A COMPARISON OF FIVE POTENTIAL EVAPO-TRANSPIRATION METHODS IN THE TROPICAL AND SUBTROPICAL MONSOON REGION IN BANGLADESH

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ABSTRACT

In the field of climatology, hydrology as well as agriculture, PET which is formally named as potential evapo-transpiration has been an important variable influencing them as a vital index. Estimation of the PET properly has always been an esteemed effort because with the change of various environmental factors it always varies inconsistently. Consequently, the proper measurement of this index is really fundamental because of its influence on different environmental models. An effort concerned with the comparison of five most commonly used empirical estimation methods of PET has been made in this study in some tropical as well as subtropical regions in Bangladesh. Atrociously but virtually, appreciable deviations and inconsistency has been noticed from the comparison of different methods. Different parameters such as mean temperature, daylight hours, saturation vapor pressure, temperature range, extra-terrestrial radiation, solar shortwave radiation, mean monthly sunshine hours, possible maximum sunshine hours, net radiation and ground heat flux has been correlated for the estimation of PET in these five methods. Priestly-Taylor method is suitable for cold region whereas solar radiation method, net radiation method and Priestley-Taylor method is radiation based method and Hargreaves method is a temperature based method which is more suitable in warmer climates. To recapitulate in short, results of the study are expected to be useful for those involved in agricultural activities like the optimum yield of different crops in different monsoons of a year and in different climatic conditions in Bangladesh.

Keywords: Potential evapo-transpiration, Hargreaves method, Solar shortwave radiation based method, Net radiation based method, Hamon’s method, Priestley-Taylor method.
Introduction

A good estimation of evapo-transpiration is vital for proper water management, allowing for the improve efficiency of water use, high water productivity and efficient farming activities. For estimating water requirement the consumptive use or evapo-transpiration is estimated which depends widely with several factors related to climate. Moreover, an accurate measurement of evapo-transpiration is always required in hydrology as well as water resource engineering for various types of climatologic modeling and also to well adopt with the varying climate. However, lots of empirical relations have been established and proposed for the betterment of the assessment of evapo-transpiration but for using a sustainable assessment model a practically simulated comparison between these models is always required. Gigliola Elena Urecche (2011) investigated the potential evapo-transpiration and dryness/drought in Covurlui field and Brates floodplain using Penman formula and Thornthwaite formula. His analysis concluded with some examples of practical importance. The analysis recommends the effect of evapo-transpiration on the agriculture at different regions of the study area. Moreover, J. Norrie et al. (1994) also investigated the effect of potential evapo-transpiration as a means of predicting irrigation timing in greenhouse tomatoes grown in peat bags using Penman equation. More recently, Aikman and Houter (1990), using the Penman-Monteith equation for potential evapo-transpiration (PET) estimates (Penman, 1948), constructed a model predicting the energy absorbed from incident total solar radiation in a glasshouse tomato crop. Furthermore, Nilson A. Villa Nova et al. (2006) also reviewed the simplified Penman method for estimation of potential evapo-transpiration. In addition, The comparison between the diurnal values of ETo measured in weighing lysimeters with elevated precision and estimated by either the Penman-Monteith method or the Simplified-Penman approach in study also points out a fairly consistent agreement among the potential demand calculation criteria. Long before that, E. L. Skidmore et al. (1669) examined the influence of wind on the potential evapo-transpiration using Bowen ratio method. Joshua B. Fisher et al. (2010) also adopted Penman–Monteith, Priestley–Taylor, Thornthwaite for computing evapo-transpiration for implement it into the field of geographical ecology. Radiative or turbulent fluxes is also been used by C. Matsoukas et al. (2011) to estimate the potential evapo-transpiration trends over land. L. Menzel et al. (2008) tested the relevance of stream flow modelling in semi-arid environments using the comparison of four evapo-transpiration measurement equations. Afterwards, Keltoum Chaouche et al. (2010) analyzed the precipitation, temperature and evapo-transpiration in a French Mediterranean region. Again, Vu Van Nghi et al. (2008) investigated the effect of potential evapo-transpiration hydrological model response at the Nong Son Basin where the Penman-Monteith method, Leaf area index (LAI) as well as Normalized difference vegetation index (NDVI) has been used. A completely new index named Reconnaissance Drought index which can be directly related with Standardized Precipitation Index (SPI) has been established by G. Tsakiris et al. (2005) using evapo-transpiration. M.C. Acreman et al. (2003) used eddy correlation with evapo-transpiration characteristics of wetland. F. C. Sperna Weiland et al. (2012) evaluated an optimum method to evaluate the potential evapo-transpiration to apply it into hydrological model study. A more related investigation by Jianbiao Lu et al. (2005) has been performed where six empirical methods to calculate potential evapo-transpiration has been used for regional use in the southeastern United States. Similarly, C. Xu et al. (2005) also adopted similar type of methodology where seven models have been adopted to calculate the evapo-transpiration and groundwater recharge using lysimeter measurement data in Germany. Potential evapo-transpiration has also been used by XU Xing-Kui et al. (2011) as a function of several climatic factors including humidity, wind, air temperature and solar radiation. The present study has been carried out using six models of evapo-transpiration and thus the value of PET of 18 stations has been compared.

