Land Suitability Modelling of Agricultural Geographical Indication Products under Climate Change Scenarios

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ABSTRACT
As a response to the geographical environment, agricultural land suitability is one of the determining factors for the distinctive quality of agricultural geographical indication products, including coffee sector. The sustainability toward its land suitability is required, considering that the status of geographical indications on a product will remain as long as its distinctive characteristics can be maintained. However, climate change affects the land suitability of agricultural products, thus, indirectly threatens the geographical indication status of the registered products. This study aims to predict the future coffee's land suitability as an agricultural geographical indication product in Indonesia. A baseline period (1999 to 2010) was used to identify current coffee land suitability, while future land suitability was predicted in the time horizons of the 2030s (2021 – 2040); 2050s (2041 – 2060); 2070s (2061 – 2080); and 2090s (2081 – 2100). Maximum Entropy (MaxEnt) and ArcMap software were used to determine the spatial distribution of land suitability. Results showed the declining trend of agricultural land suitability of registered geographical indication products in selected climate change scenarios. This study suggests that mitigating land suitability changes due to climate change is considered important to maintain the geographical indications status on agricultural products in Indonesia.

Keywords: *Climate change, coffee, geographical indication, land suitability, spatial modeling.*

1. INTRODUCTION

Indonesia has its own pride for having abundant natural resources and various top quality crops, specifically in coffee sector. As the fourth coffee producing country in the world, Indonesia contributed 6.93% of the world's coffee supply in 2019 [1]. Indonesia's coffee total production reached 729.074 tons, consisting 73,29% of Robusta coffee, 26,02% of Arabica coffee, and 0,69% of Liberica coffee [2].

Coffee plantations are scattered across several region in Indonesia, including Sumatera, Java, Sulawesi, Flores, and Papua. Each region has different environmental conditions that affect the characteristics of the coffee products. It has been reported that the taste or aroma of coffee is strongly related to the geographical area of its plantation [3], [4]. Coffee is one of agriculture product which have different variants based on its area of origin, known as specialty coffee. A relationship between specialty coffee quality and regional environmental characteristics was determined as the basis for determining the origin of coffee products [5]. Hence, a Geographical Indications (GIs) status is often attached to coffee products in Indonesia.

GIs emphasize product quality that is formed due to geographical environmental factors, including human factors, natural factors, or a combination of the two factors, resulting in certain qualities that are different from other products. Current statistics of GIs products in Indonesia show that 33,7% (31 of 92 registered products) are coffee sector, consist of 19% arabica coffee, 13% robusta coffee, and 2% liberica coffee [6]. Accordingly, the coffee products are considered to represent the sustainability of geographical indication status of agricultural products in Indonesia.

Future sustainability of coffee production will be threatened due to climate variability and change [7], [8]. Recent research has evidenced relationships between coffee's vulnerability and increasing temperatures. In the other hand, the increase in temperature that occurred in the last decade indicates that climate change has a

significant impact on agricultural products [9], [10], including the coffee sector. Due to changing climate conditions, there have been increasing concerns about the future quantity and quality of the coffee yield in the decades to come. Some publications showed the declining suitable area (in excess of 50%) and extinction of coffee plantations [11], [12]. This study aims to predict the future coffee's land suitability as an agricultural geographical indication product in Indonesia using climate historical big data. A Species Distribution Models (SDMs) were used to understand the land suitability changes. We also used a combination of GIS and Maxent model to project the land suitability in selected climate change scenario.

2. METHODS

2.1. Species Presence Records

We used the presence of coffee plantations in Indonesia, i.e. arabica, robusta, and liberica, as the presence records data. The data was obtained from the Directorate General of Intellectual Property (DGIP; http://ig.dgip.go.id/) to determine the specific plantation area. One distribution record was selected in each 2,5 x 2,5 grid, thus, 4.683 records consisting of 2.050 records of arabica, 2.018 records of robusta, and 615 records of liberica were obtained.

