The 2nd International Conf. on Water Resources & Arid Environment (2006)

A Study on the Efficiency of two Empirical Equations FAO-Blaney-Criddle and Thornthwaite for Estimating Potential Evapo-Transpiration Data in Hashem Abad Synoptic Station-Gorgan, Iran

N. Jandaghi, M. Pairavand and N. Biroudian

Gorgan Univ. of Agric. Sci. and Natural Res., Iran

Abstract

In hydrological cycle, evaporation and transpiration are two reduction factors. They have an important role in changing the water supply and water budget in watersheds. In semiarid regions, up to 96% of yearly precipitation devote to evaporative process. In our country majority of areas have arid and semiarid, so this study is very important. In this investigation, raw data which were demanded, like mean temperature, wind speed, numbers of sunny hours, minimum of relative humidity, pan evaporation ,in Hashem Abad station was prepared monthly, for a-11 years statistical period. Then with usage of empirical equations like Thornthwaite, FAO Blaney-Criddle and FAO-Penman-Monteith (standard method) the data of potential evapo-transpiration was calculated monthly, seasonal and yearly. The data of A class evaporation pan was multiplied in pan coefficient, then these achieved data was used in statistical analysis. In order to comparison and determination of significant difference between 4 treatments, the F-test was used. The results of F-test show that, in more months and all seasons FAO-Blaney-Criddle method can be used instead of standard method and there is no statistical difference between them. In evaluation of yearly data there is no statistical difference between FAO-Blaney-Criddle and standard method, but between two methods Thornthwaite and evaporation pan with standard method there is a statistical difference.
Keywords: Pan Evaporation, Evapo-transpiration, Thornthwaite, FAO-Blaney-Criddle, FAO-Penman-Monteith, Hashem Abad.

Introduction

In the hydrological cycle and water budget evaporation and transpiration have important role. About 57% of precipitation in the continents back to the atmosphere directly (Alizadeh, 2002). Evaporation from water bodies are about 112% of precipitation. In the semi- arid zone which covers most of the Iranian platue, evaporation can be till 96% of annual precipitation. In the average about 50% of all precipitation loose in evaporation process in the catchments. Therefore, investigation on evapo-transpiration process could be very important in this country.

The most precise method for estimating evapo-transpiration in the ecosystems is the application of weighting lysimeters. Actually, using this types of lysimeters are very expensive and the lysimetric data are very rear in this country, so using the experimental models are very suitable (Shariffan and , 2004). There has been developed different method for estimating evapo-transpiration previously, such as Thornthwaite, Thornthwaite and Mather, Blaney and Criddle and Jensen and et al. (Bastos and *et al.*, 2000).

In the recent years the model of Penman-Monteith has been studied and improved by expertise. The last edited model has been presented by FAO in the Publication No.56 (Allen and *et al.*, 1998). This model is named as FAO-Penman-Montieth (FPM). Allen and *et al.* (1998) have suggested FP-M model in the many areas of the world. Among the different empirical models, FP-M model has been suggested as standard method for estimating evapo-transpiration by the International Irrigation and Drainage Committee and FAO (Hargreaves, 1994).

Because of insufficient meteorological data in the country, using complicate models such as FP-M is impossible, so, the most of experts use simple methods for estimating evapo-transpiration. Among the existing empirical methods two models of Thornthwaite and FAO-Blaney-Criddle have been vast application. Propose of this study was to recognition of these models efficiencies to introduce special model for other areas.

Methods and Materials

Primarily, the existing meteorological data from Hashem Abad Station in Gorgan, Iran have been collected. It is a synoptic type station and belong to Iranian Meteorological Organization. The elevation of the station is 13.3 meter and it is located in a vast plane with 54˚ 16́ E longitude and 36˚ 51́ N latitude. During the data collection period in the station only actual information have been used. So, the duration of data was 11 years (1992-2002).