Description of the Project Area

Bangladesh is a part of the largest delta in the world and the nature of the climate is a typical monsoon. Bangladesh has an area of 1,44,430 square kilometer between latitudes 20°03’N and 26°75’N and longitudes 88°03’E and 92°75’E. The country is bounded by India to the west, north and east. In the extreme southeast, it is bounded by Burma. In the south of Bangladesh, the Bay of Bengal situated. About 6 percent of the land is covered with permanent streams and estuaries. High temperature, heavy rainfall, often excessive humidity and fairly marked seasonal variations are the main climatic characterization factors. Again more than half of the area is Himalayan mountain chain has made the climatic tropical over most of the country. This study has been made with 18 meteorological stations shown in Table 1 as follows.

Methodology

To determine the potential evapo-transpiration five mostly used empirical methods have been adopted that is Hargreaves method, Solar shortwave radiation based method, Net radiation based method, Hamon’s method, Priestley-Taylor method and thus compared the value of PET at 18 stations. The basic procedure of these five methods is described as follows.

Hargreaves method

The estimation of PET is calculated by the equation:

\[
PET = 0.0023 \times (T_{\text{mean}} + 17.78) \times (TD)^{0.5} R_a
\]
Where, \(PET = \) potential evapo-transpiration, \(mm/day\), \(T_{mean} = \) mean temperature of the month, \(^oC\), \(TD = \) difference between maximum and minimum air temperatures, \(^oC\), \(R_s = \) extraterrestrial radiation, \(mm/day\).