2.2. Bioclimatic Variables

Nineteen bioclimatic variables for current condition (1950–2000) and future scenarios (2030s, 2050s, 2070s, and 2090s) were collected from the Worldclim database (http://www.worldclim.org/) with 2,5' resolution. For future scenarios, the bioclimatic data of 2030s represent mean values from 2021 to 2040, the 2050s represent mean values from 2041 to 2060, the 2070s represent mean values from 2061 to 2080, and the 2090s represent mean values from 2081 to 2100. We applied a general circulation model (GCM) predictions under Shared Socio-economic Pathways (SSPs) scenarios of 126 (SSP1-2.6) and 370 (SSP3-7.0) to estimate future climate change. SSP1-2.6 represented a climatic scenario with a low concentration of greenhouse gases, the radiative forcing will drop to 2.6 W/m^2 in 2100, while SSP3-7.0 represented a global warming trend without climate policy intervention, the radiative forcing will rise to 7.0 W/m^2 in 2100 [13].

Variance Inflation Factors (VIFs), a statistical approach used to avoid correlation between variables, were used to exclude collinearity among variables [14], [15]. Variables with VIF > 10 were considered to have high collinearity, thus, a total of 8 environment variables were used in this study (Table 1).

Table 1. Bioclimatic Variables used in the model

Variable	Description	Included
bio1	Annual mean temperature	
bio2	Mean diurnal range	Yes
bio3	Isothermality	Yes
bio4	Temperature seasonality	Yes
bio5	Maximum temperature of the warmest month	
bio6	Minimum temperature of the coldest month	
bio7	Temperature annual range	
bio8	Mean temperature of the wettest quarter	Yes
bio9	Mean temperature of the driest quarter	
bio10	Mean temperature of the warmest quarter	
bio11	Mean temperature of the coldest quarter	
bio12	Annual precipitation	
bio13	Precipitation of the wettest month	Yes
bio14	Precipitation of the driest month	Yes
bio15	Precipitation seasonality	
bio16	Precipitation of the wettest quarter	
bio17	Precipitation of the driest quarter	
bio18	Precipitation of the warmest quarter	Yes
bio19	Precipitation of the coldest quarter	Yes

Source: Worldlim database (*http://worldclim.com/current*) in 5arcmin resolution

2.3. MaxEnt Model

The concept of MaxEnt modelling is to generate the probability distribution of a species from its subject distribution (pixels) that have maximum entropy and estimate the value of other pixels in the study area [16], [17]. The model uses presence data, further mentioned as environmental variables, to estimate the probability distribution of coffee plantations [17].

3. RESULTS

3.1. Predicted Land Suitability of Indonesian Coffee

Land suitability classification refers to [18], [19]: high suitability (>0.66), medium suitability (0.33 – 0.66), low suitability (0.05 – 0.32), and unsuitable (< 0.05). Current and predicted land suitability for coffee plantations, i.e. liberica, robusta, and arabica, in Indonesia was shown in Figure 1; while the predicted

land suitability changing was shown in Figure 2. The areas marked as green showed areas predicted to be suitable for coffee plantations but currently without coffee plantation, thus, needs more concern. The areas, mostly, were classified in medium to high suitability. Yellow areas were classified as suitable, indeed the coffees are currently being cultivated. Red areas represented the unsuitable area, however, the coffees are being cultivated in current scenario. While the other areas showed unsuitable for coffee plantations. Based on MaxEnt model, the west coast of Sumatra, the south coast of Java, and Sulawesi were predicted as suitable for Robusta and Arabica plantations, while Liberica plantation was predicted to be suitable on the east coast of Sumatera. Table 1 depicts the areas of different suitability levels under selected climate change scenarios.

3.1.1. Predicted Land Suitability of Liberica Coffee

Liberica coffee (*Coffea liberica*) is considered to have less economic value compared to Arabica and Robusta due to its low yield. However, this coffee is more tolerant of disease and adapts well to peatlands. The coffee has a unique characteristic and aroma, i.e. a caramelly, greenish, chocolate, acidy and sweet, with relatively low caffeine level [20]. Currently, two Liberica coffee has registered in GIs (Table 2)

The suitability of the Liberika coffee plantations was predicted to be still concentrated in Riau, however, the land suitability will tend to decrease in Jambi (Figure 2a). In the RCP 1.2 scenario, the predicted area of high suitability for Liberica coffee plantations was expected to decrease until the 2090s, however, will increase in the 2070s. The medium suitability area will also increase in the 2050s, then, decrease in the 2070s, and slightly increase in the 2090s. Areas of low suitability and unsuitable were predicted to be relatively steady in the future. While in the RCP 3.7 scenario, the area of high suitability was also predicted to significantly decrease in the future. The predicted area of high, medium, and low suitability were both decreases in the future, while the unsuitable area will slightly increase (Table 1).