The required meteorological monthly data for this study were:

- Mean maximum temperature,
- Mean minimum temperature,
- Mean daily temperature,
- Mean relative humidity,
- Minimum relative humidity,
- Total sun shine duration
- Mean Wind velocity in 2 meter height
- Evaporation from A class pan

Then by using empirical model such as: Thornthwaite, FAO-Blaney-Criddle and FPM, amount of potential evapo-transpiration was calculated.

The Thornthwaite model:

$$ETP = 16.2\left(\frac{10T_i}{I}\right)^{\alpha} \qquad \text{(Equation 1)}$$

$$I = \sum_{i=1}^{12} (\frac{T_i}{5})^{1.514}$$ (Equation 2)

$$\alpha = (0.657I^3 - 77.1I^2 + 17920I + 492390) * 10^{-6}$$ (Equation 3)

Where, *ETP* is monthly crude potential evapo-transpiration in mm., T_i is Mean monthly temperature in C°., *I* is thermal index and α depended to annual thermal index and can be calculated by using formula (3).

Then the calculated *ETP* improved by using formula (4):

$$ETP_c = ETP(\frac{D.N}{360})$$ (Equation 4)

Where, ETP_c is monthly potential evapo-transpiration in mm., *D* is the mean amount of duration between sun rise and sundown in hour, and *N* is Number of days in the month.

The FAO-Blaney-Criddle Model:

$$ETo = a + b[P(0.46T + 8.1)]$$ (Equation 5)

$$a = 0.0043(RH_{\min}) - \frac{n}{N} - 1.41$$ (Equation 6)

$$b = 0.82 - 0.0041(RH_{\min}) + 1.07(\frac{n}{N}) + 0.066(u_{day}) - 0.006(RH_{\min})(\frac{n}{N}) - 0.0006(RH_{\min})(U_{day})$$

(Equation 7)

Where *ETo* is the evapo-transpiration of reference plant in the ecosystem in mm./day, *T* is mean monthly temperature in C°., *P* is sun light index, *a* and *b* are climatic indices, $RH_{\min}$ is minimum relative humidity in percent, *n* is actual number of sun shine hours, *N* is possible number of sun shine hours and U_{day} is wind velocity at 2 meter height in m/s.

The FAO-Penman-Monteith Model (FPM):

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma[890/(T + 273)]U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)}$$ (Equation 8)

Where, *ETo* is the evapo-transpiration of reference plant in the ecosystem in mm./day, R_n is net solar radiation on vegetation cover $(MJm^{-2}d^{-1})$., *T* is the mean air temperature at 2 meter height in C°., U_2 is the wind velocity at 2 meter height m/s., $e_a - e_d$ is vapor pressure deficit at 2 meter height (KPa), Δ is vapor pressure curve gradient $(KPaC^{-1})$., γ is the humidity index $(KPaC^{-1})$ and *G* is heat adsorption to the soil $(MJm^{-2}d^{-1})$.

The calculation related to FPM method has been done through *CROPWAT* software in computer. Then by using the data of A class evaporation pan, water body potential evaporation has been calculated with formula (9).

$$E = K(Epan) \quad \text{(Equation 9)}$$

Where, *E* is potential evaporation from water body in mm., $Epan$ evaporation depth from A class pan and *K* is the pan coefficient.

Results and Discussion

After estimation the amount of potential evapo-transpiration by using three different empirical models; Thornthwaite, FAO-Blaney-Criddle and FP-M (as reference) and also the measurement of potential evaporation from A class pan (table 1-4), comparison between 3 methods and standard model (FPM) has been done by F-test and Tukey's pairwise comparison. Because, the number of data was less than 30, the normality test (Anderson-Darling) and variance similarity test (Bartlett) were applied (Ryan and *et al.*, 1985).

Table 1- The data of Thornthwaite potential evapo-transpiration in Hashem Abad, Gorgan synoptic station in mm.

