A COMPARISON OF FIVE POTENTIAL EVAPOTRANSPIRATION METHODS AND RELATIONSHIP TO NDVI FOR REGIONAL USE IN THE MONGOLIAN GRASSLAND

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ABSTRACT:

Potential evapotranspiration (PET) is an important parameter of water budgets at different spatial scales and is a critical variable for understanding regional biological processes. It is often an important variable in estimating actual evapotranspiration (AET) in rainfall-runoff and ecosystem modelling. However, PET is defined in different ways in the literature and quantitative estimation of PET with existing mathematical formulas produces inconsistent results. The objectives of this study are to contrast five commonly used PET methods and quantify the 10 days PET of selected 3 meteorological stations in the Mongolian grassland. The temperature based (Hargreaves-Samani), combination Penman-Monteith method (FAO56-PM), radiation based (Makkink, and Priestley-Taylor) and Mass transfer based (Dalton aerodynamic) PET methods are compared. Also we examined temporal responses of remotely sensed NDVI to evapotranspiration during a four years period (2001-2004). 10 days NDVI values for Mongolian grassland region were calculated using National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) NDVI images. The study found that PET values calculated from the five methods were correlated with correlation coefficient 0.60 to 1.0. However, showed that PET values from different methods were significantly different from each other. Greater differences were found among the Dalton aerodynamic PET method than other four PET methods. In general, the combination Penman-Monteith method (FAO56-PM) and Hargreaves-Samani method performed better than the other PET methods in the Mongolian grassland. Based on the criteria of availability of input data and correlations with ground measurement ET values, the Hargreaves-Samani and combination Penman-Monteith methods (FAO56-PM) are recommended for regional applications in the Mongolian grasslands.

1. INTRODUCTION

Although several variations of the definition exist, potential evapotranspiration (PET) can be generally defined as the amount of water that could evaporate and transpire from a vegetated landscape without restrictions other than the atmospheric demand (Thornthwaite, 1948; Penman, 1948; Jensen *et al.*, 1990). There exist a multitude of methods for the estimation of potential evapotranspiration *ET* and free water evaporation E, which can be grouped into five categories: (1) water budget (e.g. Guitjens, 1982), (2) mass-transfer (e.g. Harbeck, 1962), (3) combination (e.g. Penman, 1948), (4) radiation (e.g. Priestley and Taylor, 1972), and (5) temperature-based (e.g. Thornthwaite, 1948; Blaney-Criddle, 1950). The availability of many equations for determining evaporation, the wide range of data types needed, and the wide range of expertise needed to use the various equations correctly make it difficult to select the most appropriate evaporation method for a given study. The objectives of this study are to: (1) contrast five commonly used PET methods that have potential to be incorporated into regional scale hydrologic modelling in global change studies, and (2) quantify PET across the climatic gradient of the Mongolian grassland and to examine of NDVI influence on ET under different climatic seasons. In previous studies shows the high values of evaporative fraction are related with were vegetated area, low values corresponding to bare soil and sparsely vegetated in arid and semi arid region of Mongolia. Tuya .S et al (2003). This paper reports finally, the overall applicability of the selected methods is examined and their predictive ability for the study region is discussed.

2. THE STUDY AREA AND DATA

In this study include grassland-steppe region of Mongolia. The area covers between the latitudes of $45^0 00'$N and $50^0 00'$N and the longitudes $96^0 00'$E and $118^0 00'$E. The range of this study area is considered on (Figure1). The Mongolian steppe grasslands have strong continental climate characterized by rainfall (from 100 to 350 mm) occurring mostly during the warmer months of June, July and August. The growing season is short, generally from 80 to 100 d. The climate data we used in this study 10 days (from 2001 to 2003) by selected 3 grassland meteorological stations. This study used NOAA AVHRR 8km 10 days Maximum Value Composite NDVI images also during 2001-2003 years.

