Rainfall induced Geohydraulic and Evapotranspiration Characteristics: An Indian Case Study

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Abstract: - Evaporation demand or potential evaporation is projected to increase almost everywhere in the world in future climate scenarios. Estimation of evapotranspiration (ET) is important for determining the agro-climatic potential of a particular region, water requirements of field crops, irrigation scheduling, and suitability of crops or varieties, which can be grown successfully with the best economic returns therefore numerous models have been developed for determining evapotranspiration. The present study was taken for Jorhat, Assam with the main objective of the present study is to highlight the governing equations for infiltration and compare three temperature-based methods for determining reference evapotranspiration namely Thornthwaite, Blaney-Criddle, and Ivanov method. The results obtained from the methods were compared with the evapotranspiration data measured using the class A pan. The interrelationship between the class A pan data and the other reference evapotranspiration method is also determined in the study. Moreover, the result obtained shows that the average monthly ET estimated by Blaney-Criddle, Thornthwaite, and Ivanov methods are 1.57, 3.05, and 2.62 mm/month. The correlation coefficient result shows that all the three methods compared well with the observed pan evaporation. the results of this investigation suggest that the Blaney-Criddle is the better method as compared to the Thornthwaite and Ivanov methods under climatic conditions of Jorhat. Furthermore, the engineering properties of soil collected from the study area were determined and presented in this study.

Key-Words: - Blaney-Criddle; Class A Pan; Ivanov; Potential evapotranspiration, Soil Properties; Thornthaite.

Received: March 30, 2021. Revised: February 18, 2022. Accepted: March 21, 2022. Published: April 27, 2022.

1 Introduction

Water foot printing is a valuable method for estimating future usage for agricultural production and consumer goods. In arid places, irrigation can help to mitigate the hazards associated with rain-fed agriculture's unpredictability. [1,2] Efficient water use can increase crop diversity and produce higher yields, enhance employment, and lower food prices. [3,4] PET (potential evapotranspiration) is a notion that is mostly independent of soil and plant conditions but has been demonstrated to be influenced by climatic factors. PET's temporal fluctuations and measurement of its trend may be used in hydrological modeling, agricultural water management, irrigation planning, and water resource management.[3, 5]

The PET needs to be estimated to determine the crop water requirements using crop-specific coefficients. There are numerous different formulae available in the literature for the calculation of PET. [5-10] Several limitations are there in data availability for the Indian conditions. Water managers need to have a thorough understanding of the evapotranspiration process. They should also study the engineering properties of the soil to understand the geohydraulic properties. A study of the geohydrologic balance for an area generally includes an analysis of the total water loss from all sources. The determination of potential evapotranspiration is of interest to agriculturists and hydrologists. In this study, the relation of evaporation to climatic factors, geographic location, and the vegetative cover has been investigated. Most of the methods are based on empirical formulae. After an extensive literature review, this study uses three temperature-based methods namely Blaney-Criddle, Thornthwaite, and Ivanov.

Jong and Tugwood [11] investigated long-term climatic data from selected regions in Canada They found the Priestly-Taylor model appropriate for a station with vapor pressure deficits and high wind speeds. The Empirical Robertson model appeared to require regional calibration to improve potential evapotranspiration estimates. Lu et al., [12] compared three temperatures based and three radiation-based potential evapotranspiration models. They found that PET values calculated from the six methods were highly correlated. Based on the criteria of availability of input data and correlations with AET values, the Priestly-Taylor, Turc, and Hamon methods are recommended for regional applications. Trajkovic and Gocic [13] found that the Penman-Monteith can be used as the standard method of estimating reference evapotranspiration. They further mentioned that It cannot be widely used due to its requirement of numerous weather parameters. Shahidian et al., [14] have recommended the turc method for humid or semi-humid areas, they found the Thornthwaite equations tend to underestimate ET. They further recommended the priestly-Taylor and Makkinik equations should not be used in winter months in locations with high latitudes such as North Europe. Stanford and Selnick [15] found that a regression equation can predict evapotranspiration at any given site based solely on climate or climate and land cover variables with an R2 value of 0.87 or greater.

