A PRELIMINARY STUDY ON EVALUATING HYDRAULIC PROPERTIES CALCULATOR TO PREDICT SOIL AVAILABLE WATER OF SELECTED TROPICAL MONSOON SOIL, INDONESIA †

[UN ESTUDIO PRELIMINAR SOBRE LA EVALUACIÓN DE LA CALCULADORA DE PROPIEDADES HIDRÁULICAS PARA PREDECIR EL AGUA DISPONIBLE DE UN SUELO TROPICAL SELECCIONADO DE MONZÓN, INDONESIA]

K. Komariah[1*], M. Bima Gegana-Sakti[1], D. Priyo-Ariyanto[1], Sumani[1] and R. Putu Widiani-Priswita[2]

[1]Soil Science Department, Faculty of Agriculture, Sebelas Maret Univerisity, Jl. Ir. Sutami No. 36A, Kentingan, Surakarta, 57126, Indonesia.
**Email:komariah@staff.uns.ac.id*
[2]Environmental Science Dept., Post Graduated School, Sebelas Maret University, Jl. Ir. Sutami No. 36A, Kentingan, Surakarta,57126, Indonesia
**Corresponding author*

SUMMARY

Background: Hydraulic properties calculator had been employed by many researchers worldwide, as it is simplified soil water properties prediction by resulting a model. However, the model was formulated by investigating soil samples from all over the USA, which are not similar with Indonesian soil due to different climatic zone. **Objective:** To evaluate the accuracy of Hydraulic Properties Calculator for Indonesian soil, which is categorized developed under the tropical monsoon climate. **Methodology**: Undisturbed soil samples were collected from 36 land units of 4 soil types surrounding Karanganyar Regency, Indonesia. Soil properties data included soil permeability, pH (soil reaction), pF, organic matter, particle density, bulk density, porosity, and texture were analyzed using Pearson's correlation, regression analysis, multiple linear regression, and pair T-Test (α=0.05). **Results**: The results showed the coefficient of determination (R^2) of soil available water using laboratory analysis and hydraulic properties calculator was 0.959, but paired t-test resulted P<0.01. This means despite high value of R^2, both methods produced different soil available water results. **Implications:** Further study is required to formulate new model is to predict soil available water of Indonesian soil. **Conclusion:** The hydraulic properties calculator is less accurate to predict soil Available Water (AW) of selected Indonesian soil.

Key words: soil texture; soil type; gravimetric soil moisture; multiple linear regression; soil properties.

RESUMEN

Antecedentes: la calculadora de propiedades hidráulicas ha sido empleada por muchos investigadores en todo el mundo, ya que simplifica la predicción de las propiedades del agua del suelo al generar un modelo. Sin embargo, el modelo se formuló investigando muestras de suelo de todo Estados Unidos de América, que no son similares al suelo de Indonesia debido a la diferente zona climática. **Objetivo:** Evaluar la precisión de la calculadora de propiedades hidráulicas para el suelo de Indonesia, que se clasifica desarrollado bajo el clima monzónico tropical. **Metodología:** Se recolectaron muestras de suelo inalterado de 36 unidades de tierra de 4 tipos de suelo que rodean Karanganyar Regency, Indonesia. Los datos de propiedades del suelo incluyeron permeabilidad del suelo, pH (reacción del suelo), pF, materia orgánica, densidad de partículas, densidad aparente, porosidad y textura se analizaron mediante correlación de Pearson, análisis de regresión, regresión lineal múltiple y prueba T de pares (α = 0.05). **Resultados:** Los resultados mostraron que el coeficiente de determinación (R^2) del agua disponible en el suelo mediante análisis de laboratorio y calculadora de propiedades hidráulicas fue de 0.959, pero la prueba t pareada resultó P <0.01. Esto significa que, a pesar del alto valor de R^2, ambos métodos produjeron diferentes resultados de agua disponible en el suelo. **Implicaciones:** Se requieren más estudios para formular un nuevo modelo para predecir el agua disponible en el suelo del suelo de Indonesia. **Conclusión:** La calculadora de propiedades hidráulicas es menos precisa para predecir el agua disponible del suelo (AW) de suelo indonesio seleccionado.