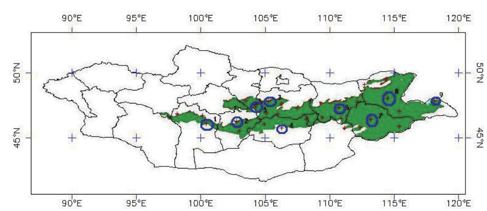

Figure 1. The study area with 3 selected grassland meteorological stations

3. METHODS

3.1 Penman-Monteith method

The FAO Penman-Monteith method for calculating reference (potential) evapotranspiration *ET* can be expressed as (Allen *et al*., 1998):

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

where e_s= saturated vapor pressure at air temperature (Pa)
e_a= actial vapor pressure (Pa)
T= air temperature
Δ = slope of the saturation vapor pressure-temperature curve at the mean temperature (kPa $^oC^{-1}$)
γ = the psychrometric constant (kPa $^oC^{-1}$)
U_2 = the wind speed measured at 2m height (sm^{-1})
Rn = Net radiation ($MJm^{-2}d^{-1}$)
G = Soil heat flux ($MJm^{-2}d^{-1}$)

3.2 Hargreaves-Samani method

The original Hargreaves method (1985) for calculating ET_0 is based on only mean daily maximum and mean daily minimum temperature:

$$ET_0 = 0.0023*0.408RA* (Tavg + 17.8)*TD^{0.5} \quad (2)$$

where RA= extraterrestrial radiation expressed in (MJ m^{-2} day^{-1}), Tavg = average daily temperature (^{0}.C) defined as the average of the mean daily maximum and mean daily minimum temperature
TD= the temperature range, computed as the difference between mean daily maximum and mean daily minimum temperature. The constant 0.408 is used to convert the radiation to evaporation equivalents in mm. RA can be obtained from tables (Hargreaves 1994), equations (Allen et al. 1998). The two other parameters, 0.0023 and 17.8, were obtained by Hargreaves et al. (1985) by fitting measured ET0 values to Equation (1).

3.3 Priestley-Taylor method.

The PET is estimated as (Jensen et al., 1990):

$$\lambda PET=\alpha\frac{\Delta}{\Delta+\gamma}(Rn-G) \quad (3)$$

where PET = Daily PET in mm/day
λ = Latent heat of vaporization in MJ/kg
α = calibration constant = 1.26
Δ = Slope of the saturation vapor pressure-temperature curve in kPa/^{o}C.
γ = Psychrometric constant kPa/^{o}C.
Rn = Net radiation in $MJ.m^{-2}.day^{-1}$.
G= Heat flux density to the ground in $MJ.m^{-2}.day^{-1}$.
It can be estimated as (Jensen et al.,1990):

$$G=4.2\frac{(T_{i+1}-T_{i-1})}{\Delta t}=-4.2\frac{(T_{i+1}-T_{i-1})}{\Delta t} \quad (4)$$

where T_i = Mean air temperature in ^{o}C for the period i.
Δ t = The difference of time days between two periods.

3.4 Makkink method

$$PET = 0.25 * (\Delta/(\Delta + \gamma) * R_s - 0.12 \quad (5)$$

where R_s = daily solar radiation, Mj/m^2/day
Δ = slope of the saturation vapor pressure curve
γ = psychrometric constant

3.5 Dalton mass-transfer method

The mass-transfer method is one of the oldest methods (Dalton, 1802) and is still an attractive method for estimating free water surface evaporation because of its simplicity and reasonable accuracy. The mass-transfer methods are based on the Dalton equation, which for free water surface can be written as:

$$E=f(u)(e_s-e_a) \quad (6)$$

where f(u) = wind function
e_s= the vapour pressure at the evaporating surface (kPa),
e_a = the vapour pressure of the atmosphere above (kPa)

4. RESULTS AND DISCUSSION

The in this comparative study, 10 days evapotranspiration from Penman-Monteith method (Equation (1)) and other four empirical methods, i.e., Equations (2), (3), (5), and (6), respectively, was computed with their original constant values involved in each equation. The Pearson correlation coefficients were calculated the values ranged from 0.60 to 1.00. Among these correlation coefficients at the selected 3 sites, the Hargreaves-Samani and Makkink PET methods had the highest value (R =0.99), while the Dalton mass transfer PET method had the lowest values (< = 0.94) with other methods (Tables 2, 3 and 4). Across the 3 sites, greater differences were found radiation based Priestley-Taylor method than other methods (Figures 2, 3 and 4). The PET values predicted by the Penman-Monteith, Hargreaves-Samani and Makkink methods were found to be similar in magnitude, especially for the Hargreaves-Samani and Penman-Monteith methods, which had a correlation coefficient of 0.98-0.99 between the two. A visual comparison shows (Figures 2, 3 and 4) that the value of α = 1.26 in Priestley-Taylor method seemed too high and Dalton mass-transfer method predicted the lowest PET values for the region. The Penman-Monteith, Hargreaves-Samani and Makkink methods worked quite well original values of the constants and were close to the mean estimates for all methods. Table 1. Showed NDVI strongly related with Hargreaves-Samani method than other PET methods in study area.

