The impact of climate change on arabica suitability area and opportunities to reduce vulnerability

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Abstract. Arabica is a global premium coffee commodity whose land suitability is vulnerable to climate change. The presence of exposure and sensitivity will have a potential impact such as a decrease in the quality and quantity of production. This study analyzes how the level of vulnerability of climate change to the development of land suitability of Arabica species and analyzes the potential of Arabica agroforestry by the community. The method used is quantitative with a quantitative approach that utilizes secondary data for spatial processing. Modeling results show that climate change leaves 6% of the area that has the suitability of Arabica species in Indonesia at this time. There is a 67% loss of land suitability nationally and has the potential to shift the new land suitability area by 28% in 2050. Many areas are at a moderate level of vulnerability that is lost, which is 87% of the total land suitability loss. The areas that have a very high value of climate change vulnerability is not necessarily a highly degraded land. The development of Arabica coffee agroforestry can contribute 29% to efforts to increase adaptation capacity to reduce climate change vulnerability from the perspective of land use diversification.

1. Introduction
Arabica is a leading coffee commodity that dominates 70% of the total global coffee market, followed by Robusta and Liberica [1]. Coffee production in Indonesia currently at 85% is still dominated by Robusta (BPS, 2018). The latest statistics show that there has been an increase in national per capita demand of 14% [2]. These conditions should open opportunities for improving the welfare of coffee farmers in Indonesia. Consideration of land suitability for arabica is needed to optimize production [1]. The ideal conditions for the future of Arabica plantations are dealing with climate change events. Many researchers have conducted studies related to climate change vulnerability in agriculture in various countries [3–8]. Climate change impacts on the migration of pests and plant diseases from warmer regions, prolonged dry seasons, and extreme weather due to climate change resulting in a decrease in the quantity and quality of coffee production that threatens the income of coffee farmers [9]. Climate change disrupts the land suitability for agricultural commodities. It is predicted that climate change will decline land suitability of coffee commodities globally by 49% for arabica species and 54% for robusta types from 2010 to 2050 [10].
Farmers are faced with high-risk resource utilization activities. The magnitude of uncertainty in agriculture needs to be managed to protect farmers from loss [11,12]. Though coffee cultivation in Indonesia has been going on since the 1700s through forced cultivation in Java, then spread to Sumatra, Sulawesi, and Bali. There are six contributions of coffee commodities to the national economy are a source of foreign exchange, farmer income, job creation, regional development, agribusiness, and agroindustry drivers, and supporting environmental conservation [13].

Coffee farmers need to be supported to reduce the level of vulnerability to climate change, or even be able to find benefits and optimize it [14]. Coffee cultivation by the community (traditional) is generally developed with an agroforestry system [15–17]. This research was designed to analyze the level of climate change vulnerability to the development of arabica land suitability and analyze the potential of Arabica agroforestry by the community as an effort to increase adaptation capacity to reduce the level of vulnerability to climate change.

2. Literature review

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2.1. Vulnerability to climate change

Vulnerability indicates conditions where the system cannot adjust to the impact of a change [18]. Vulnerability differs in temporally and spatially. Vulnerability (V) in a social context is a function of exposure (E), sensitivity (S) and adaptation capacity (AC), which is formulated as [19]:

\[ V = f (E, S, AC) \]

The changes in patterns and rainfall, as well as temperature increases, become high-risk exposures to coffee cultivation. El-Nino events characterized by prolonged dry months resulted in a decrease in the quality of coffee also causing a decrease in the production of 34.79%. La-Nina, which is characterized by prolonged wet months, reduces coffee production by 98.5%. Every 1°C temperature rise will reduce coffee production by 30.4% [20]. The decline in the quality and quantity of coffee due to climate change as illustrated in Figure 1, will have an impact on the life of coffee farmers [21].

![Figure 1. The impact of climate change on coffee](image)

Changes that occur in the wet and dry months, isothermal, precipitation affect coffee production [22]. Exposure to climate change to the coffee plantations provides vulnerability to the welfare of farm households. The poorer of household has a higher level of vulnerability [23].
Climate change affects the suitability of the coffee commodity area. The direction of slopes, slope, and land use land cover can be adapted to support coffee production [22]. The higher the adaptation capacity, the less susceptibility will be [24].

