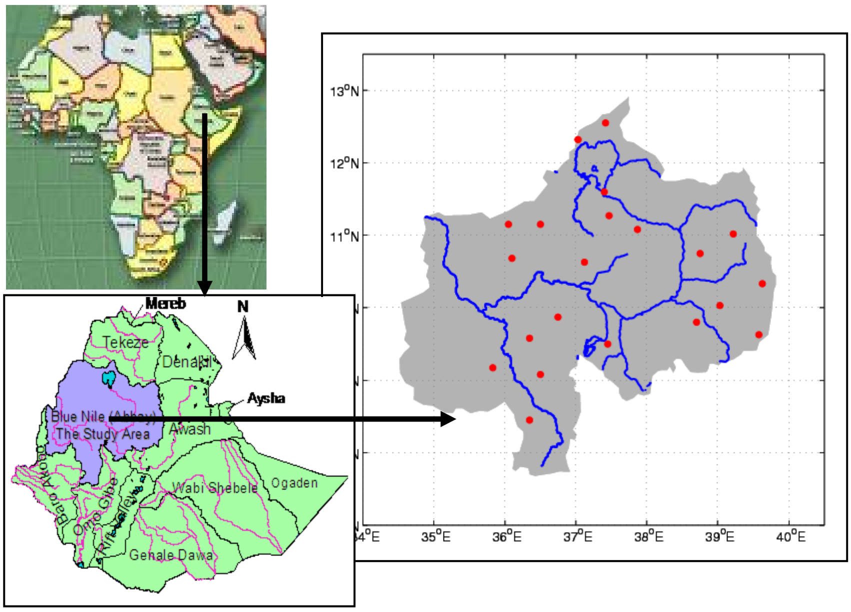

Figure 1 The location of upper Blue Nile Basin within Ethiopia

Mean annual air temperature varies between 27°C in the western lowlands to 12°C in the northeastern highlands of the Basin. Overall Basin seasonal temperature fluctuates in the narrow range of 17 to 20°C, which is a typical characteristic of the African tropics, with a small seasonal temperature range allowing year-round water loss through evaporation (Fig. 2).

The seasonal monthly relative humidity varies between 45% (during the dry months) to over 80% (in the wet months of July and August), with significant seasonal variation (Fig. 2). The actual sunshine duration over the Basin varies between 4.5 hours during the wet season when there is high cloud activity, to about 9 hours in the dry months starting from November. The aerodynamic conditions of the Basin can be characterized as light, with wind speed varying between 1.3 m/s to 1.8 m/s.

method of estimating PET and have been used in many similar studies to compare or develop Penman-Montheith equivalent estimates from other equations [14, 11, 12].

Various forms of relationship between the PM estimated PET and the temperature variables (maximum, minimum or mean temperature) were explored on the basis of multi-regression analysis. Finally by close investigation and studying the residual of the discrepancies from the estimates, the equation was fine tuned by modulating the altitude differences in the basin. Altitude is an important parameter that controls some portion of variation of PET and was used to fine tune the station estimates of the PET using the developed equation.

