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The Effect of Elevation Differences on the Estimation of Plant Evapotranspiration in the Kuranji Watershed

Anastasia Catur Lestari[1*], Darwizal Daoed[2], Nurhamidah[3], Junaidi[4]
[1,2,3,4] Civil Engineering, Faculty of Engineering, Universitas Andalas, Indonesia
*Corresponding Author, e-mail: anastasialestari67@gmail.com

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ABSTRACT

This study compares evapotranspiration (ETo) values obtained from direct field observations with estimates from empirical models at different elevation. The empirical models used are Modified Penman, Penman-Monteith, Blaney-Criddle, Hargreaves, and Radiation. This research was conducted in the Batang Kuranji Watershed, specifically in Pauh Subdistrict (174 m above sea level) and Nanggalo Subdistrict (18 m above sea level), from August 6th to August 31st, 2023. Daily temperature, humidity, wind speed, and solar radiation data, collected using Thermo-Pro devices and from relevant agencies, were used as input for the empirical models. Three field experiments were carried out in the form of: evaporation plots, evapotranspiration plots without infiltration influence, and evapotranspiration plots with infiltration influence. Furthermore, the observed ETo values in the field were 90.67 mm/month in Nanggalo and 90.00 mm/month in Pauh. The empirical models produced estimates comparable to field observations. Analysis of the coefficient of determination (R^2) revealed that the Modified Penman empirical model was the most suitable with field experiments and showed a very strong relationship (R^2 = 0.96). The results of this study can be used as a basis for managing rice irrigation water and developing better ETo prediction models, especially in the Batang Kuranji Watershed. The authors identify areas needing further research to enable the model's use for calculating evaporation across an entire growing season.

Keywords: *Evapotranspiration; Elevation; Thermo-Pro; Field Experiments; Empirical Models*

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INTRODUCTION

Evapotranspiration is a combined process of evaporation from the air surface and transpiration, which is evaporation originating from green plants [1], and a major component in the hydrological cycle that plays an important role in agricultural, forestry, and environmental management.[2]Evapotranspiration is defined as the process of air transfer from the soil system to the atmosphere through two main mechanisms: transpiration, which is the evaporation of air from plant tissues, and evaporation, which is the evaporation of air from the soil surface [3]. If there is enough air in the plant, evapotranspiration is referred to as potential evapotranspiration. Therefore, the relationship between air requirements in green plants is closely related to evapotranspiration. Climate factors that influence such as temperature, relative humidity, wind speed, and solar radiation as well as different regions determine the efficiency of the greening system [4].

It is very difficult to distinguish between evaporation and transpiration if the land is vegetated [5] . The amount of evapotranspiration can be measured directly using tools such as

Evapotranspirometers and Lysimeters[6]. In addition, changes in altitude also affect evapotranspiration, mainly through two main factors: air temperature and wind speed. At altitudes of less than 2000 m, increasing wind speed tends to decrease the rate of evapotranspiration. Conversely, at altitudes above 2000 m, lower air temperatures become the dominant factor that increases the rate of evapotranspiration [7]. However, direct evapotranspiration measurements are very difficult to carry out, especially on the island of Sumatra, due to the absence of adequate tools.

Until now, many methods have been researched to estimate ETo (Potential Evapotranspiration), however, due to the availability of observed data, it is difficult to choose the optimal one. Therefore, several comparative studies and evaluations of various methods have been carried out, one of which is in the eastern sea area of Italy using the Hargreaves model [8] and the evaluation of these alternative methods shows that the Hargreaves method is the most accurate, approaching Penman-Monteith in various evaluation variables [9].

In the Flores Island region, which is a semi-arid area in Indonesia, evapotranspiration calculations are carried out due to the high rate of evapotranspiration and the research results show that the Thornthwaite method provides a greater evapotranspiration value than the Blaney-Criddle method [10].

In the study [11], the results of several empirical formulas from each method were compared and validated using relative error, the Nash-Sutcliffe efficiency test, and the Root Mean Square Error. It was found that the multiple linear regression method is the most suitable for estimating evaporation in the Nganjuk region, reinforced by the existence of [12] research that calculates evaporation and evapotranspiration at the Maros Climatology Station, South Sulawesi by comparing empirical models using climate data and the Visual Basic program in Microsoft Excel, thereby obtaining the largest R2 value in the Priestley method: 0.980 and Jensen-Haise: 0.889.

Among the many ETo methods, the Penman–Monteith model from the Food and Agriculture Organization (FAO) (hereinafter referred to as the FAO Penman–Modification) has been used as the basis for many previous comparative analyzes abroad [13][14][9], while in Indonesia the Penman-Modification method is widely used to analyze irrigation water requirements and water availability balance in Irrigation Areas [15].

