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Research paper

Comparative results of the average daily net radiation (R_{nd}) from meteorological observation data and Landsat–8 remote sensing imagery areas of Hoa Binh province

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Abstract: Net radiation (Rn) is the solar energy absorbed by vegetation and land and water surfaces as a key driving force for evapotranspiration. Therefore, the accuracy of the Rn value affects the determination of evapotranspiration from different models. The article presents the results of calculating the average daily net radiation value according to the FAO–56 model, IRMAK model, and Remote sensing model. The results of calculating the average daily net radiation value at the Hoa Binh province's meteorological and hydrological monitoring stations according to the FAO–56, IRMAK, and Remote Sensing models have the value of 17.593 MJ/m^2/day, 16.389 MJ/m^2/day, and 18.531 MJ/m^2/day, respectively. The difference of R_{nd} between the FAO–56 model and the IRMAK model is –1.20 (MJ/m^2/day), corresponding to 6.84%, and the difference of R_{nd} between the FAO–56 model and the Remote sensing model is 0.94 (MJ/m^2/day), corresponding to 5.58%. The largest and smallest difference between R_{nd}_FAO–56 and R_{nd}_IRM values at Lam Son hydrological station and Hoa Binh meteorological station is –1.885 (MJ/m^2/day) match up 10.10%, and –0.31 (MJ/m^2/day) match up 1.75%, respectively. In addition, the largest and smallest difference between R_{nd}_FAO–56 and R_{nd}_VT values at Lac Son meteorological station and Lam Son hydrological station is 2.80 (MJ/m^2/day), corresponding to 17.49%, and 0.23 (MJ/m^2/day), corresponding to 1.18%, respectively. The average daily net radiation value due to percentage at meteorological and hydrological monitoring stations between R_{nd}_FAO and R_{nd}_VT: the difference of 0–5% is 5/8 stations, 5–10% is 1/8 stations, 10–15% is 1/8 stations and 15–20% is 1/8 stations, accounting for 62.5%, 12.5%, 12.5% and 12.5%, respectively.

Keywords: Net Radiation; FAO–56; Irmak; Sebal Manual; Jackson; Hoa Binh.

1. Introduction

Net radiation (Rn) is defined as the difference between the incoming and outgoing radiation fluxes including both long and shortwave radiation at the surface of Earth. It is a key quantity for the estimation of surface energy budget and is used for various applications including climate monitoring, weather prediction and agricultural meteorology. Remote sensing provides an unparalleled spatial and temporal coverage of land surface attributes, thus several studies have attempted to estimate net radiation (or its components) by combining remote sensing observations with surface and atmospheric data [1–4]. Rn (coupled with soil heat flux, as available energy) serves as a key driving force for evapotranspiration (ET). Over the years, various ET models have been developed that use remote sensing and ancillary surface and ground-based observations [5–7]. Several of the recent ET models primarily use remote sensing data for ET estimation [8–10]. Yet, all these ET models require estimates of R_n.

In Vietnam, several typical research works use satellite image data in determining net radiant energy for evapotranspiration, such as: According to [11] the researchers calculated the amount of evapotranspiration from solar radiation extracted from the Modis remote sensing image with an average absolute error of not more than 10% for the northern region of Vietnam. Calculating evapotranspiration by the hour using Priestley–Taylor method from net radiant energy extracted from Modis satellite images applied to the topography of North Vietnam with average absolute error not greater than 10% [12]. Comparing the average daily net irradiance estimate extracted from the Modis satellite image with the results from the meteorological observations, the calculation of the net radiant energy from the Modis image has an average absolute error of 6% [13]. However, the studies mainly used Modis satellite images without experimenting with other types of optical satellite images.

This paper presents the results of extraction of net radiant energy from Landsat–8 satellite images according to the SEBAL model based on the principle of solar radiation balance to estimate evapotranspiration in Hoa Binh province.

2. Materials and Methods

2.1. Description of study site

Hoa Binh is a mountainous province in the Northwest region, adjacent to the Red River Delta, located 73 km away from Hanoi on the National Highway 6 Hanoi–Hoa Binh–Son La. The whole province has an area of about 4,578.1 km^2. It borders Phu Tho province to the north, Ha Nam and Ninh Binh provinces to the south, Hanoi to the east and northeast, Son La province to the west and northwest, and Thanh Hoa province to the southwest. The outstanding features of Hoa Binh's topography are low and medium-high mountains, complicatedly divided, 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 20–35^o, some places are over 40^o, accounting for about 46% of the province's area. Low mountains and hills (Southeast) have an area of 246,895 hectares, accounting for 54% of the province's area, with an average slope of 10–25^o, an average altitude of 100–200 m. Alternating mountainous terrain, there are low valleys, narrow valleys stretching along large rivers and streams.

Hoa Binh is located in a tropical monsoon climate with typical weather: hot, humid and cold winters. The average temperature in the year is 23^{o}C; average rainfall is 1,800 mm/year; relative humidity 85%; average annual evaporation of 704 mm. The climate of the year is divided into two distinct seasons. Summer starts in April and ends in September, the average temperature is above 25^{o}C, on some days it can reach 43^{o}C. The average monthly rainfall is over 100 mm, with the highest time of 680 mm (1985). Rain usually concentrates in July and August, which accounts for 85–90% of the whole year's rainfall. 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^{o}C, the lowest temperature is 3^{o}C, average monthly rainfall is 10–20 mm. Due to topographical features, Hoa Binh also has a Northwest climate with dry and cold winters, hot and humid summers (in the Northwest high mountains); the climate in the Northern Delta is more temperate (in the low mountainous areas) [14].

