Spatial analysis for land suitability of Arabica coffee (*Coffea arabica* L.) in Bogor District

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**Abstract.** Arabica coffee requires land suitability criteria to support its growth and productivity. If an area has infertile soil conditions and has a climate that is not in accordance with the criteria for growing Arabica coffee, then several alternative solutions are needed to determine the suitability of land in that area. Insufficient knowledge about suitable land can contribute to inefficient land use. Information on land suitability for Arabica coffee in Bogor district is not yet available. This study aimed to analyse the spatial distribution of potential land to develop of Arabica coffee commodities in Bogor. Hence, spatial analysis of land suitability was carried out by utilizing the capabilities of the Geographic Information System used an overlay based on Digital Elevation Model (DEM), agroclimatic variables, physical (adequate depth, soil texture), soil chemical properties (pH, base saturation, cation exchange capacity/CEC and land use information. The proportion of land suitability for Arabica coffee was classified into suitable, marginally suitable, and not suitable consisted of 398.68 ha, 32,209.4 ha, and 266,617 ha of which area size. The potential land for Arabica coffee showed that there was 126 ha for S2 suitability class, 18,681.00 ha for S3 suitability class, and 280,418.58 ha for the non-potential land.

**Keywords:** GIS, land use, overlay, suitable.

1. **Introduction**

*Coffea arabica* L. and *Coffea canephora* Pierre ex A. Froehner are the two major coffee species that play an important economic value in the world. Arabica produces around 60% of the world’s coffee production. Compared with Robusta coffee, Arabica coffee grows at higher altitudes with lower yields. Arabica also has lower resistance to weather shocks, pests, and diseases than Robusta. Even though there is a considerable variation, Arabica coffee is twice as expensive as Robusta. Arabica coffee quality is measured through an exercise called cupping and is the most critical determinant of Arabica coffee prices in high-value markets [1]. Arabica beans tend to have a sweeter, softer taste, with flavors of sugar, fruit, chocolate, and berries. Arabica coffee contains more lipids and sugars. It also has higher (sometimes wine-like) acidity than Robusta. As one of the coffee producers, Indonesia is known as the world’s five largest exporters of coffee. The average national coffee consumption was 370,000 tons, with 8.22% of the growth rate per year. It shows that Indonesia has good prospects in the development of coffee products [2]. However, farmers face several problems, particularly for smallholder farmers which dominate the number of coffee plantations.
Bogor district is one of the Arabica coffee-producing areas in West Java Province, Indonesia. The area of coffee plantations continued to increase to 6,407.70 ha in 2019. Currently, the area of Arabica coffee reaches 584 ha, with produce 155,993 kg of coffee beans. Areas of Arabica coffee are located in Sukamakmur, Cisarua, Megamendung, Pamijahan and Babakan Madang sub-districts [3]. Arabica coffee requires land suitability criteria to support its growth and productivity. Insufficient knowledge about suitable land can contribute to inefficient land use [4]. The expansion of coffee plantation land is one of the main components in the revitalization of plantations and development of Bogor coffee commodities by the Government. Based on data, the land use for coffee plantations is still deficient. Hence, to optimize the potential of Arabica coffee, the analysis is required to determine the level of regional suitability by utilizing the geographic information system. It will help in analyzing and defining the suitability of land and spatial distribution of potential land for the development of coffee commodities in Bogor district. This study aimed to analyze the spatial distribution of potential land to develop Arabica coffee commodities in Bogor.

2. Materials and Method

The research was held from July to November 2020 at Bogor, West Java. Bogor is located at the coordinate point 6° 18'NL dan – 6° 47' SL and 106° 01′− 107°103’ EL (Figure 1). Mainly the city lies on the highlands, hills, and mountains with the constituent rocks dominated by volcanic eruptions consisting of andesite, tuff, and basalt. Soil type is dominated by volcanic material, including latosols, alluvial, regosols, podsolic, and andosols.