Palabras clave: textura del suelo; tipo de suelo; humedad gravimétrica del suelo; regresión lineal múltiple; propiedades del suelo.

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INTRODUCTION

Currently, water availability is a major problem for agricultural management practices. Hence, knowing the soil Available Water (AW) capacity of the land is important for irrigation efficiency. Readily Available Water (RAW) capacity is the soil moisture between permanent wilting points (pF 4.2) and field capacity (pF 2.54). According to Janik et al. (2007) nowadays the measurement of available water requires expensive and complicated methods and less practical. So it takes a method or model that can measure the amount of water available in the soil. Groundwater is Measurements of available soil water use the method by determining the water retention curve (Jury and Horton, 2004).

Chamber Pressure is an equipment to measure soil pF, which is very accurate. But in another hand, it is expensive, and the process requires a relatively long time (Sreelash et al., 2017). Another method namely Potentiometer method, the measuring process is fast but expensive and less accurate (Kashyap and Kumar, 2021). So, an approach to determine water capacity using a curve based on the soil properties parameters are necessary.

Rawls et al. (1982) conducted a study of available soil water capacity curves using soil properties as research parameters. Parameters used include texture, bulk density, particle density, porosity, pF, and organic matter, have found Hydraulic Properties Calculator. Hydraulic Properties Calculator produced by Saxton is able to predict water available only by using texture (sandy, silty, clay). The findings were obtained from the analysis of 1,323 soil samples with 32 state from all places considered to represent the USA to determine the available water curves. Hydraulic Properties Calculator is a practical tool for determining available soil water capacity and has been cited by more than 1,700 scientific articles worldwide and is widely used.

The Hydraulic Properties Calculator invented by Rawls and Saxton is a practical tool for determining the soil AW (Saxton and Rawls, 2006), which is also has been adopted by researchers in Indonesia (Zaki, 2017; Yasin, 2012; Nahib et al., 2021). However, since it was formulated from soil in the USA, the accuracy on its usage for soil outside USA with different characteristics is important. No research has been done to evaluate the accuracy of Hydraulic Properties Calculator for soil in Indonesia. Hence this research is aimed at evaluating the accuracy of Hydraulic Properties Calculator for soil in Indonesia, which are developed under the tropical monsoon climate.

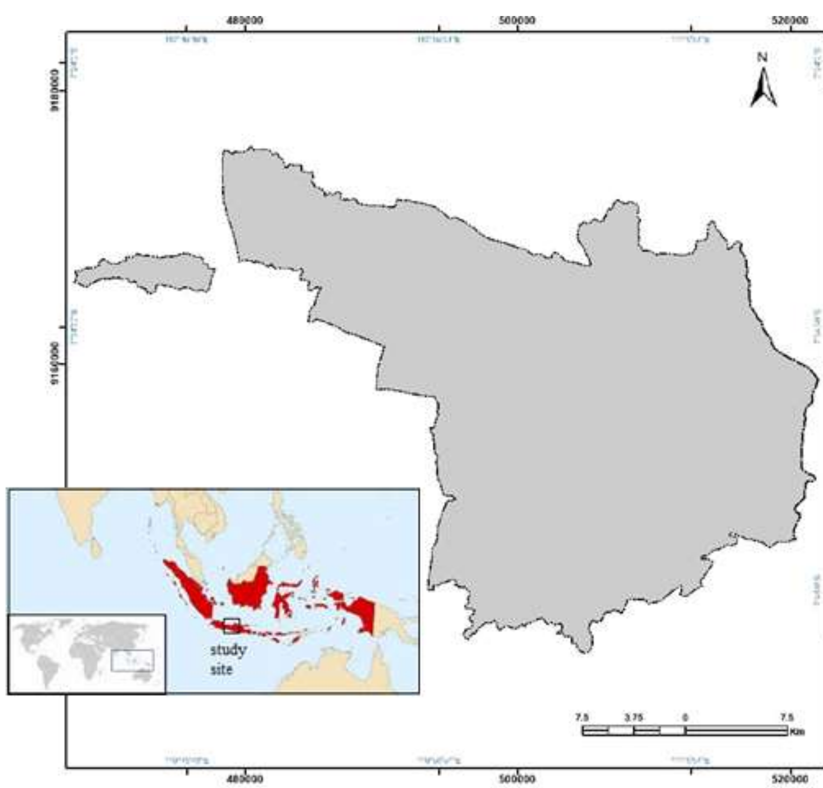

Figure 1. Study site, Karanganyar Regency, Indonesia.

