DETERMINATION OF EVAPOTRANSPIRATION USING SOLAR RADIATION AND METEOROLOGICAL DATA APPLYING DIFFERENT METHODS: A CASE STUDY HOA BINH PROVINCE

Le Hung Chien(1), Doan Ha Phong(2), Tran Xuan Truong(3), Ngo Thi Dinh(1)

(1) Viet Nam National University of Forestry

(2) Viet Nam Institute of Meteorology, Hydrology and Climate Changer

(3) Ha Noi University of Mining and Geology

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Abstract: *Evapotranspiration (ET) is a significant parameter that needs to be determined and accurately estimated in many practical applications such as the management and use of water domestic, agricultural production, and forestry. The content of the article presents four methods that include the Makkink method (1957), Abtew method (1996), Priestley & Taylor method (1972), Hargreaves & Samani method (1982, 1985) to calculate evapotranspiration from meteorological data at monitoring stations in Hoa Binh province. The results of evapotranspiration calculated from the methods are compared and evaluated for accuracy with direct measurement data at the province's hydro-meteorological stations, attend to the management, forecasting water demand in agriculture and forestry, and design of irrigation works with climate conditions of Hoa Binh province. The results indicate that the average evapotranspiration values at the hydro-meteorological stations of Makkink method (1957), Abtew method (1996), Priestley & Taylor method (1972), Hargreaves & Samani method (1982, 1985) to calculate evapotranspiration from meteorological data at monitoring stations in Hoa Binh province. The results of evapotranspiration calculated from the methods are compared and evaluated for accuracy with direct measurement data at the province's hydro-meteorological stations, attend to the management, forecasting water demand in agriculture and forestry, and design of irrigation works with climate conditions of Hoa Binh province. The results indicate that the average evapotranspiration values at the hydro-meteorological stations of Makkink method (1957), Abtew method (1996), Priestley & Taylor method (1972), Hargreaves & Samani method (1982, 1985) on 04th June 2017 were 8.1 mm, 5.8 mm, 7.8 mm and 11.3 mm, respectively. The average error of evapotranspiration at meteorological stations calculated according to the methods compared with the average evapotranspiration at meteorological stations measured directly is 5.2%, 24.7%, 1.3%, 46.7%, respectively. Calculating evapotranspiration by the Makkink method with coefficients a = 0.9 and b = 0 gives the most accurate results with the highest correlation coefficients R^2 = 0.969 and RMSE = 0.346. According to the results, the Priestley-Taylor and Makkink method is proposed to calculate the evapotranspiration for the Hoa Binh area.*

Keywords: *Evapotranspiration, Makkink method, Priestley - Taylor method, , Hoa Binh Meteorological station.*

1. Introduction

Evaporation is the process whereby loquid water is converted to water vapor or gaseous state. Evaporation is the first step in the water cycle that water is changed from the liquid into the vapor in the atmosphere. Evaporation is the return of water into the atmosphere through the diffusion of water molecules from soil, vegetation, water bodies, and other wet surfaces [1]. Transpiration is the phenomenal release of water vapor into the air from the surface of the leaves of a plant stem as a physiological response of the plant to combat the dryness around it.

Corresponding author: Doan Ha Phong
E-mail: doanhaphong.imhen@gmail.com

The total amount of water lost through the diffusion of water molecules into the atmosphere is known as transpiration. Other factors affecting evaporation are solar radiation, air humidity, temperature and wind velocity.

Evapotranspiration is a term used to describe the total amount of plant evaporation and transpiration from the earth's surface to the atmosphere over a long period of time to clarify the relationship with annual precipitation [2]. This is an important variable in hydrological research. ET is usedful information for agricultural planning, urban planning, irrigation scheduling for crop growth patterns, regional water balance study, agro-climatic zoning, and design and operation irrigation systems [3]; [4]; [5]. Direct measurements of ET around the world are rare, therefore, there is a lack of actual observational data to provide a qualitative improvement opportunity for various hydrological methods, since direct measurements of ET are costly and usually performed by high micro-quantum techniques. It is predicted that the direct impact of climate change on water resources is mainly evapotranspiration. Hydrological change creats one of the most important potential impacts on global climate change in the tropical areas [6]. It is clear that climate change will increase temperature and changes in precipitation. High temperatures will cause high evaporation, affecting hydrological systems and water resources. Therefore, accurate quantification of the ET is important and necessary not only for the long-term management of water resources but also for the design and operation of irrigation facilities specifically for the heavily cropped land region under climate change conditions. For many years, scientists around the world have tried to find many experimental methods to calculate ET values for different types of climate zones. These methods estimate ET by mathematical formula based on research and experimental results [7]. The typical methods are Penman method [8], Jensen-Haise method [9], Blaney-Criddle method [10], Hargreaves-Samani method [11]; Thorn-Thwaite method [12], and Van Bavel method [13]. Each method has its own advantages and is applicable to each specific climate zone. Some methods are essentially modified versions of others. The main concern in ET estimation is the reliability and accuracy of the methods [3]. Many methods have been developed from a certain point of view for a particular climate area, so it often fails to estimate the amount of evapotranspiration that might occur under other climatic conditions. This is also a challenging problem in accurately forecasting the ET value. For these reasons, it is essential to select an appropriate method for the regional climate as well as the availability of data. In this research, Makkink method (1957), Abtew method (1996), Priestley & Taylor method (1972) and Hargreaves & Samani method (1982, 1985) are used to compare the effectiveness and reliability in estimating ET for climate zones in Hoa Binh province.