The various facts that have been presented emphasize the need for a comprehensive evaluation of the suitability of the PET model for different regions or climate zones that are different from the region of its development. These limitations become obstacles in the calibration and optimization of the PET model. As a result, various comparative studies and evaluations of various methods have been carried out globally [13].

Evapotranspiration calculations are not only based on empirical formulas, some researchers conduct field experiments to obtain actual evapotranspiration values. The results obtained from the empirical Eto value with the actual Eto in rice plants do not have significantly different values [16] which aims to determine the water requirements needed in irrigation canals [17].The calculation and determination of evapotranspiration rates in Indonesia requires further study, especially to support irrigation scheduling.

Further study is needed to calculate and determine the evapotranspiration rate in Indonesia, especially to support irrigation scheduling. Given the limited availability of lysimeters at most climatological stations[6], the selection of an appropriate estimation method is crucial.

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Therefore, this research focuses on calculating empirical methods based on climatological data measured directly in the field, then comparing them with three field experiment methods at different elevations. The results of this comparison will serve as a reference for calculating plant water requirements and irrigation water requirements in the irrigation area[3] located in the Kuranji watershed at various elevations of the Batang Kuranji watershed.

TOOL AND METHOD

Data Collection

This study began with the collection of primary and secondary data needed for empirical formula calculations. Primary data, consisting of temperature and humidity, were measured using Thermo-Pro TP359 devices placed at two locations with different elevations. These direct observations of rice plants in the two areas also provided data on plant evapotranspiration. Secondary data, specifically solar radiation, were obtained from the Teluk Bayur Maritime Meteorology Station.

Place and Time of Research

Based on its geographical location, the rice field research in Pauh subdistrict is at position 0°55'34.7"S 100°27'22.6"E with an elevation of 174 masl and in Nanggalo subdistrict it is at position 0°54'14.5"S 100°22'32.8"E with an elevation of 8 masl. This research was conducted from August 6th to August 31st, 2023.

Research Procedure

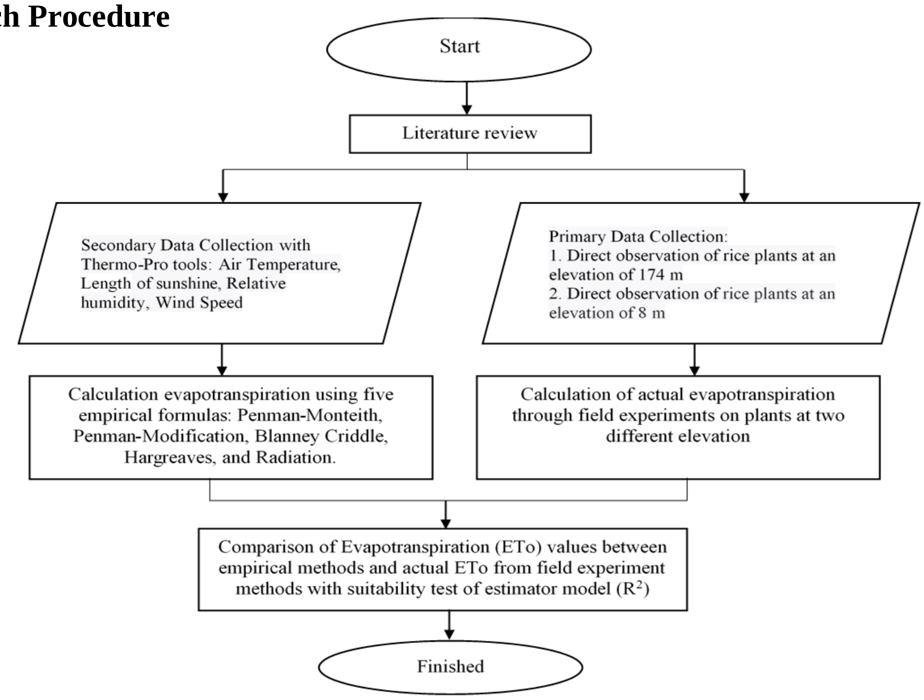

Figure 1. Research Flowchart

This study measures evapotranspiration (ETo) through two approaches, namely empirical calculation using the Penman-Monteith, Modified Penman, Blanney-Criddle, Hagreaves, and Radiation methods. The required climate data in the form of air temperature, relative humidity, wind speed from two different locations were measured using Thermo-Pro TP359, while solar radiation data were obtained from related agencies.