3.1.2. Predicted Land Suitability of Robusta Coffee

Robusta coffee (*Coffea canephora*) is grown in low altitude areas, ranging from about 900 meters to 1,200 meters above sea level. Robusta is recognized to have more intense “roasted/smoky” and “sweet” sensory notes [21], yet less expensive than Arabica [22]. A total of twelve Robusta coffee products have been certified in Indonesian GIs certificates, cultivated on several islands in Indonesia including Sumatra, Java, Bali, Sulawesi, Maluku, and Nusa Tenggara (Table 2).

The suitability of the Robusta coffee plantations was predicted to significantly decrease in the Jambi and South Sumatera Province, indicated by the red area in the province. Some areas are investigated still suitable for Robusta coffee growth, represented in yellow areas, including in Java, as well as parts of Sumatra and Sulawesi. Furthermore, Aceh and Central Sulawesi are predicted to have areas that are suitable for Robusta plantations in the future (Figure 2b). Table 1 shows a decrease in the predicted high suitability area of the Robusta coffee plantation under RCP 1.2 scenario until the 2070s, and slightly increase in the 2090s. The same result was also found in the medium and low suitability areas. Areas of unsuitable were predicted to be relatively steady in the future. In the RCP 3.7 scenario, the areas of high, medium, and low suitability were also predicted to significantly reduce in the future, while the unsuitable area will slightly increase.

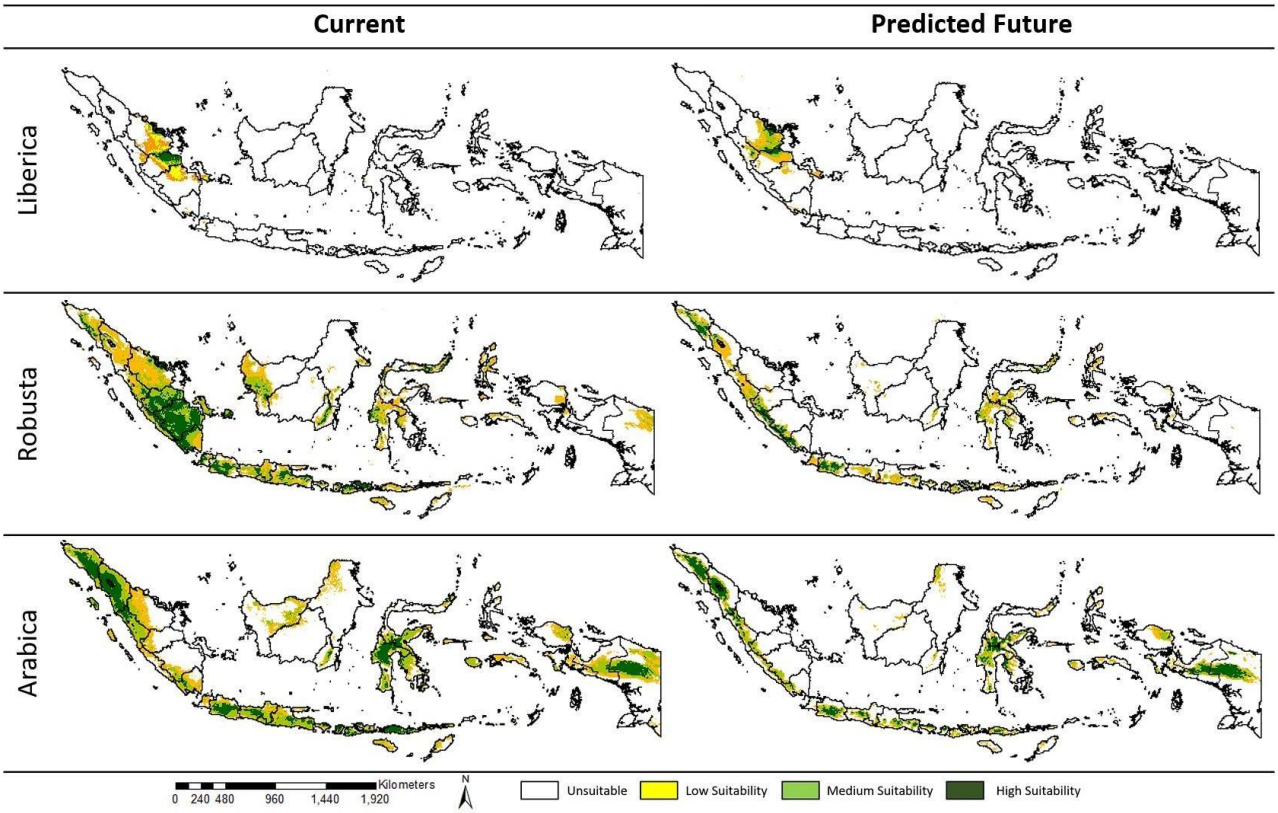
3.1.3. Predicted Land Suitability of Arabica Coffee

