The impact of climate change on land suitability and cocoa productivity in Tulakan District, Pacitan Regency

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Abstract. The existence of global warming, directly or indirectly, will have an impact on climate change which will threaten the productivity of cocoa plantations. This study aims to (1) determine the correlation between rainfall, relative humidity, and temperature to cocoa productivity and (2) determine the correlation between land suitability and cocoa productivity in Tulakan District, Pacitan Regency. The method used in this research was a descriptive exploratory method with a purposive sampling technique of collecting soil samples on land map units that have been determined based on various map overlays. There are five land map units (LMU) with a total area of 2.624 Ha with each LMU repeated three times. Regression correlation analysis was conducted to determine the relationship between rainfall and relative humidity on land suitability and cocoa productivity. The analysis showed that there was a negative correlation between rainfall and cocoa productivity ($r = -0.892$, $p < 0.05$), as well as relative humidity and cocoa productivity ($r = -0.950$, $p < 0.05$). There was a positive correlation between land suitability and cocoa productivity ($r = 0.895$, $p < 0.05$). Land map unit 1,2,3 were the best class of land suitability with the lowest limiting factor (relative humidity and available P), and it has high cocoa productivity. The higher rainfall and relative humidity will affect the lower cocoa productivity.

1. Introduction
Cocoa is one of the mainstay plantation commodities in Indonesia which has an important role in the national economy [1]. Cocoa is currently the third-largest source of non-oil and gas foreign exchange after rubber and oil palm [2]. The type of land use as determined by land capability class in Pacitan Regency is forest (93,649.10 Ha) and agroforestry (1,909.35 Ha) [3]. The Department of Agriculture of Pacitan recently started to intensify cocoa cultivation, especially in Tulakan District. Based on [4], Tulakan is dominated by dry soil types, which is around 14,422.89 Ha of the total area, where this type of soil is suitable for plantation crops, especially cocoa, cloves and coconut. In the field of cocoa plantations, Tulakan District is an area that has the largest cocoa plantation area in Pacitan Regency and has the largest amount of cocoa production among other districts.

Climate is one of the environmental components that determine the success of plant cultivation, including cocoa cultivation. The effects of climate change on agriculture result in increased crop damage due to extreme heat, problems in agricultural planning arise due to unreliable forecasts (uncertainty), increased moisture pressure, increased soil erosion, changed annual rainfall [5], and flooding. Changes in rainfall and seasonal temperatures can also change the growing season, planting calendar and harvest.

In addition, the availability of water for irrigation and drinking water is less predictable because rainfall is more varied [6]. Previous research explained that rainfall is one of the main factors that trigger...
soil erosion. Soil erosion causes soil damage which will have an impact on decreasing soil quality and crop productivity [7]. Various studies explain that climate has an impact on agricultural productivity. This is the same as the opinion [8] which explains that decreased water availability during growth and water pressure can play a role in reducing agricultural productivity. Fluctuating rainfall patterns will affect cocoa productivity. The amount of rainfall will affect the production of a plant [9]. According to [10], drought can reduce cocoa production yields, while too heavy and excessive rainfall will encourage flower decline and increase pest and disease infections in cocoa. Based on [3], Pacitan Regency had drought potential with high and very high-level risk, the level of potential of drought will increase by 2030.

Climate elements in the form of rainfall, temperature and relative humidity are important in plant cultivation because they are one of the parameters in determining the level of land suitability, namely as a condition for growing a plant. The level of land suitability affects the productivity of a plant. The selection of suitable land to achieve optimal productivity can be done well if it is carried out through the land evaluation stage by developing land requirements [11]. Based on the description above, the purpose of this study was to (1) determine the correlation between rainfall, relative humidity, and temperature to cocoa productivity and (2) determine the correlation between land suitability and cocoa productivity in Tulakan District, Pacitan Regency.