MATERIALS AND METHODS

This preliminary study was conducted from October 2017 to January 2018, located in Karanganyar Regency (7°28'00" - 7°46'00" S; 110°40'00" - 110°70'00" E), Indonesia as presented in Figure 1. This study employed survey method supported by laboratory and statistical analysis. The soil type of research site was classified as Vertisols, Alfisols, Inceptisols and Andisols, as presented in Figure 2a. Figure 2b indicates the slope was classified into five classes (0%-8%; 8%-15%; 15%-25%; 25%-40%; and >40%), with the contour map of intervals 50 m is presented in Figure 2c. Figure 2d presents the land cover classes as rice field, upland, plantation, and forest. According to overlaying process of soil type, slope and land cover maps, the total of 36 land units (Fig. 3) were obtained, and 3 samples were taken at each land unit as replication for both disturbed and undisturbed samples.

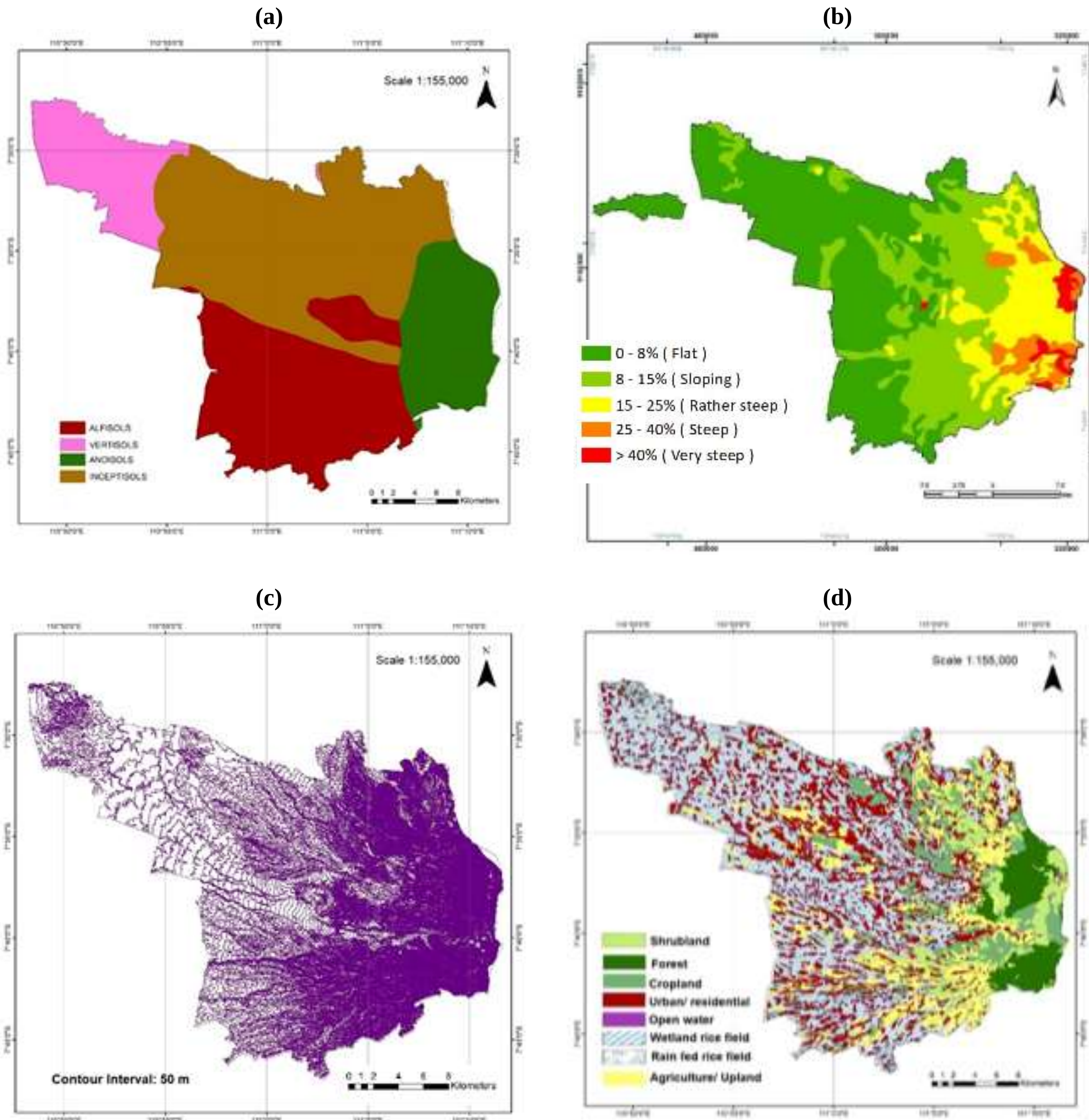

Figure 2. Maps of soil type (a), slopes (b), contour of interval 50 m (c), and land cover (d).

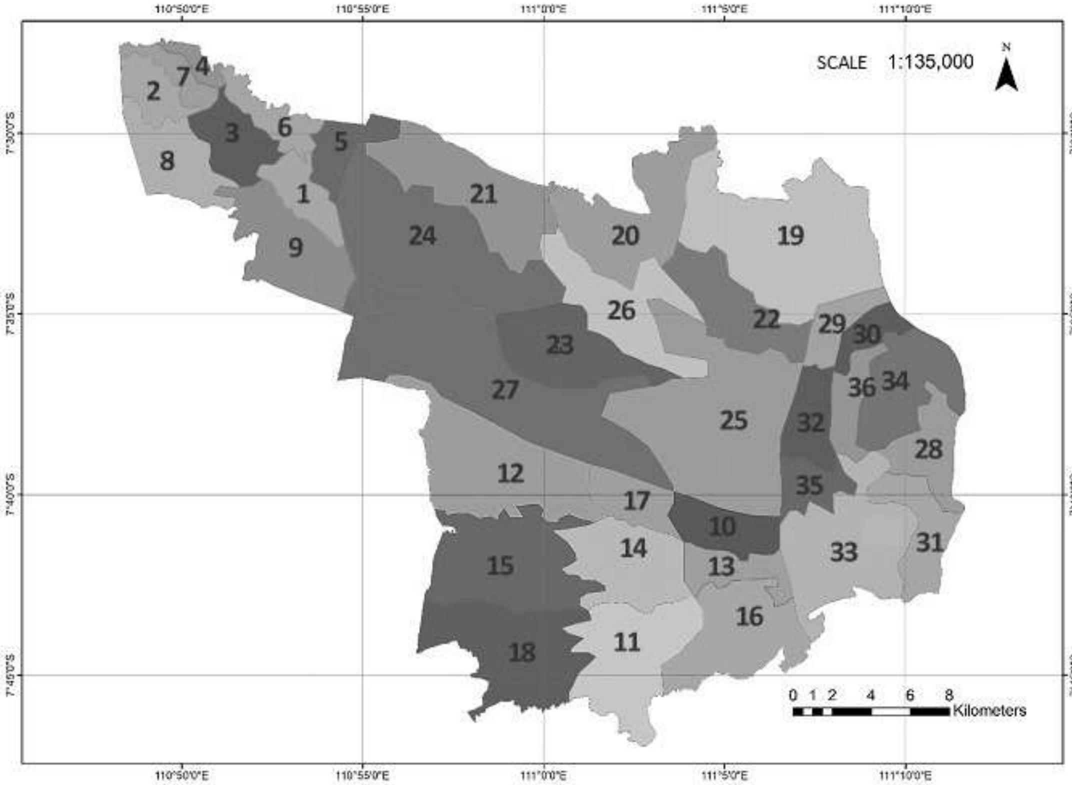

Figure 3. Land units map of study site.