Year / Duration	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Jun	12.18	12.17	12.11	12.07	12.04	12.00	11.89	12.02	11.93	11.92	11.97
Feb	12.93	12.93	12.90	12.89	12.88	12.86	12.81	12.86	12.83	12.82	12.85
Mar	23.02	23.07	23.34	23.54	23.66	23.86	24.36	23.78	24.17	24.25	23.99
Apr	49.97	50.32	52.23	53.66	54.54	56.09	59.91	55.48	58.42	59.03	57.01
May	79.81	80.56	84.73	87.88	89.84	93.32	102.04	91.95	98.62	100.01	95.40
Jun	130.72	132.39	141.70	148.85	153.33	161.38	182.02	158.21	173.85	177.17	166.24
Jul	157.11	159.30	171.53	180.99	186.93	197.64	225.32	193.41	214.32	218.79	204.13
Aug	146.44	148.49	159.86	168.66	174.18	184.14	209.88	180.21	199.66	203.81	190.18
Sep	112.54	114.01	122.13	128.39	132.31	139.36	157.45	136.58	150.28	153.20	143.62
Oct	79.04	79.91	84.70	88.36	90.64	94.71	105.01	93.10	100.95	102.61	97.15

Nov	29.26	29.41	30.22	30.82	31.18	31.83	33.40	31.58	32.79	33.04	32.21
Dec	11.34	11.33	11.26	11.21	11.18	11.13	11.01	11.15	11.05	11.03	11.10
Winter	48.14	48.17	48.36	48.49	48.58	48.72	49.02	48.66	48.93	48.99	48.81
Spring	260.50	263.28	278.66	290.40	297.72	310.79	343.97	305.64	330.89	336.22	318.65
Summer	416.09	421.80	453.53	478.04	493.43	521.14	592.64	510.19	564.27	575.80	537.93
Autumn	119.64	120.65	126.18	130.39	133.00	137.66	149.41	135.83	144.79	146.68	140.45
Year	844.4	853.9	906.7	947.3	972.7	1018.3	1135.1	1000.3	1088.9	1107.7	1045.8

Table 2- The data of FAO-Blaney-Criddle potential evapo-transpiration in Hashem Abad, Gorgan synoptic station in mm.

Year / Duration	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Jun	23.97	22.24	27.77	24.43	37.87	26.20	33.63	36.85	36.32	39.21	35.81
Feb	34.65	27.39	40.39	30.67	39.43	27.52	48.54	52.89	50.14	50.37	34.87
Mar	69.09	62.14	73.56	47.47	62.71	74.56	82.61	77.81	118.99	97.11	62.37
Apr	71.32	101.94	83.59	98.71	65.81	105.36	112.58	90.99	116.13	116.92	83.94
May	105.30	116.17	130.85	135.16	121.88	160.49	150.52	148.77	149.79	156.98	120.82
Jun	156.59	146.88	143.27	178.41	175.77	171.38	207.70	192.74	206.51	171.03	202.57
Jul	153.46	161.34	145.92	185.26	191.46	155.13	173.01	203.50	207.36	198.55	208.27
Aug	137.91	156.39	140.04	144.38	165.61	143.86	170.94	179.27	192.20	197.15	164.92
Sep	119.90	117.79	118.91	131.79	126.15	125.57	126.09	133.29	127.00	140.89	127.80
Oct	82.56	80.25	85.64	93.17	83.80	99.50	91.88	91.95	79.76	99.62	119.66
Nov	54.28	34.69	45.57	58.75	55.27	50.98	53.02	47.19	48.34	64.99	50.86
Dec	28.88	17.81	30.21	24.66	35.79	28.95	30.35	30.45	32.95	43.98	27.80
Winter	127.72	111.77	141.72	102.57	140.01	128.29	164.78	167.55	205.45	186.69	133.05
Spring	333.22	364.99	357.72	412.27	363.46	437.23	470.80	432.49	472.44	444.93	407.33
Summer	411.28	435.51	404.87	461.43	483.22	424.56	470.04	516.05	526.55	536.59	500.98
Autumn	165.71	132.72	161.42	176.58	174.86	179.43	175.25	169.59	161.05	208.59	198.33
Year	1037.9	1045.0	1065.7	1152.8	1161.6	1169.5	1280.9	1285.7	1365.5	1376.8	1239.7