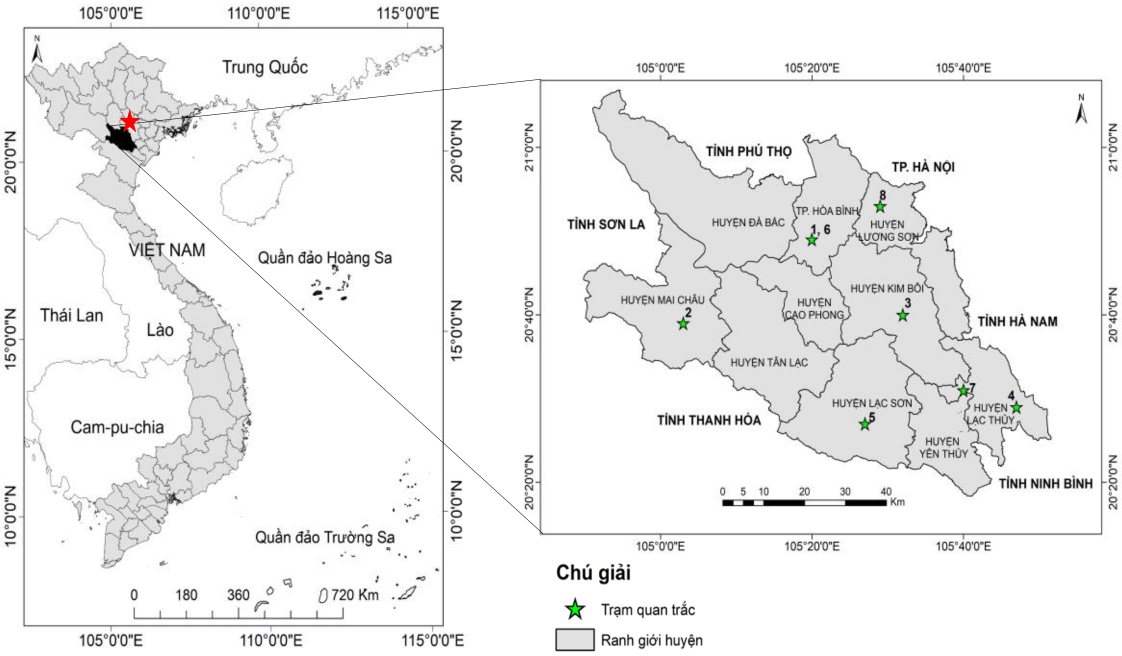


Figure 1. Research area and monitoring stations.

2.2. Meteorological data

Meteorological data for the calculation of evapotranspiration from various methods were collected from Hoa Binh hydrometeorological stations on June 4, 2017, provided by the Center for hydrometeorology 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 June 4, 2017.

No.	Station Name	Coordinates			Strongest wind (m/s)		Average humidity (%)	Sunshine duration (hours)	Temperature (ºC)		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	Southwest	5	50	12.1	41.0	31.0	9.6
2	Mai Chau Meteorology	105.03	20.39	165.5	Northwest	8	65	10.0	40.0	25.3	5.7
3	Kim Boi Meteorology	105.32	20.40	61.1	Northwest	4	64	10.6	40.9	27.5	7.0
4	Chi Ne Meteorology	105.47	20.29	11.3	Northwest	6	71	11.6	40.3	29.6	7.8
5	Lac Son Meteorology	105.27	20.27	41.2	Northwest	4	69	9.3	40.1	27.2	4.6
6	Hoa Binh Hydrological	105.20	20.49	22.6	Southwest	6	52	12.0	40.8	30.7	9.5

No.	Station Name	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)	
7	Hung Thi Hydrological	105.40	20.31	20.1	Northwest	5	70	11.4	40.5	30.0	8.0
8	Lam Son Hydrological	105.29	20.53	25.4	Southwest	7	67	12.3	40.9	30.5	9.2

2.3. Satellite image material

Landsat–8 satellite image obtained on June 4, 2017 [15]. The image was geometrically corrected according to the administrative map of Hoa Binh province, reference system VN–2000.

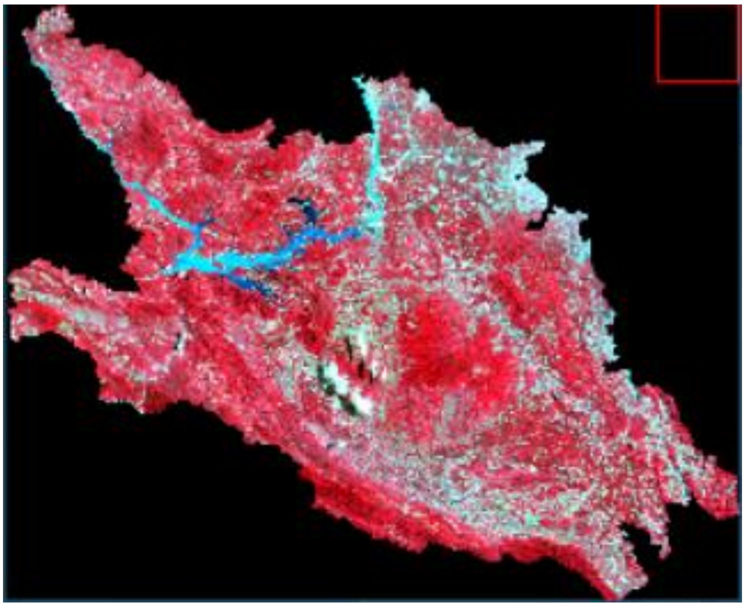


Figure 2. Landsat satellite image on June 4, 2017 adjusted and cut according to the administrative boundaries of Hoa Binh province.