About 60% of the world’s coffee production is arabica coffee [23]. Compared to robusta coffee, arabica is considered to have higher organoleptic quality. Arabica coffee is one of the main contributors of chlorogenic acid which is needed by the human body [24]. This species presents a different chemical composition where arabica coffee has a stronger aroma, lower caffeine content, and less bitter taste. These characteristics results in the selling value of arabica coffee being higher than other species [25].

There are several factors that affect the taste of arabica coffee. Arabica coffee requires land with altitude of more than 1000 meters with an environmental temperature between 15°C to 20°C [27]. In addition to environmental conditions, the taste of Arabica coffee is also influenced by varieties, post-harvest activity, and processing techniques [26].

Currently, there are 17 arabica coffee products that have been registered as GIs products (Table 2). Arabica coffee’s cultivation area spread across the archipelago, from Sumatra to Papua. Based on the RCP 1.2 scenarios (Table 1), predicted area of high, medium, and low suitability were expected to decrease in the future. Areas of low suitability and unsuitable were predicted to remain relatively increased in the future. In the other hand, the predicted area of high and medium suitability for Arabica coffee plantations under RCP 3.7 scenario was expected to decrease until the 2070s, and slightly increase in the 2090s. The declining area, shown in red, mainly occurred in North Sumatera, West Sumatera, South Sulawesi, as well as East and West Nusa Tenggara, as shown in Figure 2c.

Figure 1. Current and future land suitability for coffee plantations in Indonesia