Table 3-The data of FAO-Penman-Monteith (standard method) potential evapo-transpiration in Hashem Abad, Gorgan synoptic station in mm.

Year / Duration	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Jun	37.2	34.1	31	34.1	40.3	40.3	37.2	49.6	49.6	52.7	52.7
Feb	50.4	39.2	50.4	42	53.2	36.4	58.8	64.4	64.4	61.6	47.6
Mar	77.5	65.1	74.4	52.7	68.2	74.4	80.6	77.5	120.9	93	68.2
Apr	90	117	96	111	81	111	123	102	132	135	99
May	117.8	124	127.1	142.6	124	158.1	145.7	161.2	142.6	167.4	127.1
Jun	156	147	129	171	174	165	192	168	195	171	189
Jul	148.8	155	139.5	186	182.9	142.6	148.8	176.7	189.1	192.2	186
Aug	130.2	145.7	124	130.2	151.9	136.4	161.2	155	170.5	176.7	151.9
Sep	108	102	105	114	114	111	111	114	120	123	117
Oct	80.6	68.2	71.3	86.8	74.4	89.9	83.7	83.7	80.6	93	120.9
Nov	57	39	42	51	48	54	48	48	54	75	48
Dec	37.2	27.9	40.3	31	31	34.1	34.1	31	40.3	52.7	43.4
Winter	165.1	138.4	155.8	128.8	161.7	151.1	176.6	191.5	234.9	207.3	168.5
Spring	363.8	388.0	352.1	424.6	379.0	434.1	460.7	431.2	469.6	473.4	415.1
Summer	387.0	402.7	368.5	430.2	448.8	390.0	421.0	445.7	479.6	491.9	454.9
Autumn	174.8	135.1	153.6	168.8	153.4	178.0	165.8	162.7	174.9	220.7	212.3
Year	1090.7	1064.7	1030.0	1152.4	1142.9	1153.2	1224.1	1231.1	1359.0	1393.3	1250.8

Table 4- The data of class A pan evaporation in Hashem-Abad, Gorgan synoptic station in mm.

Year / Duration	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Jun	8.60	16.60	25.79	22.44	20.96	18.43	21.06	23.56	21.99	24.97	21.78
Feb	24.29	22.87	42.36	38.16	27.07	27.94	33.48	33.91	37.32	37.92	28.70
Mar	24.85	19.46	36.19	21.46	21.77	23.20	29.21	25.31	35.06	35.32	20.12
Apr	71.79	103.46	81.13	99.15	75.36	83.55	79.36	71.61	78.54	84.21	66.09
May	106.00	116.61	121.81	147.84	126.02	123.97	109.88	116.90	131.92	123.92	105.48
Jun	153.05	142.96	148.15	187.03	158.57	139.29	150.30	169.76	168.50	145.17	172.61

