Analysis of rainfall data to develop the classification criteria for identifying agro-climate resources on the field

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Abstract. The issue of climate change demands an update on the existing agro-climate map of Indonesia. For this purpose, in 2019 the Indonesian Agro-climate Resource Map was prepared. One of the stages of mapping is rainfall classification. This paper describes the analysis of rainfall to produce the classification used in the Indonesian Agro-climate Resource Map. The analysis used the monthly and annual rainfall data from 4087 stations with various observation lengths period between 1980-2010. The results of the analysis show that there is a proportional relationship between annual rainfall and the number of consecutive wet months ($R^2 = 0.776$), as well as an inversely proportional relationship between annual rainfall and the number of consecutive dry months ($R^2 = 0.64$), and between the number of consecutive dry months with the consecutive wet months ($R^2 = 0.72$). The results of the rainfall analysis divided the criteria for annual rainfall into 3 categories, namely wet (>2500 mm/year), moderate (1500-2500 mm/year) and dry, (<1500 mm/year); dividing the criteria for dry months into 3 categories, namely <3, 3-7, and >7 months; and dividing the criteria for the number of wet months into 4 categories, namely <3, 3-4, 5-9, >9 months. To improve the adaptation capacity of users and to assist quickly identification in the field, a Triangle Diagram is designed which can be used to identify the value of annual rainfall, the number of consecutive wet months, the number of consecutive dry months and the crop planting patterns.

1. Introduction
Among the characteristics of climate change is the change in rainfall over a certain period. Some researchers describe that there has been a trend of decreasing annual rainfall in several places. Hidayat, Pandiangan, and Pratiwi (2018) state that the intensity of annual rainfall in Serang has a negative trend with a reduction rate of 10.75 mm per year during the 1981-2017 period [1]. Susilokarti, Arif, Susanto, and Sutiarso (2015) described that there has been a decreasing trend of rainfall intensity of 1.60 mm/year in Subang Regency during the 1975-2012 period [2]. Runtunuwu and Syahbuddin (2007) also described that the changes in rain patterns that occurred during the 1879-2006 period had resulted in a decrease in the planting period both in wet years, normal years, and in dry years [3]. Apriyana et al. [4] also describes the changes in the inter-annual cropping calendar due to rainfall variability. The results of the above-mentioned research, as well as several other studies, reveal that climate change results in changes to existing climatic conditions in various regions in Indonesia, and results in a shift in climate classification proposed by several climatologists [5],[6],[7],[8].

There are several climate classification systems that are popular and widely used in the agricultural sector, including Koppen, Oldeman, Schmidt-Ferguson, or the Balitklimat agricultural climate resource atlas. Trewartha also made modifications to the Koppen classification system in the 1960s and 1980s [9],[10],[11],[12],[13],[14]. The Köppen climate classification divides the world's climates into five
major climate groups based on annual rainfall, precipitation for the driest month, and average temperature for the coldest month. The five major groups are tropical climates given the notation A, dry or desert climates given the notation B, cool or subtropical climates given the notation C, continental climates given the notation D, and polar climates given the notation E [9],[12]. Tropical climates are characterized by an average temperature of the coldest month greater than or equal to 18 °C. Then, Koppen divides tropical climate A into 3 subgroups, namely: wet tropical climate (Af) characterized by average rainfall in the driest month always more than 60 mm/month and generally occurs in areas with annual rainfall >2500 mm/year; The tropical monsoon climate (Am) is characterized by the occurrence of the driest month which generally occurs after the peak of winter with the intensity of the rainfall in the driest month less than 60 mm/month but greater than or equal to (100-0.04 annual rainfall); Then the climate of tropical savanna (Aw or As) is characterized by the driest month rainfall is lower than (100-0.04 annual rainfall) (Figure 1) [9],[10],[12].

Oldeman suggests an agro-climate map of Sumatra based on the distribution of monthly rainfall. The map is mainly used to see the potential for rice development in Sumatra. Oldeman uses the wet month criterion if the long-term average rainfall is greater than 200 mm per month, and the dry month criterion if the average is lower than 100 mm. Oldeman said that the potential for rice planting is a period that is not a dry month. Oldeman's classification of dry months is 0-1 months, 2-3 months, 4-6 months, and 7-12 months. The dry month classification results in the classification of potential planting periods of 11-12 months, 9-10 months, 6-8 months, and <6 months (Figure 5) [15],[16],[7].

Figure 1. Koppen climate classification [10].