2. Materials and methods

2.1. Study area

This research was conducted in five locations (land map unit); Wonanti, Jatigunung, Tulakan, Bungur and Ngumbul Sub District, Tulakan District, Pacitan Regency, East Java Province. The research was conducted from October 2020 - January 2021. The characteristics of each land unit can be seen in Table 1. The soil type of the all land map unit is Typic Dystrudept, which had B horizon (cambg endopedon) which a horizon that is starting to develop, indicated more stabl [12].

| LMU | Soil Type     | Location     | Ordinat                  | Slope (%) | Elevation (mdpl) | Land Use |
|-----|---------------|--------------|--------------------------|-----------|------------------|----------|
| 1   | Typic Dystrudept | Wonanti     | 111°12'35,475"E 8°11'9,385"S | 3 - 8%    | 490              | Moorland |
| 2   | Typic Dystrudept | Jatigunung  | 111°15'11,944"E 8°9'25,329"S | 8 - 15%   | 382              | Agroforestry |
| 3   | Typic Dystrudept | Tulakan     | 111°17'46,611"E 8°42'7,46"S | 3 - 8%    | 479              | Agroforestry |
| 4   | Typic Dystrudept | Bungur      | 111°17'49,54"E 8°9'10,677"S | 8 - 15%   | 493              | Agroforestry |
| 5   | Typic Dystrudept | Ngumbul     | 111°18'19,956"E 8°355,741"S | 8 - 15%   | 623              | Agroforestry |

2.2. Data

The method used in this research is a descriptive exploratory method with a purposive sampling technique of taking soil samples on land map units that have been determined based on various map overlays. There are five land map units (LMU) with a total area of 2,594,411 hectares with each land map unit repeated three times. Primary data in the form of soil fertility data were obtained from survey results and laboratory analysis. The data obtained were then interpreted based on the concept of land evaluation with matching with the growing requirements for cocoa. The determination of land suitability class is based on limiting factors. The land suitability level classification is S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable). Meanwhile, secondary data on
climate in the form of rainfall, temperature, relative humidity (2013-2017) were obtained from the powernasa application [13], while secondary data on cocoa production and cocoa planting area were obtained from [14].

2.3. Method
Regression and correlation analysis is used to measure the relationship between two or more variables. In this study, the variables analyzed for correlation and regression were rainfall, temperature, humidity and land suitability (independent factors) on productivity (dependent factors). Linear regression uses simple linear regression with the function: \( Y = a + bX + e \). In the \( r \) test, testing the hypothesis: \( H_0: r = 0 \) (meaning that there is no relationship or correlation between variable \( X \) and variable \( Y \)). \( H_1: r \neq 0 \) (meaning that there is a relationship or correlation between variable \( X \) and variable \( Y \)).

3. Results and discussion

3.1. Climate characteristics in the research area
The climate in agriculture is one of the ecosystem components and production factors that are very dynamic and difficult to control. Climate includes rainfall, temperature and relative humidity, which is often a limiting factor in agricultural production due to its diverse and open nature. The influence of climate in agriculture needs to be considered in the process of evaluating land suitability. Based on secondary data obtained (2013-2017), Tulakan District has two seasons, namely the rainy season which occurs from October to June with an average rainfall of 1678.94-2716.09 mm/year, while the dry season occurs from July until September.

The determination of climate classification in Tulakan District using the Schmidt-Ferguson classification. The average monthly rainfall in Tulakan District ranges from 114.304 - 412.884 mm/month with 7 wet months and 3 dry months. Based on the Schmidt-Ferguson classification, Tulakan District had a C category with a slightly wet climate indicated by a value of \( Q = 42.85\% \) which is in the interval 33.3 - 60.0. The average rainfall in Tulakan District (2013-2017) is 1678.94-2716.09 mm/year (Table 1). This is in line with the growing requirements for cocoa, which is included in the appropriate criteria so that it is very suitable for cocoa plants.

| Year | Rainfall (mm/year) | Relative Humidity (%) | Temperature (°C) |
|------|--------------------|-----------------------|------------------|
| 2013 | 1706.19            | 80.83                 | 25.48            |
| 2014 | 2376.62            | 82.64                 | 25.82            |
| 2015 | 2045.64            | 81.14                 | 25.92            |
| 2016 | 1678.94            | 80.47                 | 25.70            |
| 2017 | 2716.09            | 83.78                 | 26.51            |

Source: [12].