2.3. Net radiant (Rn) from the meteorological observations calculation method

2.3.1. FAO –56 net radiation (R_{nd}) method

The daily net radiant energy value (R_{nd}) calculated according to the FAO–56 model [16–17] is a physical model, using directly observed data at hydrometeorology such as daily temperature (T_{mean}), sunshine duration hours (n), air humidity (RH), wind speed (u), and combination of geographical coordinates, altitude at meteorological monitoring stations. The FAO–56 model proposes the following formula for calculating net radiant energy:

$$R_{nd} = R_{nS} - R_{nL} \quad (1)$$

where R_{nd} is the net radiant per day (MJ/m^2/day); R_{nS} is the short wave net radiant (MJ/m^2/day); R_{nL} is the long wave net radiated (MJ/m^2/day).

The short wave net radiant (R_{nS}) [16] is calculated by the formula:

$$R_{nS} = (1 - \alpha)R_S \quad (2)$$

where α is the soil surface difference (albedo), α = 0.15 for soil surface; α = 0.23 for green cover and α = 0.05 for all other surfaces; R_S is incoming solar radiant energy (MJ/m^2/day).

The long wave net radiant (R_{nL}) [16] is calculated by the formula:

$$R_{nL} = \sigma\left[\frac{T^4_{maxK} + T^4_{minK}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_S}{R_{SO}} - 0.35\right) \quad (3)$$

where R_{nL} is a long wave net radiated energy (MJ/m^2/day); σ is the Stefan–Boltzmann constant (4.903 10^{-9} MJ/K^4/m^2/day); $T_{max\ K}$ is the highest temperature of the day ^oK (^oK = ^oC + 273.15); $T_{min\ K}$ is the lowest temperature of the day ^oK (^oK = ^oC + 273.15); e_a is the steam pressure [kPa]; R_S is incoming solar radiant energy (MJ/m^2/day); R_{SO} is the solar radiant energy when the sky is clear (MJ/m^2/day).

2.3.2. IRMAK net radiation (R_{nd}) method

The regression model [18] was proposed by the Environmental and Water Resources Institute (EWRI) of The American Society of Civil Engineers (ASCE) to calculate the average daily net irradiance Rnd of the form R_{nd} after:

$$R_{nd} = -0.054T_{max} + 0.111T_{min} + 0.462R_s - 49.243d_r + 50.831 \quad (4)$$

where T_{max}, T_{min} is the highest and lowest air temperature of the day (^oC); R_S is incoming solar radiant energy (MJ/m^2/day); d_r is the inverse of the relative distance between the Sun and the Earth.

2.4. Method of extracting net radiant from remote sensing images

Extraction of net radiant energy absorbed by the ground at time i (R_{ni}) according to the SEBAL model [19] is calculated by the formula (5):

$$R_{ni} = R_{S\downarrow} - \alpha R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\varepsilon_o)R_{L\downarrow} \quad (5)$$

where R_{ni} is the earth surface net radiation (W/m^2); $R_{S\downarrow}$ is incoming short–wave radiation (W/m^2); $R_{L\downarrow}$ is incoming longwave radiation (W/m^2); $R_{L\uparrow}$ is outgoing longwave radiation (W/m^2); ε_o is the broad–spectrum heat emission; α is the differential rate of the soil surface.

The modules for calculating the net absorbed radiation by the ground (R_{ni}) are proposed to be implemented according to the diagram of figure 3.

2.4.1. Calculate pixel value from numeric DN to spectral radiant energy value $\boldsymbol{L_\lambda}$

According to United States Geological Survey (USGS) (2013) [15], the spectral radiant energy value for each image channel L_λ is calculated according to the following formula (F01):

$$L_\lambda = M_L * Q_{CAL} + A_L \quad (6)$$

where L_λ is the spectral radiant energy value (W/m^2); M_L is the radiance Multiplier; Q_{CAL} is the quantized and calibrated standard product pixel values (DN); A_L is the radiance add.

2.4.2. Convert pixel value from numeric (DN) to surface reflectance (Reflectance)

When taking satellite images, the sensor converts the wavelength of light into a brightness value (DN value) and converts it to an integer unit. Each image pixel corresponds to a DN value. Therefore, in order to get closer to the actual information, many factors must be corrected to bring back the surface reflectance (SR reflectance), till then the application of satellite images has practical significance. According to the United States Geological Survey (USGS) (2013) [15] the reflectance value for each image channel P_λ is calculated according to the following formula (F02):

$$\rho_\lambda = \frac{M_P Q_{cal} + A_P}{\sin(\theta_{SE})} \quad (7)$$

where M_ρ is band-specific multiplicative rescaling factor from the metadata; A_ρ is band-specific additive rescaling factor from the metadata; Qcal is quantized and calibrated standard product pixel values (DN); θ_{SE} is local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).