![Figure 1. The administrative map of Bogor District](image)

This research was conducted by spatial analysis of the land suitability of Arabica coffee in Bogor. It was based on the Digital Elevation Model (DEM), agroclimatic variables, soil maps, physical, chemical properties of the soil, and land use by utilizing GIS. GIS techniques can be a powerful tool for assessing the suitability of agricultural land. The analysis was carried out using the analytical tools available in the GIS. The input data was processed using an interpolation and classification process based on the land suitability criteria of each parameter.

Data or parameters were collected into a single data unit through an overlay process by combining data using union tools. These data were used as the basis for determining land suitability through a comparison method (matching) with the conditions criteria for growing Arabica coffee (Table 1) [5]. Overlays are maps of various themes that can be overlapped to produce new mapping units with new information [6]. Merging data was done to facilitate the subsequent analysis process. The technological approach by utilizing GIS makes it easy to process input, merge, and analyze spatial data. The technological approach defines GIS as a set of tools for input, storage and retrieval, manipulation, analysis, and output of spatial data. The flow chart of land suitability analysis is shown in Figure 2.
Table 1. Land suitability class for Arabica coffee.

| Land characteristics | Very suitable (S1) | Suitable (S2) | Marginal suitable (S3) | Not Suitable (N) |
|----------------------|-------------------|--------------|------------------------|-----------------|
| Climate              |                   |              |                        |                 |
| Rainfall (mm)        | 1,500-2,000       | 2,000-2,500  | 2,000-3,000            | <1,000, >3,000  |
| Dry month (<60 mm/month) | 2-3              | 3-4         | 4-5, 1-2               | <1, >5          |
| Altitude (m above sea level) | 1,000-1,500     | 1,500-1,750 | 1,750-2,000           | >2,000          |
| Slope (%)            | 0-8               | 8-25        | 25-45                  | >45             |
| Soil Physical properties |                |              |                        |                 |
| Adequate depth (cm)  | >150              | 100-150      | 60-100                 | <60             |
| Soil texture         | sandy loam        | loamy sandy  | clay                   | sand            |
| Drainage             | Well-drained      | moderately   | well drained           | somewhat poorly drained, somewhat excessively drained |
| Soil Chemical properties |            |              |                        |                 |
| pH                   | 5.5-6.0           | 6.1-7.0      | 7.1-8.0                | >8              |
| CEC (me/100 g)       | >15               | 10-15        | 5-10                   | <5              |
| Base Saturation (%)  | >35               | 20-35        | <20                    |                 |

(Source: Direktorat Jenderal Perkebunan 2012)

Figure 2. Research flowchart.
3. Results and discussion

Rainfall maps are obtained from the average rainfall data that occurred in each station climatology sub-district in the Bogor district. Rainfall and dry months data in the study area were based on agroclimatic variables required for Arabica growing. It was interpolated to produce a spatial distribution of rainfall as given in Table 2.

| No | Station          | Rainfall (mm/year) | Length of (Months) |
|----|-----------------|--------------------|--------------------|
|    |                 | Wet    | Dry    | Wet    | Dry    |
| 1  | Naringgul       | 2,364  | 8      | 4      |        |
| 2  | Gunung mas      | 2,430  | 6      | 6      |        |
| 3  | Citeko          | 2,460  | 8      | 4      |        |
| 4  | Gadog           | 2,948  | 9      | 3      |        |
| 5  | Ciawi           | 3,020  | 8      | 4      |        |
| 6  | Katulampa       | 3,143  | 9      | 3      |        |
| 7  | Kebun raya      | 3,661  | 11     | 1      |        |
| 8  | Empang          | 3,451  | 11     | 1      |        |
| 9  | Cibalagung      | 3,553  | 11     | 1      |        |
| 10 | Staklim bogor   | 3,568  | 11     | 1      |        |
| 11 | Cimanggu        | 3,706  | 11     | 1      |        |
| 12 | Ciriung         | 3,914  | 10     | 2      |        |
| 13 | Depok           | 2,484  | 7      | 5      |        |
| 14 | Beji depok      | 2,251  | 7      | 5      |        |
| 15 | Tunggilis       | 1,770  | 6      | 6      |        |
| 16 | Dayeuh          | 2,412  | 7      | 5      |        |
| 17 | Klapa nunggal   | 1,915  | 6      | 6      |        |
| 18 | Citayam         | 2,902  | 9      | 3      |        |
| 19 | Cariu           | 2,094  | 8      | 4      |        |
| 20 | Jasinga         | 2,389  | 9      | 3      |        |
| 21 | Leuwiliang      | 3,197  | 8      | 4      |        |
| 22 | Parung panjang  | 2,286  | 8      | 4      |        |
| 23 | Tanjung rasa    | 1,783  | 6      | 6      |        |