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As for the actual ETo in the form of field experiments, the following is an explanation of the process of implementing the three research experiments:

1. Experiment 1, which was carried out by filling the box with water, aimed to determine the evaporation rate at the research location [18].
2. Experiment 2, which was an evapotranspiration experiment carried out without the influence of infiltration. This was done by placing soil and rice plants inside a box.
3. Experiment 3, which was a simulation of the evapotranspiration process under actual field conditions, including the influence of infiltration and daily water exchange. This research was conducted by placing a 30 cm deep plastic box in the middle of a field containing rice plants 15-20 cm high above the ground surface. The purpose of using the plastic box was to determine the boundaries of the research area.

After obtaining the values from each approach, the next step was to calculate the coefficient of determination (R2) which aimed to determine the level of validity of the equation chosen in the calibration stage[19], a comparison was made between the results of the empirical ETo method and the validation of the actual ETo data. From the results of the empirical ETo method, there is one method that will later show results close to field experiments and the magnitude of the R2 value is expressed as a percentage. The value of the coefficient of determination is $0 \leq R^2 \leq 1$[12].

Figure 2. Field experiments

In addition to the factors mentioned, the observed water level decline in the field is also influenced by percolation, daily water replacement, and effective rainfall. Percolation is highly dependent on soil texture, however, in this study, that factor was not measured.

Thermo-Pro TP359

The Thermo-Pro TP359 is a digital thermometer and hygrometer, commonly used for measuring temperature and humidity in various settings like homes, offices, and greenhouses. It's designed to provide accurate readings and may be part of a broader range of instruments for climate monitoring[20].

Data Analysis using Empirical Method

Penman-Modification

Calculation of reference evapotranspiration using the Penman FAO Corrected formula (Department of Public Works, 1986) [21].

$$ETo=c\ [W.Rn+(1-W).f(U).(es-ea)] \tag{1}$$

Description:
ETo = Reference Evapotranspiration (mm/day);
C = Correction factor due to day and night climate conditions;
W = Weighting factor for the influence of air temperature and location altitude;
Rn = Net radiation equivalent to evapotranspiration (mm/day)

Penman-Monteith[14]

$$ETo = \frac{0.408\Delta Rn + \gamma \frac{900}{(T+273)} U2(es - ea)}{\Delta + \gamma(1 + 0.34U2)} \quad (2)$$

Description:
ETo = reference plant evapotranspiration (mm/day)
Rn = net solar radiation above the plant surface (MJ/m2/day)
T = average temperature (°C)
U2 = wind speed at a height of two meters above ground level (m/s)
es = saturated water vapor pressure (kPa)
ea = actual water vapor pressure (kPa)
Δ = slope of the water vapor pressure curve against temperature (kPa/°C)
γ = psychrometric constant (kPa/°C)

Blaney-Criddle

The Blaney-Criddle method, used to estimate potential evaporation (consumptive use), has been tested through a series of experimental studies in the American West involving various types of plants. The results showed that temperature, duration of sunshine, and plant moisture requirements are factors that influence the magnitude of evapotranspiration [10]

$$ETo = P\,(0.46T+8) \quad (3)$$

Description:
T = average air temperature (^{o}C);
p = % of the number of hours of sunshine per month in 1 year (attachment)

Hargreaves[12]

$$ETo = 0.00135(T + 17.78)Rs \quad (4)$$

Description:
T = average air temperature (°C);
Rs = solar radiation (MJ/M2/day);

Radiasi

In estimating potential evaporation, the Radiation Method utilizes temperature data and sunshine duration data[11]

$$ETo = C(W.Rs) \quad (5)$$

Description:
C = Correction factor influenced by air humidity (RH) and wind speed (m/s);
W = Weight factor between temperature and solar radiation;
Rs = Solar radiation (mm/day).

Data Analysis using Plant Evapotranspiration

Factors that affect plant evapotranspiration are the plant coefficient and reference evapotranspiration. According to Stannard, et al. (2023) [22], the plant coefficient (Kc) is calculated based on the evaporation ratio, which is measured based on observations in areas

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with uniform vegetation conditions. At the same time, the reference value of evapotranspiration can vary depending on research needs. Some researchers use evapotranspiration from open land without vegetation as a reference for evapotranspiration.
The calculation of plant evapotranspiration values can be measured directly [21]:

$$ETc = \text{Kc x ETo} \quad (6)$$

Description:
ETc = Plant Evapotranspiration (mm/day);
Kc = Plant coefficient (FAO reference);
ETo = Reference Evapotranspiration (mm/day)

Table 1. Plant coefficient value (Kc)

Month	Nedeco/Prosida		FAO	
	Reguler Varieties	Superior Varieties	Reguler Varieties	Superior Varieties
0,5	1,20	1,20	1,10	1,10
1,0	1,20	1,27	1,10	1,10
1,5	1,32	1,33	1,10	1,05

Test of the Suitability of the Estimation Model
The coefficient of determination (R^2) serves as a measure of how well an independent variable explains a dependent variable. Calculated after applying empirical formulas and compared against observed field data, R^2 can be readily determined using software like Microsoft Excel, often visualized through graphs. This value, ranging from 0 to 1 and expressed as a percentage, reveals the predictive capacity of the independent variable. An R^2 closer to 1 signifies a strong relationship and a good model fit, whereas a value approaching 0 indicates a weak relationship and a less effective model[12].