2. Materials and Methods

2.1. Research location

Hoa Binh is a mountainous province in the Northwest region, adjacent to the Red River Delta, located 73 km away from Ha Noi on the National Highway 6 Ha Noi - Hoa Binh - Son La. The whole province has an area of about 4,578.1 km². It borders Phu Tho province to the North, Ha Nam and Ninh Binh provinces to the south, Ha Noi to the east and Northeast, Son La province to the west and Northwest, and Thanh Hoa province to the southwest. The distinct features of Hoa Binh's topography are low and medium-high mountains, complicatedly divided terrain, steep slopes and stretching in the direction of Northwest - Southeast, divided into two distinct regions: The average high mountain area in the Northwest has an average altitude of 600 - 700 m, the highest place is the top of Phu Canh (Da Bac) 1,373 m. The average slope is from 20° to 35°, some places are over 40°, accounting for about 46% of the province's area. Low mountains and hills (Southeast) has an area of 246,895 hectares, accounting for 54% of the province's area, with an average slope 10 - 25°, an average altitude of 100 - 200 m. Alternating mountainous terrain, there are low valleys, narrow valleys stretching along large rivers and streams.

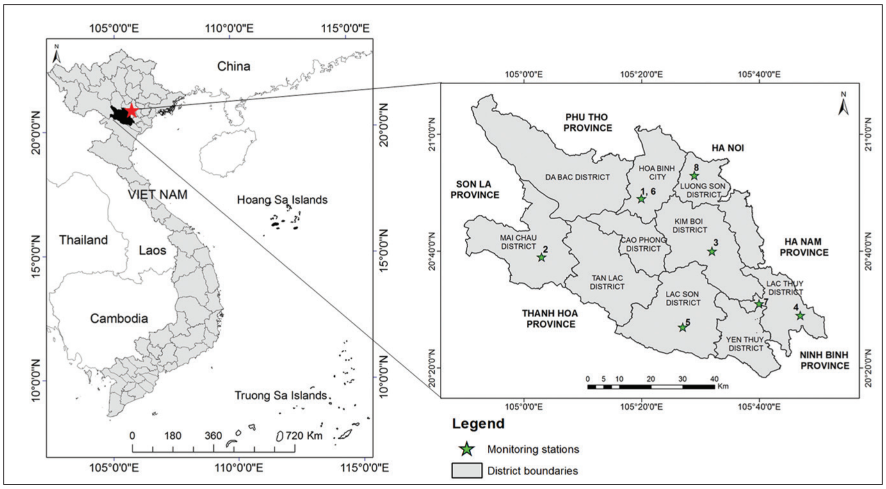

Figure 1. Research area and monitoring stations

Hoa Binh is located in the tropical monsoon climate with characteristics following hot, humid, cold winter. The average temperature in the year is 23°C, average rainfall is 1,800 mm/year, relative humidity 85%, and average annual evaporation of 704 mm. The climate of the year is divided into two distinct seasons. The summer begins in April and ends in September. The average temperature is above 25°C, reach a peak on the day around 43°C. The average monthly rainfall is over 100 mm, and the average monthly rainfall highest is 680 mm (in 1985). Rain usually concentrates in July and August, which accounts for 85 - 90% of the whole year's rainfall. The winter begins in October of the previous year and ends in March of the following year, the average temperature in the month fluctuates between 16 - 20°C, the lowest temperature is 3°C. Rainfall in October about 20 mm [14]. Due to topographical features, Hoa Binh also has Northwest climate with dry and cold winters, hot and humid summers (in the Northwest high mountains), and the climate in the Northern Delta is more temperate (in the low mountainous areas).

2.2. Meteorological data

Meteorological data for the calculation of evapotranspiration from various methods were collected from Hoa Binh hydro-meteorological stations on 4th June 2017 provided by the Center for Hydro-Meteorology of Hoa Binh Province (Table 1). According to Table 1, the wind speed of the monitoring points ranges from 4 m/s to 8 m/s, the average humidity is from 50% to 71%, the total number of sunshine hours is from 9.3 to 12.3 hours, and the amount of actual water evaporation from 4.6 mm to 9.6 mm.