Site	Penman-Monteith	Hargreaves-Samani	Priestley-Taylor	Makkink	Dalton mass-transfer
Orkhon	0.730816	0.787776	0.750304	0.78695	0.64241
Choibalsan	0.796604	0.832108	0.751744	0.789816	0.820321
Khalkhgol	0.632252	0.696918	0.624473	0.663762	0.647883

Table 1. Correlation coefficients between NDVI and selected five PET methods (2001-2003).

PET Methods	Penman-Monteith	Hargreaves-Samani	Priestley-Taylor	Makkink	Dalton mass-transfer
Penman-Monteith	1.000	0.975	0.970	0.976	0.879
Hargreaves-Samani	0.975	1.000	0.988	0.997	0.910
Priestley-Taylor	0.970	0.988	1.000	0.993	0.897
Makkink	0.976	0.997	0.993	1.000	0.900
Dalton mass-transfer	0.879	0.910	0.897	0.900	1.000

Table 2. Pearson correlation coefficients among five PET methods (site #1. Orkhon 2001-2003)

PET Methods	Penman-Monteith	Hargreaves-Samani	Priestley-Taylor	Makkink	Dalton mass-transfer
Penman-Monteith	1	0.974287	0.951688	0.969568	0.905842
Hargreaves-Samani	0.974287	1	0.980319	0.989528	0.946947
Priestley-Taylor	0.951688	0.980319	1	0.992723	0.923984
Makkink	0.969568	0.989528	0.992723	1	0.943299
Dalton mass-transfer	0.905842	0.946947	0.923984	0.943299	1

Table 3. Pearson correlation coefficients among five PET methods (site #2. Choibalsan 2001-2003)

PET Methods	Penman-Monteith	Hargreaves-Samani	Priestley-Taylor	Makkink	Dalton mass-transfer
Penman-Monteith	1	0.969711	0.945138	0.969171	0.937889
Hargreaves-Samani	0.969711	1	0.983113	0.994686	0.951346
Priestley-Taylor	0.945138	0.983113	1	0.991641	0.935391
Makkink	0.969171	0.994686	0.991641	1	0.948193
Dalton mass-transfer	0.937889	0.951346	0.935391	0.948193	1

Table 4. Pearson correlation coefficients among five PET methods (site #3. Khalkhgol 2001-2003)

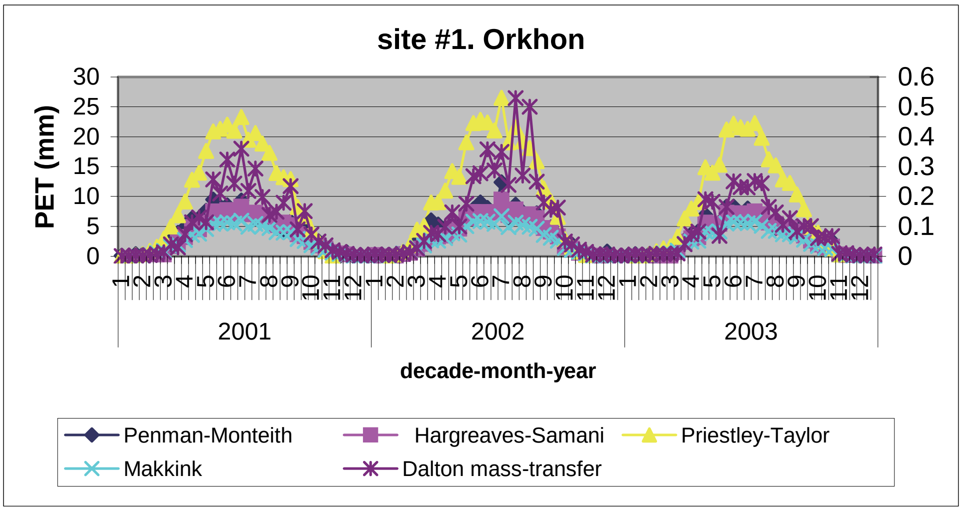

Figure 2. Comparison of 10 days PET by five methods at the meteorological station Orkhon