Table 2. Coefficient Interpretation

Interval Coefficient	Relantionship Level
0.80 – 1.00	Very Strong
0.60 – 0.79	Strong
0.40 – 0.59	Strong Enough
0.20 – 0.39	Low
0.00 – 0.19	Very Low

RESULTS AND DISCUSSION

Results Climate data
Based on the results of daily climate data calculations from the Thermo-Pro tool and related agencies in Nanggalo subdistrict and Pauh subdistrict.

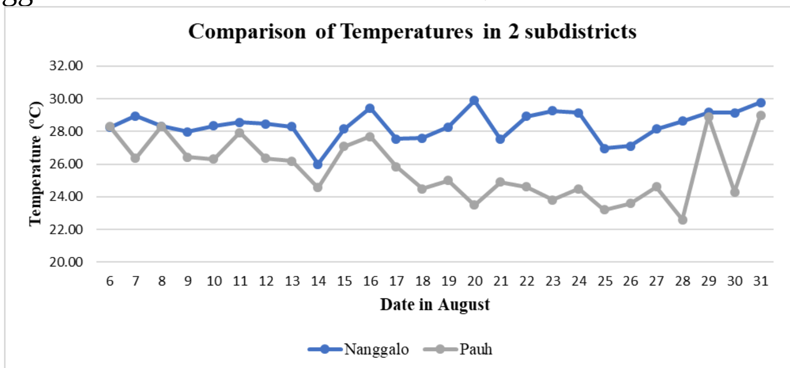

Figure 3. Temperature

Temperature is the most significant climatic factor influencing evapotranspiration rates. It is also the only environmental physical parameter projected to change due to climate change, particularly the increased concentration of greenhouse gases [3]. Daily average air temperature data recorded from August 6th to 31st, 2023, using the Thermo-Pro TP359 device at two locations with different altitudes, are presented in Figure 3. The results show that there is an inverse relationship between elevation and air temperature. The higher the elevation, the lower the air temperature tends to be, and vice versa.

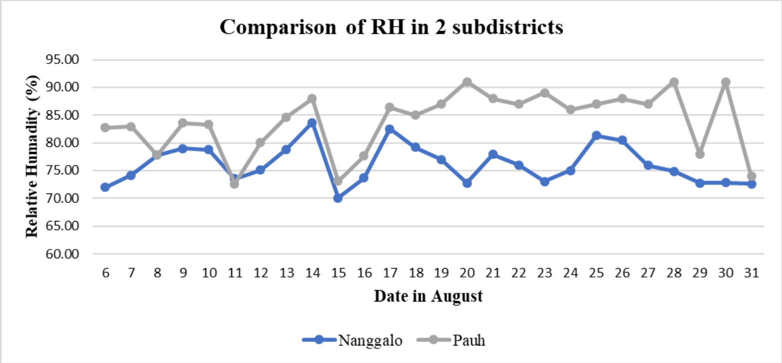

Figure 4. Relative Humidity

Daily average relative humidity, expressed in kilopascals (kPa), is required data. If this data is unavailable, it can be estimated using maximum and minimum relative humidity data (%), or through psychrometric measurements (dry and wet bulb temperatures in °C) [21] . The relative humidity data shown in Figure 4 were obtained from a Thermo-Pro device. The analysis results indicate that Nanggalo Subdistrict has a lower air humidity value compared to Pauh Subdistrict. These findings suggest a relationship between the altitude of the research location and air humidity, where the lower the altitude, the higher the air humidity tends to be. Air humidity itself is influenced by the water vapor content in the atmosphere.