The highest average rainfall in Bogor District appeared in December-May, ranging from 232-517 mm/month, so it was considered the rainy season, with the highest peak of rain was in April. Meanwhile, the lowest average rainfall happened in June-September, which reached 32.6-99.5 mm/month, with the lowest rainfall occurring in July. The dry month affects the process of primordial flower formation, initiation of flowering, pollination, and fertilization [7]. During the flowering process, coffee requires a dry month for the success of the pollination process so that it can produce fruit. If rain drops during the pollination period, usually the pollen will clump, and the flowers will be damaged so that pollination will not occur or fail to become fruit.

Based on the rainfall parameters, the criteria for S1 class in Bogor covered an area of 8,466.18 ha, while S2 covered 93,355.56 ha, S3 for 95,822.85 ha, and an area of 97,281.20 ha was for N class. Based on the number of dry months, the area classified as S1 was 97,760.18 ha, S2 was 111,131.20 ha, S3 was 76,008.10 ha, and N was 12,165.77 ha. The spatial distribution of land suitability based on rainfall and dry months in Bogor District is indicated in Figure 3.
Figure 3. Spatial distribution of land suitability based on a) rainfall and b) dry months

The next growing criteria were the altitude to compile data that was suitable for Arabica coffee cultivation in all areas of Bogor. It required elevation data as the contour data. This data is obtained from the Indonesian Earth Map in the form of a shapefile with a line type. The contour data was further processed based on the selection of altitude lines following the requirements of growing Arabica coffee. Data then were grouped by land suitability class. The spatial distribution of land suitability for Arabica coffee based on altitude in Bogor Regency is shown in Figure 4a.

Figure 4. Spatial distribution of land suitability based on a) altitude and b) slope

Altitude, a known surrogate variable for temperature, is the main driver of the epidemics of coffee leaf rust (CLR) diseases. Incidence and severity were highest in the lowland fields than highland, where poorly managed plantations of local varieties which are grown under the open sun were also more dominant. CLR intensity decreased with the increase in altitude at the highlands, where well-managed and improved varieties are grown under the shade [8]. The land areas which were suitable for Arabica coffee growth are classified as very suitable (S1) for 23,124.50 ha, quite suitable (S2) was 17,180.35 ha, marginal (S3) was, 23,216.14 ha, and not suitable (N) was 233,932.20 Ha.

Based on the slope angle, the slopes were divided into several classes such as flat (0-8%), sloping (8-15%), slightly steep (15-25%), steep (25-45%), and very steep (≥ 45%). The land slope data obtained from the soil map of Bogor was then adjusted to the criteria for the coffee land suitability class. Coffee land suitability classes are grouped as S1 class with a slope of 0-8%, S2: 8-25%, S3: 25-45%, N: > 45%.

The parameters of the observed physical properties of the soil included effective depth, soil texture, and drainage speed. Soil texture was determined by the size of the soil particles represented by the percentage of sand, silt, and clay in the soil [9]. The texture was the relative ratio between the fractions of sand, silt, and clay, i.e., soil particles which effective diameter was 2 mm. This parameter was one of
the most essential soil characteristics that affect soil moisture, drainage, infiltration, and retention of nutrient and water capacity [10].