Table 1. Hydrometeorological data at meteorological monitoring stations in Hoa Binh area on 04/06/2017

No.	Station	Coordinates			Strongest wind (m/s)		Average humidity (%)	Sunshine duration (hours)	Temperature (°C)		Actual water evaporation (mm)
		Longitude	Latitude	Altitude (m)	Direction	Wind speed			T (max)	T (min)	
1	Hoa Binh Meteorology	105.20	20.49	22.7	South west	5	50	12.1	41.0	31.0	9.6
2	Mai Chau Meteorology	105.03	20.39	165.5	North west	8	65	10.0	40.0	25.3	5.7
3	Kim Boi Meteorology	105.32	20.40	61.1	North west	4	64	10.6	40.9	27.5	7.0
4	Chi Ne Meteorology	105.47	20.29	11.3	North west	6	71	11.6	40.3	29.6	7.8

No.	Station	Coordinates			Strongest wind (m/s)		Average humid ity (%)	Sunshine duration (hours)	Temperature (°C)		Actual water evaporation (mm)
		Longi tude	Lati tude	Alti tude (m)	Direc tion	Wind speed			T (max)	T (min)	
5	Lac Son Meteorology	105.27	20.27	41.2	North west	4	69	9.3	40.1	27.2	4.6
6	Hoa Binh Hydrological	105.20	20.49	22.6	South west	6	52	12.0	40.8	30.7	9.5
7	Hung Thi Hydrological	105.40	20.31	20.1	North west	5	70	11.4	40.5	30.0	8.0
8	Lam Son Hydrological	105.29	20.53	25.4	South west	7	67	12.3	40.9	30.5	9.2

2.3. Evapotranspiration calculation methods

2.3.1. Makkink method (1957)

The Makkink method (1957) [15] is currently widely used due to the simplification of some of the field measurement index used by the FAO 56 Penman - Monteith method. Makkink proposes the following method of calculating evapotranspiration from solar radiation:

$$ET = a\frac{\Delta}{\Delta+\gamma}\frac{Rs}{\lambda}+b \qquad (1)$$

Where: *ET* - the amount of evapotranspiration (mm/day); R_s - solar radiation (MJ/m²/day); *Δ* - slope of saturation vapour pressure curve (kPa/°C), *γ* - psychrometric constant (kPa/°C), *λ* - latent heat of vaporization (MJ/kg) to; *a, b* - linear coefficient of the Makkink method.

The linear coefficients of the Makkink method used in the calculation of evapotranspiration from determined surface at the method's proposal time (1957) were: *a = 0.61* and *b = 0.12*. However, linear coefficients *a* and *b* depend on climatic conditions and topographical factors of each region in the world. According to Hasen's research in the Netherlands, 1984, the coefficients *a, b* have the values *a = 0.70* and *b = 0*. On the other hand, a combination of Uppsala University (Sweden) and Louisiana University (USA) by Xue and Singh conducted a survey in 1999, the coefficients a and b have values of 0.77 and 0.22, respectively.

2.3.2. Abtew Method (1996)

Abtew (1996) [16] uses a simple method to calculate evapotranspiration based on solar radiation as follows:

$$ET = K\frac{R_s}{\lambda} \qquad (2)$$

Where: *ET* - the amount of evapotranspiration (mm/day); R_s - solar radiation (MJ/m²/day); *λ* - latent heat of vaporization (MJ/kg); *K = 0.53* - Dimensional coefficient.

2.3.3. The Priestley-Taylor Method (1972)

Priestley-Taylor (1972) [17] proposed a method to calculate the amount of evapotranspiration from solar radiation energy as follows:

$$ET = a\frac{\Delta}{\Delta-\gamma}\frac{Rn}{\lambda}+b \qquad (3)$$

Where: *ET* - the amount of evapotranspiration (mm/day); *Rn* - the daily net radiation (MJ/m^2/day); *Δ* - the saturation vapor pressure curve *(kPa/°C)*; *γ* - psychrometric constant (kPa/°C); *λ* - latent heat of vaporization (MJ/kg); *a, b* are the linear coefficients of the Priestley-Taylor method.

The linear coefficients a, b of the Priestley-Taylor (1972) method used to calculate the amount of evapotranspiration from the topographical surface have the following values: *a = 0.61* and *b = 0.12*; in 1984, tested in Europe (Switzerland), *a = 0.90* and *b = 0* and tested in Asia (Taiwan), 2005, *a = 1.00* and *b = 0*.

2.3.4. The Hargreaves Samani Method (1982, 1985)

Hargreaves and Samani (1982, 1985) [11] proposed the following formula for evapotranspiration:

$$ET = 0.0135(T+17.8)R_s/\lambda \qquad (4)$$

Where: *ET* - the amount of evapotranspiration (mm/day); R_s - solar radiation (MJ/m²/day); λ - latent heat of vaporization (MJ/kg); T - air temperature (°C).

2.3.5. Statistical analysis, accuracy assessment method

The regression analysis, basic statistics, deviation, and error calculations in the study were calculated using IBM SPSS Statistics 20 software based on 95% distribution of the series with correlation coefficient calculated in the paper as the Pearson correlation coefficient.

