Geographic distribution of cocoa cultivation: Multicriteria analysis based on agroclimatic and biophysical parameters

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Abstract

The cultivation of cocoa (Theobroma cacao.L.) is an important base for the economy of many Ecuadorian families; however, the effects of climate change on the crop are becoming more noticeable, negatively affecting production and the reduction of agricultural soils. For this reason, the objective of the study was to determine the geographic distribution of cocoa cultivation through multicriteria analysis based on agroclimatic and biophysical parameters. Farmers' perception was measured through 12 questions using the Likert scale, which were treated by internal consistency analysis (Cronbach's alpha) considering a reliability greater than 0.70. The modeling of agroecological zoning in the period 2041-2060 of cocoa cultivation was carried out with a Geographic Information System (GIS) software under the Shared Socioeconomic Pathways (SSP) of climate change, using agroclimatic parameters (temperature, precipitation and altitude) and biophysical parameters (slope, soil texture, depth, hydrogen potential, natural drainage, organic matter and fertility level). The results indicate that 36% of cocoa farmers reported that rainfall causes an increase in pests and diseases in their plantations. The SSP1 scenario for the period 2041-2060 is favorable for the crop, due to agroclimatic conditions whose temperature is 25 to 26 °C, while the SSP5 scenario corresponds to moderate zones with 62%, i.e., the more natural resources are consumed, the less agricultural areas are available, making the soil vulnerable for agricultural activity.

KeyWords: Climate change, climate variability, scenarios, zoning, agro-ecological requirements.

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Introduction

Cocoa is derived from the seeds of Theobroma cacao.L., an evergreen tree typical of tropical regions (Cinar et al., 2021). Cocoa is generally native to the Amazon, but is now cultivated in the tropics, especially in South American countries, West and Central Africa, India, and Southeast Asia (Maney et al., 2022). Global cocoa production was valued at $24.5 billion in 2019 and is forecast to grow at a compound annual growth rate (CAGR) of 3.10%, to reach a value of $30.2 billion by 2026. Based on product type, the cocoa beans segment accounted for the largest contribution in the market and is expected to continue to lead throughout the forecast period (Kumar & Sable, 2019).

Cocoa is one of the main crops in Ecuador, occupying 12% of the cultivated area. Most of the cocoa production is destined for export, for the production of chocolate (Perez Neira, 2016). For this reason, the Instituto Nacional de Investigaciones Agropecuarias (INIAP, 2014) has one of the most important cocoa germplasm banks in the world with more than 2,500 accessions collected in different areas of the country, which have high yield characteristics, suitable for different agroecological zones and resistance to the main diseases that affect the crop due to the contamination caused by climate change (Perez Neira, 2016).

Climate change resulting from human activities is responsible for an approximate warming of 1.10˚C since 1850-1900, and it is predicted that the global temperature averaged over the next 20 years will reach or exceed a warming of 1.50˚C (IPCC, 2021). In this regard, cocoa farmers are aware of the causes and effects on the crop, however, studies have revealed that a small number of farmers tend to adapt to the changing climatic conditions (Wongnaa & Babu, 2020).

Climate change is a threat that is negatively affecting cocoa production, due to intense periods of drought and irregular rainfall causing the incidence of pests and diseases (CAF, 2020). In addition, it alters the development of the pods and affects farmers' economies (Agbongiarhuoyi et al., 2013). In this sense, climate change decreases the areas for agricultural productivity and, therefore, decreases the rate at which poverty can be reduced, estimating that by 2025 in Latin America, 6.90% of the total population would remain in poverty, due to the loss of 5.60% of the agricultural product due to global warming (Samaniego et al., 2017).

It is necessary to carry out the future agroecological zoning of the crop, considering the agroecological requirements according to the physiological and productive development, based on the methodology that allows identifying the sectorization of a territory with different criteria (Suárez et al., 2013). Being the (ZAE) one of the most useful tools to recognize the capacities of the land that allows defining zones based on combinations of topography, soil, land use and climatic characteristics (Nabati et al., 2020).

Finally, the climatic conditions in the Quinsaloma canton are intense rains and droughts, which generate the proliferation of pests such as witches' broom, monilla and black corncob in the crops. In addition, the agroclimatic and biophysical variables have a significant influence on the agroecological zoning of cocoa cultivation, estimating that the optimal zones will decrease considerably, even more so in the SSP5 scenario. The objective was to determine the geographical distribution of cocoa cultivation: multicriteria analysis based on agroclimatic and biophysical parameters.

MATERIALS AND METHODS

Localization

The research was conducted in the canton of Quinsaloma, province of Los Ríos, Ecuador, its geographical location is at 79°18' and 79°28' West longitude and 0°59' and 1°19' South latitude, its slope is 67 and 86 meters above sea level, the territorial extension reaches 275 km2, bordering to the north with the province of Cotopaxi, to the south with the canton of Ventanas, to the west with the canton of Quevedo and to the east with the province of Bolívar (Figure 1) and the characteristic climate of the area is sub-tropical humid (Ochoa et al., 2018).