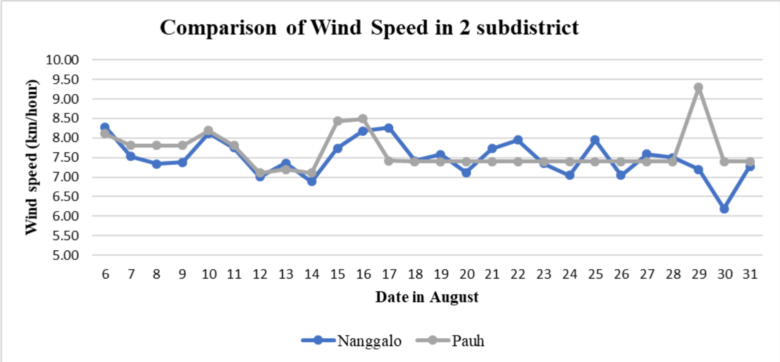

Figure 5. Wind Speed

High wind speeds have a significant impact on evaporation. By creating air turbulence, they facilitate the removal of water vapor from the evaporating surface, leading to greater water loss. This movement of air is driven by pressure differences, flowing from high to low pressure. Figure 5 shows a peak wind speed of 9.25 m/second on August 29, 2023.

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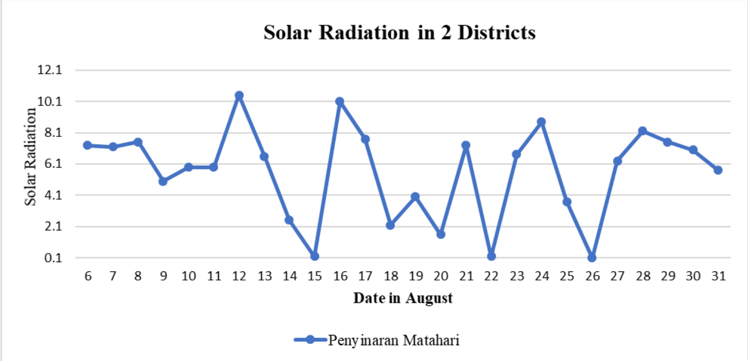

Figure 6. Solar Radiation

Daily solar radiation for the Kuranji Watershed is shown in the graph above. These data were obtained from BMKG Teluk Bayur, a climatological institution located near the research area.

Calculation Evapotranspiration of Field Experiment

The results of plant evapotranspiration are in the form of direct field observation data (ETc). Subsequently, the ETc results are adjusted by subtracting several factors that affect the observations, such as the percolation value (water absorbed into the soil) and the WLR value (clean water replacement). Meanwhile, to obtain the Reference Evapotranspiration (ETo) value from the equation ETc = Kc × ETo, the plant evapotranspiration (ETc) result is divided by the correction factor (Kc) from the FAO table [21].

The observations carried out by the researchers consisted of three experiments. The following is an explanation of the results of actual ETo observations in the field at two different heights:

Field experiment results in two research locations revealed variations in evapotranspiration values. The highest monthly evaporation (80 mm/month) occurred in Nanggalo subdistrict in experiment 1. In experiment 2, Nanggalo recorded the highest actual evapotranspiration (93 mm/month). However, in experiment 3, the Pauh subdistrict showed the highest field ETo value (106 mm/month), influenced by percolation, infiltration, and air placement. Factors such as higher air temperature, lower humidity, and solar radiation in both research locations contributed to the tendency of higher actual evapotranspiration in Nanggalo.

Calculation of Empirical Models and Field Experiments in Nanggalo subdistricts

After conducting field experiments using three different methods, the authors compared the measurement results with empirical calculations performed at two research locations with different altitudes. These results will serve as a reference in the field of water resources for future research as a basis for managing paddy rice irrigation water and developing better ETo prediction models, especially in the Batang Kuranji Watershed.

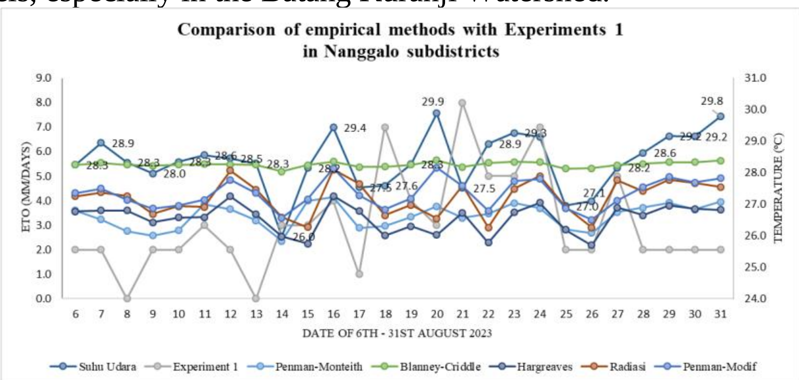

Figure 7. Comparison of empirical methods with experiments 1

Experiment 1 involved a study conducted by filling water into a box, aimed at observing the evaporation rate occurring at the research site. The results of this field experiment were based on the decrease in the water level over 24 hours. The graph above illustrates the ETo values that closely approximate the empirical values derived from Experiment 1.