3. Research results

3.1. Results of calculating evapotranspiration from the methods

3.1.1. The Makkink (1957) method of evapotransp iration calculating results

Using formula (1) to calculate the evapotranspiration value according to the Makkink method (1957) with the cases with coefficients a, b respectively, specifically the case ET_Mk1 has coefficients a *= 0.61, b = 0.12*, the ET_Mk2 case has *a* coefficient *a = 0.9, b = 0*, the ET_Mk3 case has *a* coefficient *a = 1, b = 0*, the ET_Mk4 case has *a* coefficient *a = 0.85, b = 0* and the ET_Mk5 case has *a* coefficient *a = 0.77, b = 0.22.* The results show that the case ET_Mk2 with *a = 0.9, b = 0* gives the best results with the difference between the evapotranspiration from the data calculated by the comparison method with direct observation results at meteorological stations ranging from -1 mm to 2.5 mm and an average of 0.4 mm (Table 2). Thus, the calculated value of evapotranspiration on June 4, 2017 was lowest at Lac Son meteorological station and highest at Hoa Binh meteorological station and Lam Son hydrological station with values of 7.1 mm and 8.6 mm, respectively. The average amount of evapotranspiration at the stations is 8.1 mm. The mean square error between the actual measurement results and the Makkink method (1957) in the case of ET_Mk2 is 1.3 mm.

Table 2. Calculation results of evapotranspiration and evapotranspiration values according to the Makkink (1957) method

No.	Station	The amount of evapotranspiration according to the Makkink method (ET_Mk, mm/day)					Actual evapotranspiration (mm/day)	Difference from actual evapotranspiration (mm/day)				
		ET_Mk1	ET_Mk2	ET_Mk3	ET_Mk4	ET_Mk5		ET_Mk1	ET_Mk2	ET_Mk3	ET_Mk4	ET_Mk5
1	Hoa Binh Meteorology	5.9	***8.6***	9.5	8.1	7.5	9.6	-3.7	***-1.0***	-0.1	-1.5	-2.1
2	Mai Chau Meteorology	5.1	***7.4***	8.2	7.0	6.6	5.7	-0.6	***1.7***	2.5	1.3	0.9
3	Kim Boi Meteorology	5.4	***7.8***	8.6	7.3	6.9	7	-1.6	***0.8***	1.6	0.3	-0.1
4	Chi Ne Meteorology	5.7	***8.3***	9.2	7.8	7.3	7.8	-2.1	***0.5***	1.4	0.0	-0.5
5	Lac Son Meteorology	5.0	***7.1***	7.9	6.7	6.3	4.6	0.4	***2.5***	3.3	2.1	1.7
6	Hoa Binh Hydrological	5.9	***8.5***	9.4	8.0	7.5	9.5	-3.6	***-1.0***	-0.1	-1.5	-2.0
7	Hung Thi Hydrological	5.7	***8.2***	9.1	7.7	7.2	8	-2.3	***0.2***	1.1	-0.3	-0.8
8	Lam Son Hydrological	6.0	***8.6***	9.6	8.2	7.6	9.2	-3.2	***-0.6***	0.4	-1.0	-1.6
	Mean	**5.6**	***8.1***	**8.9**	**7.6**	**7.1**	**7.7**	**-2.1**	***0.4***	**1.3**	**-0.1**	**-0.6**
	Mean square error							**2.7**	***1.3***	**1.8**	**1.3**	**1.5**

Note: ET_Mk1 case: a = 0.61, b = 0.12, ET_Mk2 case: a = 0.9, b = 0, ET_Mk3 case: a = 1, b = 0, ET_Mk4 case: a = 0.85, b = 0, ET_Mk5 case: a = 0.77, b = 0.22

The correlation between the actual evapotranspiration value and the Makkink evapotranspiration value in 5 cases is shown in Figure 2. The analysis results show that the case ET_Mk2 has the highest correlation with coefficient of determination *$R^2 = 0.969$* and the lowest error (*RMSE = 0.346*). Therefore, Makkink method with coefficients *a = 0.9, b = 0* can be used to calculate evapotranspiration for Hoa Binh area.