2.2. Suitability of Arabica coffee fields
Coffee comes from the African continent and belongs to the genus Coffea and consists of about 70 species. The agronomically dominant species are Coffea arabica and Coffea canephora or Robusta, and a small portion is Coffea liberica and Coffea excelsa which only contribute 1-2% of global production. Coffee is grown in tropical countries throughout the year at latitudes between 22 ° N and 26 ° S. It takes about three years from germination for first fruit production, then bushes and can be productive for up to 80 years, even though the maximum economic age is 30 years [25].

Land suitability for coffee commodities is influenced by elevation, slope, soil type, rainfall, and temperature. The land suitability criteria for each type of coffee are different [26]. Traditionally the arabica type is categorized as "shade coffee" [1], with land suitability for the arabica type as Table 1.

| Table 1. The criteria of arabica land suitability |
|-----------------------------------------------|
| Criteria | Suitable *) | Not suitable |
| Climatic | | |
| Temperatures (°C) | | |
| - Mean annual | 14-26 | <14,> 26 |
| - Mean max. annual | 26-32 | > 32 |
| - Mean daily minimum | 17-24 | <18,> 32 |
| - The temperature of the coldest month | 4-14 | <4 |
| Rainfall (mm) | 800> 2200 | <800 |
| - Annual | 0-6 | > 6 |
| - Length of the dry season (months) | | |
| Relative humidity (%) | 20-90 | > 90, <20 |
| Soil | | |
| Slope (%) | | |
| - Without irrigation | 4-30 | > 30 |
| - With irrigation | 0-16 | > 16 |
| Hydrous conditions | | |
| - Drainage | Good, moderate, imperfect | Poor, drainable freq. |
| - Submersion | Non- occasionally | - |
| Physical characteristics | | |
| - Depth of soil (cm) | 50-200 | <50 |
| - Texture | Loam silty-clayey-sandy. | Sand |
| - % of coarse elements> 2mm | 3-55 | | |
| Chemical characteristics | | |
| - pH (H2O) | 4.5-5.5 | > 55 and <4.5 |
| - Apparent CEC (meq / 100 g clay) saturation in cations of layer 0-15 cm (%) | 16-80 | - |
| - Organic carbon of layer 0-15cm (%) | <0.8-2.4 | - |

*) Suitable: S1 (Best); S2 (Average); S3 Marginally [25]
2.3. Agroforestry

Agroforestry is one form of forest resource management that adopts an approach of integrating environmental, economic and cultural values that are adaptive to various management objectives and social values [27]. Operationally, agroforestry is carried out by integrating trees on agricultural land that is useful to prevent environmental degradation and increase agricultural productivity. The occurrence of carbon sequestration, improved hydrological processes, soil stability, biodiversity protection, and other benefits are beneficial to improve community welfare. Agroforestry is carried out to bridge the interests of agricultural optimization with forest protection [28].

Four basic aspects affect farmers’ decisions to implement or not implement agroforestry, namely: feasibility, profitability, acceptability, and sustainability [29]. Recognition of local wisdom is one of the keys to the successful implementation of agroforestry in a community, in addition to socio-economic, biophysical and market conditions. Integration of trees with annual crops can provide short, medium and long-term income [30].

3. Method

This research uses a quantitative approach. This research was systematically arranged to answer the research objectives using quantitative methods. Researchers assess each research variable based on the results of data collection on the research location.

3.1. Study sites

![Figure 2. Ecoregion of Indonesia [31]](image)

Indonesia is a tropical country consisting of ± 1.88 million km2 of terrestrial ecoregions and 6.31 million km2 of marine ecoregions, Figure 2 [32]. The terrestrial ecoregion consists of marine, terrestrial, alluvial, karst, volcanic mountain peat, hills and structural and denudational links with varying slopes [33].

3.2. Data

This research was conducted using secondary data from literature studies, previous studies, official government statistical data and spatial data sources detailed as in Table 2., which represents the variables of this study.
Data processing is done using Geographic Information System (GIS) tools, using ArcGIS 10.3 software. Map data number 1 through number 6, except number 2 has been collected in digital format. Researchers digitize data number 2, henceforth quantitative analysis based on the results of spatial data processing as Figure 3. Data were analyzed based on scores for each type of data in this study as Table 2.