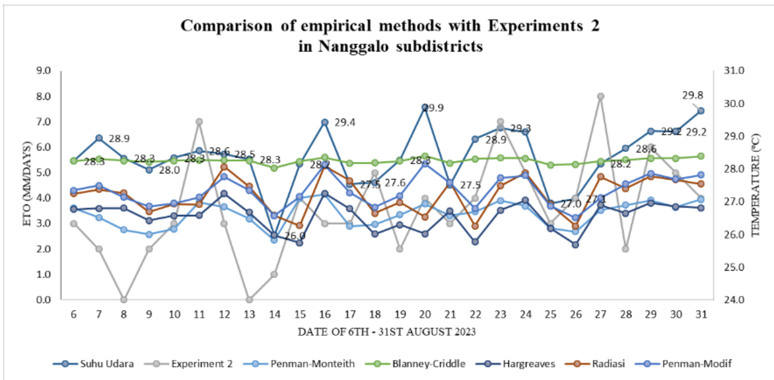

Figure 8. Comparison of empirical methods with experiments 2

The graph above shows a comparison of empirical formulas with experiment 2 conducted in Nanggalo Subdistrict. Experiment 2 represents the results of evapotranspiration without the influence of infiltration at the research site, as the soil and rice plants were placed in boxes. To validate the empirical method that approximates the experiment, a model fit estimator test will be performed.

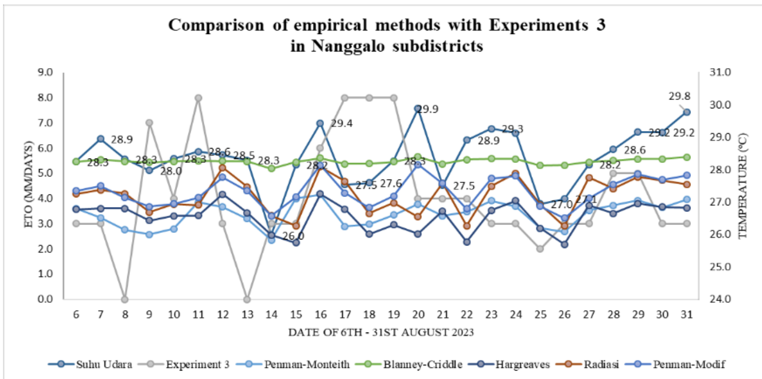

Figure 9. Comparison of empirical methods with experiments 3

The graph above illustrates the comparison of empirical method values with experiment 3. In experiment 3, the evapotranspiration process was conducted under actual conditions, including the influence of infiltration and daily water replacement at the research site.

Calculation of Empirical Models and Field Experiments in Pauh subdistricts

For this stage, the author explains the results of the comparison in Pauh subdistrict in the form of a comparison graph. The results from the graph are based on calculations from various sources.

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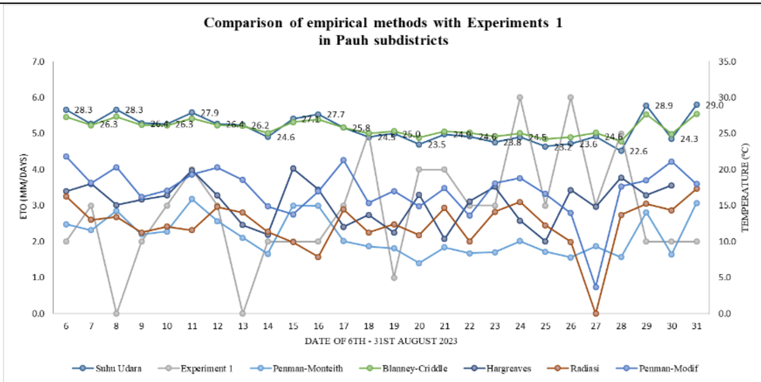

Figure 10. Comparison of empirical methods with experiments 1

The comparison between the empirical formula and Experiment 1 in Pauh subdistrict shows that the field evaporation value closest to the empirical formula is the Penman-Modified model. However, for data accuracy, a hypothesis test with a determination coefficient must be conducted.