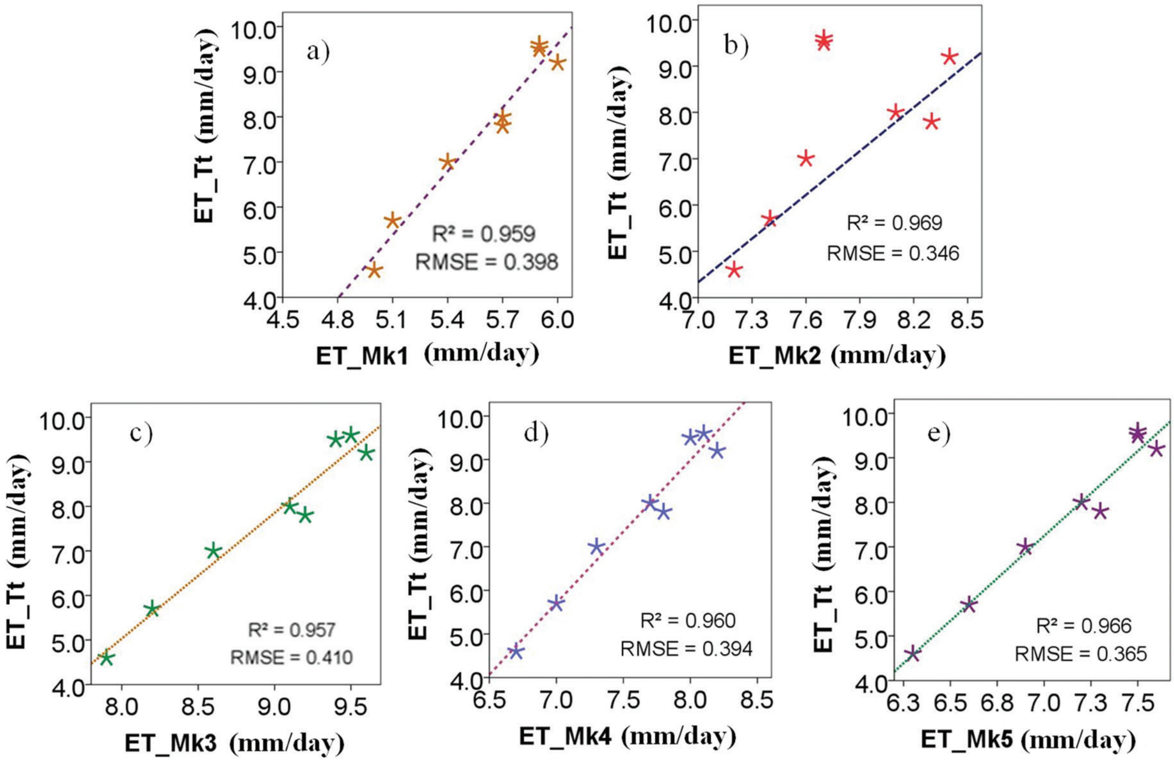

Figure 2. The correlation between actual evapotranspiration (ET_Act) and Makkink evapotranspiration (ET_Mk) with a) ET_Mk1 case: a = 0.61, b = 0.12, b) ET_Mk2 case: a = 0.9, b = 0, c) ET_Mk3 case: a = 1, b = 0, d) ET_Mk4 case: a = 0.85, b = 0 and e) ET_Mk5: a = 0.77, b = 0.22 on 04/06/2017

3.1.2. Abtew (1996) method of evapotranspiration calculating results

Formula (2) is used to calculate the evapotranspiration value according to Abtew (1996) method, the calculation results are shown in Table 3. The results show the difference in evapotranspiration value from the method calculation compared with the results of direct observation at meteorological stations varies from -3.5 mm to 0.6mm and on average of 1.9 mm. The calculated value of ET according to the Abtew (1996) method on June 4, 2017 shows the lowest evapotranspiration at Le Son meteorological station with a value of 5.2 mm, the highest evapotranspiration at Le Son meteorological station, Hoa Binh meteorological station and Lam Son hydrological station is 6.1 mm. The average amount of evapotranspiration at the stations is 5.8 mm. The mean square error between the actual measurement result and the calculated result from Abtew (1996) method is 2.5 mm.

Table 3. Calculation results of evapotranspiration and evapotranspiration values according to the Abtew (1996) method

No.	Station	The amount of evapotranspiration according to the Abtew method (ET_At, mm/day)	Actual evapotranspiration (mm/day)	Difference from actual evapotranspiration (mm/ day)
1	Hoa Binh Meteorology	6.1	9.6	-3.5
2	Mai Chau Meteorology	5.4	5.7	-0.3
3	Kim Boi Meteorology	5.6	7.0	-1.4
4	Chi Ne Meteorology	5.9	7.8	-1.9
5	Lac Son Meteorology	5.2	4.6	0.6
6	Hoa Binh Hydrological	6.0	9.5	-3.5
7	Hung Thi Hydrological	5.8	8.0	-2.2
8	Lam Son Hydrological	6.1	9.2	-3.1
	Mean	5.8	7.7	-1.9
	Mean square error			2.5

Figure 3 shows the evapotranspiration calculated by the Abtew method is strongly correlated with the actual evapotranspiration with $R^2 = 0.964$ and *RMSE = 0.372*. However, the results of calculations using the Abtew method are quite different from the results of direct observations at meteorological stations. Therefore, the Abtew method should not be used to calculate evapotranspiration for Hoa Binh province.

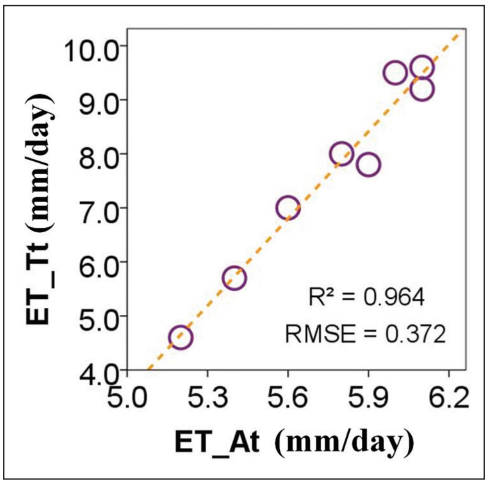

Figure 3. The correlation between actual evapotranspiration (ET_Act) and Abtew evapotranspiration (ET_At) on 04/06/2017