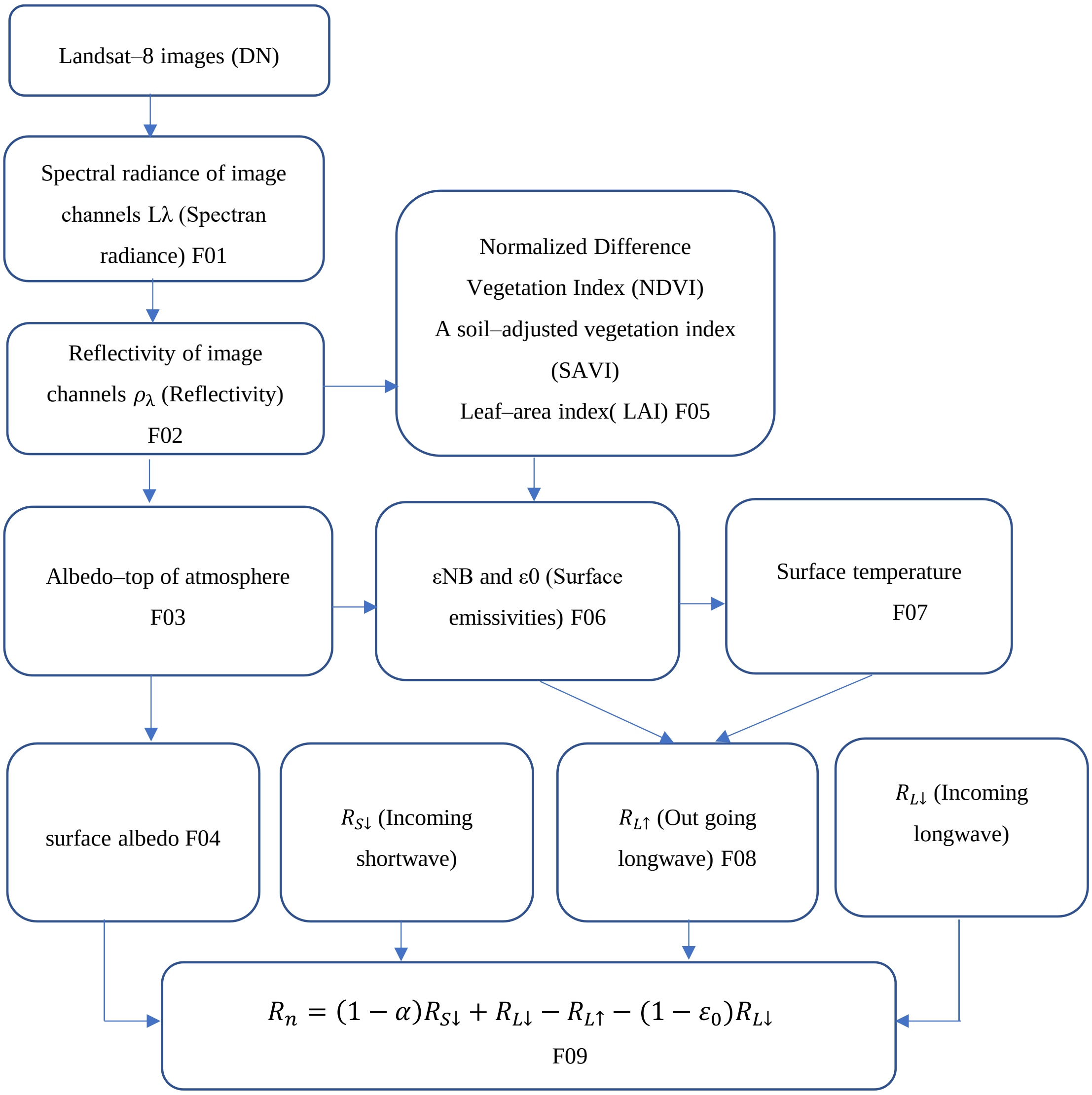


Figure 3. Calculation diagram of the net radiation absorbed by the ground R_n.

2.4.3. Calculate the surface difference (α)

The land surface differential (α) is calculated by correcting the top–atmospheric differential α_{toa} for atmospheric transmission (F04).

$$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{\tau_{SW}^2} \quad (8)$$

where α_{toa} is the difference at the top of the atmosphere; $\alpha_{path\_radiance}$ is the average portion of the incoming solar radiation across all bands that are backscattered to the satellite before it reaches the earth's surface; τ_{sw}^2 is the atmospheric transmissivity. The value $\alpha_{path\_radiance}$ ranges from 0.025 to 0.04 for the SEBAL model and suggests a value of 0.03 [19].

2.4.4. Calculate the incoming shortwave radiation value ($R_{S}\downarrow$)

Incoming shortwave radiation is the direct flow of diffuse solar radiation to the earth's surface (W/m^2). It is calculated under clear sky conditions, which is a constant for the time using the image:

$$R_{S\downarrow} = G_{sc} \times \cos\theta \times d_r \times \tau_{sw} \quad (9)$$

where G_{sc} is the solar constant (1367 W/m^2); τ_{sw}^2 is the atmospheric transmissivity calculated by the formula; d_r is the inverse of the relative distance between the Sun and the Earth; θ is the local sun elevation angle (SUN_ELEVATION). Usually $R_{S\downarrow}$ is in the range of 200–1000 W/m^2 depending on the location and time of taking pictures.

2.4.5. Calculate outgoing longwave emission value ($R_{L}\uparrow$)

The longwave emission $R_{L\uparrow}$ is calculated in (F08), calculated by the Stefan–Boltzmann formula as follows:

$$R_{L\uparrow} = \varepsilon_o \times \sigma \times T_s^4 \quad (10)$$

where σ is the Stefan–Boltzmann constant (5.67×10^{-8} $W/m^2/K^4$); T_s is the soil surface temperature (^oK); ε_o surface emissivity coefficient used to calculate the total longwave energy emission from the surface. $R_{L\uparrow}$ values are in the range of 200–700 W/m^2 depending on the location and time the image was taken.