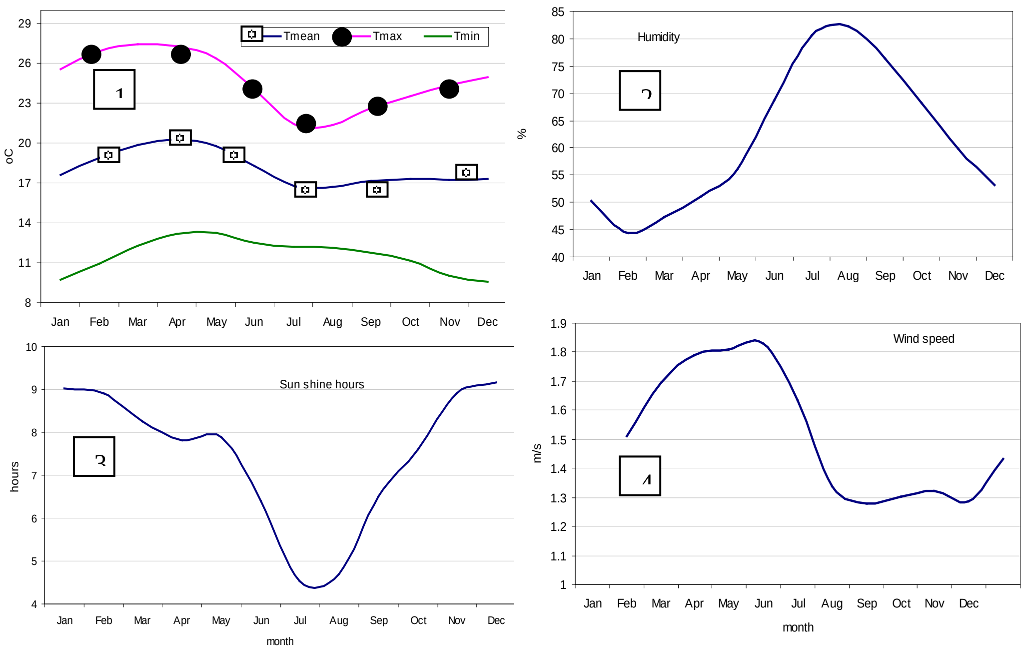

Figure 2 Climatic characteristics of Abbay Basin based on areal average of the 23 stations
1) Temperature (°C); 2) Relative humidity (%); 3) Actual sunshine hours;
4) Wind speed (m/s)

DEVELOPMENT METHODOLOGY

The development of the regional PET estimation involves primarily estimation of the monthly potential evapotransipration (PET) values using FAO modified Penman-Montheith (PM) equation for calibration of the estimates from the developed regional equation. FAO modified Penman-Monthieth Equation is universally accepted [7]

FAO 1998 PENMAN-MONTEITH METHOD

The modified FAO-Penman method [7] is a grass reference evapotranspiration equation used to compute PET from green vegetated grass surface with unlimited water source. Which means the equation is used to as a standard potential evapotranspiration estimator in the field of agriculture by modulating using crop factor. It is derived from the original Penman-Monteith equation by assigning certain parameter values based on a specific reference surface. This equation has an assumed height of 0.12 m, a fixed surface resistance (r_a) of 70 s m^{-1} and an albedo of 0.23. The zero plane displacement height and roughness lengths are estimated as functions of the assumed crop height, so that r_a, becomes a function of the measured wind speed only. The height for the temperature, humidity, and wind measurements is assumed to be 2 m. The latent heat of vaporization (λ) is assigned a constant value of 2.45 MJ/kg. The modified FAO-Penman method [7], the terms and definition of the terms are given Eq. (1) as:

$$PET = \frac{0.408\Delta\left[R_n - G\right]}{\Delta + \gamma(1 + 0.34u_2)} + \frac{\gamma}{\Delta + \gamma(1 + 0.34u_2)}\frac{900u_2(e_s - e_a)}{(T + 273)} \quad (1)$$

where:

- PET = Potential Evapotranspiration (as reference ET), mm/day
- R_n = net radiation;
- G = soil heat flux index, MJ m^{-2}/day
- e_s = saturation vapour pressure, kPa
- e_a = actual vapour pressure, kPa
- e_s-e_a = saturation vapour pressure deficit, kPa
- Δ = slope of the saturation vapour pressure temperature relationship, kPa/°C
- γ = psychrometric constant, kPa/°C
- u_2 = wind speed (m/s) at 2 m height
- λ = latent heat of vaporization (MJ/kg)

Other required equations are summarized in Table 1 below. For the sake of simplicity this Penman-Monteith method is referred hereafter as PM.

THE DATASET

More than 45 climatic stations were located in the Abbay basin from Ethiopia National Meteorological Agency. The stations consist of different classes, and historical records varied from station to station. Some stations have kept records as far back as the 1950s and 60s, while others only have data starting in 2000. It was noted that missing data is a common phenomenon. Therefore, the author limited the analysis to stations that have intact data sets and seemingly reliable records.