3.1.3. Priestley-Taylor (1972) method of evapotranspiration calculating results

By applying formula (3) to calculate the evapotranspiration value according to the Priestley-Taylor (1972) method for the cases with coefficients *a, b* respectively, specifically the case ET_Pt1 with *a = 0.61, b = 0.12*, ET_Pt2 case with *a = 0.9, b = 0*, ET_Pt3 case with *a = 1, b = 0*, and ET_Pt4 case with *a = 0.85, b = 0*. The results of above method are shown in Table 4. It can be seen that the ET_Pt4 case with *a = 0.85, b = 0* gives the best results, close to the direct measurement results from the field. The difference in evapotranspiration from the calculated data compared with the results of direct observations at meteorological stations varies from -1.9 mm to 2.6 mm and is 0.1 mm on average. The calculated result according to Priestley-Taylor (1972) method on 04/06/2017 shows the lowest evapotranspiration at Le Son meteorological station of 7.2 mm, the highest at Lam Son hydrological station with 8.4 mm. The average amount of evapotranspiration at the stations is 7.8 mm. The mean square error between the actual measurement and the Priestley-Taylor (1972) method with ET_Pt4 is 1.6 mm.

Table 4. Calculation results of evapotranspiration and evapotranspiration values according to the Priestley-Taylor (1972) method

No.	Station	The amount of evapotranspiration according to the Abtew method (ET_Pt, mm/day)				Actual evapotran-spiration (mm/day)	Difference from actual evapotranspiration (mm/day)			
		ET_Pt1	ET_Pt2	ET_Pt3	ET_Pt4		ET_Pt1	ET_Pt2	ET_Pt3	ET_Pt4
1	Hoa Binh Meteorology	5.6	8.1	9.0	***7.7***	9.6	-4.0	-1.5	-0.6	***-1.9***
2	Mai Chau Meteorology	5.4	7.8	8.7	***7.4***	5.7	-0.3	2.1	3.0	***1.7***
3	Kim Boi Meteorology	5.6	8.0	8.9	***7.6***	7	-1.4	1.0	1.9	***0.6***
4	Chi Ne Meteorology	6.1	8.8	9.7	***8.3***	7.8	-1.7	1.0	1.9	***0.5***
5	Lac Son Meteorology	5.3	7.6	8.5	***7.2***	4.6	0.7	3.0	3.9	***2.6***
6	Hoa Binh Hydrological	5.7	8.2	9.1	***7.7***	9.5	-3.8	-1.3	-0.4	***-1.8***
7	Hung Thi Hydrological	6.0	8.6	9.6	***8.1***	8	-2.0	0.6	1.6	***0.1***
8	Lam Son Hydrological	6.2	8.9	9.9	***8.4***	9.2	-3.0	-0.3	0.7	***-0.8***
	Mean	5.7	8.3	9.2	***7.8***	7.7	-2.0	0.6	1.5	***0.1***
Mean square error							2.7	1.7	2.2	***1.6***

Note: ET_Pt1 case: a = 0.61, b = 0.12, ET_Pt2 case: a = 0.9, b = 0, ET_Pt3 case: a = 1, b = 0, ET_Pt4 case: a = 0.85, b = 0

The correlation coefficient between the actual evapotranspiration and the water evaporation calculated by the Priestley-Taylor (1972) method is shown in Figure 4. The calculated results show the value of water evaporation according to the Priestley-Taylor method has a relatively low correlation with actual evapotranspiration, the coefficient of determination R^2 ranges from 0.385 to 0.408 in all 4 cases. But the mean square error between the actual evapotranspiration and the evapotranspiration in the case of ET_Pt4 is 1.6 mm and the average evapotranspiration value at the stations differs barely from the direct measurement results. Therefore, the Priestley-Taylor method with coefficients $a = 0.85$ and $b = 0$ can be used to calculate evapotranspiration for Hoa Binh area.