The method for soil properties analysis referred to (Jury and Horton, 2004) included soil permeability using permeameter method; soil pH using digital pH tester (Oakton waterproof 30); soil pF using pressure plate apparatus method with chamber pressure Daiki DIK-3404 ; soil organic matter using Walkley and Black method; soil particle density using pycnometer method; bulk density using gravimetric method; soil porosity calculated from ratio of bulk density and particle density; soil texture using 3 fraction pipette method. Linear and multiple regression, Pearson correlation and pair t-test were carried out to analyze the data at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The soil characteristics of study site are presented in Table 1. Table 1 indicates Vertisols had the highest available water (15.12 %vol.) followed by Alfisols, Inceptisols and Andisols (9.81, 7.19 and 3.90, respectively). Soil permeability was the lowest in Vertisols (0.94 cm/h) and the highest in andisols (11.00 cm/h), similarly to soil porosity. The sand fraction content supports the soil porosity, because the highest content of sand fraction in Andisols

Soil Available Water (AW) resulted from laboratory observation using pressure plate apparatus (actual) and calculated with hydraulic properties calculator (HPC) at each soil type in all land units are presented in Table 2 and the mean in Figure 4, respectively. Table 2 shows the highest soil available water (AW) of Vertisols observed using pressure plate apparatus in laboratory (LAB) and calculated using Hydraulic Properties Calculator (HPC) were 17.37 and 13.30 %vol., respectively; while the lowest were 13.84 13.10 %vol., respectively. On the other hand, the highest soil AW of Alfisols from Lab and HPC analysis were 10.26 and 11.80 %vol., respectively; and the lowest were 9.11 and 10.50 % vol., respectively. Overall, Table 1 shows soil AW observed from laboratory analysis were lower than that calculated with Hydraulic Properties Calculator (HPC) at Inceptisols and Andisols. The highest soil AW obtained by laboratory analysis at Inceptisols and Andosols were 8.06 and 4.98 % vol., respectively; while it was 10.8 and 9.60 % vol., respectively generated from HPC. Figure 4 demonstrates the mean of soil AW of Vertisols was higher observed with LAB (15.12 %vol.) than calculated with HPC (13.19 %vol.). In the contrary, soil AW observed in LAB were lower than calculated with HPC in Alfisols, Inceptisols and Andosols.

In specific, the distinct difference produced by both LAB and HPC method can be seen in Andisols (Figure 4), where the HPC method resulted in very high soil AW (9.29 %vol.), while LAB method was only 3.90 % vol. This probably due to Andisol soil is dominated by allophanic minerals and amorf (non-crystalline mineral) imogolites, which called as pseudo sand (NRCS, 2006) with very low clay content and high permeability (Table 1). The high permeability also leads Andisols having the lowest soil AW (Figure 4) compared to other soil types. On the other hand, high clay content in Vertisols (Table 1) may have promoted the lowest soil AW differences in Figure 4. This is because clay type is very important in determining soil AW. For instance, Alfisols is dominated by clay caolinite minerals, with 1: 1 clay mineral type (1 layer of tetrahedral alumina and 1 layer of silica octahedral); while Vertisols contains of 2: 1 clay mineral type (Vereecken et al., 1989), and high carbon evolution within four weeks (Aguilar, Bautista and Díaz-Pereira, 2011). The 2:1 clay mineral type leads Vertisols to hold more water, hence soil AW is higher than other soil types (Jury and Horton, 2004). This is confirmed that clay content and type may had also influenced the accuracy of soil AW comparison of HPC method with LAB analysis. The higher the clay content, the higher the accuracy.

Table 1. The mean characteristics of each soil type at study site.

