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The Relationship of Soil Types to the Dynamics of Groundwater Availability for Rice (*Oryza sativa* L.) and Corn (*Zea mays* L.) Plants in Pohuwato Regency

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Abstract

The model for estimating groundwater availability for plants often overlooks the type of soil and the capacity of plants to absorb water from it. This study employs laboratory soil tests and statistical analyses to examine the relationship between various soil types in Pohuwato Regency and the variations in Groundwater Availability (KAT) levels for rice and corn plants. The results indicate that Andosol and Litosol are the soil types with the highest Field Capacity values in Pohuwato Regency, ranging from 331 mm to 403 mm. Meanwhile, Alluvial and Regosol soil types exhibit the lowest Permanent Wilting Point values in the Pohuwato Regency, ranging from 23 mm to 53 mm. The study results revealed a very high average correlation value of 0.907 between Field Capacity and the Permanent Wilting Point concerning the Groundwater Availability model. The research data, which includes soil characteristics and the Groundwater Availability model for rice and corn cultivation in Pohuwato Regency, can serve as a foundation for strategies that farmers can employ to enhance their future agricultural productivity.

Keywords: Agriculture, Alluvial, Andosol, Field Capacity, Permanent Wilting Point

1. Introduction

The primary agricultural commodities in Pohuwato Regency are rice and corn, which cover 65.83% of the total agricultural business in the regency as of 2023. Every year, the agriculture, forestry, and fisheries sectors contribute around 59% to 60% of the Gross Regional Domestic Product at Current Prices (PDRB-AHB) in Pohuwato Regency (BPS Kab. Pohuwato, 2023). However, in these farming efforts, farmers often use land resources excessively, such as planting corn on steep slopes. Several types of land have many limiting factors (Yahya et al., 2023).

Based on the Oldeman Climate Type classification by BMKG, the Regency of Pohuwato is the driest area among all districts in Gorontalo Province, with Oldeman Climate Type E mapping evenly throughout the region. Yang et al.'s (2021) research indicates that when groundwater levels decrease, plants can experience drought and water stress, which ultimately affect agricultural yields and crop quality.

Hadisusanto (2010) stated that on the surface of land covered by plants or vegetation, water loss through evaporation and transpiration occurs simultaneously and is difficult to separate, thus giving rise to the term evapotranspiration. Evaporation on the surface of the land, in addition to being determined by weather/climate, is also determined by the soil factor itself. Prijono and Laksmana (2016) further explained that the rate of transpiration is influenced by factors such as vegetation characteristics, soil characteristics, environment, and cultivation patterns.

The research conducted by Kusumastuty (2021) used temperature and rainfall data from RCP 4.5 and 8.5 climate modeling as one of the databases to calculate water availability for plants, employing the Thornthwaite and Mather water balance calculations. The projections span the years 2020-2049. Field Capacity and Permanent Wilting Point data in Lampung Province were obtained through laboratory soil testing. The determination of the soil samples tested did not take into account the type of soil found in Lampung Province. The final product of the research is a projection of the food crop planting schedule

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in Lampung Province. Another relevant study is the study conducted by Rahim et al. (2015). The study was conducted using a corn planting simulation model to investigate the impact of corn growth under water deficit and surplus conditions. The final result of the study was an analysis of the water balance simulation model, as well as the impact of water deficit and surplus on corn growth. The study did not conduct sampling or direct research on corn farming objects and their land in Gorontalo Regency.

The amount of water required by plants and their ability to absorb water from soil particles vary depending on the type of plant (FAO, 1998). This point is also indicated by the water content of the permanent wilting point for various kinds of plants, each of which has a distinct value. Therefore, detailed calculations of the water available to plants and their water requirements are carried out by considering the types of soil and plants in the area. Determining the water content at field capacity and permanent wilting point conditions is necessary for scheduling irrigation, assessing crop water requirements, and evaluating land suitability for various land uses. (Darmayati & Sutikto, 2019). The water content at field capacity and wilting point is influenced by the texture, structure, and porosity of the soil (Alberta, 2015). In this study, the relationship between water availability and water needs is expressed by the water balance.