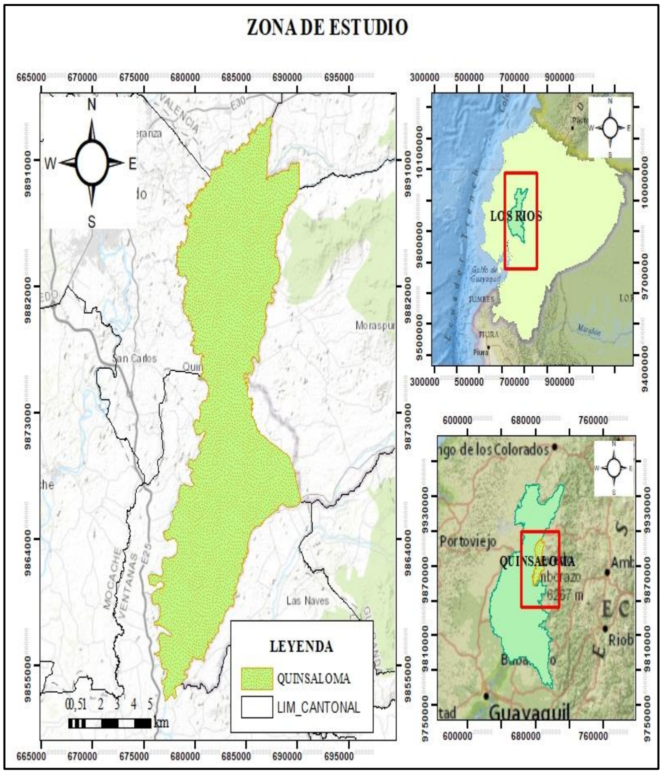

Figure 1. Location map of the Quinsaloma canton

The Method

The research design was non-experimental, based on Transectional or cross-sectional research, obtaining information data in an exploratory and descriptive way. On the other hand, the determination of the perception of farmers in the sample frame was the methodology of INEC (2021), which analyzes the strata by area of minimum stratification unit (Table 1) with agricultural use of cocoa.

Table 1. Agricultural Research Sampling Frame Strata

Stratum	Surface area of the EMU in agricultural use (ha)
Stratum 1	345 – 576
Stratum 2	115 – 345
Stratum 3	0 – 115

Ha= Hectare, UME= Minimum Unit of Stratification

The reliability of the instrument was assessed in the SPSS statistical software through the internal consistency analysis (Cronbach's alpha) considering reliability greater than 0.70 (Tuesca-Molina et al., 2021). Similarly, Principal Component Analysis (PCA) was used (Aidoo et al., 2021) through Bartlett and Kaiser-Meyer-Olkin (KMO) stratification test. The degree of significance was evaluated based on the methodology reported by (Applied Petrology Group, 2001) in the second one KMO values < 0.50 were considered unacceptable (Martinez Ques et al., 2022). In the total variance explained a range of 70-80% was considered (UCLA, 2021), finally, the analysis of the components was Varimax rotation, based on the variables whose value is greater than 0.65, as shown in Table 2 (Applied Petrology Group, 2001).

Table 2. Rotated Component Array

Questions	Component		
	1	2	3
Do you believe that droughts and floods are a product of climate change?	0,40	0,13	**0,68**
Has cocoa production been affected by the drought?	0,06	0,17	**0,89**
Do you think heavy rains can help the proliferation of pests or diseases?	0,11	**0,78**	0,34
Do you believe that diseases or pests such as witches' broom, monilla and black cob are generated due to climatic variations?	0,29	**0,71**	0,23
Do you consider that the use of agrochemicals contributes to the increase of climate change?	0,33	**0,76**	-0,08

Questions	Component		
	1	2	3
Would you be willing to receive training on strategies to mitigate environmental impacts in cocoa farming?	**0,75**	0,33	-0,06
Would you be willing to adopt new management measures on your crops in order to improve production yields and as a climate change adaptation measure?	**0,85**	0,27	0,15
Would you apply conservation techniques in your crop such as organic fertilizers, spraying instead of fumigation, triple washing of agrochemical containers, among others?	**0,85**	0,16	0,31
Do you think it is necessary to be informed about the events caused by climate change in agriculture?	**0,77**	0,20	0,29

Note: The values in bold are those that make up the components.