The average temperature and relative humidity in Tulakan District (2013-2017) varied from 25.48 - 26.51°C and 80.47 - 83.78% (Table 2). Based on growing requirements for cocoa, the average temperature is a highly suitable category (S1), while the relative humidity is a marginally suitable category (S3) [15]. The excessive relative humidity can increase pest and disease attacks on cocoa, while too high a temperature can inhibit shoot growth and produce small leaves (2). Criteria for land suitability class for cocoa can be seen in Table 3.
Table 3. Criteria for cocoa land suitability class.

| Parameter          | Highly Suitable (S1) | Moderately Suitable (S2) | Marginally Suitable (S3) | Not Suitable (N) |
|--------------------|----------------------|--------------------------|--------------------------|------------------|
| Rainfall (mm/year) | 1,500 – 2,500        | 2,500 – 3,000            | 1,250 – 1,500            | < 1,250          |
|                    |                      |                          | 3,000 – 4,000            | > 4,000          |
| Average Temperature (°C) | 25 – 28            | 20 – 25                  | 32 – 35                  | < 20             |
|                    |                      |                          | 28 – 32                  | > 35             |
| Relative Humidity (%) | 40 – 65             | 65 – 75                  | 75 – 85                  | > 85             |
|                    |                      |                          | 35 – 40                  | < 30             |

Source: [14].

3.2. Cocoa productivity

Cocoa is one of the leading plants cultivated in Tulakan District, Pacitan Regency. Cocoa cultivation in Tulakan District is carried out with low input management by optimizing the local natural resources. Cocoa productivity was influenced by environmental aspects and cultivation techniques. Cultivation techniques determine plant growth and production, including the quality of cocoa beans. Soil, climate, pests, diseases, plant genetic potential are also the main factors that regulate land productivity which can be measured from yields/plant biomass [16].

![Figure 1. Cocoa productivity in Tulakan District.](image)

Based on BPS data (2013 - 2017), the level of cocoa productivity fluctuates from year to year, which tends to decline (Figure 1). The highest cocoa productivity was found in 2015, then in 2016 decreased slightly until 2017, it can be seen that cocoa productivity began to experience a drastic decline.

3.3. The analysis correlation between rainfall and cocoa productivity

Analysis correlation showed that there was a significant negative correlation between rainfall and cocoa productivity (r = -0.892, p <0.05) (Figure 2). Analysis regression between the independent variable (rainfall) and the dependent variable (cocoa productivity) showed that the R square value was 0.7948, which means that rainfall has an effect of 79.48% on cocoa productivity while the remaining 20.52% is influenced by other variables.
Increased rainfall will increase soil loss which causes soil damage [17], [18], [7]. Damaged soil will lose a lot of nutrients and organic matter, causing land productivity to decrease [19]. In a study [6] it was explained that an increase in rainfall would cause a decrease of 0.0065 tons of cocoa. Previous research [20] also explained that high rainfall can harm several metabolic processes that contribute to pod development. Cocoa is a crop that is susceptible to excessive rainfall and drought [21]. According [22], explained that the direct impact of climate change on productivity was drought (low water availability in the soil), which can reduce cocoa production and can even kill many cocoa trees. Drought has also been associated with an increase in disease infections in cocoa including fungal diseases which are the main cause of the loss of 30% of cocoa yields worldwide [23].

3.4. The analysis correlation between relative humidity and cocoa productivity

Correlation analysis showed a significant negative correlation between relative humidity and cocoa productivity \( r = -0.950, p < 0.05 \) (Figure 3), meaning that if the relative humidity is too high, cocoa productivity will decrease. Based on regression analysis with relative humidity as the independent variable and cocoa productivity as the dependent variable, it shows an \( R^2 \) square value of 0.9023, which means relative humidity affects cocoa productivity by 90.23% while 9.77% is influenced by other variables. Increased relative humidity, run-off and erosion can damage cocoa trees if soil conditions are not able to inhibit their negative effects [22].
Increased relative humidity, runoff, and erosion can damage cocoa trees if soil conditions are not able to inhibit the negative effects [22]. A study [20] explained that increasing relative humidity in cocoa cultivation can reduce yields because high humidity can increase the incidence of fruit rot disease in cocoa. The relative humidity is related to rainfall. According to [24], rainfall has been reported to be beneficial for yields in the early stages of pod development but becomes less influential in later stages and can even have a negative effect when the pods reach maturity, as humid conditions can lead to increased disease incidence. This is in line with [25] which explains that high humidity will clog the development of beans so that the quality of cocoa beans decreases.