2. Material and Methods

The research was conducted in the Pohuwato Regency area, which spans a latitude range of 0.27° to 0.01° North and a longitude range of 121.23° to 122.44° East. Pohuwato Regency is administratively divided into 13 sub-districts. There are four types of soil in Pohuwato Regency, based on the Pohuwato Regency Spatial Plan map (BPS Kab. Pohuwato, 2023), namely Alluvial, Andosol, Litosol, and Regosol soil types. The location of the rice and corn plant sample points is determined based on this type of soil.

Sampling was carried out using a non-probability sampling approach with purposive sampling properties. Each sample to be taken was determined based on the type of soil and the vegetative phase criteria of the plant. Samples were taken by lifting the soil to a depth of 15 centimeters using a hoe and crowbar. The rice and corn samples taken were plants in the vegetative phase with an average planting age of one month. Each sample was taken to the Agrotechnology Laboratory, Faculty of Agriculture, Gorontalo State University, for Field Capacity and Permanent Wilting Point tests.

Table 1. Sampling Locations

No	Soil Type	Plant	Subdistrict	Longitude (°N)	Latitude (°E)
1	Alluvial	Rice	Duhiadaa	0.470726	121.923829
2		Corn	Marissa	0.471645	121.945525
3	Andosol	Rice	Taluditi	0.637847	121.852070
4		Corn	Taluditi	0.63848	121.851316
5	Lithosol	Rice	Randangan	0.485056	121.798757
6		Corn	Randangan	0.519741	121.812277
7	Regosol [a]	Corn	Dengilo	0.5836191	122.098908

[a] There are no Regosol soil samples for rice plants because there are no rice fields in the Regosol soil location in Pohuwato Regency.
Source: Processed Data (2024).

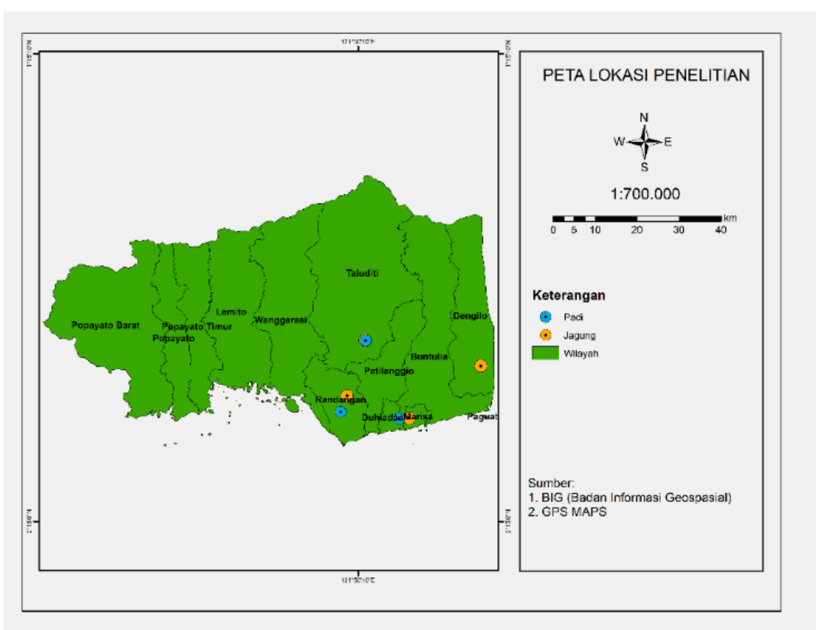

Figure 1. Map of Sampling Location Points

The field capacity value is determined by calculating the soil water content of the field capacity condition for soil samples in Pohuwato Regency. Soil samples for the Permanent Wilting Point use intact soil samples along with plants, such as corn and rice, which are conditioned to be air-dry and not given water until the soil reaches the Permanent Wilting Point condition, indicated by the yellowing of the plant leaves and their subsequent fall. After that, soil testing for Permanent Wilting Point conditions was carried out at the Laboratory of the Faculty of Agriculture, State University of Gorontalo. Field Capacity and Permanent Wilting Point testing of soil samples was carried out using the oven-drying method at the Laboratory of the Faculty of Agriculture, State University of Gorontalo.

