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Refining the irrigation water requirement model for paddy field land preparation by empirical data

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Abstract. Currently, the reference for establishing irrigation water requirements for paddy field land preparation (KAIPL) relies on the Van de Goor & Zijlstra (VGZ) model, assuming a constant discharge. While practical for planning, this method often leads to wasteful implementation. Thus, this study aims to introduce a refined model for determining KAIPL (modified model of VGZ, called MVGZ), emphasizing water efficiency through intermittent irrigation. The proposed model integrates inundation during specific periods and at varying water levels applied to three distinct soil textures. To validate its effectiveness, the model was compared against field measurements conducted at two locations in Karawang, West Java, and Gowa, South Sulawesi. Findings reveal distinct coefficients for heavy, medium, and light soil textures—0.79, 0.76, and 0.73 respectively. Compared to the VGZ model, the developed model demonstrates significant water savings ranging from 10% to 36%, ensuring more efficient irrigation practices. Thus, the MVGZ model emerges as a promising tool for determining KAIPL with enhanced water conservation capabilities.

1 Introduction

Climate change, characterized by rising air temperatures due to increasing concentrations of greenhouse gases, significantly impacts water resources [1]. Various extreme events such as droughts, floods, irregular rainfall patterns, heatwaves, and other extreme occurrences are being observed globally [2, 3]. As drought incidents rise, the use of irrigation water continues to increase, but this has not led to a corresponding rise in agricultural production [4]. Considering these phenomena, adaptation and mitigation efforts are crucial to reducing the negative impacts of climate change.

In the context of water management, particularly irrigation water for agriculture, paddy cultivation is known to be the sector that requires the most irrigation water. Excessive use of irrigation water is often observed, which is neither effective nor efficient. This aligns with studies from the FAO and other research indicating that agriculture consumes the largest amount of water compared to other sectors, particularly industry and urban areas [5, 6]. The

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greatest use of irrigation water in agriculture is for rice farming [7]. This is understandable since paddy rice generally uses a continuous flooding system, including the determination of irrigation water for land preparation (KAIPL).

Currently, the determination of KAIPL is based on Planning Criteria-01 (KP-01) concerning the Irrigation Network Planning of 2013. In KP-01, KAIPL is determined using the Van de Goor & Zijlstra (VGZ) equation, assuming a constant irrigation water rate for 30 or 45 days. Compared to KAIPL values in other countries such as China, Japan, Korea, and the Philippines, the values tend to be higher. Comparative studies using the Cropwat 8.0 model, developed by the FAO, indicate that the KP-01 method still results in higher values [8]. Additionally, KP-01 does not adequately consider the diverse soil textures in Indonesia or water-saving irrigation methods such as intermittent irrigation. This method can save between 22% and 76% of water [9], and it has been implemented in Indonesia with water savings of 26% to 40% [10, 11].

Therefore, it is necessary to review the VGZ model by considering soil texture factors and intermittent irrigation. By focusing on these two factors, irrigation water requirements, particularly in land preparation can be determined more accurately, leading to significant water savings and improved efficiency in irrigation water use. This study aims to: 1) refine the VGZ model considering soil texture and water-saving irrigation methods, and 2) evaluate the developed model by field observation data.

2 Materials and Methods

2.1 Time and Location

Field data collection was conducted to evaluate the modified model for determining irrigation water for land preparation (KAIPL). The research was implemented in two locations: Karawang, West Java, and Gowa, South Sulawesi (Figure 1). At the first location, data collection took place from July to August 2022, using two experimental plots for 20 and 30 days land preparation. At the second location, data collection was carried out in two periods: from August 15 to 30, 2022, for the first season, and from December 5 to 26, 2022, for the second season. Each location includes two plots, with sizes of 3200 m² and 3300 m² in Karawang and 1800 m² and 2000 m² in Gowa. These locations were selected due to their varying rainfall patterns according to the Oldeman climate classification. These climatic differences will influence the amount of irrigation water required