**Table 2. Spatial data in this study**

| Map title                                                                 | Classification                              | Score |
|---------------------------------------------------------------------------|---------------------------------------------|-------|
| 1. Administration and zone                                               |                                             |       |
| - Topographic Map (2016-2018), Geospatial Information Agency             | Province                                    | -     |
| - Forest Areas Map (2018), Ministry of Environment and Forestry (MoEF)   | Forest area, non-forest area                | -     |
| 2. Arabica suitability change area                                        |                                             |       |
| - Arabica Land Suitability Map (2010), Schroth, et al. (2015)            | Not, lost, fixed, new suitability           | 0 - 3 |
| - Arabica Land Suitability Projection Map (2050), Schroth, et al. (2015) |                                             |       |
| 3. Existing arabica distribution                                          |                                             |       |
| - Distribution of Indonesian Arabica Map (2011), Neubert (2011)          | The potential, cultivated area              | 1-2   |
| 4. Vulnerability                                                          |                                             |       |
| - Climate Change Vulnerability Map (Update February 2020), MoEF          | Very low-very high                          | 1 - 5 |
| 5. Land degradation                                                       |                                             |       |
| - Land Degradation Map (2018), MoEF                                      | Undergraded-very degraded                   | 0 - 4 |
| 6. Weighting factor                                                       |                                             |       |
| - Indicative Map and Areas of Social Forestry (SF) Rev. IV (2020), MoEF  | Non-SF, SF and Private land                 | 0 - 1 |
To answer the final goal of this research, the researcher compiled a classification based on the results of data processing that had been carried out, as in Table 3. The overlay results from the suitability data of Arabica land, vulnerability, distribution of existing and non-existing gardens, and land degradation resulted in a total score between 0-14. Land management allocation data for the community consisting of definitive and indicative SF, private land and non-SF become weighting factors that determine the legality of developing Arabica agroforestry in Indonesia.

### Table 3. Classification of Arabica agroforestry potential

| Classification       | Total score |
|----------------------|-------------|
| 1. Very high potential | 0 - 2       |
| 2. High potential     | 3 - 5       |
| 3. Moderate potential | 6-8         |
| 4. Low potential      | 9-11        |
| 5. Not potential      | 12-14       |

### 4. Results and discussion

#### 4.1. Arabica suitability changes area

The maximum entropy method (Maxent) is widely used by researchers to model the spatial distribution of agricultural commodities [34–36]. A spatial model of land suitability for Arabica commodities in Indonesia has been prepared using the maximum entropy method (Maxent) which utilizes World-Clime data [37] which is calibrated with the current coffee production zone, to produce an estimated model of the spatial distribution of Arabica coffee commodities in Indonesia [38]. The coffee production zone means the distribution area of existing coffee plantations [39] and excluded at locations identified as altitudinal belts indicated by deep valley topography and mountain top [38] whose value exceeds the suitability limit of arabica area [25].

Climate change is projected to change the suitability of the global coffee area [10]. At a higher level of data, similar findings also occur in Indonesia, Table 4 [38]. Spatial data analysis shows that land suitability for Arabica commodities in 2050 decreased by 67% and there was a shift in new land suitability in 2050 by 28% of land suitability in 2015. Land suitability of arabica that could survive was only 6%.

### Table 4. Change in the suitability of arabica land

| Province             | Suitability area during climate change model (2015-2050) | ± Σ (Ha) |
|----------------------|----------------------------------------------------------|---------|
|                      | Lost          | Fixed   | New     |         |
| 1. Aceh              | 387,851       | 293,810 | 193,737 | 875,397 |
| 2. Nort Sumatera     | 652,816       | 310,153 | 81,480  | 1,044,449 |
| 3. East Java         | 52,692        | 43,593  | 33,740  | 130,024 |
| 4. Bali              | 45,939        | 27,680  | 7,252   | 80,871  |
| 5. East Nusa Tenggara| 90,386        | 17,952  | 4,724   | 113,062 |
| 6. West Sulawesi     | 68,791        | 37,513  | 122,494 | 228,798 |
| 7. South Sulawesi    | 274,600       | 123,184 | 219,063 | 616,847 |
| 8. Central Sulawesi  | 50,389        | 13,188  | 70,315  | 133,892 |
| 9. South East Sulawesi| 166,765      | 33,568  | 9,870   | 210,204 |
| ± total (Ha)         | 1,790,229     | 900,641 | 742,675 | 3,433,545 |
| Percentage           | 52%           | 26%     | 22%     | 100%    |
Factors of change in temperature, rainfall, duration of wet and dry months are determinants of climate suitability for Arabica production zones. Nine provinces in Indonesia are declared as Arabica commodity centers, and each province has different suitability change characteristics to climate change. North Sumatra Province suffered the most loss of the suitability of arabica area in 2050. South Sulawesi Province will experience the greatest shift in the suitability of arabica area so that this region became the province with the most affected area of land suitability of Arabica due to climate change. The spatial distribution of changes in land suitability is as shown in Figure 4.