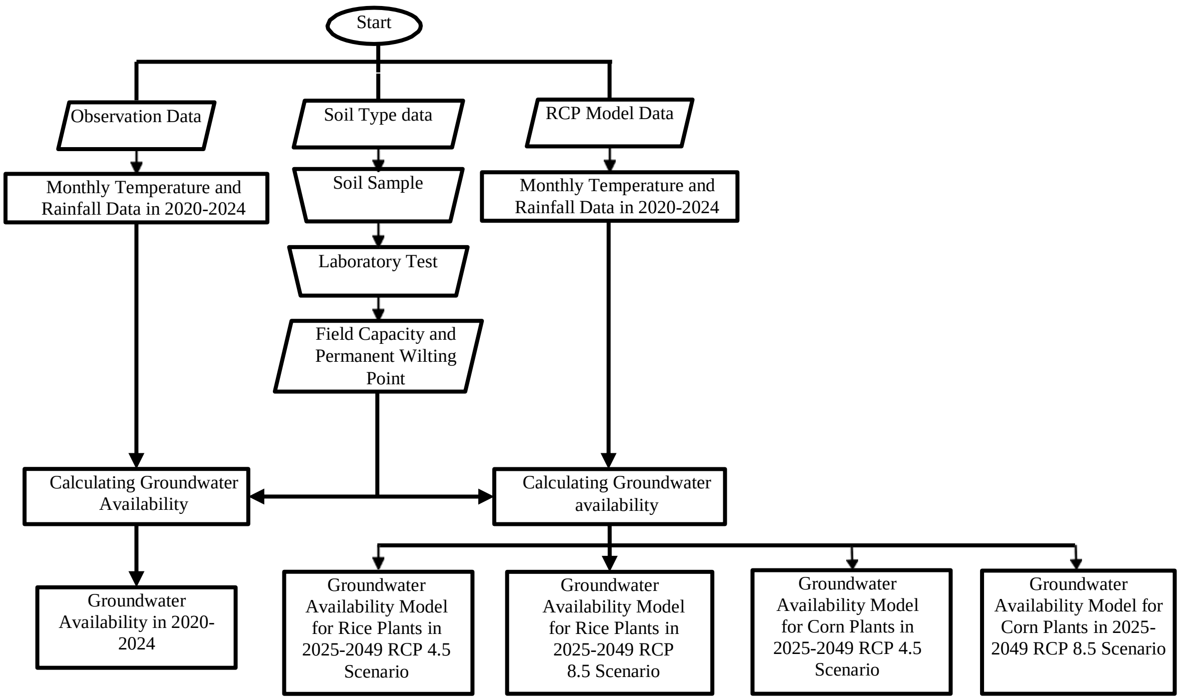

Figure 2. Research Flow Diagram

Secondary data, including rainfall, temperature, and coordinate points and elevation of rainfall measurement posts, are needed for calculating Groundwater Availability (KAT). These data were obtained from the Gorontalo Province Climatology Station. Additionally, rainfall and temperature model data for Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios are also required to analyze the Groundwater Availability estimation model from 2020 to 2049. These data were obtained from the BMKG Climate Change Information Center.

Representative Concentration Pathways (RCP) is a model of future climate elements that considers emission change scenarios, divided into four hypotheses: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. The four Representative Concentration Pathway (RCP) scenarios are numbers that indicate changes in radiation strength of +2.6, +4.5, +6.0, and +8.5 watts per square meter, respectively, until the year 2100. The middle-level scenario is a stable scenario, RCP 4.5, and the highest scenario, without mitigation efforts, is RCP 8.5 (Nazarenko et al., 2015).