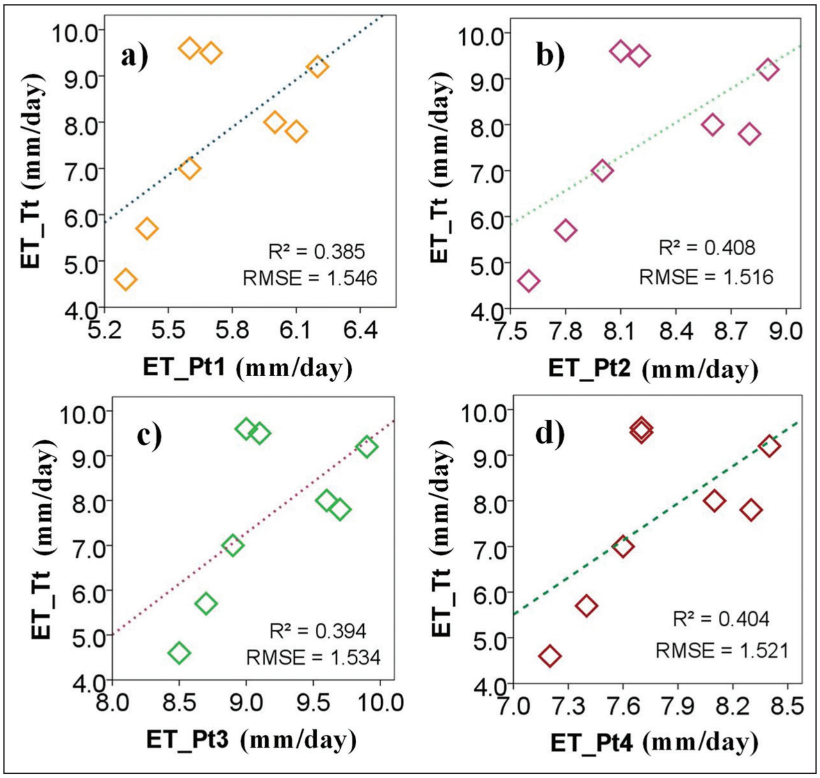

Figure 4. The correlation between actual evapotranspiration (ET_Tt) and evapotranspiration calculated by Priestley-Taylor method (ET_Pt) with a) ET_Pt1 case: a = 0.61, b = 0.12, b) field ET_Pt2 case: a = 0.9, b = 0, c) ET_Pt3 case: a = 1, b = 0, d) ET_Pt4 case: a = 0.85, b = 0 on 04/06/2017

3.1.4. Hargreaves Samani (1982) method of evapotranspiration calculating results

Applying formula (4) to calculate the evapotranspiration value according to the Hargreaves Samani (1982) method, the calculation results are shown in Table 5. The results show the difference in evapotranspiration from calculated data compared with the results of direct observation at meteorological stations has a relatively large variation of unequal values from 0.4 mm to 8.1 mm and an average of 3.6 mm. The calculation value at the time of June 4, 2017 shows that the lowest evapotranspiration at Hoa Binh meteorological station is 10.0 mm, the amount of evapotranspiration at Hoa Binh meteorological station is 10.0 mm. The highest water vapor at Mai Chau meteorological station is 13.8 mm. The average amount of evapotranspiration at the stations is 11.3 mm. The mean square error between the actual measurement and the Hargreaves Samani method (1982, 1985) is 5.0 mm.

The correlation coefficient between the calculated values of actual evapotranspiration and the value calculated by the Hargreaves Samani (1982, 1985) method is shown in Figure 5. The evapotranspiration according to the Hargreaves Samani method is highly correlated with the actual evapotranspiration. However, the RMSE accuracy is up to 1.110. Thus, the method of calculating evapotranspiration by Hargreaves Samani is not the optimal method for calculating ET in Hoa Binh area.

Table 5. Calculation results of evapotranspiration and evapotranspiration values according to the Hargreaves Samani (1982, 1985) method

No.	Station	The amount of evapotranspiration according to the Abtew method (ET_Hs, mm/day)	Actual evapotranspiration (mm/day)	Difference from actual evapotranspiration (mm/ day)
1	Hoa Binh Meteorology	10.0	9.6	0.4
2	Mai Chau Meteorology	13.8	5.7	8.1
3	Kim Boi Meteorology	12.9	7.0	5.9
4	Chi Ne Meteorology	10.5	7.8	2.7
5	Lac Son Meteorology	12.3	4.6	7.7
6	Hoa Binh Hydrological	10.1	9.5	0.6
7	Hung Thi Hydrological	10.4	8.0	2.4
8	Lam Son Hydrological	10.4	9.2	1.2
	Mean	11.3	7.7	3.6
	Mean square error			5.0

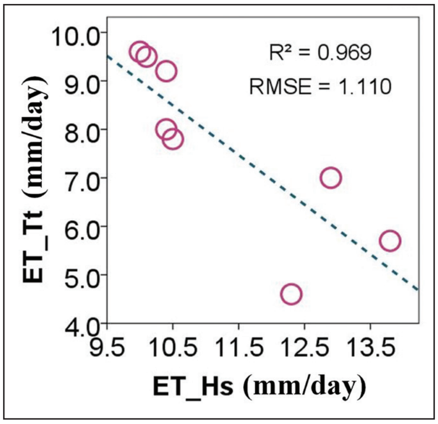

Figure 5. The correlation between actual evapotranspiration (ET_Act) and evapotranspiration calculated by Hargreaves Samani method (ET_Hs) on 04/06/2017

3.2. Comparison of evapotranspiration calculation results from different methods

Figure 6 illustrated that the lowest mean evapotranspiration calculated by the Abtew (1996) method is 5.8 mm, the highest mean evapotranspiration calculated by the Hargreaves Samani method (1982, 1985) is 11.3 mm, the difference from the average evapotranspiration from direct measurement is -1.9 mm and 3.6 mm, respectively. Evaporation at the monitoring stations according to the Priestley-Taylor method (1972) in the case of ET_Pt4 and the Makkink (1957) method in the case of ET_Mk2 with the evapotranspiration close to the directly measured at meteorological observation stations.