2.4.6. Calculate the incoming longwave radiation value ($R_{L\downarrow}$)

The incoming longwave radiation value $R_{L\downarrow}$ is the stream of thermal radiation descending from the atmosphere (W/m^2). It is calculated according to the Stefan–Boltzmann formula as follows:

$$R_{L\downarrow} = 0.85 \times (-\ln \tau_{sw})^{0.09} \times \sigma \times T_{cold}^4 \quad (11)$$

where σ is the Stefan–Boltzmann constant (5.67×10^{-8} $W/m^2/K^4$); τ_{sw} is the atmospheric transmissivity; T_{cold} gives a cold score according to the near-ground temperature field. Typical $R_{L\downarrow}$ values are in the range of 200–500 W/m^2 depending on the location and time taken to take pictures.

2.4.7. Calculate the value of the net radiant energy reaching the earth's surface (R_{ni})

The net radiation reaching the ground surface is calculated according to formula (5) of the SEBAL model. R_n values are in the range of 100–800 W/m^2 depending on the topographical surface.

2.4.8. Calculate the average daily value of net radiant reaching the land surface (R_{nd})

According to [20] Solar radiation at time i, R_i ($W/m^2/h$) is calculated by the formula:

$$R_i = R_{max} \sin(\pi . t/DL) \quad (12)$$

where R_{max} is the solar radiation at noon (12:00 PM); DL is the length of day (from sunrise to sunset); t is the time from sunrise to time i. To calculate the average daily radiation use the following integral formula:

$$R_{nd} = \int_0^{DL} R_{max} \sin(\pi.t/DL) = J.R_i \quad (13)$$

where J is the coefficient; R_i is the net radiation at time i.

3. Results and discussion

3.1. Results of calculating net radiant (Rn) from meteorological observations data

3.1.1. FAO–56 net radiation (R_n) calculating results

Using the formula (1), (2), (3) and directly measured data at meteorological monitoring stations in Hoa Binh province. The results of calculating R_{nd} according to FAO–56 are shown in Table 2.

Table 2. Results of calculation of average daily net radiation according to the FAO–56 model.

No.	**Monitoring stations**	**A= σ*(T⁴maxK + T⁴minK)/2**	**B = 0.34–0.14(ea)1/2**	**C = 1.35*(Rs/Rso)–0.35**	**Rnl (MJ/m²/d)**	**Rns = (1–α) Rs (MJ/m²/d)**	**Rnd–FAO 56 = (R_{nS}–R_{nL}) (MJ/m²/d)**
1	Hoa Binh Meteorology	44.8617	0.0987	0.9236	4.0900	21.6421	17.552
2	Mai Chau Meteorology	43.0300	0.0893	0.7769	2.9862	19.2066	16.220
3	Kim Boi Meteorology	43.8821	0.0802	0.8229	2.8977	19.8794	16.982
4	Chi Ne Meteorology	44.2660	0.0607	0.8912	2.3932	21.0519	18.659
5	Lac Son Meteorology	43.5602	0.0744	0.7335	2.3771	18.3895	16.012
6	Hoa Binh Hydrological	44.7183	0.0956	0.9168	3.9199	21.5264	17.606
7	Hung Thi Hydrological	44.4355	0.0603	0.8772	2.3515	20.8217	18.470
8	Lam Son Hydrological	44.6937	0.0630	0.9369	2.6370	21.8757	19.239
	Mean						**17.593**

From Table 2, it is clear that the average daily net radiation of value R_{nd} according to FAO–56 at Hoa Binh hydrometeorological monitoring stations on June 4, 2017 is 17,593 MJ/m²/day. The value of R_{nd}_FAO–56 varies from 16,012 MJ/m²/day (at Lac Son meteorological station) to 19,239 MJ/m²/day (at Lam Son hydrological station).

3.1.2. IRMAK net radiation (R_{nd}) calculating results

Using the formula (4) and directly measured data at meteorological monitoring stations in Hoa Binh province to calculate net radiant energy according to IRMAK. The results are shown in Table 3.

From Table 3, it is clear that the average daily net radiation value of R_{nd} calculated by IRMAK (R_{nd}_IRM) at Hoa Binh hydrometeorological monitoring stations on June 4, 2017 is 16,389 MJ/m²/day. Rnd_IRM value varies from 14,921 MJ/m²/day (at Lac Son meteorological station) to 17,336 MJ/m²/day (at Lam Son hydrological station).

Table 3. IRMAK daily average net radiation (R_{nd}) calculating results (Rn_IRM).

No.	Monitoring stations	A= –0.054* T_{max}	B = 0.111* T_{min}	C = 0.462*Rs	D = 49.243*d_r +50.831	R_{nd}–IRM (MJ/m^2/d)
1	Hoa Binh Meteorology	–2.2140	3.4410	12.9853	3.0333	17.246
2	Mai Chau Meteorology	–2.1600	2.8083	11.5239	3.0333	15.206
3	Kim Boi Meteorology	–2.2086	3.0525	11.9276	3.0333	15.805
4	Chi Ne Meteorology	–2.1762	3.2856	12.6312	3.0333	16.774
5	Lac Son Meteorology	–2.1654	3.0192	11.0337	3.0333	14.921
6	Hoa Binh Hydrological	–2.2032	3.4077	12.9158	3.0333	17.154
7	Hung Thi Hydrological	–2.1870	3.3300	12.4930	3.0333	16.669
8	Lam Son Hydrological	–2.2086	3.3855	13.1254	3.0333	17.336
	Mean					**16.389**