Figure 2. Agro-climatic zone classification in Sumatra [15].
Rejekiningrum et al., (2003) designed a Climate Resource Atlas for Indonesian Agriculture in 2003. The atlas provides information on the distribution of regional rainfall patterns and recommended cropping patterns for food and horticultural crops [14]. The design of the climate resource atlas uses a compilation of 10-30 years of rainfall data from around 2,000 stations spread throughout Indonesia. The analysis uses the criteria for the amount of annual rainfall and rainfall patterns. Annual rainfall is grouped into six classes, namely <1,000 mm/year (I), 1,000-2,000 mm/year (II), 2,000-3,000 mm/year (III), 3,000-4,000 mm/year (IV), 4,000-5,000 mm/year (V), and >5,000 mm/year (VI). Rainfall patterns are classified into four main patterns, namely: Single pattern or simple wave with the lowest rainfall in July/August (A), Fluctuating pattern or multiple waves (B), Double pattern or double wave (C), and the simple wave with the highest rainfall in July/August (D).

The Balitklimat Team (2019) designed a 1: 500,000 Scale of Indonesian Agro-climate Resources Atlas. The preparation of the map is aimed at updating the map information and climate classification system, especially those related to its use in the agricultural sector. The novelty of this classification is the use of the latest data for the 1981-2010 period collected from 4,031 rainfall stations, as well as the novelty of spatial analysis using geostatistical methods through co-kriging interpolation techniques with altitude. The Agro-climate Resource Map provides 18 classifications of Agro-climate Types which are a combination of 3 classes of annual rainfall (wet, moderate, dry), 3 classes of consecutive dry months, and 4 classes of consecutive wet months [17],[18].

This paper aims to reveal the rainfall analysis process used to make classification criteria for the Indonesian Agro-climate Resource Map, as well as reveal the idea of designing a triangle diagram that can be used as a tool in identifying agro-climate resources in the field.

2. Methodology

2.1. Time and place of research
The research was a desk work that carried out in year 2019 at the Agro-climate and Hydrology Research Institute Laboratorium.

2.2. Data Collecting
The rainfall data is collected from 4087 weather stations throughout Indonesia with an observation period of 10-30 years. The distribution of the selected rainfall stations is presented in Figure 3.

Figure 3. The distribution of 4087 weather stations used in the analysis of the design of the Agro-climate Resource Map [18].
2.3. Analysis and interpretation of rainfall data for map classification reference

The analysis and interpretation of rainfall data includes the interpretation and classification of annual rainfall, the classification of the number of consecutive dry months, and the classification of the number of consecutive wet months. The technical analysis carried out includes a scatter plot of data, determination of trend lines, and data interpretation.

2.4. Design of triangular diagram tools for field observations

The agro-climate resource map can be used to identify the condition of agro-climate resources at an observation point in the field. However, there are practical aspects of its use for survey or field identification. So a triangle diagram is designed as a tool for identifying agro-climate resources that can be used in the field.

3. Results and Discussion

3.1. Analysis and classification of annual rainfall

Figure 4 presents a scatter plot between the amount of annual rainfall and rainfall intensity in the driest month, as well as showing the statistical relationship between the two parameters. The diagram in Figure 4 shows that 40.3% of the 4087 stations have the Af climate type according to the Koppen classification with the driest month rainfall \( > 60 \text{ mm/month} \) or an annual rainfall \( > 1500 \text{ mm/year} \). Otherwise, the remaining 59.7% have the Am or Aw / As climate type with the driest month rainfall \( < 60 \text{ mm/month} \) or an annual rainfall \( < 1500 \text{ mm/year} \).

Figure 4 also shows that the mathematical relationship between rainfall intensity in the driest month (\( y \)) and the amount of annual rainfall (\( x \)) is illustrated by the equation \( y = 0.0435x - 45.882 \) or \( x = 22.989y + 1054.759 \) with a value of \( R^2 = 0.3864 \) or \( r = 0.6216 \). Based on this mathematical equation, the driest month rainfall reaches a zero value in the annual rainfall of 1055 mm/year or around 1000 mm/year. The driest month rainfall of 60 mm/month occurs in annual rainfall of 2434 mm/year or about 2500 mm/year. This is in line with Koppen's classification that stations included in the Wet Tropic climate type are those with the driest month rainfall \( > 60 \text{ mm/month} \) or annual rainfall \( > 2500 \text{ mm/year} \) (Figure 4) [9], [10].

![Figure 4](image_url)

**Figure 4.** The relationship between the value of annual rainfall and rainfall intensity in the driest month in 4087 rainfall stations in Indonesia.