3.5. The analysis correlation between temperature and cocoa productivity
The correlation analysis between temperature and cocoa productivity showed uncorrelated \(r = -0.845, p> 0.05\) (Figure 4). Although, temperature and cocoa productivity is not significant, it cannot be ignored because temperature plays a vital role and a well-known role in evapotranspiration and water demand. Previous studies showed that an increase in temperature causes a decrease in cocoa production [23].

![Figure 4. Correlation between temperature and cocoa productivity.](image)

Cocoa as a tropical plant can be planted optimally at temperatures of 20 – 32°C. This is by [26], which states that cocoa can grow well at temperatures varying from 30 – 32°C with a maximum average and a minimum average of 18 – 21°C and an absolute minimum of 10°C. Temperatures below 10°C will inhibit the rate of photosynthesis. According to [27], the ideal outdoor temperature range for transportation should be between 15°C and 25°C. Leaf temperature affects the resistance of the stomata, decreasing the resistance as the temperature increases. A decrease in temperature below the lower limit causes condensation, while an increase in temperature can cause fermentation [25].

3.6. The analysis correlation between land suitability and cocoa productivity
Land suitability class for cocoa was obtained through survey results and analysis of each LMU. The sampling points used in the classification of land suitability were taken from 5 areas and repeated three times. The actual land suitability map can be seen in Figure 5. While the results of the actual land suitability classification can be seen in Table 4.

Land map unit 1, 2, 3 have the same class land suitability, marginally suitable (S3) with the limiting factors are relative humidity and available phosphor. The class of land suitability land map unit 4 is marginally suitable (S3) with the limiting factors are relative humidity, pH, available P, and available K. But for land map unit 5, the limiting factors are relative humidity, base saturation, pH, organic C, available P and available K. Land map unit 1,2,3 were the best class of land suitability with the lowest limiting factor.
Table 4. Actual land suitability class for cocoa in Tulakan District.

| LMU | Land Suitability | Limitation Factors | Area (Ha) |
|-----|------------------|--------------------|-----------|
| 1   | S3- wa,na        | Relative humidity, Available P | 439.8     |
| 2   | S3- wa,na        | Relative humidity, Available P | 650.4     |
| 3   | S3- wa,na        | Relative humidity, Available P | 211.3     |
| 4   | S3- wa,na        | Relative humidity, pH, Available P, Available K | 853.8     |
| 5   | S3- wa,na        | Relative humidity, Base saturation, pH, organic C, Available P, Available K | 468.7     |
|     | **TOTAL**        |                    | **2,624** |

Figure 5. Map of actual land suitability for cocoa in Tulakan District.

The correlation between the land suitability and cocoa productivity had a significant positive correlation ($r = 0.895$, $p < 0.05$) (Figure 6), meaning that the land unit with the best land suitability class with the lowest limiting factor had high cocoa productivity. The low of limiting factors will have the high of land suitability class [28]. Based on the results of regression analysis with the land suitability of cocoa as the independent variable and cocoa productivity as the dependent variable, it shows an $R^2$ square of 0.8008, which means that the land suitability level of cocoa affects cocoa productivity by 80.08% while the remaining 19.92% is influenced by other variables.

The main obstacle in cocoa development is low productivity, due to land selection that does not consider soil and climatic conditions suitable for cocoa growth. The importance of evaluating land suitability in land use planning is that land can be used optimally, productively and sustainably based on its potential [29]. The evaluation of land suitability of cocoa is prepared by considering the conditions for growing cocoa and according to its production potential. According to [30], land suitability evaluation is needed to overcome constraints on land to increase productivity. The lower the limiting factors, the more appropriate the class of land suitability.
4. Conclusion
Climate change had a significant effect on cocoa productivity. There was a negative correlation between rainfall and cocoa productivity as well as relative humidity and cocoa productivity. Meanwhile, temperature and cocoa productivity are not correlated. There was a positive correlation between land suitability and cocoa productivity. Land map unit 1,2,3 were the best class of land suitability with the lowest limiting factor (relative humidity and available P), and it has high cocoa productivity. The higher rainfall and relative humidity will affect the lower cocoa productivity.