Table 1: The intermediate FAO Penman-Montieth (PM) equations

Equations	Definitions of terms
$Rn = (1-\alpha)\left(a_s + b_s\frac{n}{N}\right)S_o - \left(0.9\frac{n}{N} + 0.1\right)\left(0.34 - 0.14\sqrt{e_a}\right)\sigma T^4$	Rn is the net radiation simplified from the original equation that contains the net short wave and the long wave radiation, MJm^{-2}day^{-1}, a_s = 0.25 and b_s= 0.50 (FAO)
$G = 0.07(T_{i+1} - T_{i-1})$ or $G = 0.14(T_i - T_{i-1})$	G is soil heat flux (MJm^{-2}day^{-1}) based on air temperature, T, where i is the current month. The second equation is used when T_{i+1} is unknown for the last data point
$e_s = \frac{e^o(T\max) + e^o(T\min)}{2}$ $e^0(T) = 0.6108Exp(\frac{17.27T}{T + 237.3})$	e_s mean saturation vapour pressure (kPa); $e^o(T)$ is the saturation vapour pressure at the air temperature T (°C) in kPa
$\Delta = \frac{4098e^o(T)}{(T + 237.3)^2}$	Δ = is the slope of saturated vapour pressure, T is the mean air temperature (^{o}C)
$e_a(RH) = \frac{RH_{mean}}{100}\left[\frac{(e^o(T\min) + e^o(T\min))}{2}\right]$	e_a (RH) is the actual vapour pressure, kPa. This form of e_a and relative humidity (RH) relationship is used to derive e_a in this paper
$\gamma = \frac{c_p P}{\varepsilon\lambda} = 0.665 * 10^{-3} P$ $P = 101.3\left(\frac{293 - 0.0065Z}{293}\right)^{5.26}$	γ is the psychrometric constant, kPa^{o}C^{-1}; P is atmospheric pressure. As λ varies only slightly over normal temperature ranges, a single value of 2.45 MJkg^{-1} was adapted as recommended in FAO Penman-Monteith equation; c_p is specific heat of constant pressure, 1.013*10^{-3} in MJkg^{-1} ^{o}C^{-1}; ε is the ratio of the molecular weight of water vapour/dry air, 0.622. Z is elevation in m.a.s.l

Data from 25 stations out of 45 were found to be reliable and intact (no data missing). Later, two stations were found to have unacceptably large discrepancies in wind speed data and these stations were also dropped from the analysis. In the end, data from 23 stations were used (Table 2). The data required for the application of the PM method, like maximum and minimum temperature, actual sunshine duration, humidity and wind speed for the period of 1992 to 2004, was used for the evaluation study. Even though the quality of data is undoubtedly a concern in this part of the world due to poor regular monitoring and maintenance, the part of the data used in this study was carefully selected and relatively better. In addition, the stations are also fairly evenly distributed over the basin (Fig. 1) offering the opportunity to estimate the areal average PET as an indicator to the basin PET.