Several important things related to the Koppen classification, among others:
1. The wet tropical climate type has rainfall \( > 2,500 \text{ mm/year} \).
2. The desert climate type (very dry) has rainfall \( < 880 \text{ mm/year} \) and the steppe climate type (dry) generally has 880-1500 mm/year.
Based on this, the criteria for the classification of annual rainfall in the mapping of Indonesia’s Agro-climate Resources are as follows:

a) Wet climate type is an area that has an annual rainfall of >2,500 mm/year,
b) Moderate climate type is an area that has an annual rainfall of 1,500-2,500 mm/year, and
c) Dry climate type is an area that has an annual rainfall <1,500 mm/year.

3.2. The relationship between the number of consecutive dry months, the number of consecutive wet months, and the annual rainfall

Figure 5 presents (a) the scatter plot between the annual rainfall and the number of consecutive dry months and (b) the frequency of dry months in the Wet, Moderate, and Dry climate categories respectively. The criterion for a dry month is a month that has an average rainfall intensity of <100 mm/month. There is a negative exponential relationship between annual rainfall (x) and the number of consecutive dry months (y) through the equation y = 15,306 exp (0.0006x) with R² = 0.6404 or the value of r = 0.8002 (Figure 5-a), meaning that the lower the annual rainfall, the higher the number of dry months in a row. Figure 5-b reveals that the number of consecutive dry months in a Wet climate ranges from 0-6 months, with a high frequency ranging from 1-4 months. The number of consecutive dry months in Moderate regions ranges from 2-7 months, with a high frequency ranging from 4-6 months. The number of consecutive dry months in Dry climates ranges from 5-11 months, with a high frequency ranging from 6-8 months.

Figure 5. The relationship between annual rainfall and number of consecutive dry months; (a) scatter plot of data between annual rainfall and number of consecutive dry months, and (b) frequency of dry months in the wet, temperate, and dry climates, respectively.

Figure 6 presents (a) a scatter plot between the annual rainfall and the number of consecutive wet months and (b) the frequency of wet months in the Wet, Temperate, and Dry climates, respectively. The criteria for a wet month are months that have an average rainfall intensity of >200 mm/month. There is a positive logarithmic relationship between annual rainfall (x) and the number of consecutive wet months (y) through the equation y = 4.4573 ln (x) -29.433 with R² = 0.766 or the value of r = 0.8752 (Figure 6-a), meaning that the higher the amount of annual rainfall, the higher the number of wet months in a row. Figure 6-b reveals that the number of consecutive wet months in a Wet climate ranges from 5-10 months, with a high frequency ranging from 6-7 months. The number of consecutive wet months in Moderate regions ranges from 2-6 months, with a high frequency ranging from 4-5 months. The number of consecutive wet months in Dry climates ranges from 0-3 months, with a high frequency ranging from 2 months.
Figure 6. The relationship between annual rainfall and number of consecutive wet months; (a) a scatter plot between the annual rainfall and the number of consecutive wet months, and (b) the frequency of wet months in the Wet, Temperate and Dry climates, respectively.

Figure 7 presents a scatter plot between the number of consecutive wet months and the number of consecutive dry months. The mathematical relationship between wet months (BB) and dry months (BK) is negative or inversely proportional. The relationship between the two variables can be exponential through the equation $BK = 15.036 \exp(0.0006 \, BB)$ with $R^2 = 0.6404$ or $r = 0.8002$, or linear through the equation $BK = 8.3601 - 0.8416 \, BB$ with $R^2 = 0.723$ or $r = 0.850$. One unique thing that can be seen in Figure 8 includes (a) the highest number of BK and BB is generally around the value of 11, and (b) the smallest number of BK and BB is around 5 or 6. Rainfall data plotted in Figure 8 illustrates whereas apart from dry months and wet months, which number does not reach 12, there is always at least 1 humid month, that is, months that have an average rainfall intensity of 100-200 mm/month. There is no station that has a combination of BK and BB which both have low scores.

The results of the scatter plotting and equation analysis involving dry months and wet months did not simply the classification criteria for wet months and dry months, respectively. Then the determination of the criteria for the classification of dry months and wet months refers to the Oldeman classification [15]. Dry month (BK) classification criteria, namely: >7 month, 3-7 months, <3 months, respectively to describe the potential for 1, 2, and 3 times planting food crops. The classification criteria for wet months (BB), namely: >9 month, 5-9 month, 3-4 month, and <3 months, respectively to describe the potential for planting 3 times rice, 2 times rice, 1-time rice, or without rice.