Jul	143.99	148.83	159.22	163.37	167.23	133.91	138.67	178.78	168.39	171.99	168.44
Aug	122.68	150.35	135.35	139.40	147.10	110.38	129.93	153.00	162.53	184.33	142.18
Sep	101.59	96.99	94.27	121.47	101.64	89.21	77.31	111.25	104.37	139.67	101.01
Oct	67.92	65.32	63.99	69.02	49.50	62.79	43.49	57.66	61.00	65.34	78.11
Nov	38.47	34.27	30.11	43.74	30.43	30.72	27.45	29.90	31.73	37.67	36.27
Dec	17.32	17.05	19.55	20.96	19.28	17.05	17.65	21.19	19.49	21.29	16.63
Winter	57.73	58.92	104.34	82.06	69.79	69.57	83.75	82.78	94.37	98.20	70.61
Spring	330.84	363.04	351.09	434.02	359.95	346.81	339.54	358.27	378.97	353.30	344.18
Summer	368.26	396.18	388.84	424.25	415.97	333.49	345.91	443.03	435.28	495.99	411.62
Autumn	123.71	116.64	113.65	133.72	99.20	110.57	88.59	108.75	112.22	124.30	131.00
Year	880.6	934.8	957.9	1074.1	944.9	860.4	857.8	992.8	1020.8	1071.8	957.4

After, Tukey and F tests, monthly, seasonal and annual data produced by three methods and the reference model (FPM) were compared. The results of Tukey's pairwise comparison with Minitab software, among different methods has been shown in table (5). In this table the star marked numbers conducted the significant difference between a pair of methods.

Table 5- The results of Tukky`s test to comparison and determination of significant difference between FAO-Penman-Monteith (standard method) and other methods

FAO-Penman-Monteith & FAO-Blaney-Criddle		FAO-Penman-Monteith & Thornthwaite		FAO-Penman-Monteith & Pan evaporation		Month, Season or year
-16.87*	-3.95	23.23 *	36.14	-27.60 *	-14.69	Jun
-20.61 *	-3.31	30.15 *	47.45	-28.14 *	-10.84	Feb
-17.59	13.21	38.37 *	69.17	-66.36 *	-35.56	Mar
-29.18	1.96	38.10 *	69.23	-43.09 *	-11.96	Apr
-20.26	12.83	31.95 *	65.04	-35.39 *	-2.3	May
-12.97	30.40	-9.77	33.61	-23.47	10.63	Jun
-11.48	36.15	-47.62	0.01	-33.34	14.29	Jul
-8.27	37.17	-52.89 *	-7.44	-27.86	17.59	Aug
0.33 *	28.07	-36.68 *	-8.94	-22.98	4.76	Sep
-6.03	19.61	-20.37 *	5.27	-35.45 *	-9.81	Oct
-7.57	7.57	12.28 *	27.41	-25.13*	-10.01	Nov
-12.10 *	-0.84	19.85 *	31.10	-23.40 *	-12.15	Dec
-51.22	2.11	95.59 *	148.92	-118.26 *	-64.93	Winter
-51.5	34.5	71.2 *	157	-100.3 *	-14.5	Spring
-14.7	96.6	-132.4 *	-21.1	-79.4	31.9	Summer
-20.26	20.89	17.19 *	58.34	-78.55 *	-37.45	Autumn
-111	127	95.59 *	148.92	-350 *	-112	Year

*The star marked numbers conducted the significant difference between two methods

After, Tukey and F tests, monthly, seasonal and annual data produced by three methods and the reference model (FPM) were compared. The results of Tukey's

pairwise comparison with Minitab software, among different methods has been shown in table (5). In this table the star marked numbers conducted the significant difference between a pair of methods.

In the study of monthly data, between standard model (FPM) and the other three methods, it was concluded that the Thornthwaite method have the minimum level of fitting with standard model and only in the three months of year there was not significant difference. The A class pan method was very similar to the Thornthwaite method. The FAO-Blaney-Criddle method was highly fitted to the standard model and in the eight months of year there was not significant difference between them. It was also concluded that only in the two months; June and July all three methods were fitted to the standard model. In addition it can be concluded that the maximum level of fitness is related to the warm season and the minimum fitness is for cold season.