Racz et al., [16] in their paper stated that Makkink and Shuttleworth-Wallace, Blaney-Criddle, and Makkink models were found to be the closest to the Penman-Monteith –FAO-56 method as a reference value. Based on the correlation between the models' results, Pereira and FAO-56 models agreed most with the Pan Evaporation measurement. Tomar [17] analyzed the Impact of different meteorological parameters and their inter-relationship with observed values of pan evaporation at Udham Sing Nagar district situated in the Tarai region of Uttarakhand. Evaporation is maximum during the summer season (March, April, and May) and minimum during the monsoon season (June, July, and August). Manikumari and Vinodhini [18] have developed a model using the reference evapotranspiration by three different regression models. Analysis was carried out based on the data collected in the command area of the Veeranam tank system during the period 1987-2008. The SVR models proposed by them showed a marginal improvement over MLR models. Mashru and Dwivedi [19] evaluated eight commonly used evapotranspiration estimation models for Junagadh city of Gujarat. Daily records of meteorological parameters i.e. maximum temperature, minimum temperature, relative humidity morning, wind speed, bright sunshine hours, and pan evaporation record for 10 years were collected for the study.

2 Study Areas

Jorhat is a prominent city in the Indian state of Assam. Majuli is the world's biggest riverine island, formed by the Brahmaputra River. According to the 2011 census, the district spans 2,851 square kilometers and has a population of 1,091,295 people. evaporation data acquired using a Class A-Pan were gathered from the Meteorological Observatory of Assam Agriculture University in Jorhat, Assam, from 2007 to 2016. Figure 1 depicts the Kakodonga Watershed

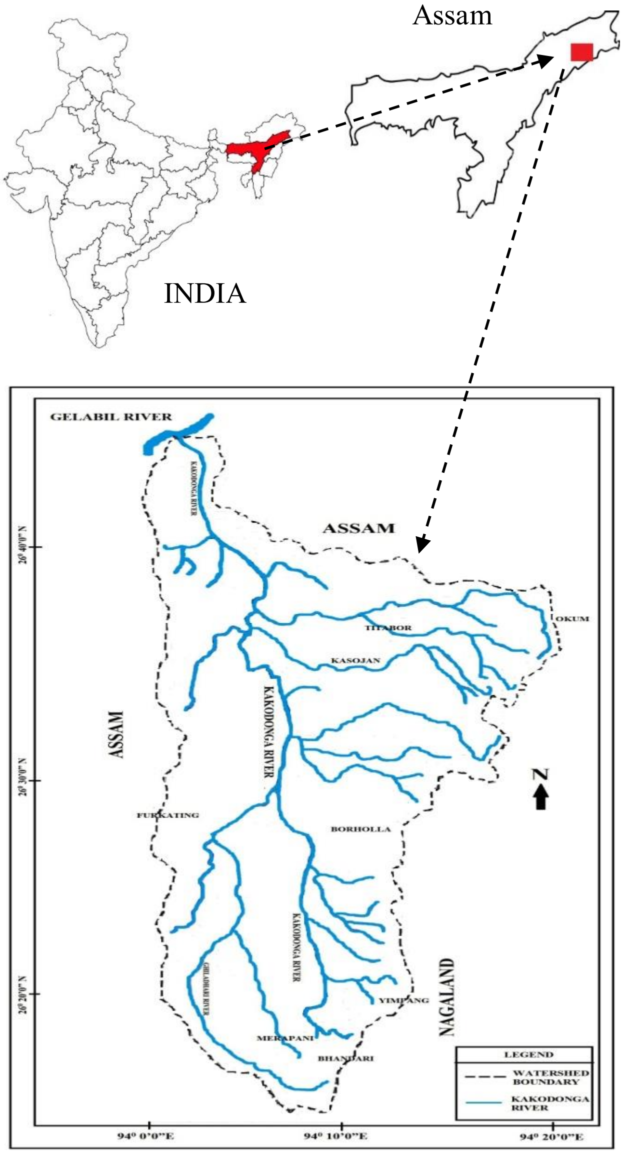

Fig. 1: Study Area

3 Methodology

This section contains the systematic procedures that have been followed throughout the research study's progress. The flow chart in Fig. 2 depicts the Research Methodology's methodical progression. The steps are outlined below.

i) Integration of previous research: Journals and articles about the issue are gathered, reviewed, and discussed. The research work on Kakodonga is completed using the articles as a guide.
ii) Data collection: Assam Agriculture University, Jorhat, provided data on temperature, relative humidity, wind speed, and bright sunlight hours.
iii) Analytical Model: Three evapotranspiration models are chosen after a review of the journal and the availability of data.
iv) Construct and Interpretation: The data collected is utilized to design the framework of the research project, and interpretation is carried out to determine the outcomes.