SOIL TYPE	Available Water (% vol.)	SOIL PERMEABILITY (cm/h)	OM (%)	pH	CLAY (%)	SILT (%)	SAND (%)	SOIL POROSITY (%)
Vertisols	15.12	0.94	2.48	6.86	62.26	21.53	16.21	11.62
Alfisols	9.81	3.10	2.20	5.48	44.94	13.44	41.62	16.87
Inceptisols	7.19	6.66	2.03	6.08	40.63	13.18	46.19	17.76
Andisols	3.90	11.00	1.59	5.60	28.09	11.14	60.77	32.16

Note: OM = organic matter

Table 2. Actual (using pressure plate apparatus) and calculated (using hydraulic properties calculator/ HPC) soil Available Water (AW) at each land unit.

Land unit no.	SOIL TYPE	*HPC* AW	Actual AW	Land unit no.	SOIL TYPE	*HPC* AW	Actual AW
		--- % volume ---				--- % volume ---	
1.	Vertisols	13.10	13.84	19.	Inceptisols	10.60	7.54
2.	Vertisols	13.30	15.76	20.	Inceptisols	10.30	6.39
3.	Vertisols	13.30	16.66	21.	Inceptisols	10.80	7.99
4.	Vertisols	13.30	17.37	22.	Inceptisols	10.40	6.39
5.	Vertisols	13.10	14.47	23.	Inceptisols	10.50	7.05
6.	Vertisols	13.20	14.71	24.	Inceptisols	10.50	7.53
7.	Vertisols	13.10	14.29	25.	Inceptisols	10.40	6.62
8.	Vertisols	13.10	14.31	26.	Inceptisols	10.50	7.12
9.	Vertisols	13.20	14.63	27.	Inceptisols	10.80	8.06
10.	Alfisols	10.70	9.16	28.	Andisols	9.10	3.39
11.	Alfisols	10.80	9.85	29.	Andisols	9.50	4.27
12.	Alfisols	10.80	9.98	30.	Andisols	9.35	3.95
13.	Alfisols	10.70	9.54	31.	Andisols	9.10	3.14
14.	Alfisols	10.90	10.04	32.	Andisols	9.60	4.98
15.	Alfisols	11.00	10.05	33.	Andisols	9.40	4.06
16.	Alfisols	10.50	9.11	34.	Andisols	8.90	3.24
17.	Alfisols	11.80	10.26	35.	Andisols	9.10	3.70
18.	Alfisols	11.70	10.26	36.	Andisols	9.60	4.30

Note: AW HPC = available water calculated from Hydraulic Properties Calculator analysis; AW LAB = available water from laboratory analysis using pressure plate apparatus.

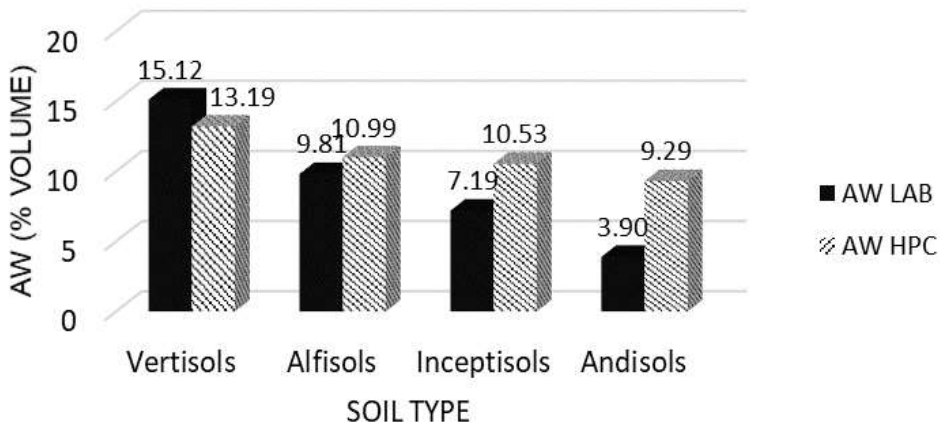

Figure 4. Mean soil available water (AW) of each soil type (Note: AW HPC = available water calculated from Hydraulic Properties Calculator analysis; AW LAB = available water from laboratory analysis using pressure plate apparatus).