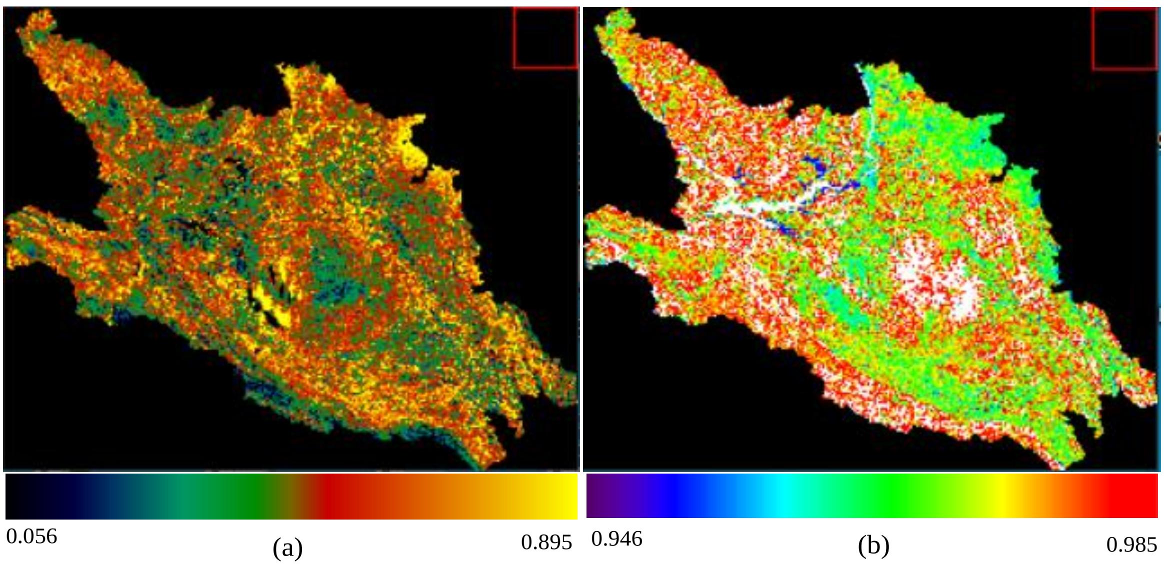
3.2. Results of calculating daily net radiant (Rnd) using Landsat–8 remote sensing image data

3.2.1. Calculate net radiant at time i (R_{ni}) using Landsat–8 remote sensing image data

Applying formula (5) to calculate net radiation value using Landsat–8 remote sensing image data and intermediate formulas (8), (9), (10), (11) to calculate values soil surface differential rate (α); broad-spectrum heat emission (ε_0); incoming shortwave radiation value ($R_{S\downarrow}$); outgoing longwave radiation ($R_{L\uparrow}$); incoming longwave radiation ($R_{L\downarrow}$). The results are shown in figure 4.

$$R_{S\downarrow} = G_{sc} \times \cos\theta \times d_r \times \tau_{sw} = 926.28 \text{ (W/m}^2\text{)}$$

$$R_{L\downarrow} = 0.85 \times (-\ln \tau_{sw})^{0.09} \times \sigma \times T_{cold}^4 = 325.87 \text{ (W/m}^2\text{)}$$



(a) (b)

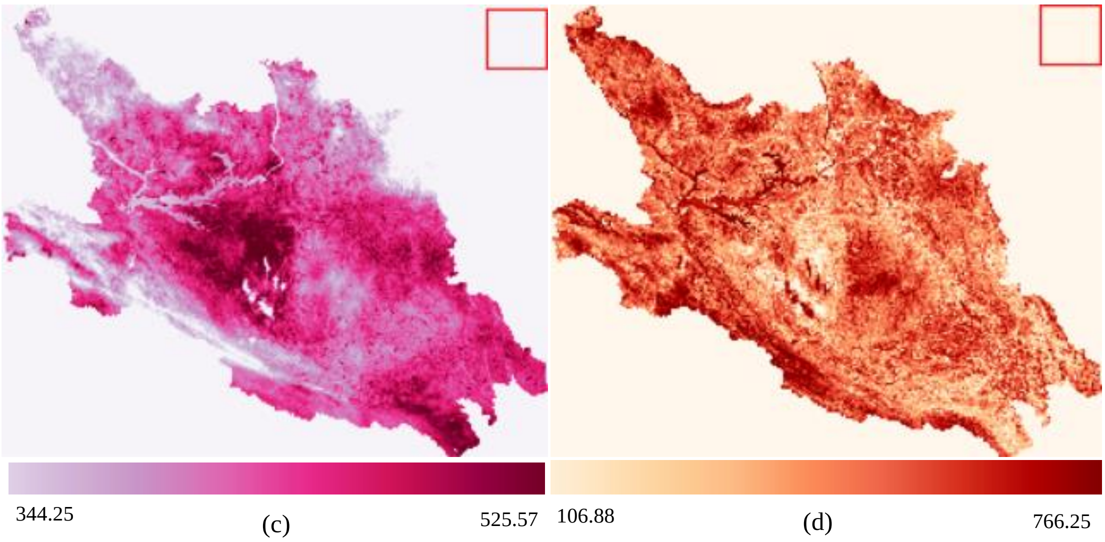


Figure 4. Results of calculating net radiation at time i (R_{ni}) from satellite image on 04/06/2017: (a) The surface difference (α) calculated from the satellite image on 04/06/2017; (b) Broad-spectrum heat emission (ε_0) calculated from satellite image on 04/06/2017; (c) Value of outgoing longwave radiation (RL↑) calculated from satellite image on 04/06/2017; (d) Value of Earth surface net radiation R_{ni} (W/m^2) calculated from satellite images on 04/06/2017.

3.2.2. Calculating average daily net radiant energy (R_{nd}) from Landsat–8 using remote sensing image data

After calculating the net radiation value at time i (R_{ni}) from satellite images using formula (13) to calculate the average daily net radiation value (R_{nd}_VT) at meteorology monitoring stations statue of Hoa Binh province. The results are shown in Table 4.