### Table 1: List of meteorological stations

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Regions</th>
<th>Name of the Station</th>
<th>International Index Number</th>
<th>Year of Establishment</th>
<th>Co-ordinates</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tropical monsoon</td>
<td>Chandpur</td>
<td>941</td>
<td>1964</td>
<td>23°16’N 91°07’N</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>Tropical monsoon</td>
<td>Chittagong</td>
<td>978</td>
<td>1948</td>
<td>22°16’N 91°49’N</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>Tropical monsoon</td>
<td>Comilla</td>
<td>933</td>
<td>1883</td>
<td>23°26’N 91°11’N</td>
<td>6.1</td>
</tr>
<tr>
<td>4</td>
<td>Tropical monsoon</td>
<td>Faridpur</td>
<td>929</td>
<td>1883</td>
<td>23°36’N 89°51’N</td>
<td>8.2</td>
</tr>
<tr>
<td>5</td>
<td>Tropical monsoon</td>
<td>Feni</td>
<td>943</td>
<td>1973</td>
<td>23°02’N 91°25’N</td>
<td>6.4</td>
</tr>
<tr>
<td>6</td>
<td>Tropical monsoon</td>
<td>Hatiya</td>
<td>963</td>
<td>1965</td>
<td>22°26’N 91°06’N</td>
<td>2.4</td>
</tr>
<tr>
<td>7</td>
<td>Tropical monsoon</td>
<td>Khepupara</td>
<td>984</td>
<td>1943</td>
<td>21°59’N 90°14’N</td>
<td>1.8</td>
</tr>
<tr>
<td>8</td>
<td>Tropical monsoon</td>
<td>Kutubdia</td>
<td>989</td>
<td>1977</td>
<td>21°49’N 91°51’N</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Tropical monsoon</td>
<td>Madaripur</td>
<td>939</td>
<td>1976</td>
<td>23°10’N 90°11’N</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Tropical monsoon</td>
<td>Patuakhali</td>
<td>-</td>
<td>1905</td>
<td>24°01’N 89°14’N</td>
<td>12.8</td>
</tr>
<tr>
<td>11</td>
<td>Tropical monsoon</td>
<td>Rajshahi</td>
<td>960</td>
<td>1973</td>
<td>22°20’N 90°20’N</td>
<td>13.5</td>
</tr>
<tr>
<td>12</td>
<td>Tropical monsoon</td>
<td>Rangamati</td>
<td>859</td>
<td>1883</td>
<td>25°44’N 89°14’N</td>
<td>32.6</td>
</tr>
<tr>
<td>13</td>
<td>Tropical monsoon</td>
<td>Sitakundu</td>
<td>965</td>
<td>1977</td>
<td>23°35’N 91°42’N</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>Tropical monsoon</td>
<td>Teknaf</td>
<td>998</td>
<td>1977</td>
<td>20°52’N 92°18’N</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>Tropical monsoon</td>
<td>Dinajpur</td>
<td>883</td>
<td>1883</td>
<td>25°39’N 88°41’N</td>
<td>36</td>
</tr>
<tr>
<td>16</td>
<td>Sub-tropical monsoon</td>
<td>Ishurdi</td>
<td>907</td>
<td>1963</td>
<td>24°08’N 89°03’N</td>
<td>14</td>
</tr>
<tr>
<td>17</td>
<td>Sub-tropical monsoon</td>
<td>Rangpur</td>
<td>895</td>
<td>1883</td>
<td>24°22’N 88°42’N</td>
<td>16.8</td>
</tr>
<tr>
<td>18</td>
<td>Sub-tropical monsoon</td>
<td>Sylhet</td>
<td>891</td>
<td>1952</td>
<td>24°54’N 91°53’N</td>
<td>35.5</td>
</tr>
</tbody>
</table>

**Solar shortwave radiation based method**

It is the easiest method in calculating evapo-transpiration because the data needed for this equation is available. The formula for calculating evapo-transpiration is,

\[
PET = -0.611 + 0.149 R_s + 0.079 T_{mean}
\]

Where, \(PET = \) potential evapo-transpiration, \(mm/day\), \(T_{mean} = \) mean temperature of the month, \(^oC\), \(R_s = \) solar shortwave radiation, \(MJm^{-2}d^{-1} = (0.075 + 2 \times 10^{-5}z) Ra\), \(Z = \) elevation of the station, \(m\), \(Ra = \) extraterrestrial radiation, \(MJm^{-2}d^{-1}\)

**Net radiation based method**

The equation for calculating potential evapo-transpiration according to this method is,

\[
PET = 0.489 + 0.289R_n + 0.023T_{mean}
\]

Where, \(PET = \) potential evapo-transpiration, \(mm/day\), \(R_n = \) net radiation, \(MJm^{-2}d^{-1} = [Ra (1-R)\times(0.18\times0.56n/N) - \sigma T^4(0.56-0.092\sqrt{ed})\times(0.1 + 0.9 n/N)]\times2.45\), \(R_s = \) extraterrestrial radiation, \(mm/day\), \(R = \) reflection coefficient = 0.25 for green cropped land, \(N = \) possible maximum sunshine hours, \(hr\), \(n = \) mean monthly sunshine hours, \(hr\), \(T_{mean} = \) mean monthly temperature, \(^oC\), \(\sigma = \) Stefan Boltzman’s constant = \(2.10 \times 10^{-9} mm/day\), \(ed = \) saturation vapor pressure at mean air temperature, \(mm\) of Hg