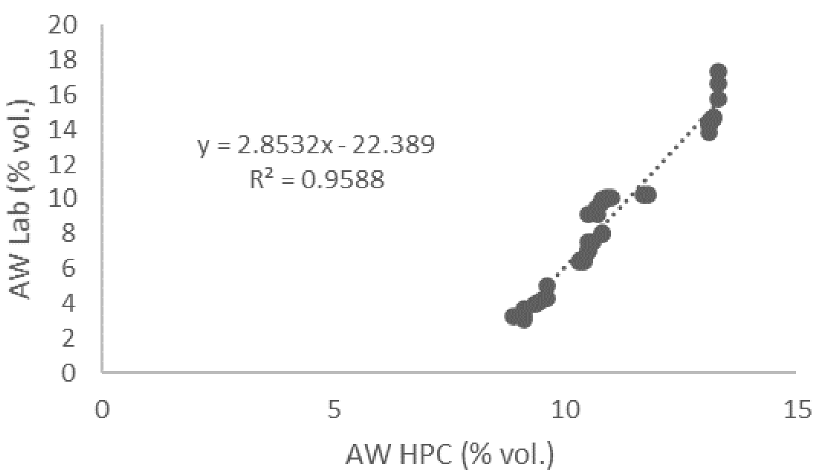

Figure 5. Linear Regression of Soil AW LAB and Hydraulic Properties Calculator (HPC).

Linear regression (Figure 5) analysis were employed to compare the soil AW observed from LAB analysis to that of calculated with the Hydraulic Properties Calculator (HPC) shown in Table 2. The linear regression analysis presented in Figure 5 shows the coefficient of determination (R^2) of soil AW LAB and HPC is 0.959. However, the paired t-test resulted in high significant soil AW at both method (T-value =-4.25; P-value <0.01). This means despite high value of R^2, LAB (pressure plate apparatus) and HPC method produced different soil AW. Therefore, this preliminary study found that HPC is not accurate to predict soil AW of Indonesian soil, because it developed under tropical monsoon climate, while soil in USA is developed under humid subtropical climate(Hernandez-Ochoa and Asseng, 2018). This result agrees with the finding of (Sung and Iba, 2010) which found that HPC is less accurate for Malaysian soil, because very different characteristic soil in tropical soil and subtropical soil.

Since HPC has been found to be not accurate to predict soil AW of selected Indonesian soils, a further statistical analysis was performed to find a more appropriate model to estimate soil AW based on soil physical and chemical properties. First, Pearson's correlation was employed to determine the strength and significance of linear regression between soil AW LAB with soil properties, namely soil permeability, organic matter (OM) content, porosity, pH, and texture, respectively. The result is shown in Table 3, which depicts all the soil properties observed significantly correlated with soil AW LAB. Then, multiple regression analysis was performed to produce a model for predicting soil AW and resulted

Equation (eq. 1). The Variance Inflation Factor (VIF) of each predictor is presented in Table 4.

Equation (eq. 1) shows that predicted soil AW is only influenced by soil organic matter (OM), pH, porosity, and soil permeability with coefficient of determination (R^2) = 0.909 (data is not shown). That means soil texture (clay, sand and silt) do not influence the soil AW. On the other hand, the Variance Inflation Factor (VIF value) shown in Table 4 for soil organic matter, pH, porosity, and permeability, is 8.70; 3.29; 4.49; 5.14, respectively. The low VIF number (below 10) denotes the absence of multi collinearity in the model. Multi collinearity is a condition where some independent variables on multiple regression analysis highly correlated, and causing the model resulted is not appropriate / valid (Lavery et al., 2019). This means that the model resulted to predict soil AW in equation (eq. 1) is valid.

Soil AW Model = 8.91 - 1.514 OM + 0.479 pH - 0.0124 POROSITY - 0.1394 PERMEABILITY (eq. 1)

To evaluate the accuracy of Soil AW MODEL, linear regression and paired t-test analysis were performed by comparing Soil AW Model with Soil AW LAB. The data of Soil AW LAB can be seen in Table 1, while the linear regression of Soil AW Model and Soil AW Lab is presented in Figure 6.