Table 4. Results of calculating average daily net radiation R_{nd} at meteorological observation stations using satellite images on 04/6/2017.

No.	Monitoring stations	Rni (W/m²/h)	Latitude	ω_s degree	ω_s (rad)	a	b	N	2NRni	t	J coefficient	Rnd_VT (MJ/m²/d)
1	Hoa Binh Meteorology	601.64	20.817	99.0739	1.7283	10.743	2.527	12.487	15024.956	6.321	7.9508	17.221
2	Mai Chau Meteorology	647.54	20.650	98.9943	1.7269	10.754	2.506	12.477	16158.951	6.314	7.9447	18.520
3	Kim Boi Meteorology	615.58	20.667	98.7172	1.7221	10.753	2.508	12.478	15362.578	6.310	7.9451	17.607
4	Chi Ne Meteorology	705.59	20.483	98.9149	1.7255	10.765	2.484	12.468	17594.207	6.308	7.9386	20.165
5	Lac Son Meteorology	658.4	20.450	98.8990	1.7252	10.767	2.480	12.466	16415.020	6.307	7.9374	18.814
6	Hoa Binh Hydrological	601.65	20.817	99.0739	1.7283	10.743	2.527	12.487	15025.206	6.321	7.9508	17.221
7	Hung Thi Hydrological	672.82	20.517	98.9308	1.7258	10.763	2.488	12.470	16779.619	6.310	7.9398	19.231
8	Lam Son Hydrological	679.89	20.883	99.1058	1.7288	10.739	2.536	12.490	16984.281	6.323	7.9532	19.466
	Mean											**18.531**

As shown in Table 4, the daily average value of net radiation R_{nd}_VT using Landsat–8 remote sensing images at Hoa Binh meteorological and hydrological monitoring stations on 04/6/2017 is 18,531 MJ/m^2/day. R_{nd}_VT value varies from 17,221 MJ/m^2/day (at Hoa Binh meteorological and Hoa Binh hydrology station) to 20,165 MJ/m^2/day (at Chi Ne meteorological station).

3.3. Compare the net radiation calculation results from other methods

The daily average net radiation value calculated according to the FAO–56 model is a physical model, using directly observed data at meteorological and hydrological stations such as average daily temperature, sunshine duration, relative humidity (RH), wind speed combined with geographical coordinates, the altitude at meteorological and hydrological monitoring stations. Therefore, the value of R_{nd}–FAO–56 is considered as the standard value to compare the results of R_{nd} calculation according to Irmak model (R_{nd}–IRM) and REMOTE SENSING model (R_{nd}–RS). The results of daily average net radiation calculation at 8 meteorological and hydrological monitoring stations according to 3 models R_{nd}–FAO–56, R_{nd}–IRM and R_{nd}–VT are shown in the Table 5.

Table 5. Comparison results of calculating net radiation by day Rnd between three models R_{nd}–FAO–56, R_{nd}–IRM and R_{nd}–RS.

No.	Monitoring stations	R_{nd_FAO-PM} (MJ/m^2/d)	R_{nd_IRM} (MJ/m^2/d)	R_{nd_VT} (MJ/m^2/d)	Differences between R_{nd_FAO-PM} and R_{nd_IRM} (MJ/m^2/d)	Percentage %	Differences between R_{nd_FAO-PM} and R_{nd_VT} (MJ/m^2/d)	Percentage %
1	Hoa Binh Meteorology	17.552	17.246	17.221	–0.31	–1.75	–0.33	–1.89
2	Mai Chau Meteorology	16.220	15.206	18.520	–1.01	–6.26	2.30	14.18
3	Kim Boi Meteorology	16.982	15.805	17.607	–1.18	–6.93	0.63	3.68
4	Chi Ne Meteorology	18.659	16.774	20.165	–1.88	–10.10	1.51	8.07
5	Lac Son Meteorology	16.012	14.921	18.814	–1.09	–6.82	2.80	17.49
6	Hoa Binh Hydrological	17.606	17.154	17.221	–0.45	–2.57	–0.39	–2.19
7	Hung Thi Hydrological	18.470	16.669	19.231	–1.80	–9.75	0.76	4.12
8	Lam Son Hydrological	19.239	17.336	19.466	–1.90	–9.89	0.23	1.18
Mean		**17.593**	**16.389**	**18.531**	**–1.20**	**6.76**	**0.94**	**5.58**
Mean square error					**1.43**		**1.54**	

Table 5 shows that the average difference of R_{nd} value between the FAO–PENMAN model and the IRMAK model is –1.20 (MJ/m^2/d) corresponds to 6.76% and the difference in Rnd value between the FAO–PENMAN model and REMOTE SENSING model is 0.94 (MJ/m^2/d) equivalent to 5.58%. The largest difference between Rnd_FAO–PM and Rnd–IRM values at Lam Son hydrological station is –1.90 (MJ/m^2/d) respectively 9.89% and the smallest at Hoa Binh meteorological station is –0.31 (MJ/m^2/d) respectively 1.75%. The largest difference between Rnd_FAO–PM and Rnd–VT values at Lac Son meteorological station is 2.80 (MJ/m^2/d) as 17.49% and the smallest at Lam Son hydrological station is 0.23 (MJ/m^2/d) as 1.18%. The difference in daily average net radiation value as a percentage at meteorological and hydrological monitoring stations between Rnd_FAO and Rnd_RS: in the range of 0–5%, with 5/8 stations accounting for 62.5%; in the range of 5–10 % is 1/8 stations accounting for 12.5%; in range of 10–15% is 1/8 stations accounting for 12.5% and the difference in the range of 15–20% is 1/8 stations accounting for 12.5%. Therefore, with the advantages of remote sensing image data and the difference between Rnd calculation results according to REMOTE SENSING model and FAO–56 model, it can be confirmed that remote sensing data is used to determine Rnd with the average difference of 5.58% is sufficient to ensure the reliability to calculate the average daily radiation from remote sensing images instead of using directly observed data from meteorological stations.