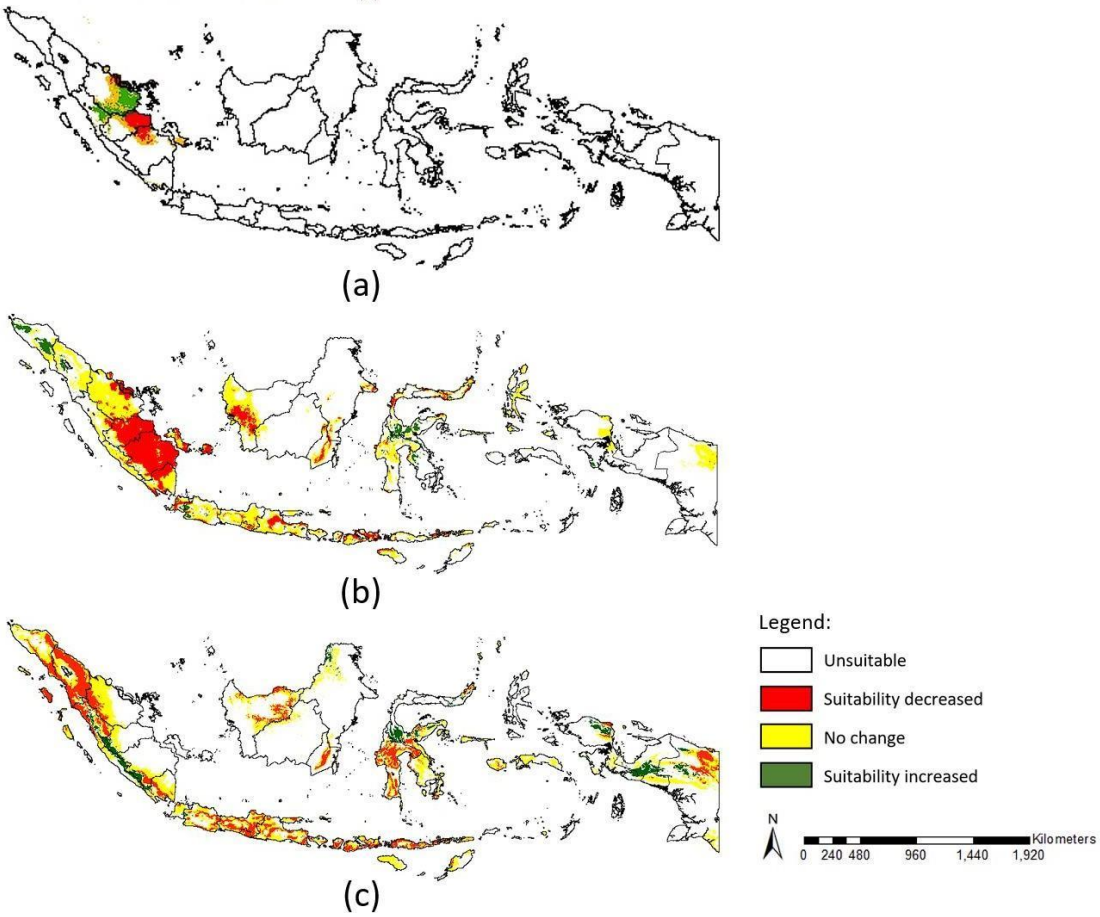


Figure 2. The predicted land suitability changes for coffee plantations in Indonesia. (a) Liberica; (b) Robusta; (c) Arabica

Table 1. Different Suitability Area Under Climate Change Scenarios (km^2)

Coffee	Scenarios	Time	Unsuitable	Low Suitability	Medium Suitability	High Suitability
Liberica	RCP 1.2	2030s	1,856,160	54,250	19,766	20,166
		2050s	1,862,500	49,178	23,331	15,257
		2070s	1,860,458	52,437	18,622	18,852
		2090s	1,873,874	45,674	20,048	10,673
	RCP 3.7	2030s	1,854,183	58,714	23,831	13,473
		2050s	1,865,213	46,817	23,962	14,228
		2070s	1,873,874	45,673	20,048	10,673
		2090s	1,873,874	45,674	20,048	10,673
Robusta	RCP 1.2	2030s	1,540,642	218,767	116,608	72,791
		2050s	1,637,843	163,180	91,126	56,754
		2070s	1,658,598	143,724	90,772	55,977
		2090s	1,645,321	146,887	96,971	59,820
	RCP 3.7	2030s	1,572,044	201,293	111,838	63,560
		2050s	1,702,305	130,318	73,910	42,815
		2070s	1,767,139	100,655	51,227	31,277
		2090s	1,805,532	80,511	42,546	21,673
Arabica	RCP 1.2	2030s	1,138,726	150,170	135,870	107,370
		2050s	1,178,380	127,840	118,460	107,920
		2070s	1,200,510	117,002	113,441	101,639
		2090s	1,190,980	118,525	117,848	105,370
	RCP 3.7	2030s	1,145,630	150,730	129,146	106,780
		2050s	1,128,860	100,775	111,474	91,673
		2070s	1,301,460	69,844	89,115	72,730
		2090s	1,350,900	49,680	64,950	68,210

More than half of certified Gis products in Indonesia are arabica coffee. Arabica coffees are widely cultivated in Indonesia thanks to the highland and volcanoes that spread across the archipelago. Arabica coffee is very suitable to be cultivated on land with an altitude of 1000-1500 meters above sea level with an average temperature between 16°C to 20°C [27]. Therefore, highland areas such as Gayo, Jayawijaya, Toraja, and Kintamani are regions that produce high-quality Arabica coffee in Indonesia.

4. DISCUSSIONS

Coffee is one of the most important plantation commodities in Indonesia. In the last five years, Indonesian coffee production has continued to increase [2]. In 2014, Indonesian coffee production reached 612,000 tons, while in 2018 it increased to 727,000 tons. Coffee cultivation is spread across various islands such as Sumatra, Java, Bali, Sulawesi, Maluku, and Nusa Tenggara, where Sumatera Island is the largest contributor to Indonesia's total coffee production. Coffee give a significant contribution to the Indonesian economy. Indonesia’s total total coffee exports in 2017 reached 467,790 tons or equivalent to USD 1.186 million (Ditjenbun, 2019). United States, Malaysia, Japan, Egypt, and Italy are the main export destinations for Indonesian coffee.