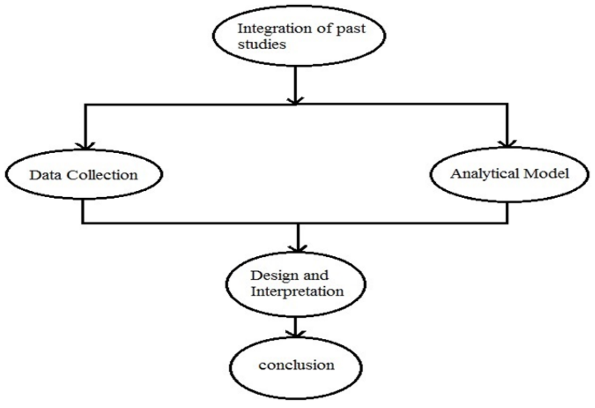

Fig. 2: Flowchart of the Research Methodology

4 Geohydraulic Characteristics

The undisturbed soil sample was taken from nearby excavation peat on the Kaziranga University campus in Assam, India, at a depth of 1 m. The collected soil mass has a natural moisture level of 17%. Clay content is 32.2 percent, silt is 25.8%, and fine sand is 42 percent, C_u = 20 and C_c = 2.25 have been determined as the uniformity coefficient and the coefficient of curvature, respectively. As a result, the soil is classed as a well-graded low-plasticity c-θsoil [20, 21]. Standard laboratory experiments were used to determine the engineering parameters of the soil, as shown in Table 1

Table 1: Engineering properties of soil [21]

Parameter		Value
The specific gravity of solids, G		2.56
Atterberg Limits	Liquid limit	24.8
	Plastic Limit	16.5
	Shrinkage Limit	6.5%
Standard Proctor Compaction Test	Maximum dry density	16.9 kN/m^3
	Optimum moisture content	7.2%
Shear Strength (by Direct Shear Test)	Unit cohesion, c	20 kPa
	Friction angle, ϕ	17o

4.1. Governing Equation for Infiltration Analysis

The 1D Richard's equation may be calculated using Buckingham Darcy's -law and the mass conservation law for water flow. as [22-25]

$$M\ (\psi)\frac{\delta\psi}{\delta t} = \frac{\delta}{\delta z}\left(k(\psi)\frac{\delta\psi}{\delta z}\right) - \frac{\delta}{\delta z}k(\psi) \quad (1)$$

Eagleson [26] and Raudkivi [27] have shown that the Horton formula, Eq. (2) can be derived from Richard's equation if $k(\theta)$ and $D(\theta)$ are assumed as constants and independent of the moisture content of the soil:

$$f_p(t) = f_c + (f_0 - f_c)e^{-\lambda t} \quad (2)$$

The Horton formula is often considered a purely empirical formula. Philip [28-30] converted Richard's equation into an ordinary differential equation and yielded an infinite series of solutions. The leading term at the surface boundary became the infiltration formula

$$f_p(t) = \frac{1}{2}S(t - t_0)^{-\frac{1}{2}} + k \quad (3)$$

An exact solution of Richard's equation was obtained by Green and Ampt [31] for a simplified wetting front movement approximation, in which a sharp boundary dividing soil of constant initial moisture content lies below the saturated soil with a moisture content of us

$$\frac{k_s}{f_p - k_s} = \ln\left(1 + \frac{k_s}{f_p - k_s}\right) + \frac{k_s(t - t_0)}{\Delta\psi\Delta\theta} \quad (4)$$

For the beginning period of infiltration (f.2ks), and by Taylor's expansion technique, the Green-Ampt formula can be simplified by taking only two terms of the expansion. After integrating, one obtains the same form of expression as the Philip formula

$$F(t) \approx \sqrt{2k_s\Delta\psi\Delta\theta}\ t^{\frac{1}{2}} + k_s t \quad (5)$$

This might suggest that the Green-Ampt formula can describe the infiltration processes for a longer period than Philip's formula. Since all three formulas are related to Richard's equation, it motivates to compare their behaviors to the numerical solution of Richard's equation.