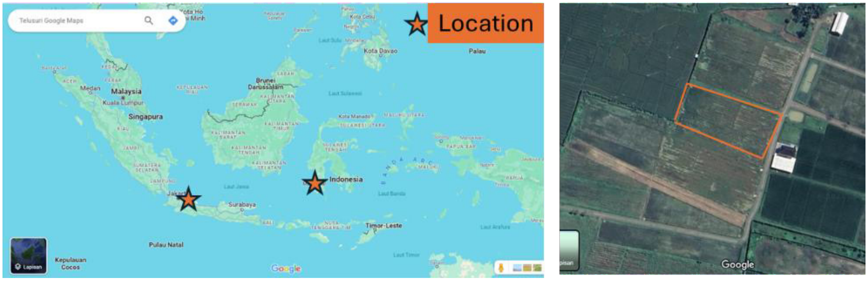


Fig. 1. Research location for developing modified model of irrigation water for land preparation.

2.2 Development of KAIPL Modification Model

The basis of the KAIPL modification model, based on the VGZ equation (hereinafter referred to as the MVGZ model), is written as follows:

$$IR = \frac{Me^{ak_f}}{(e^{ak_f} - 1)} \tag{1}$$

Where, IR is Irrigation water requirements for land preparation (mm), M is accumulation among Evaporation (E) and Percolation (P), “a” is coefficient as a function of soil texture, and kf is calculated based on the following equation:

$$k_f = \frac{MT}{S_f} \tag{2}$$

Where T is the period time of land preparation (days) and Sf is water requirements for saturation. Here, the value of “a” will be determined with optimization parameter by linear programming using Excel Solver. This method is suitable for optimizing parameters, specifically for estimating water balance parameters [10, 12]. Optimization of the value of “a” will be done by comparing the IR value from equation 1 (MVGZ Model) with the IR determined using the following water balance (IR water balance):

$$IR = \Delta WL + S_f - Re - (E_o + P) \tag{3}$$

Where ΔWL is the change in water level (mm) and Re is effective rainfall (mm). The Eo value is determined as 1.1 times the reference evapotranspiration (ETo), calculated using the Penman-Monteith equation, which is the standard equation by FAO [13]. During land preparation, the water level (WL) is maintained flooded at a approximately 3-5 cm above the ground surface every 5 days. The Sf value is based on soil texture, with several criteria: heavy soil with a porosity of 0.60, medium soil with a porosity of 0.45, light soil with a porosity of 0.30, and a soil solum depth of 30 cm. Optimization of parameter "a" was conducted using a combination of Eo and P values ranging from 5 to 11 mm, with a land preparation period of 20-45 days. The total number of these combinations is 468. The optimal "a" value is determined by the highest R^2 (coefficient of determination) value between equations 1 and 3 for each soil texture.

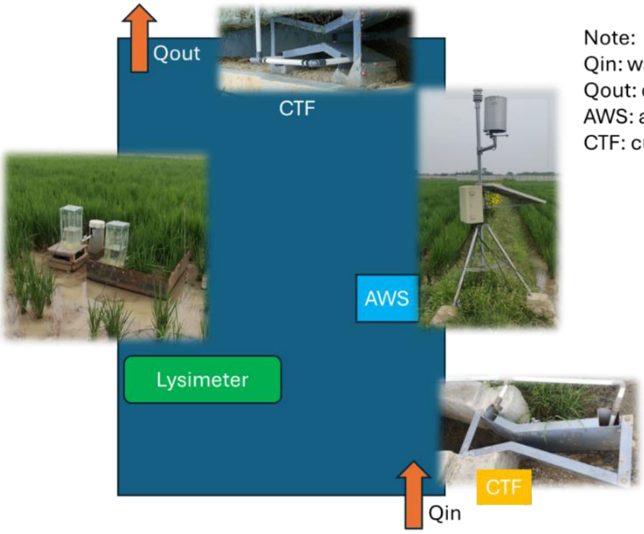
2.3 Observation Field

Field observations were conducted to evaluate the results of parameter optimization in the modified model (MVGZ) and to compare it with the original model (VGZ). These observations were used to determine total irrigation and other water balance parameters such as percolation, drainage, rainfall, actual evapotranspiration, and water level. The measurement scheme is shown in Figure 2. Irrigation was represented by the measured water inlet rate (Qin) using a Cutthroat flume (CTF). Similarly, drainage was represented by the rate of outflow (Qout). Water level, percolation, and actual evapotranspiration were measured using a lysimeter, while rainfall and other weather parameters such as solar radiation, air temperature, and humidity were measured using an Automatic Weather Station (AWS).