The mean deviation between evapotranspiration according to Abtew method, Hargreaves Samani method and actual evapotranspiration is -1,913 mm and 3,625 mm, respectively, with an error of 24.7% and 46.7%, respectively. Thus, the above two methods should not be used to calculate evapotranspiration in Hoa Binh area. The average deviation of evapotranspiration calculated by Priestley-Taylor method with coefficient *a = 0.85, b = 0* is 0.125, corresponding to the lowest error of 1.3%. Although the evapotranspiration according to this method, has quite low correlation *(R = 0.635)*, but the Priestley-Taylor method ensures the reliability to calculate ET0 in Hoa Binh province. Besides, the calculation of evapotranspiration by Makkink (1957) method with the coefficient *a = 0.9, b = 0* has an average difference of 0.4 mm, corresponding to an error of 5.2%. In addition, using the Paired-Sample T-Test for the corresponding pairs of values between the actual evapotranspiration and the evapotranspiration calculated by the methods (Table 6) shows that the evapotranspiration value of Makkink method has the highest correlation *(R = 0.984)* and the lowest error *(SE = 0.448)* with actual evapotranspiration. The value *ρ = 0.416 > 0.05* with 95% confidence shows that there is no mean difference between actual evapotranspiration and evapotranspiration value of the Makkink method.

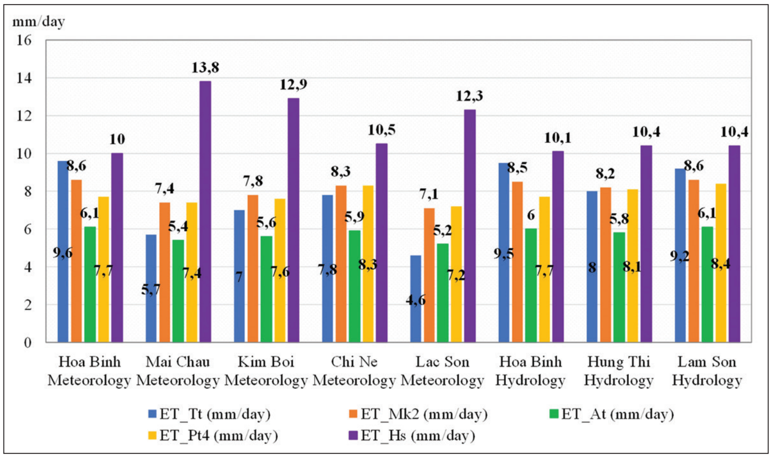

Figure 6. Comparison of evapotranspiration between methods

Note: ET_Mk2: Evaporation by Makkink (1957) method); ET_At: Absorption of water by Abtew (1996); ET_Pt4 Evaporation by Priestley-Taylor method (1972); ET_Hs Hargreaves Samani Evaporation (1982, 1985); ET_Atc Actual evapotranspiration measured

Table 6. Pearson correlation coefficient (N = 8) analysis of mean difference between actual evapotranspiration and methods

	M	R	SE	ρ
ET_Mk2 (mm/day)	0,388	0,984	0,448	0,416
ET_At (mm/ day)	-1,913	0,982	0,53	0,009
ET_Pt4 (mm/ day)	0,125	0,635	0,561	0,83
ET_Hs (mm/ day)	3,625	-0,826	1,115	0,014

Note: R (Correlation): pearson correlation, M (mean): mean, SE: Standard Error, value ρ

4. Conclusion

Research results have determined the amount of evaporation by four methods Makkink (1957), Abtew (1996), Priestley & Taylor (1972), Hargreaves & Samani (1982, 1985) from meteorological data on 04/06/2017. The average evapotranspiration according to the Makkink, Abtew, Priestley-Taylor and Hargreaves-Samani methods are 8.1 mm, 5.8 mm, 7.8 mm and 11.3 mm, respectively. Actual evapotranspiration and evapotranspiration according to Makkink, Abtew, Priestley-Taylor and Hargreaves-Samani methods have correlation and error of $R^2 = 0.969$ with error $RMSE = 0.346$, $R^2 = 0.964$ with error $RMSE = 0.372$, $R^2 = 0.408$ with error $RMSE = 1.516$ and $R^2 = 0.969$ with error $RMSE = 1.110$, respectively. Accordingly, the actual evapotranspiration is highly correlated with the ET calculated by the Makkink, Abtew and Hargreaves-Samani methods. However, the T-Test shows that the evapotranspiration according to the Makkink method has the highest correlation and the lowest error with the actual evapotranspiration (*R = 0.984* and *SE = 0.448*).

The Priestley-Taylor method gives the results of the mean deviation and the smallest mean, the evapotranspiration calculated by Priestley-Taylor is the closest to the directly measured evapotranspiration at the meteorological stations. Thus, when calculating evapotranspiration using solar radiation in Hoa Binh province, simple methods such as Abtew (1996) and Hargreaves Samani method (1982, 1985) should not be used. It is highly recommended to use Priestley-Taylor (1972) method with coefficients *a = 0.85, b = 0* and Makkink (1957) method with coefficients *a = 0.9, b = 0* to calculate evapotranspiration at Hoa Binh due to the result is the closest approximation to the direct evapotranspiration measurement.

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