It can be seen from Figure 6 that comparison of soil AW MODEL resulted from equation (eq. 1) with soil AW LAB generated R^2 = 0.9838, which indicates that equation (eq. 1) is a good model in predicting soil AW. Moreover, paired T-test analysis with α= 0.05 produced p value = 0.855, which means both laboratory analysis and model of equation (eq. 1) methods do not produce different soil AW. So that, equation (eq. 1) can be used to predict soil available water with rather high accuracy. The method approach should be proved to be practical, accurate and inexpensive (Duarte and Bautista, 2011).

Table 3. Pearson's correlations between AW LAB water with selected soil properties (α = 0.05).

Parameter	Pearson	P-value
Permeability	-0.907**	< 0.01
Soil Organic matter (SOM)	-0.921**	< 0.01
pH	0.767**	< 0.01
Porosity	-0.855**	< 0.01
Texture (Clay)	0.969**	< 0.01
Texture (Silt)	-0.305**	< 0.01
Texture (Sand)	-0.894**	< 0.01

Note: ** means highly significant at α= 0.05

Table 4. Variance inflation factor (VIF) of multi regression analysis between AW LAB and observed soil properties.

Term	VIF
Soil Organic Matter	8.70
pH	3.29
Porosity	4.49
Permeability	5.14

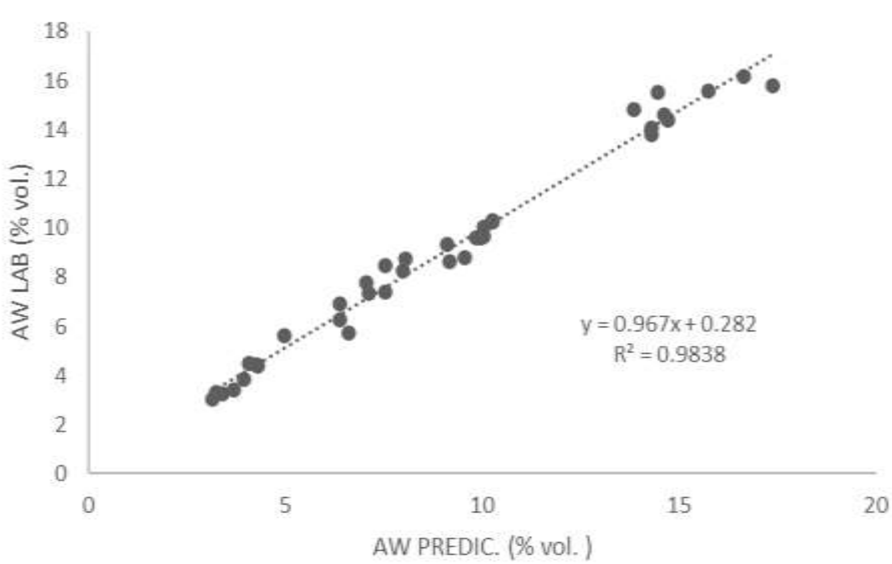

Figure 6. Linear regression of Soil AW MODEL and LAB.

Based on the above discussion, this preliminary study found that Hydraulic Properties Calculator is not accurate to predict water available for tropical monsoon soil of specific region (Karanganyar regency), Indonesia. This is because the Hydraulic Properties Calculator found by (Rawls, Brakensiek and Saxtonn, 1982) is based on studies on soils in the USA, which has different climate with Indonesia. The different climate circumstance surrounding Karanganyar regency and surroundings (Komariah et al., 2015) influenced soil formation in each area, with their unique characteristics (Purwanto, Gani and Suryani, 2020). However, since this is a preliminary study with very few numbers of sample sand limited study area, further research with expanding land unit throughout Indonesia is required.

CONCLUSION

Hydraulic Properties Calculator is not accurate to be applied to predict available water (AW) of tropical monsoon soils in Karanganyar Regency, Indonesia. So, a developed model to calculate the soil available water is:

AW = 8.91 - 1.514 OM + 0.479 pH - 0.0124 POROSITY - 0.1394 PERMEABILITY

However, more samples in further study is required to increase the accuracy of the model.

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Compliance with ethical standards. This article does not contain any studies involving animals performed by any author.

Data availability. The authors confirm that the data supporting the findings of this study are available within the article.

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