Evaluation of Potential Evapotranspiration in Central Macedonia by EmPEst

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Abstract The differentiation and the determination of reference potential evapotranspiration (PET_{ref}) is important for many geo scientifically relevant questions. The ASCE (American Society of Civil Engineers)-Penman-Monteith approach provides a facility for the estimation of PET_{ref} using meteorological input parameters. However, the equation needs a lot of different input parameters. Hence this work compares 13 different alternative equations using fewer input parameters of four meteorological stations in Central Macedonia. The stations Loutra, and Skotina are located in the South of central Macedonia, while the stations Gumenissa and Grisopigi are situated in the north. Six statistical goodness of fit measures, including mean absolute error (MAE), mean square error (MSE), relative mean absolute error (MRAE), relative mean square error (MRSE), mean bias error (MBE) and the root square mean error (RMSE), where used. Additionally a Welch *t*-test was applied to test significance of the results. Results were analyzed for monthly timescale. The calculation of the 13 different approaches of evapotranspiration has been performed by the EmPEST software.

1 Introduction

By virtue of perennially stronger to the force coming changes of the climatic conditions within the Mediterranean climate zones and therewith attended impacts on flora and fauna and due to this of the humans as part of the global ecosystem, questions about transpiration and evaporation are of eminent importance for the

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C.G. Helmis and P.T. Nastos (eds.), *Advances in Meteorology, Climatology and Atmospheric Physics*, Springer Atmospheric Sciences,
DOI 10.1007/978-3-642-29172-2_64,

understanding of coherences of interactions of earth's surface and the atmosphere. Especially for agricultural issues, which also include forestry as well as hydrological issues, there is a larger growing demand for information on quantified data of transpiration and evaporation.

Related to the modelling of the impacts of a changing climate as a basis of the before mentioned, attainment about evapotranspiration is of arbitrative interest for an adequate appraisement of changes within ecosystems over the time and herefrom deducible risks. In areas where irrigation is a major component of agriculture due to slightly precipitation, it is also of economic importance to ascertain ET as accurate as possible; in fact that ET is in these regions the most significant component of the hydrological budget together with precipitation (Alexandris et al. 2008).

Due to the high complexity, which is necessary to measure humidification it has to be harked back to mathematical functions for the determination of ET. These functions are often the only possibility to accomplish detailed analysis and modelling. The most accurate model for any climate condition is considered to be the ASCE-Penman-Monteith equation (Fontenot 2004). But due to the high number of input parameters it is in many cases impossible or very difficult to use this equation.

This work is focused on the estimation and analysis of 13 different PET_{ref} equations for four meteorological stations in the region of central Macedonia, Greece, compared with the ASCE-Penman-Monteith model. Meteorological input data for the used equations were prepared under use of MS Excel respectively Libre Office Calc. For the calculation of the equation the program EmPEst was used (Kostinakis et al. 2011). Statistical analysis is made by EmPEst for PET_{ref} equations output. Moreover R was used for additional statistical analysis.

2 Data and Methodology

2.1 Data

This elaboration was made for four meteorological stations owned by the Forest Research Institute (FRI), Thessaloniki. All stations, excluding Loutra which is situated next to the building of the Forest Research Institute near Vasilika and Thessaloniki, are located in forested areas. Therefore it is to reckon with a stronger influenced by the sea for the station in Loutra. The station Grisopigi is located in the north-east of Central Macedonia in the prefection of Serres, within the foothill of the Rhodopes. The station is to find on an east-oriented side of this mountainous area. Station Gumenissa, is situated in the north of Central Macedonia between Gumenissa and Livadia in the Prefecture of Kilikis. The station is located within the Paiko mountain range with north-east orientation. The station in Skotina is with 1,040 m located at the highest duties. It is situated in the south-west of Central

Table 1 Geographical coordinates and climate of the meteorological stations

Name	Elevation (m)	Latitude	Longitude	Climate
Loutra	30	40° 30′	23° 04′	Semi-arid
Grisopigi	605	41° 10′	23° 34′	Sub-humid
Gumenissa	1,140	40° 58′	22° 20′	Humid
Skotina	600	40° 12′	22° 14′	Humid

Macedonia on a north-west orientated slope in the south-west of Skotina. Detailed geographic coordinates for all stations can be found in Table 1.