5 Analytical Model for Evapotranspiration

This study employed three temperature-based methods: Blaney-Criddle, Thornthwaite, and Ivanov. Latitude, as well as the meteorological parameters of mean monthly temperature, mean monthly wind speed, mean monthly relative humidity, and mean monthly bright sunlight hours, were necessary for the usage of these approaches. Each approach needed one or a different combination of two or more of the parameters, but none of the methods required all of the aforementioned parameters. Each of the three approaches for calculating potential evapotranspiration using climatological data is briefly detailed in this section of the paper.

5.1 Blaney-Criddle Method

Blaney and Criddle (1950) observed that the amount of water consumptively used by crops during their growing seasons was closely correlated with mean monthly temperatures and daylight hours and the length of the growing seasons. The correlation coefficients are then applied to determine the ET for other areas where only climate data are available. The Blaney-Criddle formula is one of the best-known procedures for estimating Potential Evapotranspiration (PET) and is widely used. The popularity of the procedure is due to its simplicity and its use of readily available data. It requires the use of only two factors, namely, the temperature which is readily available from the weather stations, and information on daylight hours which is a factor-based purely on the latitude of the place.

Using the Blaney-Criddle approach, PET can be expressed as follows,

$$ET = 0.46\, P\, (T + 17.8) \quad (6)$$

5.2. Thornthwaite Method

This formula is based mainly on temperature with an adjustment being made for the number of daylight hours. An estimate of the potential evapotranspiration is calculated every month.

The Thornthwaite equation given by

$$ET = 16 \times \left(\frac{10\, Ti}{I}\right)^{a} \times \left(\frac{N}{12}\right) \times \left(\frac{1}{30}\right) \quad (7)$$

Here,

$$I = \sum_{i=1}^{12} \left(\frac{Ti}{5}\right)^{1.514} \quad (8)$$

$$a = (492390 + 17920\, I - 77.1\, I^2 + 0.675\, I^3)10^{-6} \quad (9)$$

The main advantage of this method is that only the temperature information is needed besides the sunshine hours. Generally, it is known that the Thornthwaite method gives the underestimate in the arid area while the overestimate in the humid area, respectively

5.3. Ivanov method

Concerning the relationship between evaporation rate, temperature, and relative humidity, the monthly evapotranspiration rate (mm) is obtained as follows:

$$E = 0.0018\, (25 + T^2)(100 - R) \quad (10)$$

6 Data Collection

The description of the instruments used to measure all the meteorological variables required for the study is explained briefly.

6.1 Wind speed measurement

The wind speed was recorded with a Cup Counter Anemometer (Fig. 3) at the meteorological station. The Cup Counter Anemometer recorded the amount of wind that passed through the device over time. Three semi-conical copper cups, each 127mm in diameter, with beaded borders are attached to a central spider by three brass rods. The cup assembly is friction-coupled to a vertical spindle, which has a tiny ball bearing at the top and another at the bottom. The stainless-steel cup wheel spindle is coupled to a revolution counter installed in a watertight enclosure through worm gearing. The average wind speed during the interval may be estimated by examining the counter reading at the beginning and conclusion of any time of interest.

Fig. 3: Photographic view of cup counter anemometer (Photograph taken by: Khairuz Zaman)

6.2. Temperature and Humidity Measurement

The Stevenson Screen or thermometer screen, which is typical protection for meteorological equipment (as shown in Fig.4), notably wet and dry bulb thermometers used to record humidity and air temperature, was used to measure temperature and humidity at the station. To avoid high ground temperatures, the Stevenson screen is positioned 4 feet above the ground surface. To calculate relative humidity, it has a wet bulb and a dry bulb thermometer. A maximum thermometer and a minimum thermometer are also included.