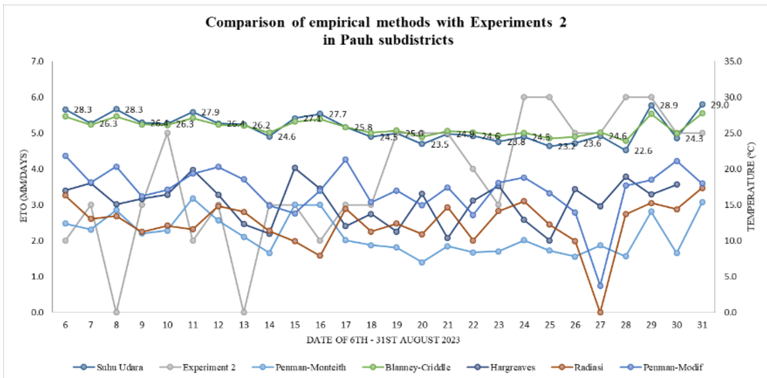

Figure 11. Comparison of empirical methods with experiments 2

The graph above was created using Microsoft Excel, with calculations based on the available data. Several empirical formula methods closely match the results of experiment 2. Therefore, the researcher will conduct a hypothesis test to determine the empirical formula that can be used for experiment 2.

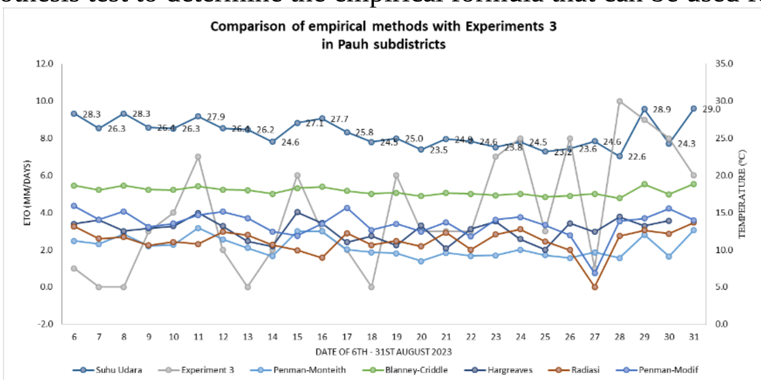

Figure 12. Comparison of empirical methods with experiments 3

In Experiment 3 in Pauh subdistrict, only a few results closely matched the empirical formula models due to several factors that were not accounted for during the field experiment, including the calculation of water inflow and outflow at the research site.

Calculation of Suitability Test of Estimation Models

Climate data (temperature, relative humidity, rainfall, sunshine duration, and wind speed) for 26 days in Pauh and Nanggalo Subdistricts were used to calculate potential evapotranspiration. Five evapotranspiration models were compared to determine the efficient model (few input parameters and uncomplicated calculation) based on the coefficient of determination (R^2) in Table 2. The results of R^2 are presented in the graph below:

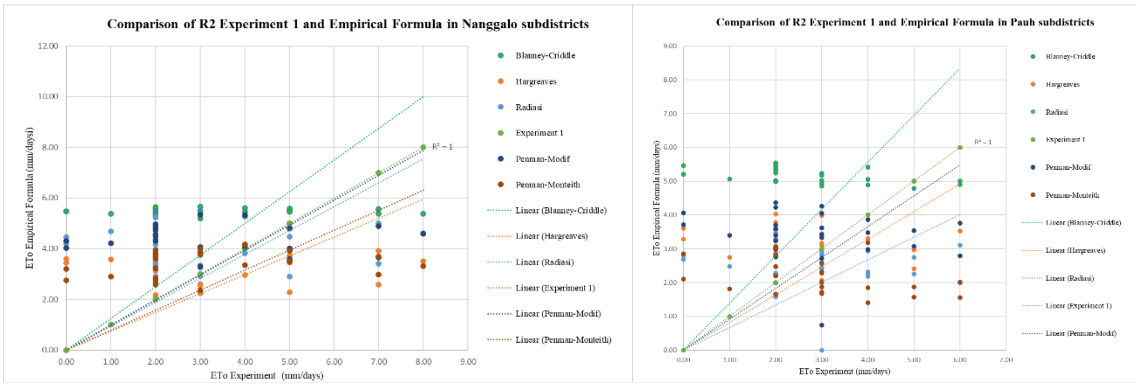

Figure 13. Comparison of empirical methods with experiments 1

Following the acquisition of evapotranspiration values from two elevations, the author identified the empirical model best matching the field experiment data using the coefficient of determination (R^2). As shown in Figure 10, the Penman-Modified model demonstrated the closest fit, with R^2 values of 0.90 (very strong) in Nanggalo subdistrict and 0.71 (strong) in Pauh subdistricts.