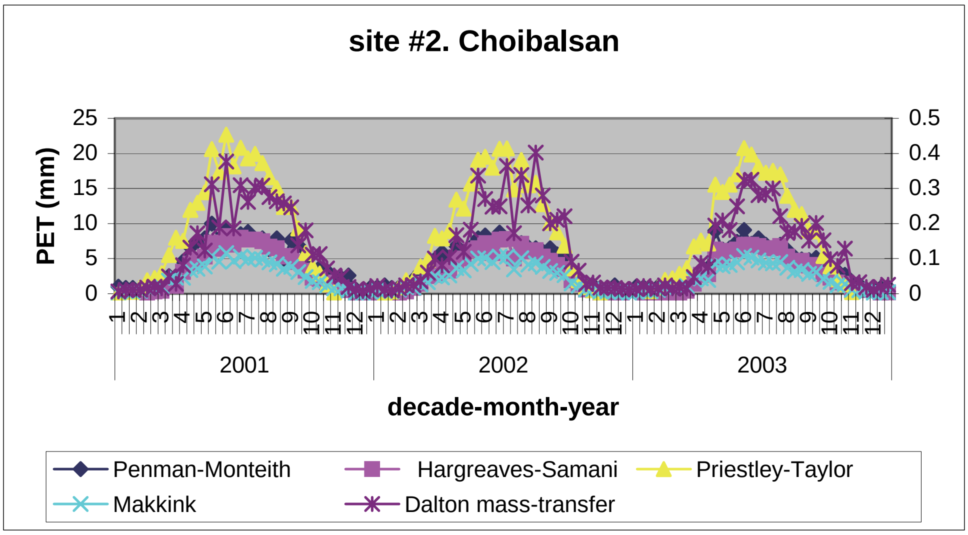

Figure 3. Comparison of 10 days PET by five methods at the meteorological station Choibalsan.

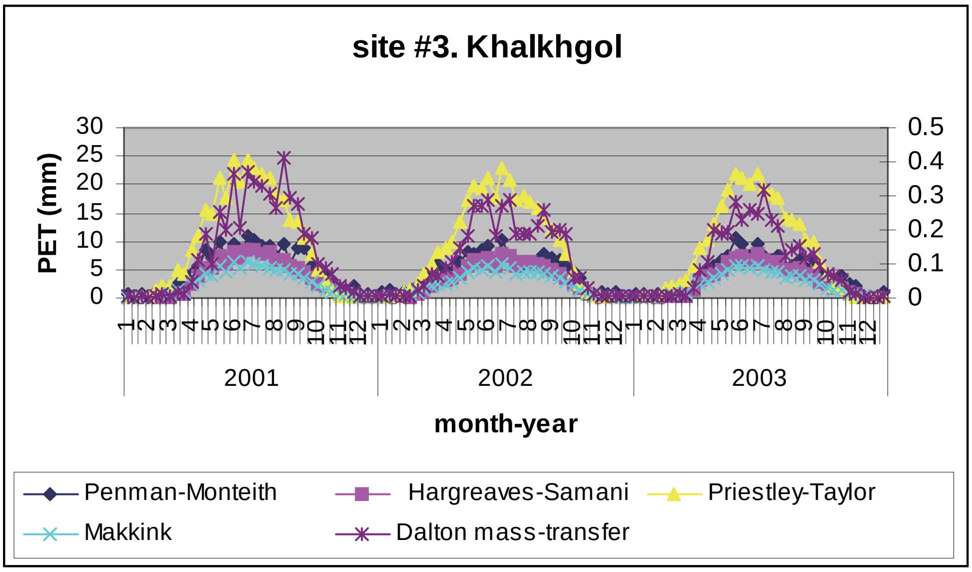

Figure 4. Comparison of 10 days PET by five methods at the meteorological station Khalkhgol.

5. CONCLUSIONS

This study suggested that PET is difficult to estimate accurately. The commonly used PET methods for this comparison study showing differences PET across the Mongolian grassland. The Priestley-Taylor method gave the highest and Dalton mass transfer lowest PET estimates in the study region. This suggests that careful calibration and verification efforts are needed when applying the Priestley-Taylor and Dalton mass transfer PET methods for this region. The Hargreaves-Samani PET method worked well under the semi-arid conditions in Mongolian grassland. However, the results of the present study suggest that this method may not be appropriate humid regions of Mongolia. We conclude that the temperature based Hargreaves-Samani method is better than the other methods in this study region. Otherwise, the Makkink and Penman-Monteith methods could be used in the dry arid and semi arid region. The Priestley-Taylor method developed for warm humid climate condition.

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