Figure 7. The relationship between the number of consecutive wet months and the number of consecutive dry months.
3.3. The Map of Indonesian Agro-climate Resources

The Indonesian Agro-climate Resource Map is prepared in the form of an atlas with a scale of 1:500,000. The Indonesian Agro-climate Resource Map was prepared as an effort to deal with climate change which is characterized by shifting seasons, changes in rainfall patterns, and the increasing frequency of extreme climate events in a region. The map is expected to be a reference in identifying climatic conditions and the management of more recent potential commodities and cropping patterns for food crops in Indonesia.

Map of Indonesian Agro-climate Resources Scale 1: 500,000 (Figure 8) has information including (1) Map of Indonesian Rainfall Stations, (2) Map of Indonesian Annual Rainfall Class, (3) Map of Rainfall Pattern of Indonesia, (4) and Map of Indonesian Agro-climate Resources. The Map of Indonesian Agro-climate Resource provides information related to cropping indices, potential cropping patterns, and selection of commodity alternatives based on rainfall patterns, as well as altitude.

The novelties in the map of agro-climate resources include: (1) using more recent rainfall data (1981-2010) from 4031 rain stations that meet data quality control and replacement of blank data, (2) delineation using geostatistical analysis with the co-kriging method with altitude, (3) Providing information on cropping index (IP), cropping patterns, and alternative commodities based on altitude.

Figure 8. Map of Indonesian agro-climate resources scale 1: 500,000 [18].

The classification uses a combination of annual rainfall (mm / year), number of consecutive dry months (months), number of consecutive wet months (months), and altitude (meters above sea level). The criteria for wet months and dry months refer to the criteria used by Oldeman (Oldeman, Las, Darwis, 1979), where wet months are months that have a rainfall intensity greater than 200 mm/month and dry months are months that have rainfall intensity lower than 100 mm/month. The classification criteria for annual rainfall are A) <1,500 mm/year; B) 1,500-2,500 mm/year, and C) >2,500 mm/year. The criteria for the classification of consecutive dry months (BK) are I) BK >7 months, II) BK: 3-7 months, and III) BK <3 months. The criteria for the classification of consecutive wet months (BB) are 1) BB> 9 months, 2) BB 5-9 months, 3) BB 3-4 months, and 4) BB <3 months. The criteria for the classification of altitude are 1) 0 - 700 meters above sea level; 2) 700-1500 meters above sea level, 3) 1,500 - 2,500 meters above sea level, and 4) >2,500 meters above sea level. The process of overlapping precisely against these criteria results in a combination of 18 classes of Indonesian Agro-climate Resources, as presented in Table 1.
Table 1. The classification of agro-climate resources contained in the Atlas of Indonesian Agro-climate Resources at a scale of 1: 500,000.

| Agro-climate Type | Climate Type | Annual Rainfall (mm/year) | Amount of Dry Month (<100 mm/month) | Amount of Wet Month (>200 mm/month) | Potential of Cropping Index | Alternative of Cropping Pattern |
|-------------------|--------------|---------------------------|-------------------------------------|------------------------------------|-----------------------------|---------------------------------|
| A.I.1             | Wet          | A. >2500                  | III. <3                             | 1. >9                              | 3.0                         | Rice-rice-rice                  |
|                   |              |                           | II. 3-7                             | 2. 5-9                             |                             | Rice-rice-palavija              |
|                   |              |                           |                                    | 3. 3-4                             |                             | Rice-palavija-palavija          |
| A.II.2            |              |                           |                                    |                                    |                             |                                 |
| A.III.3           |              |                           |                                    |                                    |                             |                                 |
| A.IIII.2          |              |                           |                                    |                                    |                             |                                 |
| A.III.3           |              |                           |                                    |                                    |                             |                                 |
| B.I.2             | Moderate     | B. 1500-2500              | III. <3                             | 2. 5-9                             | 2.0                         | Rice-palavija-palavija          |
|                   |              |                           | II. 3-7                             | 3. 3-4                             |                             | Rice-palavija                   |
|                   |              |                           |                                    | 4. <3                              |                             | Palavija-palavija              |
| B.II.2            |              |                           |                                    |                                    |                             |                                 |
| B.III.4           |              |                           |                                    |                                    |                             |                                 |
| B.III.3           |              |                           |                                    |                                    |                             |                                 |
| B.III.4           |              |                           |                                    |                                    |                             |                                 |
| C.I.3             | Dry          | C. <1500                  | III. <3                             | 3. 3-4                             | 3.0                         | Rice-palavija-palavija          |
|                   |              |                           | II. 3-7                             | 3. 3-4                             |                             | Palavija-palavija              |
|                   |              |                           |                                    | 4. <3                              |                             | Palavija-palavija              |
| C.III.3           |              |                           |                                    |                                    |                             |                                 |
| C.III.4           |              |                           |                                    |                                    |                             |                                 |
| C.III.3           |              |                           |                                    |                                    |                             |                                 |