**Hamon’s method**

The Hamon’s (1963) equation is,

\[
PET = (29.9\times D\times e_u) ÷ (T + 273.2)
\]
Where, \( \text{PET} \) = potential evapo-transpiration, \( \text{mm/day} \), \( D \) = daylight hours, \( \text{hr} \), \( T \) = mean daily temperature, \( ^\circ \text{C} \), \( e_s \) = saturation vapor pressure, kPa

**Priestley-Taylor method**

Priestley and Taylor (1972) proposed a simplified version of the combination equation (Penman, 1948) for the use when surface area generally is wet, which is a condition required for potential evapo-transpiration. The original equation has been modified below to suit the units of the database,

\[
\text{PET} = 0.408 \times 1.26 \times \left[ \frac{\Delta}{\Delta + \lambda} \right] \times (R_{\text{net}} - G_{\text{month}})
\]

Where,
\( \text{PET} \) = potential evapo-transpiration, \( \text{mm/day} \), \( R_{\text{net}} \) = net radiation as calculated in net radiation method, \( G_{\text{month}} \) = Ground heat flux = \( 0.07 \times (T_{\text{month+1}} - T_{\text{month-1}}) \), \( T_{\text{month+1}} \) = mean temperature for next month, \( ^\circ \text{C} \), \( T_{\text{month-1}} \) = mean temperature for previous month, \( ^\circ \text{C} \)

\[
\frac{\Delta}{\Delta + \lambda} = (-0.00008 \times T_{\text{mean}}^2) \times (0.0139 \times T_{\text{mean}}) + 0.4235
\]

**Results And Discussion**

For calculating PET using these five methods data of different parameters such as mean temperature, daylight hours, saturation vapor pressure, temperature range, extra-terrestrial radiation, solar shortwave radiation, mean monthly sunshine hours, possible maximum sunshine hours, net radiation and ground heat flux, have been collected as well as calculated which has been shown in following Figures 1 to 18.

Fig 1: Different Parameters vs. month at Chandpur

Fig 2: Different Parameters vs. month at Chittagong

Fig 3: Different Parameters vs. month at Comilla

Fig 4: Different Parameters vs. month at Dinajpur

Fig 5: Different Parameters vs. month at Faridpur

Fig 6: Different Parameters vs. month at Feni
The monthly values of potential evapo-transpiration of 18 stations of the country by five different methods are represented in Figures 19 to 36. The computed potential evapo-transpiration at each station of the tropical and sub-tropical region in the month of December and January is low. In the month of May to June the highest value of potential evapo-transpiration occurs in the district of Chandpur, Dinajpur, Faridpur, Feni, Htia, Ishurdi, Khepupara, Kuibidia, Madaripur, Patuakhali, Rajshahi, Rampur, Rangamati, Srimangal, Sylhet, Teknaf in which the value of PET above 2.50 mm/day.

In Harmon’s method, the value of potential evapo-transpiration varies from 2.09 mm/day at Dinajpur to 2.74 mm/day at Teknaf in the month of January. In the month of May, this value varies from 4.56 mm/day at Sylhet to 5.26 m/day at Rajshahi. In the month of December, this value varies from 2.27 mm/day at Rajshahi to 2.94 mm/day at Teknaf. However, in Hargreaves method, the value of potential evapo-transpiration varies from 2.87 mm/day at Chandpur to 3.20 mm/day at Feni in the month of January. In the month of May, this value varies from 4.6 mm/day at Teknaf to 5.70 mm/day at Ishurdi. In the month of June, this value varies from 3.95 mm/day at Teknaf to 5.25 mm/day at Khepupara. In the month of July, this value varies from 3.76 mm/day at Teknaf to 4.59 mm/day at Khepupara.