Table 2: Climatic stations used for PET estimation in Abbay Basin

No.	Station Name	Lat-itude	Long-itude.	Record Length	Tmean (°C)	Tmax (°oC)	Tmin (°oC)	Sunshine Duration (hr)	Relative Humidity (%)	Wind Speed (m/s)	Elev-ation a.msl
1	ADET	11.27	37.47	1992 - 2004	17.62	26.03	9.21	8.07	64.22	1.00	2080
2	ALEM KETEMA	10.03	39.03	1992 - 2004	19.61	25.38	13.84	8.18	43.69	1.61	2280
3	AMBA MARIAM	11.02	39.22	1992 - 2004	13.44	19.08	7.8	8.24	62.29	1.95	1900
4	ASSOSA	10.20	34.58	1992 - 2004	20.87	27.62	14.11	6.51	72.61	3.64	1600
5	AYKEL	12.32	37.03	1992 - 2004	18.78	24.03	13.53	7.29	43.47	2.47	2150
6	BAHR DAR	11.60	37.40	1992 - 2004	19.23	25.66	12.8	8.07	60.27	0.61	1770
7	BEDELE	8.45	36.35	1992 - 2004	19.15	25.71	12.59	6.84	69.93	0.54	2030
8	BULLEN	10.68	36.10	1992 - 2004	20.87	27.81	13.93	7.39	60.73	1.01	1450
9	DANGILA	11.15	36.50	1992 - 2004	16.73	24.83	8.63	7.37	72.18	1.1	2000
10	DEBRE BRIHAN	9.63	39.58	1992 - 2004	13.00	19.76	6.25	7.47	64.46	2.22	2750
11	FICHEI	9.80	38.70	1992 - 2004	14.14	20.02	8.25	7.47	63.69	1.45	2750
12	GIDDA AYANA	9.87	36.75	1992 - 2004	18.68	24.08	13.27	7.26	64.05	0.78	1850
13	GIMBI	9.17	35.83	1992 - 2004	20.19	26.2	14.18	6.62	64.31	1.25	1970
14	GONDAR A.P.	12.55	37.42	1992 - 2004	15.76	21.99	9.53	7.30	53.66	1.58	1967
15	KACHISE	9.58	36.35	1992 - 2004	15.32	20.69	9.95	7.18	65.64	1.26	2520
16	LAY-BIRR	10.63	37.12	1992 - 2004	20.68	28.93	12.43	7.41	51.13	1.15	1807
17	MEHAL MEDA	10.33	39.63	1992 - 2004	12.68	18.06	7.29	8.30	60.37	2.24	3040
18	MEKANE SELAM	10.75	38.75	1992 - 2004	16.37	21.97	10.77	7.17	60.51	1.52	1720
19	METEMA	12.58	36.10	1992 - 2004	27.22	35.61	18.83	7.50	53.59	1.41	900
20	MOTTA	11.08	37.87	1992 - 2004	16.43	23.34	9.53	8.46	57.31	1.4	2440
21	NEDJO	9.50	37.45	1992 - 2004	18.91	25.74	12.08	7.37	67.5	3.28	1800
22	NEKEMTE	9.08	36.50	1992 - 2004	16.52	22.38	10.65	6.56	67.65	0.82	2080
23	PAWEE	11.15	36.05	1992 - 2004	24.31	32.12	16.49	7.82	72.55	0.63	1053

RESULTS AND DISCUSSIONS

The performance of at site relationship between the PET and climatic variables was evaluated on the basis of Nash and Sutcliff efficiency criteria, usually denoted as (NSF) or R^2. Table 3 presents station specific results of PET as estimated from new relationships with main climatic variables (mainly temperature and humidity). The PET and maximum temperature was found relatively better correlated than PET with the mean temperature and with the humidity.

This underlies the fact that the maximum temperature is one of the dominant variables contributing to evapotranspiration. Over 50% of the stations have performance (R^2) of above 0.70 and about 40% of the stations showed adequate performance between 0.6 and 0.70. Further attempt was made to improve the relationship by incorporating other climatic variables (such as mean temperature, minimum temperature and humidity). Eventually, an encouraging relationship of PET was shown when PET was related as a function of T_{max} and T_{min}. The multi-regression between the PET and the T_{max} and T_{min} combination displayed a superior correlation (plot PET-SRE in Fig. 4). Over 60% of the stations gave R^2 of more than 0.70 and only two stations gave R^2 less than 50%. This relationship was considered to develop the regional PET equation by converting the station specific variables of temperatures into areal average quantities.