The results showed that the distribution of land suitability for coffee based on the physical properties of the soil were in the S1-S3 class. It ranged from very suitable – marginally appropriate. There was no land which was not suitable based on the parameters of soil physical properties and drainage speed. The spatial distribution of land suitability based on the physical properties of the soil is shown in Figure 5.

Figure 5. Spatial distribution of land suitability based on a) adequate depth, b) soil texture, and c) drainage.

Based on the parameters of soil chemical properties, general, Bogor was very suitable (S1) and quite suitable (S2) for coffee growth. Soil pH value can be used as an indicator of soil chemical fertility because it can reflect the availability of nutrients in the soil. Base saturation indicated the ratio between the number of all cations (acidic cations and basic cations) contained in the soil adsorption complex. The soil was fertile if the base saturation was >80%, the soil fertility was moderate if the base saturation was between 50-80% and infertile if the base saturation was <50%. Based on the nature of the soil with 80% base saturation, is based cation will be free so it could exchange more quickly than soil with 50% base saturation [11].

Cation exchange capacity (CEC) is one of the chemical properties of soil closely related to the availability of nutrients for plants. It is an indicator of soil fertility and nutrient retention capacity. CEC is the capacity of clay to adsorb and exchange cations. CEC is influenced by clay content, clay type, and organic matter content. Soil CEC describes soil cations such as Ca, Mg, Na and can be exchanged and absorbed by plant roots [9]. The spatial distribution of land suitability based on chemical properties can be seen in Figure 6.
The area of land suitability class for Arabica coffee, which was based on each parameter (agroclimatic variable, soil physical, and chemical properties) is presented in Table 3. Table 4 shows the suitability class for Arabica coffee in Bogor, which was in the moderately suitable (S2) class of around 398.68 ha, marginal (S3) 32,209.42 ha, and not suitable (N) 266,617.31 ha. Based on Table 3, rainfall and altitude in Bogor district are growth limiting factors in the S1 suitability class (very suitable).

According to the regulation of the Minister of Public Works and Public Housing concerning guidelines for the preparation of provincial spatial plans, No. 15/PRT/M/2009, protected areas consisted of protected forest areas, water catchments, river/lake/reservoir borders, local wisdom, nature reserves/cultural reserves, disaster-prone areas, geological protections, and animal protection. Some parameters were not only protected but some ideal distances or boundaries must be avoided in land use. These parameters consisted of river/lake bodies, roads, and railroads/railways. The lake/situ borderline was set around the lake/situ at least 50 (fifty) meters from the edge of the highest water level that has ever occurred.

**Figure 6.** Spatial distribution of land suitability based on a) pH b) base saturation, c) cation exchange capacity.
Table 3. The suitability of land in the area (Ha) based on the category of very suitable (S1), quite suitable (S2), marginal (S3), and not suitable (N) for each parameter of Arabica coffee in Bogor.

| Parameter                        | Land Area Suitability Class (Ha) |
|----------------------------------|----------------------------------|
|                                  | S1     | S2      | S3      | N      |
| Rainfall (mm/year)               | 8,466.18 | 94,017.16 | 99,465.85 | 97,276.22 |
| Dry Month (mm/month)             | 97,760.18 | 111,592.64 | 77,703.10 | 12,169.49 |
| Altitude (meters above sea level)| 23,124.50 | 17,180.35 | 23,216.14 | 233,932.20 |
| Slope (%)                        | 105,120.00 | 106,266.57 | 53,763.79 | 34,075.05 |
| Effective depth (cm)             | 114,129.59 | 137,250.63 | 46,900.03 | 945.17 |
| Soil texture                     | 51,212.78 | 173,578.10 | 64,347.20 | 10,087.33 |
| Drainage                         | 264,649.90 | 4,984.59  | 19,505.08 | 10,085.84 |
| pH                               | 125,087.21 | 18,484.69 | 154,708.34 | 945.17 |
| Base Saturation (%)              | 201,220.51 | 97,059.73 | 0.00     | 945.17 |
| CEC (me/100 g)                   | 187,513.12 | 110,767.13 | 0.00     | 945.17 |