In the month of December, this value varies from 2.81 mm/day at Sitakunda to 4.12 mm/day at Comilla. Furthermore, in Priestley-Taylor method, the value of potential evapo-transpiration varies from 3.09 mm/day at Sylhet to 4.59 mm/day at Dinajpur in the month of January. In the month of May, this value varies from 4.84 mm/day at Patuakhali to 7.62 mm/day at Comilla. In the month of June, this value varies from 3.45 mm/day at Patuakhali to 6.99 mm/day at Comilla. In the month of July, this values varies from 3.40 mm/day at Patuakhali to 7.04 mm/day at Dinajpur. In the month of December, this values varies from 2.68 mm/day at Sitakunda to 4.12 mm/day at Comilla. In the Net radiation method, the value of potential evapo-transpiration varies from 3.43 mm/day at Sitakunda to 4.59 mm/day at Teknaf in the month of January. In the month of May, this value varies from 4.73 mm/day at Patuakhali to 5.52 mm/ day at Rajshahi. In the month of June, this value varies from 3.74 mm/day at Patuakhali to 4.83 mm/day at Rajshahi. In the month of July, this value varies from 3.68 mm/day at Patuakhali to 4.38 mm/day at Rajshahi. In the month of December, this value varies from 3.34 mm/day at Sitakunda to 4.34 mm/day at Teknaf. Again, in solar shortwave radiation method, the value of potential evapo-transpiration varies from 0.98 mm/day at Patuakhali to 1.34 mm/day at Teknaf in the month of January. In the month of May, this value varies from 1.95 mm/day at Sylhet of 2.15 mm/day at Ishurdi. In the month of June, this values varies from 2.02 mm/day at Sylhet to 2.17 mm/day at Rajshahi. In the month of July, this values varies from 2.00 mm/day at Teknaf to 2.12 mm/day at Ishurdi. In the month of December, this value varies from 1.09 mm/day at Rajshahi to 1.43 mm/day at Teknaf.

From the graph shown in 19 to 36, in the northern region of Bangladesh to PET, estimated varies from 0.98 mm/day to 7.20 mm/day. The curve of Hamon’s solar shortwave radiation, Priestely-Taylor, net radiation is approximately regular. It rose from January to MayJune and start falling to December. In the Priestley-Taylor and Hargreaves, they rise in January and fall in June-August and finally fall in December. In the middle region, the PET estimated is varied from 1.01 mm/day to 7.45 mm/day. The curve of net radiation, Hargreaves and solar shortwave radiation are approximately regular. They rise from June and fall to December. PET estimated from Priestley-Taylor method is higher than the other method in the most of stations. In the Hamon’s method, there is a steep rise in curve in June and fall in December straightly. In the southern region, the PET estimated is varied from 1.07 mm/day to 7.62 mm/day. The curves of Hargreaves, net radiation, solar shortwave radiation, Hamon’s method there is a little rise in curve from May to September otherwise they are most often parallel. In Priestley-Taylor curve there is a steep rise from June and steep fall to December.

In the hilly region, the PET varies from 1.05 mm/day to 6.70 mm/day. The curve of Hargreaves, net radiation, solar shortwave radiation method is approximately regular. The curve of Hamon’s gradually rises from January and gradually down to December. The curve of Priestley-Taylor falls from May to August and rises after August and again falls in December.
Conclusion

The study has been carried out to make a comparison among different methods of estimating potential evapo-transpiration using the data of 18 meteorological stations under tropical and sub-tropical monsoon region of Bangladesh. Having a sharp study to our precious description the following points may be stated as conclusion.

- In the tropical and sub-tropical monsoon region of Bangladesh, the PET is maximum in the month of May-July and minimum in the month of December-January.
- Patuakhali station has the highest PET and Dinajpur has the lowest PET in the study region of Bangladesh.
- In the northern region of Bangladesh, the PET is considerably lower than the southern region and the PET in hilly region is higher than others because of have rainfall in this region.
- The result obtained by applying solar radiation method, net radiation method, Hamon's method, Priestley-Taylor and Hargreaves method are compared well. Radiation method, net radiation method and Hamon's method are highly correlated and obtained result from those methods are nearly same.
- Priestley-Taylor method is suitable for cold region. Solar radiation method, net radiation method and Priestley-Taylor method are radiation based method and Hargreaves method is temperature based method.
- It can be concludes from the study that using locally determined parameter values all five empirical methods gave acceptable estimates of potential evapo-transpiration. The results of the study are expected to be useful for those involved in agricultural activities in Bangladesh.

References