To model the future agroecological zoning of cocoa cultivation, climate change scenarios were analyzed through the atmospheric general circulation model (CGM) called MIROC-ES2L (Huang et al., 2021), the sixth phase of the Coupled Model Comparison Project (CMIP6) (Arias et al., 2021). Based on the Shared Socioeconomic Pathways (SSP), selecting the SSP1 "sustainability" and SSP5 "high fuel consumption levels" scenarios (Riahi et al., 2017), the projection was performed with a resolution of 1 Km2 (Bustamante, 2017).

Agroclimatic and biophysical parameters were extracted from the Geographic Information Layers of the Geoportal (IGM) (Instituto Geográfico Militar, 2017), CMIP6 data (Eyring et al., 2016) found in the Worldclim database (Fick & Hijmans, 2017). The evaluation of the multicriteria analysis considered the variable (Table 3), using geographic information systems software with UTM projected coordinates 1984 datum WGS zone 17S, to elaborate thematic maps illustrating agroecological zoning from 2041 to 2060. The criteria for zoning were based on agroecological requirements in four categories: optimal, moderate, marginal and unsuitable (MAGAP, 2020).

Table 3. Agroecological requirements for cocoa cultivation under natural conditions

Cocoa crop decision matrix (*Theobroma cacao* L)					
Component	Parameter	Characteristics of the agroecological zoning of the crop			
		Optimum	**Moderate**	**Marginal**	**Not apt**
Agroclimatic	Temperature (°C)	24-26	21-24	18-21	<18 y >26
	Precipitation (mm)	1800-2600	2600-3200 / 1500-1800	200-1500 / 3200-3800	<1200, >3800
	Altitude	0-500	500-1000	1000-1500	>1500
Biophysical	Pending (%)	Flat (0-2), very soft (2- 5), soft (5-12), medium (12-25)	Medium to strong (25-40)	Strong (40-70), very strong (70-100), steep (100-150))	Very steep (150-200), steep (>200)
	Soil surface texture	loam, clay loam, sandy loam, sandy clay loam, sandy clay loam	Silty loam, sandy clay, silty clay, silty clay loam, silty clay loam	Loamy, silty sand	Heavy clay, sand, clayey, clayey
	Depth (cm)	Deep (>100)	Moderately deep (51-100)	Low depth (21-50)	Superficial (11-20), very

Cocoa crop decision matrix (*Theobroma cacao* L)					
Component	Parameter	Characteristics of the agroecological zoning of the crop			
		Optimum	**Moderate**	**Marginal**	**Not apt**
					superficial (0-10)
	Soil pH	Medium acid (5.5-6.0), slightly acid (6.0-6.5)	Practically neutral (6.5-7.5), neutral (7)	Acid (4.5-5.5), slightly alkaline (7.5-8.0)	Very acidic (8.5)
	Natural drainage	Good	Moderate	Good, moderate	Excessive, poorly drained
	Soil organic matter	High - Coast (>2), high - Highlands (>5.0), high - Amazonia (6.0)	Medium - Coast (1.0-2.0), Medium - Highlands (3.0-5.0), Medium - Amazon (3.0- 6.0)	Low - Coast (<1.0), low - Sierra (<3.0), low - Amazon (1.5-3.0)	----------------
	Fertility level	High	Medium	Low, very low	--------------

°C= centigrade, cm= centimeter, mm= millimeter, < less than, > greater than
Source: (MAGAP, 2020).

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RESULTS

In the Cronbach's alpha analysis, reliability of 0.875 was obtained in the first iteration, a value very close to 1, highlighting the high reliability of the questionnaire. According to the analysis, the PCA in the Keiser-Meyer-Olkin test (KMO) yielded a value of 0.848, the relationship between the variables under study being very high. Bartlett's test yielded a value of 495.271 with a significance of 0.000 less than 0.05, which means that the factorial analysis is feasible.

In the total variance explained, the most statistically significant components were grouped in 3, obtaining the accumulated variance of the sum of the squared rotation saturations of 73.29%, being an acceptable value for the conformation of the groups according to their influence and to continue with the factorial analysis. Likewise, the Varimax axis rotation was performed, reaching components that present correlation with certain variables. The first component represents “The predisposition of farmers in the canton of Quinsaloma”, the second component “Effects of climate change” and the last component encompasses “The perception of citizens regarding climate change”. The results obtained are detailed below:

In relation to the components in Figure 2, a positive correlation is shown with items (a), (b), (c) and (d). Indicating that 47.50% (a) of cocoa farmers are predisposed to attend training to increase their knowledge and improve good environmental practices in the agricultural sector. Similarly, 48.33% (b) and (c) expressed their total agreement to apply sustainable alternatives that help mitigate the effects of climate change based on the application of organic fertilizers on their crops. In addition, as an excellent option to eliminate weeds from their crops, the population indicated that it is much better to spray than to fumigate, because it affects the plantations and decertifies the soil.