All stations collect calculation relevant input parameters, which are

- Air temperature
- Relative humidity
- Wind speed
- Solar radiation

The available meteorological input data had a time series resolution of 1 h. For station Loutra and station Grisopigi data series for a time range of 8 years (2002–2010) where extracted, for station Gumenissa and station Skotina time series of 5 years (2005–2010) where exploited. Commitment for the length of the time series has been made due to the available data records and their condition. Not measured or missing input data were calculated with Excel as mentioned in Allen et al. (1998) and include:

- Net radiation (R_n)
- Extraterrestrial radiation (R_a)
- Day length (DL)
- Dew point temperature (T_{dew})

As default value for the albedo 0.23, the average value for grassland, was used (Allen et al. 1998). PET_{ref} equations, wind speed correction to a height of 2 m above ground level, and all necessary goodness of fit calculations according to this issue were determined by the software EmPEst for PET_{ref} calculation (Kostinakis et al. 2011; Xystrakis and Matzarakis 2011). Additional statistics (Welch *t*-test, RMSE) where determined under use of R. Inhomogenities in the data where corrected as mentioned in Allen et al. (1998).

2.2 Methodology

Thirteen reference potential evapotranspiration models including the approaches of Hargreaves, McGuiness, Jensen, Hansen, Caprio, Romanenko, Tuc, Makkink, de Bruin, McCloud and three versions of Hamons approach, where calculated under use of EmPEsT (Kostinakis et al. 2011; Xystrakis and Kostinakis 2010). For statistical evaluation of the model performance mean absolute error (MAE), mean relative square error (MRSE), mean relative absolute error (MRAE), mean bias error (MBE) and root mean square error (RMSE) where used. It was renounced to use regression models for the PET_{ref} model comparison in addition to the other used methods, like it can be found in many similar studies. As Willmott (1982) remarked, these methods are often inappropriate or misleading for model comparison (Alexandris et al. 2008; Willmott 1982). Also it is evident that all the used methods of the uncertainty analysis cannot make any statement about the significance of model performance. To take account of this fact a Welch *t*-test was used to determine further information on model performance and to compensate the reasonable omission of the correlation coefficient.

3 Results

Exemplary the results for integrated monthly values of the station in Gumenissa (Table 2) will be discussed. Temperature based models show relatively diffuse results. $PET_{Hargreaves}$ performed best for MSE, while $PET_{McGuiness}$ gave the best results for MRSE and $PET_{Romananko}$ for MRAE. For all other statistical tests PET_{Hamon1} performed best. An additionally made Spearman correlation showed highest correlations of this model to the mean, minimum and maximum air temperature. A graphical analysis of the MBE showed a constant underestimation of McClouds model and Hamons equation version 3. $PET_{Romanenko}$ overestimated PET_{ASCE} constantly with exception of May. All other temperature based equations underestimated PET_{ref} mainly during the colder month and tended to overestimate during growing season. PET_{Hamon1} which has to be seen as the best temperature

Table 2 Results of all goodness of fit measures including Welch *t*-test results for integrated monthly values of PET_{ref} for Gumenissa

Stat. method	Har	McG	Rom	Ham1	Ham2	Ham3	McC
Air temperature based							
MSE	834.200	871.900	1649.700	472.700	610.200	1019.000	2280.500
MAE	24.456	24.578	138.778	17.842	19.486	27.317	42.267
MRSE	0.088	0.041	0.044	0.058	0.042	0.189	1.251
MRAE	0.259	0.174	0.159	0.184	0.163	0.350	0.821
MBE	−21.183	22.722	19.203	−5.142	9.397	−25.789	−37.872
RMSE	28.882	29.527	40.616	21.742	24.702	31.921	47.755
t-value	−2.579	2.332	1.691	−0.553	0.900	−2.934	−3.786
Radiation based							
	Cap	Jen	Han	Mak	Turc	deB	
MSE	1580.500	2102.200	364.500	31.000	139.400	748.300	
MAE	32.117	38.453	18.103	4.344	10.650	25.611	
MRSE	0.047	0.055	0.020	0.004	0.009	0.032	
MRAE	0.195	0.219	0.134	0.042	0.084	0.175	
MBE	29.394	37.464	18.103	−3.139	9.578	25.611	
RMSE	39.755	45.850	19.091	5.571	11.807	27.356	
t-value	2.357	2.993	1.851	−0.346	0.984	2.471	