Table 3: Station-based regression equations

No	Station Name	Tmax		Tmean		Tmax, Tmin regression		Other Dominant Variables/Eq. form		
		Equation	R^2 (%)	Equation	R^2 (%)	Equation	R^2 (%)	Equation (X=Humidity)	Elevation	R^2 (%)
1	Adet	$y = 6.78x - 58$	77	$y = 8.58x - 32.6$	49	$y = 7.28x_1 - 1.77x_2 - 87.1$	82	$y = -1.03x + 184.6$	2080	54
2	Alem Ketema	$y = 7.03x - 37.1$	58	$y = 11.57x - 85.6$	66	$y = 5.80x_1 + 5.75x_2 - 85.4$	65	$y = -1.07x + 188$	2280	55
3	Amba Mariam	$y = 6.85x - 19.0$	50	$y = 7.98x + 4.38$	36	$y = 7.18x_1 - 1.04x_2 - 17.2$	50	$y = -0.84x + 163.9$	1900	41
4	Assosa	$y = 14.60x - 264.6$	59	$y = 17.30x - 222.5$	60	$y = 14.30x_1 + 2.47x_2 - 291.4$	60	$y = -2.49x - 319.6$	1600	73
		$y = 7.73e^{0.102x}$	67							70
5	Aykel	$y = 9.37x - 78.2$	77	$y = 13.84x - 112.9$	78	$y = 8.078x_1 + 4.157x_2 - 103.2$	79	$y = -1.41x + 208.0$	2150	67
6	Bahir dar	$y = 5.95 - 46.4$	66	$y = 7.94x - 43.23$	70	$y = 5.79x_1 + 2.48x_2 - 73.8$	80	$y = -0.70x + 156.6$	1770	33
7	Bedelle	$y = 4.42x - 6.2$	50	$y = 7.46x - 35.4$	58	$y = 4.15x_1 + 2.56x_2 - 31.6$	54	$y = -0.78x + 161.5$	2030	53
8	Bullen	$y = 7.44x - 85.3$	76	$y = 11.34x - 115.1$	62	$y = 7.61x_1 + 2.06x_2 118.9$	79	$y = -1.04x + 184.9$	1450	70
9	Dangilla	$y = 6.20x - 44.6$	71	$y = 6.99x - 7.75$	39	$y = 6.91x_1 + 1.75x_2 - 77.6$	79	$y = -0.78x + 165.8$	2000	53
10	Debre berhan	$y = 8.52x - 54.7$	62	$y = 4.47x + 55.7$	17	$y = 8.72x_1 - 0.74x_2 - 53.8$	62	$y = -1.27x + 195.6$	2750	52
11	Fitche	$y = 7.04x - 31.2$	68	$y = 8.41x - 9.2$	48	$y = 7.05x_1 - 0.07x_2 - 30.9$	67	$y = -0.81x + 165.5$	2750	42
12	Gida Ayana	$y = 4.37x + 4.5$	45	$y = 7.30x - 26.6$	50	$y = 3.47x_1 + 4.21x_2 - 29.7$	50	$y = -0.48x + 140.4$	1850	26
13	Gimbi	$y = 6.77x - 60.1$	70	$y = 10.31x - 90.9$	74	$y = 5.70x_1 + 3.86x_2 - 87.0$	74	$y = -1.17x + 192.6$	1970	62
14	Gondar	$y = 8.28x - 65.0$	80	$y = 13.29x - 92.3$	78	$y = 8.01x_1 + 3.04x_2 - 88.1$	84	$y = -1.00x + 170.8$	1967	63
15	Kachise	$y = 8.21x - 62.1$	80	$y = 10.58x - 54.2$	70	$y = 8.37x_1 - 0.44x_2 - 61.0$	81	$y = -1.01x + 174.3$	2520	67
16	Lay-Bir	$y = 6.89x - 69.2$	73	$y = 12.8x - 135.2$	83	$y = 7.24x_1 + 4.49x_2 - 134.9$	87	$y = -1.14x + 188.5$	1807	51
17	**Mehal Meda**	$y = 7.18x - 12.0$	**42**	$y = 7.99x + 15.4$	**30**	$y = 7.09x_1 + 0.38x_2 - 14.1$	**41**	$y = -0.90x + 170.9$	3040	**50**
18	Mekane Selam	$y = 8.75x - 79.2$	85	$y = 12.2x - 86.4$	70	$y = 8.72x_1 + 0.18x_2 - 80.3$	85	$y = -1.13x + 181.2$	1720	75
19	Metema	$y = 8.21x - 139.0$	77	$y = 11.83x - 168.6$	72	$y = 7.99x_1 + 2.83x_2 - 184.5$	83	$y = -1.26x + 220.9$	900	55
20	Motta	$y = 7.28x - 46.3$	66	$y = 10.4x - 46.8$	64	$y = 7.06x_1 + 2.82x_2 - 68.1$	73	$y = -0.86x + 172.7$	2440	45
21	Nedjo	$y = 8.87x - 95.1$	30	$y = 12.6x - 109.6$	16	$y = 8.74x_1 + 0.26x_2 - 100.1$	29	$y = -1.37x + 220.8$	1800	
22	Nekemte	$y = 6.60x - 46.2$	73	$y = 6.56x - 6.81$	50	$y = 6.43x_1 + 0.96x_2 - 52.6$	75	$y = -0.76x + 153.4$	2080	64
23	Pawe	$y = 4.70x - 26.5$	56	$y = 9.84x - 114.8$	79	$y = 5.17x_1 + 4.38x_2 - 113.8$	80	$y = -1.01x + 197.7$	1053	50
BN		$y = 8.38x - 86.1$	**88**	$y = 13.02x - 114.8$	**77**	$y = 8.28x_1 + 1.99x_2 - 106.4$	**89**	$y = -1.24x + 196.4$		**72**