Table 2. Location Point of BMKG Collaboration Rain Post Station in Pohuwato Regency

NO	Location	North Latitude (LU)	East Longitude (BT)	Elevation
1	Popayato	0.504	121,455	11 m
2	Lemito	0.547	121,573	14 m
3	Randangan	0.519742	121.812269	0 m
4	Marisa	0.468201	121.946585	6 m
5	Paguat	0.497	122,077	10 m
6	Taluditi	0.638505	121.851312	26 m
7	Wonggarasi	0.557	121,528	14 m
8	Dengilo	0.537420	122,091	40 m
9	Patilangio	0.51	121.86	0 m
10	East Popayato	0.52	121,487	16 m
11	West Popayato	0.484	121,361	7 m

Data Source: Gorontalo Climatology Station

Descriptive, comparative, regression, and correlation analysis techniques are used to analyze data from soil variables, namely Field Capacity and Permanent Wilting Point, and their relationship to the calculation of Groundwater Availability. The calculation of Groundwater Availability (KAT) utilizes a mathematical equation formulated by Thornthwaite and Mather (1957).

$$KAT = KL \times e^{APWL/KL}$$

Where:
KL = Field Capacity
APWL = Accumulated Potential Water Loss
e ≈ 2.71828

From the KAT results, the value of the Groundwater Availability (ATS) level can be found as follows:

$$ATS = \frac{KAT - TLP}{KL - TLP} \times 100\%$$

Information:
ATS = Groundwater availability
KAT = Soil Water Content
TLP = Permanent Wilting Point
KL = Field Capacity

The relationship between soil type and Groundwater Availability is then tested using correlation analysis. There are two types of correlation analysis: bivariate correlation and Partial Correlation. Bivariate Correlation is used to test the relationship between Field Capacity values and Permanent Wilting Point. Partial analysis is used to test the relationship between Field Capacity and permanent wilting point, controlling for the variable Groundwater Availability. The correlation value is in the range of 0 to 1. As the correlation value approaches 1, the interpretation of the relationship becomes stronger. The correlation value is approaching 0, indicating that the relationship between the variables is weakening (Roflin et al., 2022).

$$R = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \cdot \sum(Y_i - \bar{Y})^2}}$$

Information:
R = correlation value
X_i,Y_i = Variable Data
$\bar{X}$,$\bar{Y}$ = Mean of X and Y

The partial correlation formula between two independent variables (X, Y) while controlling Z is stated as follows:

$$R_{XY\cdot Z} = \frac{R_{XY} - R_{XZ} \cdot R_{YZ}}{\sqrt{(1 - R_{XY}^2)(1 - R_{YZ}^2)}}$$

Information:
R_{XY}= Pearson Correlation between X and Y
R_{XZ}= Pearson Correlation between X and Z
R_{YZ}= Pearson Correlation between Y and Z

3. Results and Discussion

3.1. Field Capacity Value

Field Capacity Testing in the Laboratory is carried out by repeated measurements three times on each sample. The Field Capacity value of each soil sample is determined based on the average of the three repeated measurements.

Table 3. Field Capacity of Soil Samples in Pohuwato Regency

No	Soil Type	Sample Name	Repeat 1 (mm)	Repeat 2 (mm)	Repeat 3 (mm)	Average (mm)
1	Alluvial	Marisa Rice	258	255	263	259 ± 2.40
2		Marisa Corn	233	228	228	230 ± 1.67
3	Andosol	Taluditi Rice	398	403	394	398 ± 2.60
4		Taluditi Corn	346	348	336	343 ± 3.76
5	Lithosol	Randangan Rice	358	345	340	348 ± 5.20
6		Randangan Corn	346	336	331	338 ± 4.64
7	Regosol	Dengilo Corn	238	238	231	236 ± 2.31

Source: Processed Data (2024)

The results of laboratory tests showed that the Field Capacity values of each soil sample had apparent differences. The highest value was found in the Taluditi Padi sample, which is an Andosol soil type, with an average of three repetitions at 398 mm. The lowest Field Capacity value was found in the Marisa Jagung sample, which is an Alluvial soil type, at 230 mm.