References
[1] Fahmid I M, Harun H, Fahmid M M, Saadah, Busthanul N 2018 IOP Conf. Ser Earth Environ. Sci. 157(1)
[2] Karim H A, Asrul L, S. B, Padjung R, Neswati R 2020 J Agric Appl Biol. 1(1) 30–7
[3] Nita I, Putra A N, Febrianingtyas A 2020 Sains Tanah J Soil Sci Agroclimatol. 17(1) 7–15
[4] BPS. 2018 Kecamatan Tulakan dalam Angka 3 54–67
[5] Herawati A, Mugiyo, Widijanto H, Isnaini, Romdhati F 2018 IOP Conf. Ser. Earth Environ. Sci. 200(1)
[6] Lawal J O, Omonona B T 2014 Comun Sci. 5(4):518–23
[7] Herawati A, Suntoro, Widijanto H, Pusponegoro I, Sutopo NR, Mugiyo 2018 IOP Conf Ser Earth Environ Sci. 129 (1)
[8] Schlenker W, Lobell D B 2010 Environ Res Lett. 5(1)
[9] Anwar M R, Liu D L, Farquharson R, Macadam I, Abadi A, Finlayson J, et al. 2015 Agric Syst 44 132-133
[10] Carr M K V, Lockwood G 2011 The water relations and irrigation requirements of cocoa (Theobroma cacao L.): A review Exp Agric. 47(4) 653–76
[11] Bassil Y 2015 Int J Innov Res Comput Commun Eng. 3(5) 3823–30
[12] Mugiyo M, Widijanto H, Herawati A, Rochman F, Rafirman R 2018 Potensi Lahan Untuk Budidaya Pisang Di Kecamatan Jenawi Karanganyar Caraka Tani J Sustain Agric. 32(2) 142
[13] NASA P 2021 Power data acces viewer [Online] Available: https://power.larc.nasa.gov/data-access-viewer/
[14] Bappeda J 2020 Kabupaten Pacitan Dalam Angka. 1st ed. BPS (Pacitan: BPS Kabupaten Pacitan) 303
[15] Ritung S, Nugroho K, Mulyani A, Suryani E 2011 Petunjuk Teknis Evaluasi Lahan untuk Komoditas Pertanian (Edisi Revisi). Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian p.171

Figure 6. Correlation between land suitability and cocoa productivity.
[16] Pusponegoro I H, Mujiyo S, Herawati A, Widijanto H 2018 *J Degrad Min L Manag*. 5(54) 2502–48

[17] Ziadata F, Bunning S, De Pauw E 2017 *Land resource planning for sustainable land management*. p. 1–68

[18] Ziadat F M, Taimeh A Y 2013 *L Degrad Dev*. 24(6) 582–90

[19] Mujiyo M, Setiawan Y Y, Herawati A, Widijanto H 2021 *J Degrad Min L Manag*. 8(2)2559–68

[20] Lawal J O, Emaku L A. 2007 *African Crop Sci Conf Proc*. May 2007 8 423–6

[21] Santosa E, Sakti G P, Fattah M Z, Zaman S, Wahjar A 2018 *J Trop Crop Sci*. 5(1) 6–17

[22] Gateau-Rey L, Tanner E V J, Rapidel B, Marelli J P, Royaert S 2018 *PLoS One*. 13(7) 1–17

[23] Crowder D W, Harwood J D 2014 *Biol Control*. 75 1–7

[24] Lahive F, Hadley P, Daymond A J 2019 *Agron Sustain Dev*. 39(1) 1–22

[25] Uygun Y, Jafari S A I 2020 *Cogent Bus Manag*. 7(1)

[26] Anim-Kwapong G J, Frimpong E B 2004 *Cocoa Res Inst Ghana*. 2 1–30

[27] Gesamtverband der Deutschen e. V 2018 Transport information service - Cocoa/Cocoa beans [Online] Available: https://www.tis-gdv.de/tis_e/ware/genuss/kakao/kakao.htm/

[28] Suntoro S, Mujiyo M, Widijanto H, Herdiansyah G 2020 *J Settlements Spat Plan*. 11(1) 9–16

[29] Zhang B, Zhang Y, Chen D, White R E, Li Y 2004 *Geoderma*. 123(3–4) 319–31

[30] Suheri N A, Mujiyo M, Widijanto H 2018 *SAINS TANAH* - *J Soil Sci Agroclimatol*. 15(1) 46

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