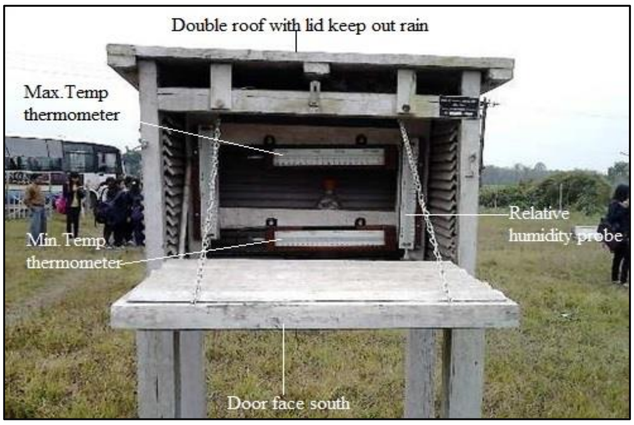

Fig. 4: Stevenson Screen (Photograph: Khairuz Zaman)

6.3. Bright Sunshine hours

A sunshine recorder, as illustrated in Fig. 5, is a device that records the amount of sunlight in a certain area or region at any particular moment. The result includes information about the weather, climate, and temperature of a certain location. At a height of 10 feet above ground level, a sunlight recorder is attached.

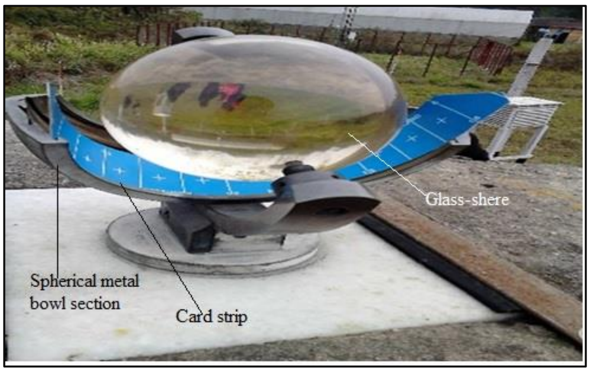

Fig. 5. Sunshine recorder used at the station (Photograph: Khairuz Zaman)

6.4. Pan evaporation

There are a variety of standardized pans for measuring evaporation, with the United States Class-A pan being the most used as shown in Fig. 6 With a diameter of 1.21m and a depth of 225mm, the pan has a capacity of about 0.3 m3. Because the basin is surrounded by air, it is mounted on a 150mm high wooden frame. Due to percolation and the necessity for water, the water level is kept around 50 mm below the rim. Every day, the water level is measured, or the difference between the current and the original water level is measured. alternatively, you measured the amount of water you put into the pan if you wanted to get the water level in the pan. As a result of the sun hitting the edges of the pan, the temperature rises, causing the evaporation to exceed the real evaporation. To adjust this result, multiply the evaporation value from the pan by a pan coefficient, which value varies according to the climatic location where your lest was taken.

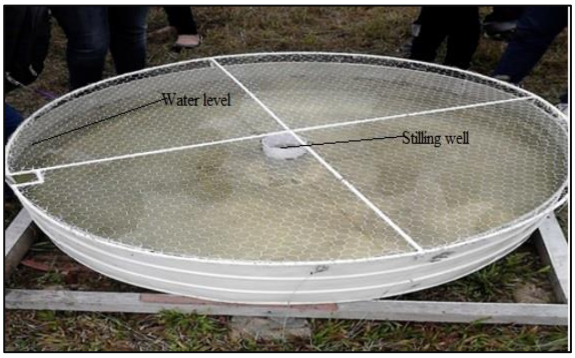

Fig. 6: USWB Class A Pan (Photograph: Khairuz Zaman)

Fig. 7: Wind vane used for showing wind direction (Photograph: Khairuz Zaman)

7 Analysis

Since the present paper aimed to evaluate the three methods, the measured evaporation was compared with the rates estimated by each method to determine the relationships between the three methods.

At first, using Eq. (6) of the Blaney-Criddle Method we get *ET* values as shown in Table 1. The below process goes on for the remaining nine months

Table 1: *ET* Values using the Blaney-Criddle Method

Months	**ET (mm/month)**
January	1.149
February	1.50
March	1.57

For the Thornthwaite method, using Eq. (7) we get *ET* values as shown in Table 2. The below process goes on for the remaining nine months.