3.2. Permanent Wilting Point Value

Table 4 illustrates that the Permanent Wilting Point value of each soil sample has a clear difference.

Table 4. Permanent Wilting Point of Soil Samples in Pohuwato Regency.

No	Soil Type	Sample Name	Repeat 1 (mm)	Repeat 2 (mm)	Repeat 3 (mm)	Average (mm)
1	Alluvial	Marisa Rice	53	53	52	53 ± 0.33
2		Marisa Corn	23	23	24	23 ± 0.33
3	Andosol	Taluditi Rice	129	134	134	132 ± 1.67
4		Taluditi Corn	161	164	161	162 ± 1.00
5	Lithosol	Randangan Rice	100	103	102	102 ± 0.88
6		Randangan Corn	111	110	112	111 ± 0.58
7	Regosol	Dengilo Corn	47	42	48	46 ± 1.73

Source: Processed Data (2024)

The highest Permanent Wilting Point value is found in the Taluditi Corn sample taken from the Andosol soil type with an average of 162 mm. At the same time, the lowest Permanent Wilting Point value of 23 mm is found in the Marisa Corn sample with the Alluvial soil type.

3.3. Correlation Test of Soil Type and Climate Change on Groundwater Availability

The analysis of the relationship between soil type and Groundwater Availability (KAT) was first carried out by distributing the KAT value data based on soil type. The KAT values for rice and corn plants in RCP scenarios 4.5 and 8.5 show apparent differences, as presented in Figure 3.

The KAT trend, based on soil type, as shown in Figure 3, indicates that each soil type can produce different output values of Soil Water Availability for various plants. The first analysis was conducted by determining the correlation value between the Field Capacity variable and the Permanent Wilting Point.