Coffee is a plantation crop that can adapt to different eco-physiological conditions in the tropics. *C. arabica* is adapted to cooler temperatures of the tropical highlands above 1000 m altitude along the equator; somewhat lower at greater latitude. It needs more than seven months of rainy weather but a relatively high temperature for an abundant differentiation of flower buds. The deep root system permits reasonably good drought tolerance. Hence, the crop grows best in tropical highlands. *C. canephora* prefers a hotter climate and is more adapted to the lowlands (below 900 m altitude), though quality improves with altitude. It requires a prolonged rainy season because of its shallower root system, tolerates high soil moisture, but needs a short dry season for extensive flowering [28]–[30]

Bioclimate conditions such as temperature have a significant impact on productivity and quality of arabica coffee [27], [29], [30], as well as liberica and robusta. Results also show that bio8 was the variable with the highest contribution affecting the suitability of arabica

coffee plantation, while liberica and robusta were bio18 and bio14, respectively (Figure 3).

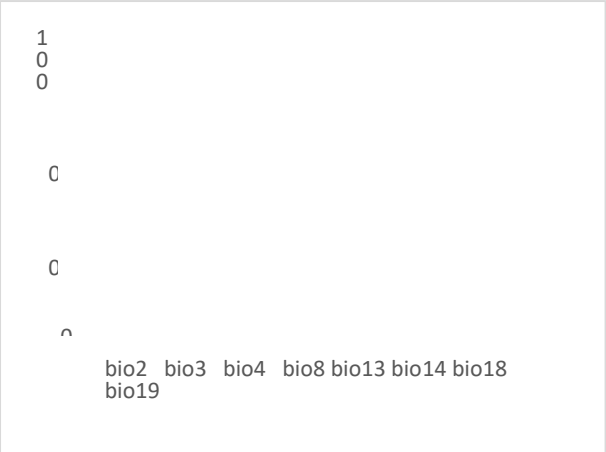


Figure 3. Percent Contribution of Selected Bioclimatic Variables

It is generally considered that the best amount of annual rainfall for Arabica coffee is between 1,400 and 2,400 mm, though a range between 800 and 4,200 mm remains acceptable. It is important that the rains are well distributed over the season or are continuous for about 7-8 months. The nature of the rainy season in terms of length and intensity of the rains is a key ecological factor determining the interval between flowering and seed maturation. Likewise, when the annual rainfall exceeds 3,000 mm leaf diseases from fungal infections develop more easily. Arabica coffee is more vulnerable to leaf diseases and pests than Robusta, especially when rainfall exceeds 3,000 mm per year. Due to its shallow root system, *Coffea canephora* can tolerate rainfall over long periods and high soil moisture, but requires a short dry season for massive flowering [29], [31].

Based on the climate change scenario, Sumatra is an area that has the potential to maintain land suitability for coffee cultivation in the future. Sumatra Island is an area that can produce three types of coffee that have been registered as GIs, i.e. Liberica, Robusta, and Arabica. This condition shows that the diversity of environmental and climatic conditions in Sumatra can create land suitability for several types of coffee at once.

Besides Sumatra, the Java also has land suitability that is quite resistant to climate change. Several highland areas and active volcanic mountains scattered on the island support the land suitability for arabica coffee. Relationships between the volcanic mountains area and coffee productivity, specifically arabica, will influence the soil fertility [32]. The conditions leads to the high availability of arabica coffee in the region, particulary have certified in Gis, i.e., Java Preanger Arabica Coffee (West Java Province, Sindoro Sumbing Arabica Coffee (Central Java Province), and Ijen Raung Java Arabica Coffee (East Java Province). Another finding that is highlighted in this study is Papua as an area with high land suitability for arabica coffee plants, and is even predicted to increase in the future. Currently, there is only one coffee product from Papua that has been registered as a geographical indication product, namely the Baliem Wamena Arabica Coffee. With good land suitability for coffee plantations, the opportunity to develop the potential of coffee in Papua is still substantial.

However, the high risk of decreasing land suitability area for coffee plantations that will occur in the future due to climate change is a threat to Indonesia. The results show that there is a tendency to decrease land suitability for arabica, robusta, and liberica coffee cultivations in Indonesia, by 26%, 39%, and 20%, respectively. On the other hand, the distribution of unsuitable land for coffee cultivation is increasing. The decrease in the distribution of land suitability for arabica coffee has also been found in several studies [12], [33]–[36].