Table 2: *ET* Values using the Thornthwaite method

Months	**ET (mm/month)**
January	2.12
February	2.30
March	2.41

Similarly, for Ivanov Method, Eq. (10) was used to compute the *ET* as shown in Table 3. This process goes on for the remaining nine months.

Table 3: *ET* Values using the Thornthwaite method

Months	**ET (mm/month)**
January	1.79
February	2.29
March	2.49

7.1 Design and Interpretation

This chapter discusses the results of the present study in the form of tables and graphs for clarity of understanding. The evaporation rate estimates made by the selected methods and their comparison with the pan evaporation data are given. Also, the correlation between all the estimated rates and the rates measured is given. The meteorological data recorded at the Meteorological Observatory of Assam Agriculture University, Jorhat Assam during the period 2007-2016 were collected. Also, the evaporation data measured using a Class-A pan was collected for the same period. Fig. 8 to Fig. 10 shows the monthly and yearly average of pan evaporation, maximum and minimum temperature, relative humidity, wind speed, and rainfall data.

Table 4: The mean monthly evaporation rates

Month	**Pan Evaporation (mm)**
January	1.09
February	1.64
March	2.37
April	2.74
May	3.31
June	2.72
July	2.93
August	2.57
September	2.12
October	1.75
November	1.82
December	1.04

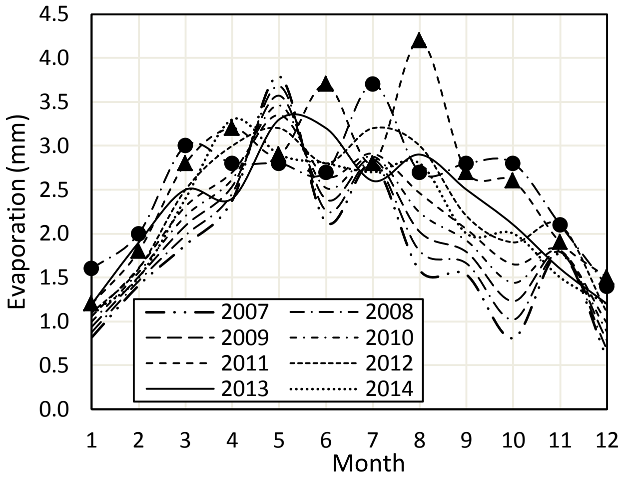

Fig 8: Monthly average graph of Pan Evaporation

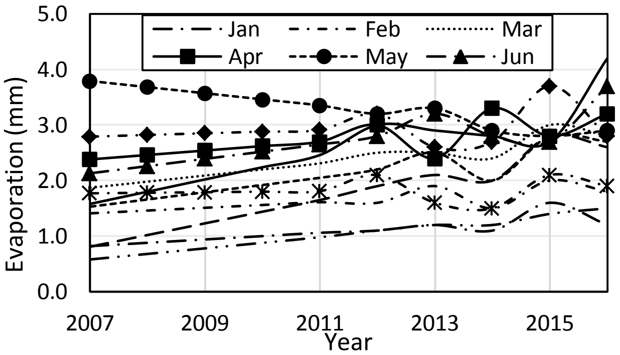

Fig 9: Yearly average graph of Pan Evaporation

The values of all the required parameters needed for estimating the potential evapotranspiration are given in the table below.

Table 5: Required climatological parameters for the calculation of potential evapotranspiration

Month	**Avg. Temp. (^{o}C)**	**Relative Humidity**	**Avg. Wind Speed (m/s)**
January	15.8	91.5	0.46
February	19.4	92	0.54
March	22	90	0.79
April	23.5	92	1
May	27.4	88.4	0.88
June	28.3	88.3	0.69
July	29.0	93.0	0.92
August	28.7	94	0.88
September	27.8	92.3	0.65
October	25.5	94.7	0.43
November	20.9	92.7	0.38
December	17.0	95.6	0.25