y=PET estimated by Penman Monteith; x = climate variable; Tmax, Tmin, Tmean=maximum, minimum and mean temperature (oC) respectively.

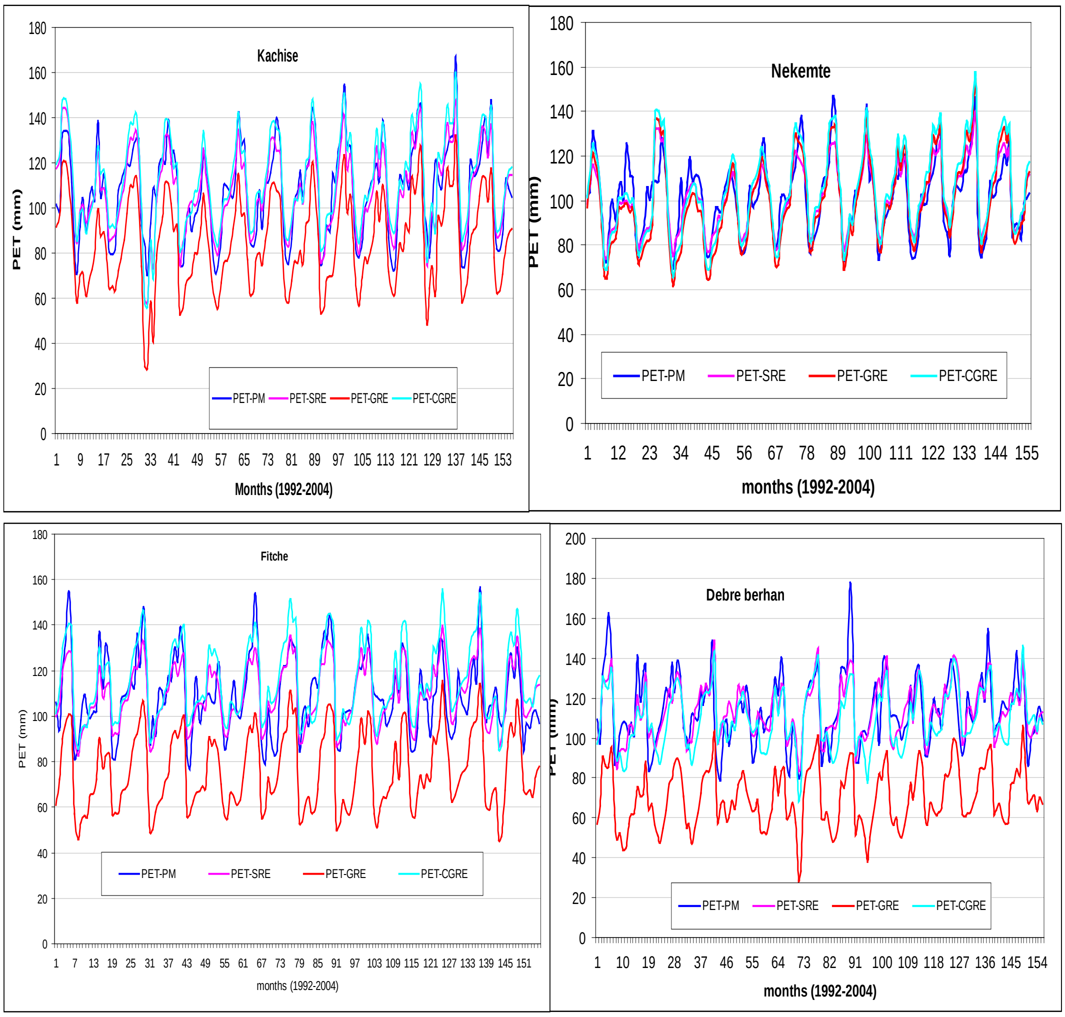

Figure 3 Plots of estimated PET using temperature-based regression equations (SRE, GRE and CGRE) with PM estimate

The multi-regression equation developed from areal average variables provides areal PET estimation of the basin, as shown in the last row of Table 3 and termed as PET-GRE in Fig. 4. The equation was developed by relating the areal average basin PET with the areal averages T_{max} and T_{min} of the station values. The overall estimation efficiency of PET over the basin using this equation yields an R^2 of about 89% (as shown in last row of Table 3). As it takes the areal averages as input the generalized equation (shown as PET-GRE in Fig. 4) was less favorable to estimate PET in any location of the Basin. As shown in Fig. 4 for four sample stations, application of the generalized equation to individual stations produced undesirably low values for the lowland stations with high mean temperatures. It also underestimated the highland stations that have low mean air temperatures. It was also noted that the generalized equation provides the best estimation results for stations with areas with elevation around 2000 m.a.s.l. This elevation mark was found to be the average elevation of the entire basin. Therefore, the estimation bias of the generalized equation was highly correlated with elevation difference and corrected as shown in Eq. (2) above by modulating with elevation difference ($\Delta E = E_A - E_S$). Equation (2) is as a regional PET estimation in the Abbay Basin (plotted as PET-CRGE in Fig. 4) and the performance of the equation is equivalent to the results of PET from individual station based on T_{max} and T_{min} relationship (Table 3) (PET-SRE).

$$PET_R = 8.28T_{max} + 1.99T_{min} - 106.4\left[1 + \frac{\Delta E}{E_A}\right] \quad (2)$$