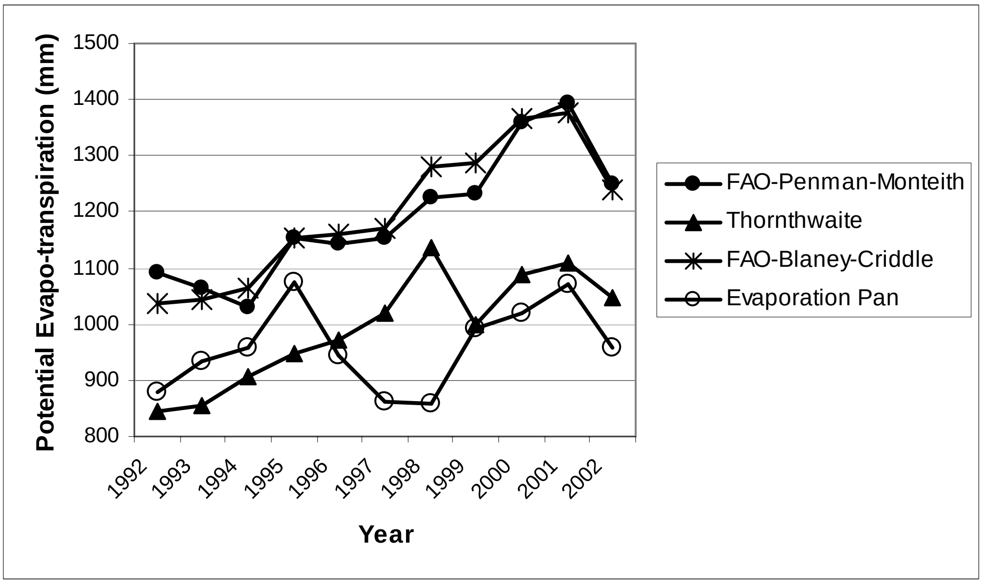

Figure 1. Annual evapo-transpiration values estimated with FPM model against the results of other methods

In the study of seasonal data, between standard model (FPM) and the other three methods, it was conducted that the Thornthwaite method at all seasons have significant difference with standard model and can not be suitable alternative for this model. The A class pan method can have a fitness with standard model only in summer. At all seasons there were not significant difference Between FAO-Blaney-Criddle and standard models. So, the FAO-Blaney-Criddle method has the maximum seasonal fitness with the model, and can be used for all seasons, therefore it is a suitable alternative for standard model.

In the yearly study of produced data, it was conducted that the Thornthwaite and pan methods have significant difference with standard model, but the FAO-Blaney-Criddle method and the standard model have a high level of similarity. So, for yearly estimation of evapo-transpiration, the FAO-Blaney-Criddle method can be a suitable alternative for standard model.

Acknowledgement

We are grateful to Dr Amir Sadoddin for his assistance in this work.

References

Alizadeh, A. 2002. Principles Of applied hydrology. 14 Ed. Astan-Ghods Pub. , Iran. pp: 735. (In Persian)

Allen, R. G, L. S. Pereira, D. Raes, and M .Smith. 1998. Crop evapo-transpiration guidelines for computing crop water requirements. ETo FAO Irrigation and drainage paper , NO . 56, Rome, Italy.

Hargreaves, C.H. 1994. Defining and using reference evapo-transpiration. Journal of *Irrigation and Drainage Engineering*, 120(6):1132-39.

J.de Brito Bastos, Jaidete M. de Souza and Tantravahi V. Ramana Rao. 2000. Potential evapo-transpiration estimates for northeast Brazil using GOES-8 data. Revista Brasileira de Engenharia Agricola e Ambiental, v.4, n.3, p: 348-354, Campina Grande , PB, DEAg/UFPB

Ryan, B.e, B.l. Jonior & Ryan, T.A. 1985. Minitab Handbook. Second Ed. PWS-Kent. Boston USA.

Sharifan, H, J. Nikbakht, A. Alizadeh, A. Soltani and M. Javerdi 2004. Estimating daily actual and potential evapo-transpiration with different return period in Golestan Province- Iran, Management and Planning Organization, Golestan Province. pp: 24. (In Persian).