**Figure 4.** Arabica land suitability model due to climate change

### 4.2. Climate vulnerability for arabica

The Government of Indonesia (GoI) through the MoEF has compiled a climate change vulnerability map [40]. The data is used as a reference in this study to be operated with a map of land suitability changes that have been analyzed in this study in the previous section. Interviews with data owners revealed that information related to exposure, sensitivity and adaptive capacity was obtained based on analysis of biophysical/environmental and socioeconomic conditions data sourced from village potential data published by the Central Statistics Agency. This information is updated periodically as is the updating of village potential data. Analytical Hierarchy Process (AHP) method is used to arrange scoring and weighting to produce information on exposure and sensitivity indexes and adaptability indexes. There is a limitation in this data that is found in blank information. This case was found in a number of areas that had suitable suitability for arabica, especially in Aceh Province.

Researchers analyzed the degree of vulnerability of climate change to projected changes in land suitability, with results as in Table 5. The high level of climate change volatility does not guarantee the high value of land suitability for arabica. The greatest losses occur at moderate levels of vulnerability. This condition is proportional to the distribution of the level of vulnerability to climate change in areas with Arabica land suitability.

| Vulnerability level | Suitability area during climate change model (2015-2050) | ± Σ (Ha) | % |
|---------------------|--------------------------------------------------------|--------|---|
|                     | Lost | Fixed | New |                  |
| Very high           | 67,546 | 25,202 | 28,552 | 121,299 | 4% |
| High                | 6,450  | 5,107  | 3,962  | 15,519  | 0.5% |
| Moderate            | 1,565,239 | 771,065 | 566,702 | 2,903,006 | 85% |
| Low                 | 63,791 | 32,307 | 64,251 | 160,349 | 5% |
| Very low            | 2,240  | 3,034  | 307    | 5,581   | 0.2% |

Table 5. Distribution of the climate change vulnerability level.
Regarding the distribution of data, in Figure 5 we find that each region has a uniform probability of the level of vulnerability to climate change. Only Aceh and North Sumatra Provinces have the lowest vulnerability value in the Arabica coffee commodity, out of 1,470 Ha the current Arabica suitability with very low vulnerability conditions leaves only 635 Ha of land that remains in 2050.

The higher the capacity of adaptation, the vulnerability level of climate change will decrease [19]. In this case, increasing the index value of adaptability can reduce the index value of exposure and sensitivity. Adaptation strategies need to be developed for the sustainability of coffee plantations.

4.3. Arabica agroforestry potential for people

[8] There are five approaches in developing strategies for developing adaptation capacity to reduce the level of climate change vulnerability in coffee commodities. The five strategies are community investment, land use diversification, storage strategies, market diversification, and migration strategies. The results of his research indicate that participation in infrastructure maintenance as a form of investment has the highest success rate, followed by the development of growing shade coffee as a strategy of land diversification and investment in land expansion related to the market.

Cultivation of coffee with a shade of one form of agroforestry. Understanding that the poorer the community, the higher the vulnerability, the government implements agroforestry activities to the community. The rehabilitation of degraded forest and land and the development of Social Forestry are several steps to protect the community to reduce the vulnerability of climate change [41].

Based on an analysis of the rehabilitation and reforestation targets on forests and degraded land, the researchers found that the target of revegetation through degraded land had a different pattern than efforts to reduce the vulnerability of climate change [42]. The focus of the revegetation of degraded land is at the two highest levels, namely degraded and very degraded, which have small conformity to the distribution of climate change vulnerability in the arabica coffee commodity, Figure 6.
Figure 6. Data distribution of vulnerability and land degradation

Based on the graphic above, the biggest data are on vulnerability at moderate levels and low degraded land. This fact shows that the action of rehabilitating forests and critical land is difficult to reach to increase the capacity of climate change adaptation capacity of Arabica coffee through these actions.