3.4. Preparation of triangular diagram tools for Indonesian Agro-climate Resources

The tool for identifying agro-climate resources in a location is a triangular diagram. The upper axis shows the number of consecutive dry months (months), the lower left axis shows the number of consecutive wet months (months), and the lower right axis shows the potential planting period (months). Each axis consists of the numbers 0 to 12 indicating the number of months. The numbers on the wet month axis are connected by a thin red line inside the triangle to the dry month axis. The dry month axis is connected by a thin red line inside the triangle to the potential planting season axis. Inside the triangle, there is a thick green line that defines the polygons of the agro-climate resource type. The name of the agro-climate resource type for each polygon is written in black letters. The inner triangle has a soft blue, yellow, and red background color whose polygon is bordered by a thin blue line. The blue color shows the areas that have a wet climate category with rainfall >2,500 mm/year, the yellow color shows the areas that have a moderate climate category with a rainfall of 1,500-2,500 mm/year, and the red color shows the areas that have a dry climate category with rainfall <1,500 mm/year. Between the yellow backgrounds bordered by the red or blue background color, there are polygons that are bordered by dotted lines and filled with shaded colors. The polygon is a transitional area that has several zones, namely the transition between wet and moderate climates and the transition between moderate and dry climates.

To use the diagram, it is necessary to value the number of wet months and the value of the number of consecutive dry months at a location as initial data. After using the diagram, information on the Type of Agro-climate Resources at that location and the climate category (wet, moderate, or dry) at that location will be generated, and then we can find out how long the potential planting period the area is.

How to use the diagram; look carefully at the triangle diagram of agro-climate resources in Figure 9, then follow the instructions as follows:

1. Plotting information on the number of wet months on the below-left axis, and information on the number of dry months on the upper axis.
2. From the axis of the number of wet months at below-right, a line is drawn to the axis of the number of dry months through the available thin red line.
3. From the axis of the number of dry months above, a line is drawn towards the axis of the potential for planting through the available thin red line.
4. The drawing of a line from the axis of the number of wet months and the axis of the number of dry months stops at the point where the two thin red lines meet. Then mark the point where the two lines meet.
5. The meeting point was observed to be located in the triangle with what background color. If it is located in blue, it means that the location is in the wet climate category, if it is yellow it means it is in the moderate climate category, and if it is red it means it is categorized as dry climate.
6. It was also observed, the meeting point included in the polygon of what type of agro-climate resource. It can be seen in the black text inside the polygon.
7. From the meeting point, a line is drawn to the axis of the potential planting period below the right until it meets one of the numbers on the bottom right axis. This figure represents the potential planting period of the location that is being identified.

![Triangular diagram of Indonesian agro-climate resources.](image)

**Figure 9.** Triangular diagram of Indonesian agro-climate resources.

4. **Conclusion**

The issue of climate change, which is characterized by a decreasing trend in rainfall, changes in rainfall patterns, is a consideration for the need to update the map of Indonesia's agro-climate resources. This paper describes the analysis and interpretation of rainfall in determining the classification criteria for the type of agro-climate resources. The data used in the analysis came from 4087 rainfall recording stations throughout Indonesia with an observation length of 30 years during the 1981-2010 period. The results of the analysis illustrate that there is a mathematical relationship between annual rainfall and the amount of rainfall in the driest month. This relationship shows that the driest month of rainfall of 60 mm/month occurs at an annual rainfall of 2434 mm/year or about 2500 mm/year.

The following parameter classifications are carried out from the analysis of rainfall data: classification of annual rainfall using the wet climate category with rainfall at an intensity of > 2500 mm/year (A), moderate climate category between 1500-2500 mm/year (B), and dry climate category at an intensity <1500 mm/year (C). The classification of the number of dry months is divided into 3 categories, namely (I) >7 months, (II) 3-7 months, and (III) <3 months. The classification of the number of consecutive wet months is divided into 4 categories, namely (1) >9 months, (2) 5-9 months, (3) 3-4
months, and (4) <3 months. To improve the adaptation capacity of users and to assist quickly identification in the field, a Triangle Diagram was also designed which can be used to identify the value of annual rainfall, the number of consecutive wet months, the number of consecutive dry months, the type of Sumberdaya Agroklimat Indonesia, and the crop planting pattern.

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