Table 4 Land suitability class for Arabica coffee.

| Land Suitability Class          | Land Area (Ha) | Percentage (%) |
|---------------------------------|----------------|----------------|
| S2 (Suitable)                   | 398.68         | 0.13           |
| S3 (Marginal Suitable)          | 32,209.42      | 10.76          |
| N (Not Suitable)                | 266,617.31     | 89.10          |

The protected forest areas are located in the southern part of Bogor district with 41,176.303 ha. The bodies of rivers and lakes/situ are almost evenly distributed and concentrated in the central and northern parts. The river and lake/situ bodies occupied a land area of 16,077.782 ha. The road was the second parameter after the railway line, which had a small distribution. The road covered up to 659.247 ha of land. The types of roads are observed as barriers were toll roads, arterial roads, and collector roads, which were primarily in the northern part. The railroad tracks were found only in the north and central parts from north to south, with 102,213 ha. The unique parameter was built-up land or settlements, which were almost evenly distributed and concentrated in the north. This can happen because Bogor district is directly adjacent to DKI Jakarta in the north. Residential land has an area of 47,786.507 ha. The distribution of limiting parameters is given in Figure 7.

The results of overlaying land suitability map with protected areas, built-up land, lakes/situ, roads, and railways, the potential land for Arabica coffee were 126 ha for S2 suitability class, 18,681.00 ha for S3 suitability class, and 280,418.58 ha for non-potential land (Table 5).
Figure 7. The socio-economic parameters that limit the determination of land suitability for Arabica coffee in Bogor consist of a) protected forests, b) rivers or lakes, c) roads, d) railroads, and e) settlements or built-up land.

The land suitability class was the S2 class which the highest limiting factor was the rainfall parameter. Land suitability classes with limiting drainage speed, and altitude factors lied in the range of 1,500 – 1,750 meters above sea level. The area for this suitability is 126 ha or 0.04% for the S2 class and 6.24% for the S3 class from 18,681 ha a total area. For the N class, the heaviest limiting factor was the altitude parameter. The lowlands areas are not recommended for Arabica coffee growing. The suitability class remains in the N range has 280,418.58 ha or 93.71% of the total area.

Potential lands for Arabica coffee development were located in Sukajaya, Babakan Madang, Caringin, Ciawi, Cigombong, Cigudeg, Cijeruk, Cisarua, Jonggol, Klapanunggal, Megamendung, Nanggung, Sukamakmur, Sukaraja and Tanjungsari sub-districts. The spatial distribution of potential land for Arabica coffee can be seen in Figure 8.

Table 5 Land class of potential land suitability for Arabica coffee.

| Land Suitability Class | Land Area (Ha) | Percentage (%) |
|-----------------------|----------------|----------------|
| S2 (Suitable)         | 126.00         | 0.04           |
| S3 (Marginal Suitable)| 18,681.00      | 6.24           |
| N (Not Suitable)      | 280,418.58     | 93.71          |
Figure 8. The spatial distribution of potential land for Arabica coffee in Bogor

4. Conclusion
Based on the spatial analysis of the suitability of Arabica coffee land that refers to the Digital Elevation Model (DEM), agroclimatic variables, soil map, soil physical/chemical properties, and land use information the proportion of land suitability class for Arabica coffee that is suitable (S2), marginally suitable (S3), and not suitable (N). The size of each area was 398.68 ha for S2 suitability class, 32,209.4 ha for S3 suitability class, and 266,617 ha for N or not suitable. The suitability of Arabica coffee land referred to the results of overlaying land suitability map with protected areas, built-up land, lakes, roads, and railways, and the potential land for Arabica coffee was 126 ha for S2 suitability class, 18,681.00 ha for S3 suitability class, and 280,418.58 ha for non-potential land.

Acknowledgments
The authors would like to thank Dr. Ir. Arief Darjanto, M.Ec as the Dean of the vocational school, Bogor Agricultural University as the sponsor of this research through a competitive grant program for vocational school applied researches.

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