The researcher offers another option, namely the community-based management approach through SF. [27] emphasized that forest resource management needs to adopt approaches that support the integration of environmental, economic and cultural values that are adaptive to various management objectives and social values. Strong correlations between indigenous peoples and poverty in forest areas have raised forest and social, political, human rights, cultural and spiritual issues within the boundaries of local wisdom and material ownership rights. The findings initiated the FAO to formulate SF in the 70s [43]. Indonesia allocates land in forest areas so that it can be legally managed independently and prosper the community. One popular commodity is non-timber forest products in the form of coffee [44]. This study places the area of Social Forestry and private land as a binary factor (0-1) in determining the potential of Arabica coffee agroforestry, Table 6.

Table 6. Arabica agroforestry accessibility area

| Land accessibility | Suitability area during climate change model (2015-2050) | ± Σ (Ha) | % |
|--------------------|----------------------------------------------------------|---------|---|
|                    | Lost       | Fixed   | New         |        |   |
| Definitive SF      | 13.923     | 5.128   | 3.781       | 22.832 | 1% |
| Indicative SF      | 105.647    | 54.963  | 32.414      | 193.024 | 6% |
| Private Land       | 578.750    | 177.342 | 31.754      | 787.846 | 23%|
| Σ accessible (A)   | 698.320    | 237.433 | 67.949      | 1.003.702 | 29% |
|                    | 20%        | 7%      | 2%          | 29%    |   |
| Non-SF             | 1,091.592  | 663.183 | 674.722     | 2,429.497 | 71% |
| Water body         | 317        | 25      | 4           | 346    | 0.01% |
| Σ unaccessible (B) | 1,091.909  | 663.208 | 674.725     | 2,429.843 | 71% |
|                    | 32%        | 19%     | 20%         | 71%    |   |
| ± A+B (Ha)         | 1,790.229  | 900.641 | 742.675     | 3,433.545 | 100% |
| Percentage         | 52%        | 26%     | 22%         | 100%   |   |

The distribution of the largest coffee agroforestry potential area is not in the forest area but private land owned by individuals covering 786.332 hectares with a level of moderate potential. The protected forest area has the potential for coffee agroforestry with SF of 120.118 Ha and production...
forest area of 95,651 Ha. Locations that are considered potential as coffee agroforestry areas through land degradation data have a history as non-forested areas, so that they are suitable as reforestation sites. Distribution per province is as Figure 7.

Figure 7. Arabica agroforestry potential area

All forest areas that are not areas allocated for SF are not an additional factor in determining the potential for coffee agroforestry because they are in conservation areas or have already been encumbered or reserved for other purposes. The final results that can be obtained are as in Table 7.

| Forest and land zone | Potential of arabica agroforestry | ± Σ (Ha) | % |
|----------------------|----------------------------------|----------|---|
|                      | Very high | High | Moderate | Low | Not |
| Conservation Forest  | 3       | 455,004 | 455,007 | 13% |
| Protected Forest     | 255     | 37,167 | 73,865 | 8,830 | 1,545,144 | 1,665,262 | 48% |
| Production Forest    | 1,311   | 26,519 | 65,599 | 2,222 | 418,824 | 514,475 | 15% |
| Non forest area      | 7,223   | 282,756 | 476,084 | 20,269 | 1,514 | 787,846 | 23% |
| Water body           | 346     | 346 | 100% |
| No data              | 10,609  | 10,609 | 0.31% |
| ± Total (Ha)         | 8,788   | 346,442 | 615,551 | 31,322 | 2,431,442 | 3,433,545 | 100% |
| Percentage           | 0.3%    | 10% | 18% | 1% | 71% | 100% |

5. Conclusion
Climate change is projected to leave only 6% of the area of Arabica species conformity in Indonesia, based on the 2015 baseline data. Climate change will eliminate land suitability for Arabica in Indonesia by 67%, and potentially add a new area of the suitability of 28% in the year 2050. The vulnerability of climate change to Arabica coffee commodities at various levels contributes to this loss. Many areas are at the level of vulnerability with moderate levels of loss, which is 87% of the total loss of land suitability. Areas that have succeeded in maintaining land suitability as well as areas projected to be new land suitability also still have potential vulnerabilities at various levels that need to be reduced. The development of Arabica coffee agroforestry can contribute 29% to efforts to increase adaptation capacity to reduce climate change vulnerability from the perspective of land use diversification.

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