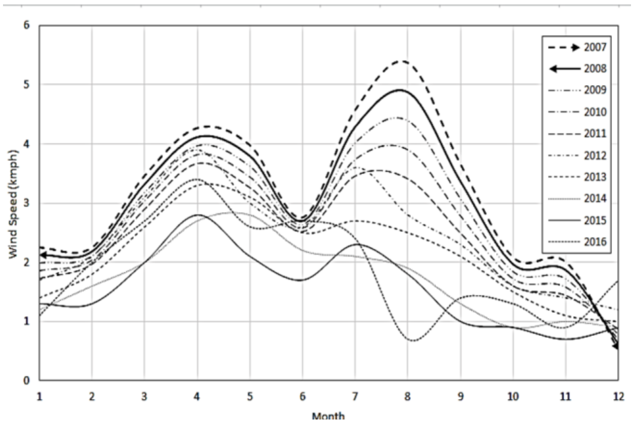

Fig 10: Monthly average graph of maximum and minimum temperature

The mean daily ET values for different months estimated by the three reference evapotranspiration estimation methods as discussed in the section above for the study area are given in Table 6. The data is represented graphically in Figure 11-13.

Table 6: The measurement of potential evapotranspiration by the mentioned methods

Month	Class-A Pan (mm)	Blaney-Criddle (mm)	Thornthwaite (mm)	Ivanov (mm)
January	1.09	1.15	2.12	1.79
February	1.64	1.50	2.30	2.29
March	2.37	1.57	2.41	2.49
April	2.74	1.45	2.97	2.79
May	3.31	1.98	3.18	4.14
June	2.72	1.29	3.96	3.87
July	2.93	1.63	3.99	2.34
August	2.57	1.64	3.82	2.74
September	2.12	1.23	3.67	3.21
October	1.75	1.94	3.03	2.39
November	1.82	2.18	2.37	2.29
December	1.04	1.36	2.20	1.15

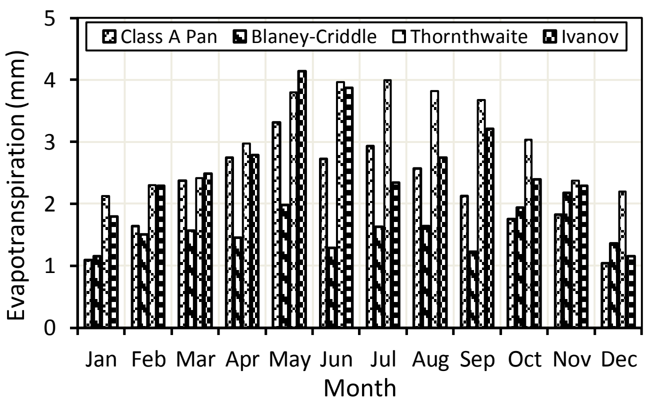

Fig 11: Comparison of different methods for estimating potential evapotranspiration through the measured evaporation in Class A Pan

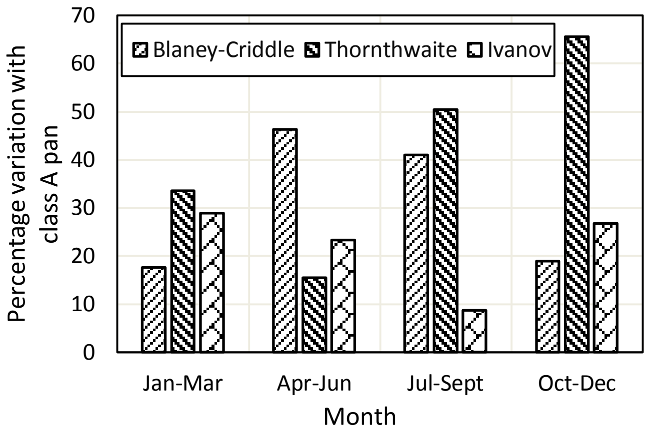

Fig 12: Percentage variation with Class A Pan

Table 7: Comparison of annual estimated with Class A pan evapotranspiration

Method	Blaney-Criddle	Thornthwaite	Ivanov	Evaporation
Annual Average (mm)	18.92	36.65	31.49	26.10