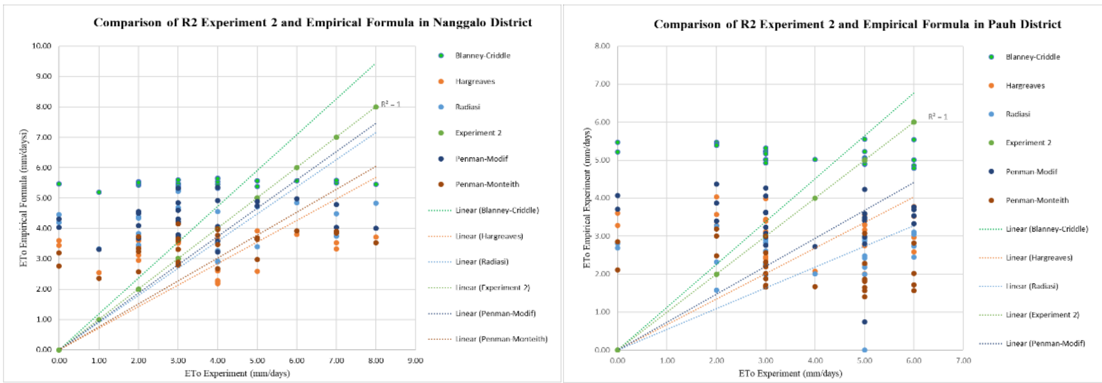

Figure 14. Comparison of empirical methods with experiments 2

In Experiment 2, the empirical method that was closest to the results in Nanggalo subdistrict was the Penman-Modified model with an R2 value of 0.76 (strong), while in Pauh subdistrict, the results of the determination coefficient test showed the Blaney-Criddle model with an R2 value of 0.43 (strong enough).

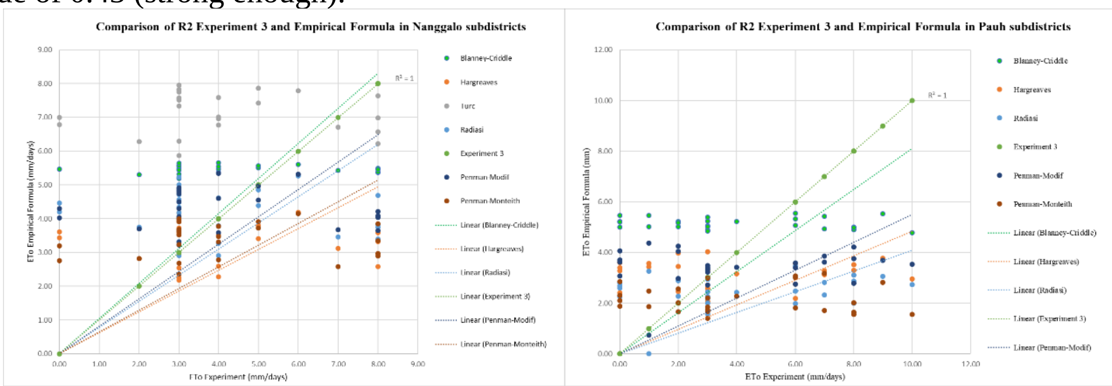

Figure 15. Comparison of empirical methods with experiments 3

In Experiment 3, the Blaney-Criddle model showed a low similarity with the results of the field experiment at both research locations. Based on Table 2: Coefficient Interpretation, the R^2 value in Pauh Subdistrict was 0.54 (strong enough), while in Nanggalo Subdistrict it was 0.73 (strong).

From the calculations that have been done, the researchers can conclude that there are two empirical models that can be used to calculate evapotranspiration values based on different altitudes in the Batang Kuranji Watershed, namely the Modified Penman model and the Blaney-Criddle model. However, from previous studies, the Penman model is an equation that has complete climate variables and is applicable to all climate conditions[16] for research locations in Indonesia. In addition, there are several factors that the authors did not consider due to limited time and equipment, so the desired results have not been maximized. However, the results obtained are in accordance with previous research procedures.

CONCLUSION

The conclusions that can be drawn from the research results are as follows:

1. The evapotranspiration results from three field experiments in August in Nanggalo Subdistrict were 80.00 mm/month, 93.00 mm/month, and 106.00 mm/month, respectively, with an average monthly temperature of 28.4°C. Meanwhile, the evapotranspiration results (ETc) in Pauh Subdistrict were 75.00 mm/month, 98.00 mm/month, and 105.00 mm/month, respectively, with an average monthly temperature of 25.7°C. These results prove that the higher the research elevation, the lower the evapotranspiration results due to the highly influential factors of air temperature and relative humidity.
2. To test the appropriate model estimation results, the coefficient of determination was used as a benchmark at each research location, and the Modified Penman method was found to be the most efficient to be used as a basis for managing paddy rice irrigation water and developing better ETo prediction models, but only at elevations of 18 masl and 174 masl in the Batang Kuranji Watershed.
3. The limitation of this research is that it is weak to be used as a reference because the research was only conducted for 26 days, so longer research is needed for better results. In addition, field experiment research should ideally be carried out using standardized equipment so that the results obtained are maximized. Therefore, more complete equipment is needed.

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