3 Results

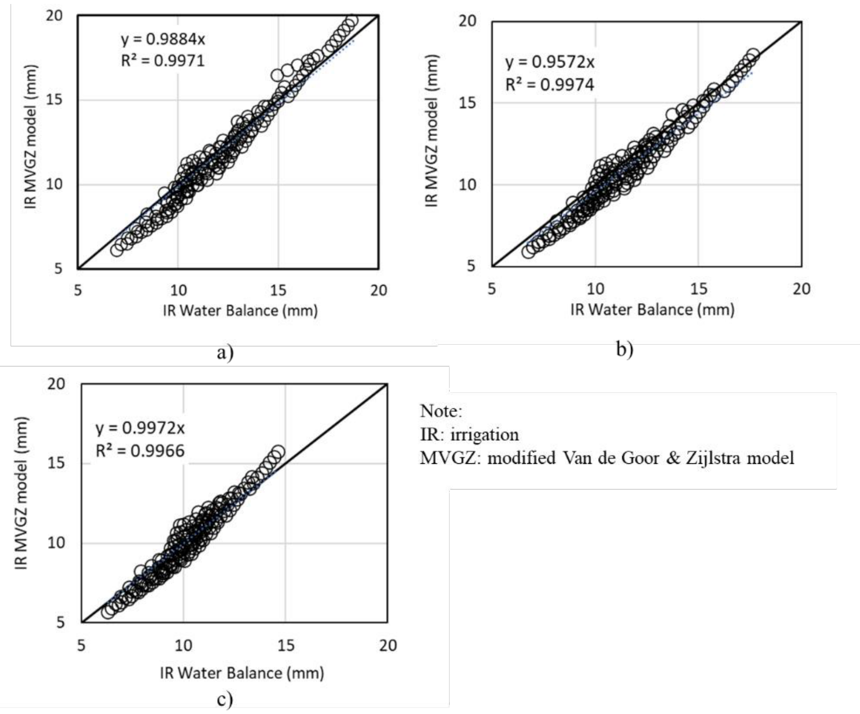
3.1 Optimization of modified VGZ Model

Figure 3 shows the comparison results of IR determination using equations 1 and 3 for determining the coefficient “a.” Using the linear programming method, the "a" value obtained is 0.79, 0.76, and 0.73 for heavy, medium, and light soil textures, respectively. The R^2 value obtained is close to 1 (0.99), indicating that the MVGZ model equation can be used for determining irrigation water needs during land preparation. In hydrology, an R^2 value generally above 0.74 is considered acceptable [14], thus the current developed model is acceptable.



Note:
Qin: water inlet rate
Qout: outflow rate
AWS: automatic weather station
CTF: cutthroat flume

Fig. 2. The scheme of field measurement in land preparation.



a)

b)

c)

Note:
IR: irrigation
MVGZ: modified Van de Goor & Zijlstra model

Fig. 3. Results parameter optimization of MVGZ model for different soil texture: a) heavy soil, b) medium soil, c) light soil.

3.2 Comparison of original and modified models

Figures 4-6 show the comparison results between the original model (VGZ) and the modified model (MVGZ) over a 20-day land preparation period. The irrigation requirement in the modified model is smaller compared to the original model, despite having the same evaporation and percolation needs. For heavy soil texture (Figure 4), the irrigation requirement in the MVGZ model ranges from 16.50 to 20.07 mm/day, while in the VGZ model it ranges from 17.64 to 21.17 mm/day. This indicates a saving of about 5-6% in irrigation water per day. The irrigation requirement in the KAIPL is positively correlated with the increase in M value (evaporation and percolation) as shown in Figure 4.

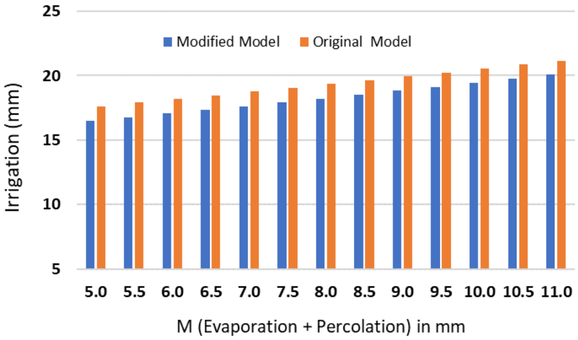


Fig. 4. Comparison irrigation water requirement for land preparation of heavy soil.