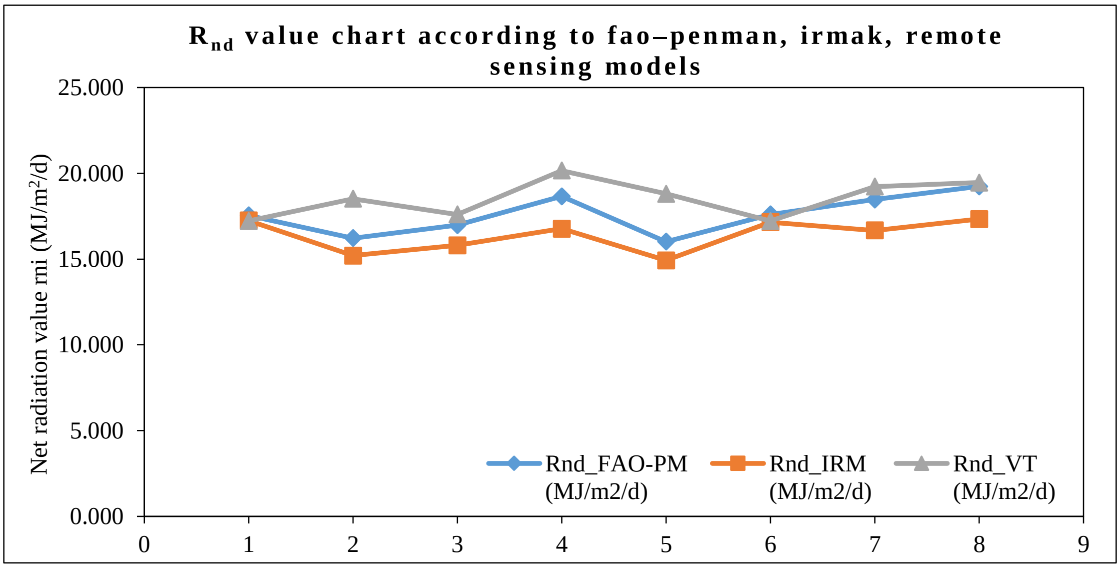


Figure 5. Daily average net radiation from three models: FAO–56, IRMAK and Remote Sensing model.

Figure 5 shows that the average net radiation per day calculated according to the IRMAK model (Rnd–IRM) is lower (–1.20 MJ/m^2/day) than the FAO–56 model. On another hand, the mean daily average net radiation calculated by the REMOTE SENSING model (R_{nd}_RS) is higher (0.94 MJ/m^2/day) than the mean daily net irradiance value according to the FAO model –56 (R_{nd}_FAO–56).

4. Conclusion

The research calculated the average daily net radiation value according to the FAO–56 model, IRMAK model from direct observation data at meteorological and hydrological stations and REMOTE SENSING models from Landsat–8 satellite images taken on June 4, 2017. The average daily net radiation value at hydrometeorological and hydrological monitoring stations calculated according to FAO–56, IRMAK, and REMOTE SENSING models is 17,593 MJ/m^2/day, 16,389 MJ/m^2/day and 18,531 MJ/m^2/day, respectively. The mean difference of R_{nd} between the FAO–56 model and the IRMAK model is –1.20 (MJ/m^2/d) as 6.84%, and the mean difference of R_{nd} between the FAO–56 model and the REMOTE SENSING is 0.94 (MJ/m^2/d) as to 5.58%. The largest difference between R_{nd} _FAO–56 and R_{nd}_IRM at Lam Son hydrological station is –1.885 (MJ/m^2/day) accounting for 10.10% and the smallest difference at Hoa Binh meteorological station is –0.31 (MJ/m^2/day) respectively 1.75%. The largest difference between the calculated values of Rnd_FAO–56 and Rnd_RS at Lac Son meteorological station is 2.80 (MJ/m^2/day) as 17.49% and the smallest at Lam Son hydrological station is 0.23 (MJ/m^2/day) equivalent to 1.18%. The difference in average daily net radiation value as a percentage at meteorological and hydrological monitoring stations between Rnd_FAO and Rnd_VT: in the range of 0–5%, with 5/8 stations accounting for 62.5%; in the range of 5–10 % is 1/8 stations accounting for 12.5 %; in the range of 10–15% is 1/8 stations accounting for 12.5% and the difference in the range of 15–20% is 1/8 stations accounting for 12.5%. Therefore, with the advantages of remote sensing image data and the difference between R_{nd} calculation results according to REMOTE SENSING and FAO–56 model, it is not exaggeragted to say that the use of remote sensing image data to determine R_{nd} with the average difference average 5.58% is reliable to calculate the average daily radiation from remote sensing images instead of using directly observed data from meteorological stations.

Author contribution statement:

Conceptualization and methodology: H.C.L., H.P.D.; validation, formal analysis: H.C.L.; investigation and project administration: C.H.L., T.X.T.; resources, data curation, software, draft: H.C.L., H.P.D.; preparation and writing–original: H.C.L., writing–review, and editing, visualization: H.P.D., T.X.T. All authors have read and agreed to the published version of the manuscript.

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