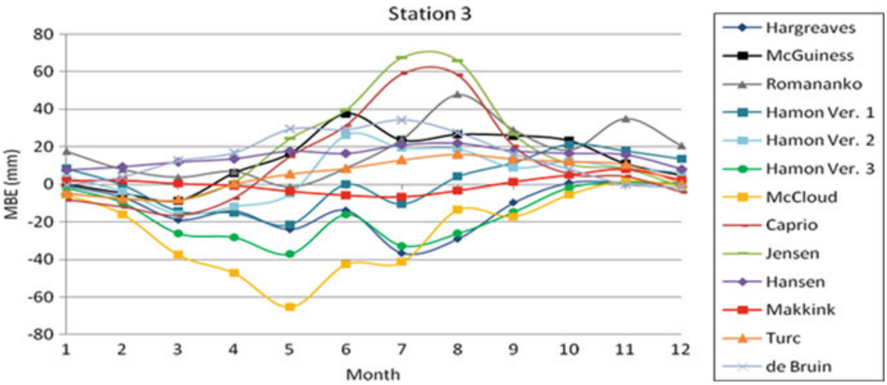

Fig. 1 MBE for integrated monthly values of PET_{ref} for Gumenissa (station 3)

based alternative to PET_{ASCE} underestimated for the first half of a year and overestimated during the second half in nearly the same range what leads to the good performance of this model also in comparison with the radiation based equations. Results for the radiation-based models show that $PET_{Makkink}$ performed outstandingly best for all statistical tests. With a MBE of −3.139 mm month^{-1}, a MAE of 4.344 mm month^{-1} and a MSE of 31.000 mm month^{-1} this equation gave by far the best results and is therefore without any alternative, also with view on the less amount on input parameters. The outstanding good performance of $PET_{Makkink}$ has also to be related to the elevation of this station and the associated climate conditions. However Makkink's model underestimated constantly what has to be fixed by an adjustment (Fig. 1).

4 Conclusions

Actually the study found different best performing models for different regions of central Macedonia as it was expected due to the results of other studies as for example Lu et al. (2005), or specific on Crete in Greece, Xystrakis and Matzarakis (2011). Hence, a north south gradient in model performance could be determined which is mainly a result of the solar radiation as the evaluation shows.

For nearly all statistical evaluations the radiation based equations performed better than the air temperature based once. This might also be due to the large influence of solar radiation. The only noticeable air temperature based equations are therefore PET_{Hamon3} for the south situated areas and $PET_{McGuiness}$ respectively $PET_{Hargreaves}$ for the north situated areas. Due to the low need on input parameters Hargreaves' equation can be seen as a good alternative.

On side of the radiation based approaches $PET_{Makkink}$ for the northern located stations in the north and PET_{Turc} respectively PET_{Hansen} for the stations in the south of central Macedonia gave the clearly best results. Nevertheless, none of the used equations gave overall best results. The good estimated of PET_{Turc} is comparable to the latest study on PET_{ref} for Crete by Xystrakis and Matzarakis (2011).

An additionally performed correlation analysis of the PET_{ref} results and the used input parameters showed a relatively high correlation of the equations with solar radiation, what points out the big influence of solar radiation for evapotranspiration within the region of central Macedonia. Therefore it is to aspire to fall back on one of the mentioned radiation based approaches as an alternative for PET_{ASCE}. For further estimations it should be thought about an adjustment of the proposed models to get even better results.

Summed up PET_{Turc} and $PET_{Makkink}$ are the suggested alternatives to the ASCE-Penman-Monteith equation for central Macedonia, Makkink's equation for the northern regions, Turc's equation for the southern regions.

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