For medium soil texture (Figure 5), the irrigation water requirements in the MVGZ model are also smaller compared to the VGZ model. The irrigation water requirement in the MVGZ model ranges between 14.29 and 17.97 mm/day, while in the VGZ model, it is the same as for the heavy soil texture because no distinction is made between soil types as stated in KP-01. This range indicates that the MVGZ model can save water by 15-19%. The greater amount of water saved in medium soil is due to the lower saturation requirement compared to heavy soil.

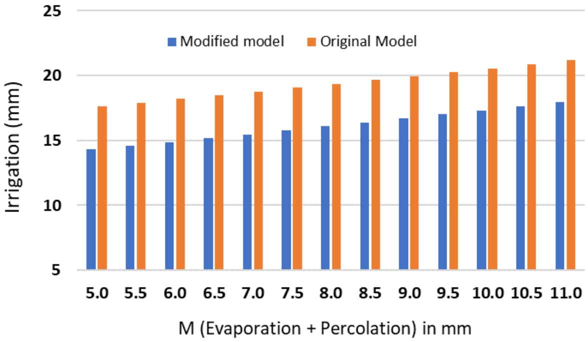


Fig. 5. Comparison irrigation water requirement for land preparation of medium soil.

Figure 6 shows the KAIPL irrigation water needs for light soil. The irrigation water requirements in the MVGZ model are significantly smaller compared to the VGZ model. The irrigation water requirement in the MVGZ model ranges between 11.93 and 15.77 mm/day. This range indicates that the MVGZ model can save water by 25-32%. The larger amount of water saved for light soil is due to the lowest saturation requirement among the different soil textures.

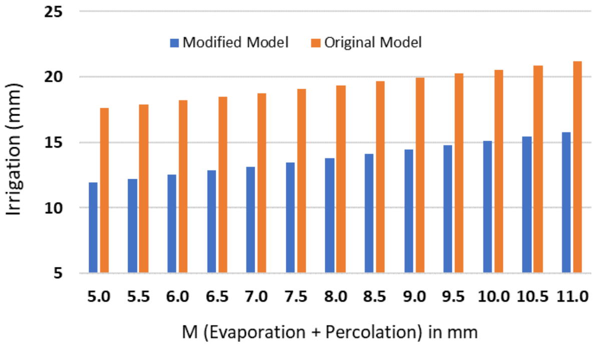


Fig. 6. Comparison irrigation water requirement for land preparation of light soil

3.3 Comparison of models with observation data field

Table 1 presents the components of the water balance from field observations. These observations indicate that the potential for water loss in the field ranges from 14-26%, which is lower than the results reported in previous research [15]. The first location requires more irrigation despite receiving higher rainfall. This results in significant runoff at the first location, leading to substantial water loss, particularly in plot 1.

Table 1. Components resulting water balance observation field

Components	Units	Karawang		Gowa	
		Plot 1	Plot 2	Season 1	Season 2
Inflow					
Irrigation	mm	257	313	143	221
Precipitation	mm	143	143	11	13
Total	mm	399	456	154	234
Outflow					
Percolation	mm	20	30	30	63
Runoff	mm	237	255	16	26
Evapotranspiration	mm	75	127	72	101
Total	mm	332	412	118	190
Difference	mm	67	44	36	44
Water loss	Percentage	26.20%	14.06%	25.22%	19.96%

At the first location, the actual irrigation requirements were 257 mm and 313 mm for the 20-day and 30-day land preparation periods, respectively (Figure 7). These values are smaller than those calculated using both the modified and original models. Compared to measurement data, the modified model still meets the actual irrigation needs in the field, yielding lower results than the original model. This demonstrates that the MVGZ model can estimate irrigation needs more precisely and efficiently than the initial model, resulting in irrigation water savings of approximately 10-11%.