The decrease in land suitability for arabica coffee as a result of climate change has some negative impacts on economic, social, and environment. An increase in temperature at the location of arabica coffee cultivation will increase the presence of mycotoxins produced by mycotoxigenic fungi [30]. Mycotoxins are natural low molecular weight products produced from the secondary metabolism of filamentous fungi [37]. *Aspergillus, Fusarium, and Penicillium* are the major mycotoxin-producing fungal species. In tropical climates where coffee is cultivated, mycotoxins fungi will grow optimally at temperatures between 25°C to 30°C [38]. In addition, decreased land suitability will increase plant stress which lead to plant diseases caused by mycotoxigenic fungi. Therefore, the decreasing level of land suitability can affect the productivity of arabica coffee plantations [30]. Climate change is predicted to reduce coffee productivity by 19% to 23% [35]. The predicted declining coffee production in the future will have further impacts, such as reduced employment opportunities, especially in small and medium-scale coffee cultivation. [36].

In some studies, CO_2 concentration is also considered as one of the bioclimatic variables affecting coffee cultivation. Recent studies have found that increasing CO_2 concentrations lead coffee species more resistant to rising temperatures by increasing photosynthesis and even potentially increasing crop yields [28], [31]. However, the concentrations of CO_2 can also have negative impact on coffee cultivation [39].

Prediction of land suitability for coffee product using big data analysis has been successfully carried out in several studies [12], [34], [36]. However, related studies, commonly, only utilized the WorldClim database. The studies have not included other bioclimatic conditions that affect climate change, specifically CO_2

concentration, as a bioclimatic variable to predict the land suitability area of Arabica coffee cultivations. In addition, the growth of mycotoxigenic fungi also needs to be considered as an influential variable, as it can affect the productivity of arabica coffee cultivations.

4. CONCLUSIONS

Future land suitability of coffee cultivations, particulary arabica, robusta, and liberica, in Indonesia were tend to increase in the future.

Big data analysis can be used to model the suitability of agricultural cultivation. The model can be generated from many databases, i.e., soil type, land elevation, CO2 concentration, as well as the altitude of a region to analyze its changes. However, the use of multiple databases should be considered to generate comprehensive research in the future.

Table 2. GIs Registered Coffee Product in Indonesia

Product Name	Geographical Origin
Kopi Liberika Tungkal Jambi	Jambi
Kopi Liberika Rangsang Meranti	Riau
Kopi Robusta Pasuruan	East Java
Kopi Robusta Lampung	Lampung
Kopi Robusta Semendo	South Sumatera
Kopi Robusta Temanggung	Central Java
Kopi Robusta Empat Lawang	South Sumatera
Kopi Robusta Pinogu	Gorontalo
Kopi Robusta Pupuan Bali	Bali
Kopi Robusta Tambora	West Nusa Tenggara
Kopi Robusta Kepahiang	Bengkulu
Kopi Robusta Sidikalang	North Sumatera
Kopi Robusta Java Bogor	West Java
Kopi Robusta Rejang Lebong Bengkulu	Bengkulu
Kopi Arabika Kintamani Bali	Bali
Kopi Arabika Gayo	Aceh
Kopi Arabika Baliem Wamena	Papua
Kopi Arabika Tanah Karo	North Sumatera
Kopi Arabika Flores Bajawa	East Nusa Tenggara
Kopi Arabika Kalosi Enrekang	South Sulawesi
Kopi Arabika Java Preanger	West Java
Kopi Arabika Java Ijen-Raung	East Java
Kopi Arabika Toraja	South Sulawesi
Kopi Arabika Java Sindoro-Sumbing	Central Java
Kopi Arabika Sumatera Simalungun	North Sumatera
Kopi Arabika Sumatera Mandailing	North Sumatera
Kopi Arabika Sumatera Koerintji	Jambi
Kopi Arabika Sumatera Lintong	North Sumatera
Kopi Arabika Flores Manggarai	East Nusa Tenggara
Kopi Arabika Sipirok	North Sumatera
Kopi Arabika Pulo Samosir	North Sumatera

Source: DGIP, 2021 (http://ig.dgip.go.id/)

AUTHORS' CONTRIBUTIONS

R B Nuary and R Setiyono led the write-up of the manuscript. R B Nuary collected the data and performed the analysis. All authors critically reviewed the paper and assisted with the interpretation of results and writing of the paper.

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