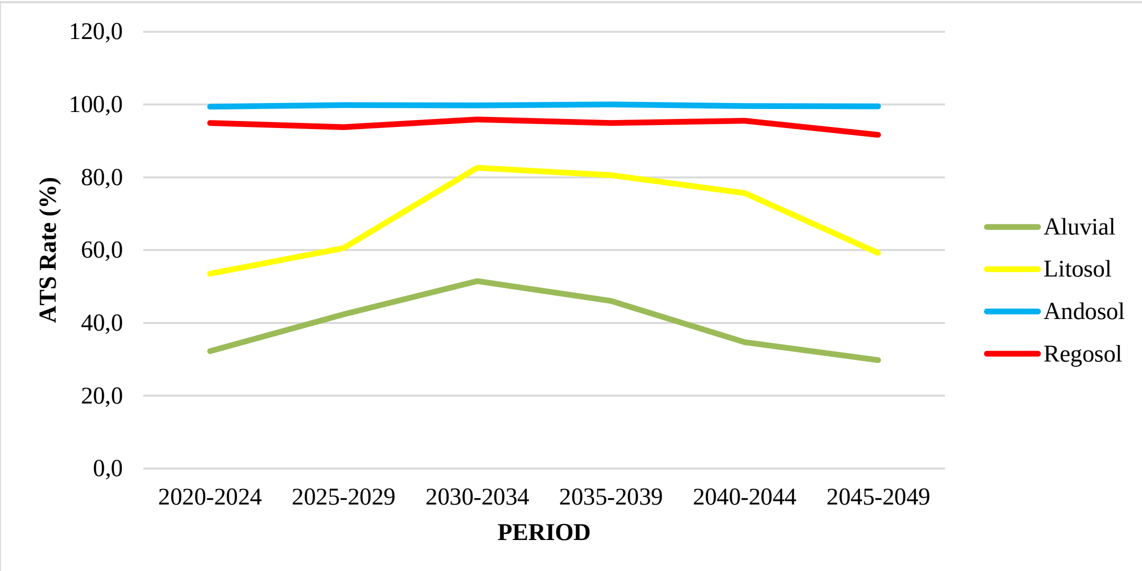

Figure 3. KAT Trend for Corn Plants in RCP 8.5 Scenario Based on Soil Type

The test results yielded a Pearson Correlation value of +0.9, indicating a firm and significant relationship between the Field Capacity value and the Permanent Wilting Point. The next test was conducted by calculating the correlation value between Field Capacity and the control variable KAT, as well as the correlation between Permanent Wilting Point and KAT. Each correlation value produced was -0.0123 and -0.124 for RCP 8.5. By obtaining the correlation value between these variables, the partial correlation value can be determined. The Partial Correlation value obtained was +0.909. This result indicates that the Field Capacity and Permanent Wilting Point variables significantly influence the results of the Groundwater Availability calculation. With the same calculation steps, the partial correlation value between Field Capacity and Permanent Wilting Point to KAT for the RCP 4.5 scenario was obtained with a value of +0.905. Thus, the average Partial Correlation value between Field Capacity and Permanent Wilting Point to KAT in both RCP 4.5 and 8.5 scenarios is +0.907.

3.4. Analysis of the Relationship between Soil Types and Groundwater Availability

According to laboratory test data, it is evident that Andosol and Litosol soil types have a higher average Field Capacity value than Alluvial and Regosol soil types. However, the high Field Capacity value in this study was also followed by a high Permanent Wilting Point in these soil types. Based on research data, the field capacity values of Andosol and Litosol soil types range from 331 mm to 403 mm. For alluvial and Regosol soil types, the range is 228 mm to 258 mm. The Permanent Wilting Point in Andosol and Litosol soil types is in the range of 100 mm to 164 mm. In contrast, the Permanent Wilting Point in Alluvial and Regosol soil types is in the range of 23 mm to 53 mm. Andosol soil is a type of volcanic soil with a high Organic carbon content (Sukarman et al., 2020). This type of soil also has a clay-to-sandy clay texture, resulting in relatively high porosity. Therefore, this type of soil also has a high-water retention capacity. However, it is also comparable to the difficulty for roots to absorb water in dry conditions. Consequently, the Permanent Wilting Point is also high, as this type of soil becomes oily when wet, exhibiting irreversible drying properties due to the formation of tight intermolecular bonds when dry. This situation makes it difficult for water and plant roots to penetrate the soil pores (Sukarman et al., 2020).

Meanwhile, Alluvial and Regosol soils are included in the Entisol order of mineral soil types, which originate from river deposition and coastal sedimentation activities, resulting in a predominantly sandy soil structure. Wijayanti and Aditya (2023) explained that the clay content and

C-organic material in Entisol-type soil are low, resulting in a low water-holding capacity. On the other hand, its high porosity provides plant roots with ample aeration space, maximizing their growth and reach and thereby enhancing the absorption of water and nutrients for plants. This result is what causes the Permanent Wilting Point in Alluvial and Regosol soil types to be lower.

4. Conclusion

The values of Field Capacity and Permanent Wilting Point for rice and corn plants on the types of soil found in Pohuwato Regency differ.

Differences in Field Capacity and Permanent Wilting Point values for rice and corn plants based on soil types in Pohuwato Regency affect the distribution model of the Groundwater Availability index in the Pohuwato Regency area for each period. The results of the study also showed a pattern of increasing groundwater availability for plants from 2030 to 2039, followed by a drastic decrease from 2040 to its peak in 2049.

Efforts to increase water supply can be implemented through dam infrastructure, water channels, and pumps, provided the water source remains sufficient. Meanwhile, if the water source is insufficient, measures that can be taken include preserving the upstream watershed, creating water reservoirs, or diverting river flows to areas that need them. Additionally, mitigation efforts can be implemented through agricultural techniques and land conservation, focusing on soil types. One approach that can be taken is to apply organic matter to the soil on soil types that are prone to drought and nutrient deficiency. Applying organic matter can increase fertility, enhance water retention capacity, and improve soil structure through the formation of soil aggregates. Another effective method is to use mulch drip irrigation, as it can reduce drought stress and significantly increase plant productivity.

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