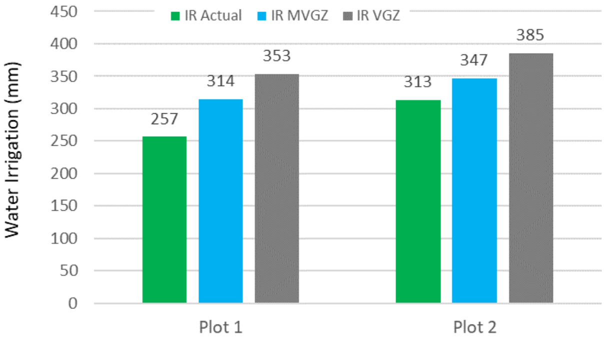


Fig. 7. Comparison actual, modified and original models of water irrigation in the first location.

The same results were observed at the second location, where the actual irrigation water needs were effectively met using the MVGZ model (Figure 8). This model successfully addressed irrigation requirements in both seasons 1 and 2. Additionally, the MVGZ model consistently proved to be more economical compared to the VGZ model, achieving irrigation water savings of 10-36%.

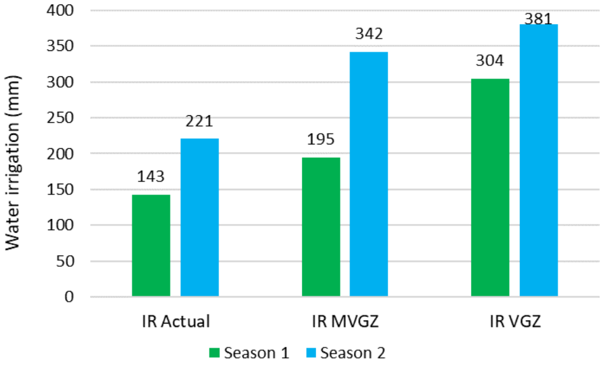


Fig. 8. Comparison actual, modified and original models of water irrigation in the second location.

4 Discussion

The modified model developed (MVGZ) demonstrates high accuracy, with an R^2 value close to 1. This indicates that irrigation water requirements during land preparation are significantly influenced by soil texture, consistent with previous research [16]. The coefficient "a" value for heavy soil is the highest compared to the other two soil textures. This indicates that the irrigation requirement for heavy soil is greater than for the other soil textures. This larger water requirement is needed for initial soil saturation due to the higher porosity of heavy soil compared to the other soil types.

The developed model is also more efficient and conserves more irrigation water compared to the existing VGZ model, with savings ranging from 5% to 32%, as shown in Figures 4-6. The highest water savings are achieved in light soil textures due to their lower porosity. Thus, the primary factor in this efficiency is the initial saturation of water requirements. In the VGZ model, the saturation need is set at 250 mm for soil without cracks (wet soil) and 300 mm for cracked soil (dry soil). These values are higher compared to data from other countries, such as the Philippines since better management in cracked soil [15]. Therefore, it is necessary to review and adopt the initial saturation values in the MVGZ model for better water conservation. In the VGZ model, continuous irrigation can cause runoff, leading to inefficient water use [17]. Additionally, continuous flooding in the VGZ model can result in water loss through seepage and increased runoff. Therefore, it is necessary to reduce irrigation in conditions that minimize seepage and runoff [18]. The findings also show that the MVGZ model, with a smaller Sf value, can save more water than the VGZ model.

Field observation (Figures 7-8) confirmed the irrigation water savings achieved by the modified model (MVGZ). This model meets actual field irrigation needs with lower water usage than the existing model (VGZ model). The savings, ranging from 10% to 36%, are consistent with previous findings, demonstrating the model's improved efficiency. These findings indicate that the developed model is particularly suitable for land preparation. The advantages of this model include its consideration of the diverse soil textures found in Indonesia and its ability to facilitate land preparation in a shorter time.

5 Conclusions

The modified VGZ model has been developed to accommodate three types of soil textures. This model includes a parameter "a," which represents the soil texture coefficient for determining water requirements for land preparation. The "a" values obtained were 0.79, 0.76, and 0.73 for heavy, medium, and light soil textures, respectively. Based on field evaluations, the modified model meets irrigation water needs while achieving water savings of 10-36% compared to the original model. Therefore, this modified model is suitable for practical application in the field.

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