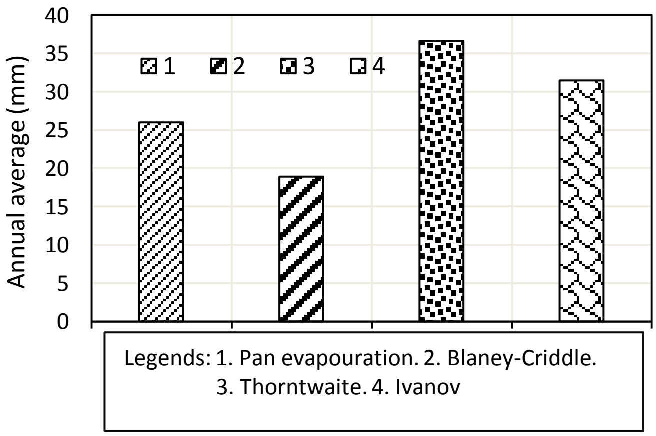

Fig 13: Comparison of the annual estimated with Class A pan evapotranspiration

The mean daily ET values for different months estimated by the three reference evapotranspiration estimation methods as discussed in the section above for the study area are given in Table 6. The data is represented graphically in Fig. 16.

From Fig 18, we can see that the estimated evapotranspiration by the Blaney-Criddle method is closer to the one measured by Class A Pan while the Thornthwaite and Ivanov methods did not show satisfying results. The peak values are found from May to June as the temperature is high during this period. On the other hand, the least ETo values are observed in December. The monthly pattern produced by different methods is not similar. The Ivanov method showed a different pattern than the other methods and also, the percentage variation of three evapotranspiration methods against Class A Pan data is shown in Fig. 19.

From Fig 19, it can be seen that the Blaney-Criddle method shows the closest relation with the pan evaporation as compared to the other two. The Ivanov method is the second appropriate method after the Blaney-Criddle method. The Thornthwaite method did not show a satisfactory result in most of the cases. Therefore, Blaney-Criddle is the most appropriate temperature-based method to estimate the potential evapotranspiration under the climatic condition of the Jorhat region.

8 Conclusions

This study provides information on the evapotranspiration (ET) estimates obtained from indirect methods by using meteorological variables for the climatic conditions of Jorhat. These evapotranspiration estimates were also compared with the observed pan evaporation values obtained from the meteorological station to obtain the correlation coefficient. The main conclusion is, that the average monthly evapotranspiration values obtained from Blaney-Criddle, Thornthwaite, and Ivanov methods are 1.57, 3.05, and 2.62 mm/month respectively. The result of this study suggests that all the models compared well with observed pan evaporation. It was observed that the performance of the Blaney-Criddle method was the best as compared to the other two methods

The soil sample collected from the study area is found to be a well-graded low-plasticity c-θ soil Reviewing kinds of the literature suggested five governing equations to compute the infiltrations.

9 Acknowledgments

The authors thankfully acknowledge the research data collected from Assam Agriculture University for carrying out the investigation. The authors also acknowledge the support and guidance received by Assistant Professor Upasana Kashyap, and Rupantar Senapaty Laboratory in Incharge The Assam Kaziranga University for their support during this research.

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Notations

ET = Evapotranspiration in mm/m.
P = Percentage of daylight in hours in a year.
T = Temperature in degree Celsius
T_i = Mean monthly temperature [°C],
N = Mean monthly sunshine hour
E = Monthly evapotranspiration rate (mm)
R = Relative humidity
T = Monthly temperature average (°C)
F = Cumulative infiltration.
$M(\psi)$ = Specific moisture capacity.
$k(\psi), k(\theta)$ = hydraulic conductivity (function of θ, ψ)
f_p= Infiltration-rate capacity when abundant rainfall supply (cm/h)
f_c= Final infiltration rate in Horton formula (cm/h)
f_0 = Maximum infiltration rate in Horton formula (cm/h)
λ = Exponential decay rate in Horton formula (1/h)
k_s = Saturated hydraulic conductivity (cm/h)
k = Hydraulic Conductivity (cm/h)
S = Soil sorptivity (cm/√h)
t = Time (h)
t_p = Ponding time (h)
$\Delta\psi$ = Deviation between saturated and initial pressure head (cm)
$\Delta\theta$ = Soil water content (cm^3/cm^3)

Conflict of Interest Statement

The authors declare that there is no conflict of interest in this paper. No financial support was received to carry out this study.

Authors' Contributions

Ghritartha Goswami has done the data analysis, interpretations and writing; Sudip Basack is responsible for overall supervision; Khairuz Zaman has collected the data; Dubai Professor did the revisions.

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