where:

PET_R = potential evapotranspiration estimate using the regional equation (in mm), $\Delta E = E_A - E_S$ and the difference between the average basin elevation (E_A = 2000 m) and elevation of the desired site location (E_S) in m.a.s.l;

$T_{\max}$ = areal average monthly maximum temperature (^{o}C)
$T_{\min}$ = areal average monthly minimum temperature (^{o}C)

The application of the regional equation gave unsatisfactory results in stations Mehalmeda, Gida Ayana and Nedjo. The estimates of PET were likewise unsatisfactory even when estimated with site specific equations developed at the stations (Table 3). The poor performance of this station is not the result of the regional equation. There is no systematic explanation why the equation is not properly estimating the PET for the above stations; however, one among the likely reasons for the poor performance of the estimates may be the quality of the data. It is noted that the interference of data inconsistency for some stations in this part of the world is not completely avoidable.

SUMMARY AND CONCLUSIONS

A regional temperature-based PET estimation method was developed as a function of areal average maximum and minimum temperature modulated by elevation difference at location where estimation is desired. The evaluation of the regional equation was made on the basis of 23 at site climate stations for the period 1992 to 2004. The method provided encouraging results in most of at site stations and can be used as an alternative approach to estimate PET in un-gauged locations of the vastly rural Abbay basin. Practitioners in agriculture and water resources planning area can benefit from using the methodology. The author cautions the use of the method doesn't substitute the availability of site specific data and should be used only under no or little data condition.

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