Meanwhile, 2.50% (a) and 1.67% (b) showed that they are not able to apply sustainable measures because they require more time and money. On the other hand, 60% (d) revealed that it is very important to be informed about climate variation events in regional, national and international agriculture in order to take actions to help mitigate the impacts within their plantations.

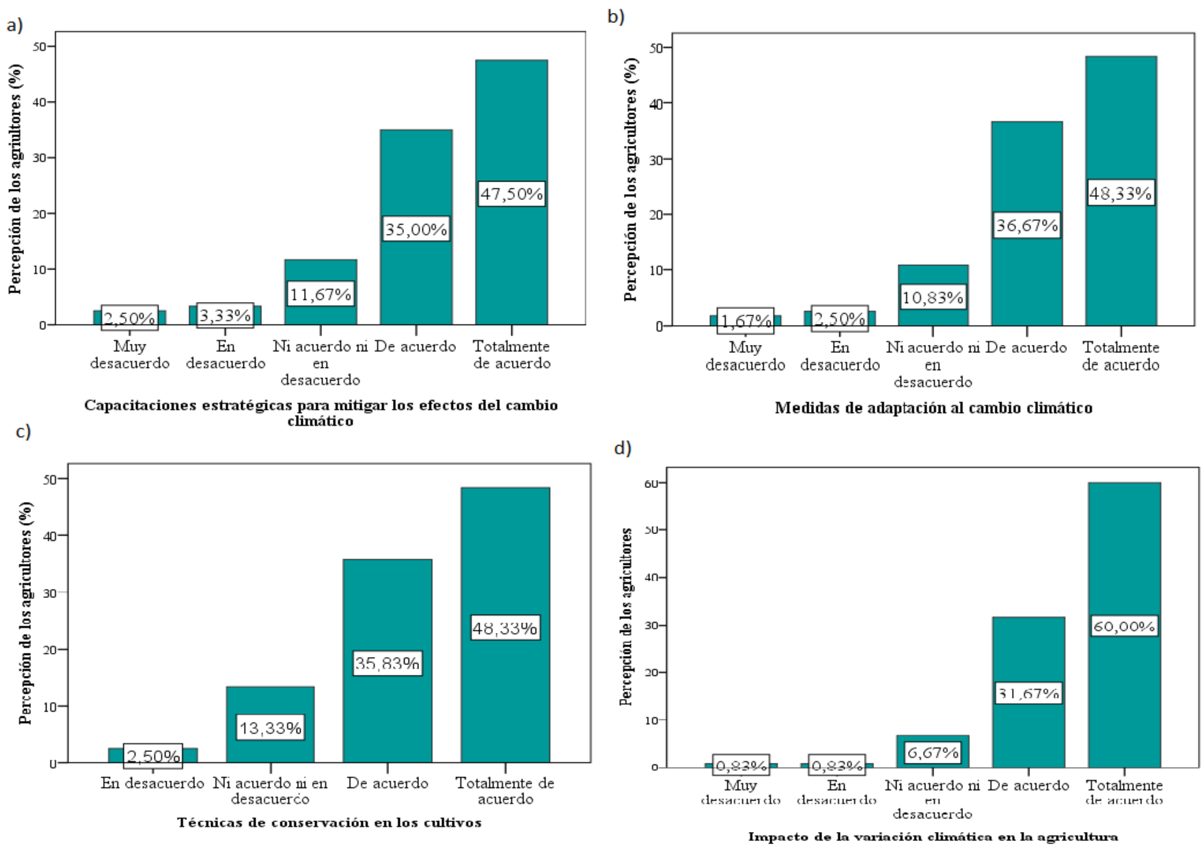

Figure 2. Predisposition of farmers in the Quinsaloma canton city

The correlation between variables (a), (b) and (c) showed that poor agricultural practices have generated several damages to cocoa plantations, highlighting that 35.83% and 31.67% (a) of farmers believe that excessive rainfall generates the increase of pests causing economic losses and sometimes the death of the plant. Similarly, 37.5% (b) of the farmers believed that pests or diseases such as the monilla fungus in conditions of high humidity, rainfall and temperature affect the growth tissues of the cocoa fruit (cob) causing considerable losses in crops, as well as witches' broom and black cob, which are caused by constant climate changes. On the other hand, farmers believe that the excessive use of agrochemicals contributes to climate variation represented by 33.33% (c) of the surveyed population from their point of view state that the direct application of agricultural inputs in the soil causes the loss of organic matter and pollution to the atmosphere.

However, 13.33% (a), 12.5% (b) and 17.50% (c) neither agreed nor disagreed with the cultural work carried out by the farmer, since they stated that the increase in pests is due to the farmer's bad practice of not pruning, cleaning the crop and planting under shade. They also pointed out that pests have always been in the crops and that it is only a matter of treating them with empirical techniques. This is a very worrying issue for society and the environment.

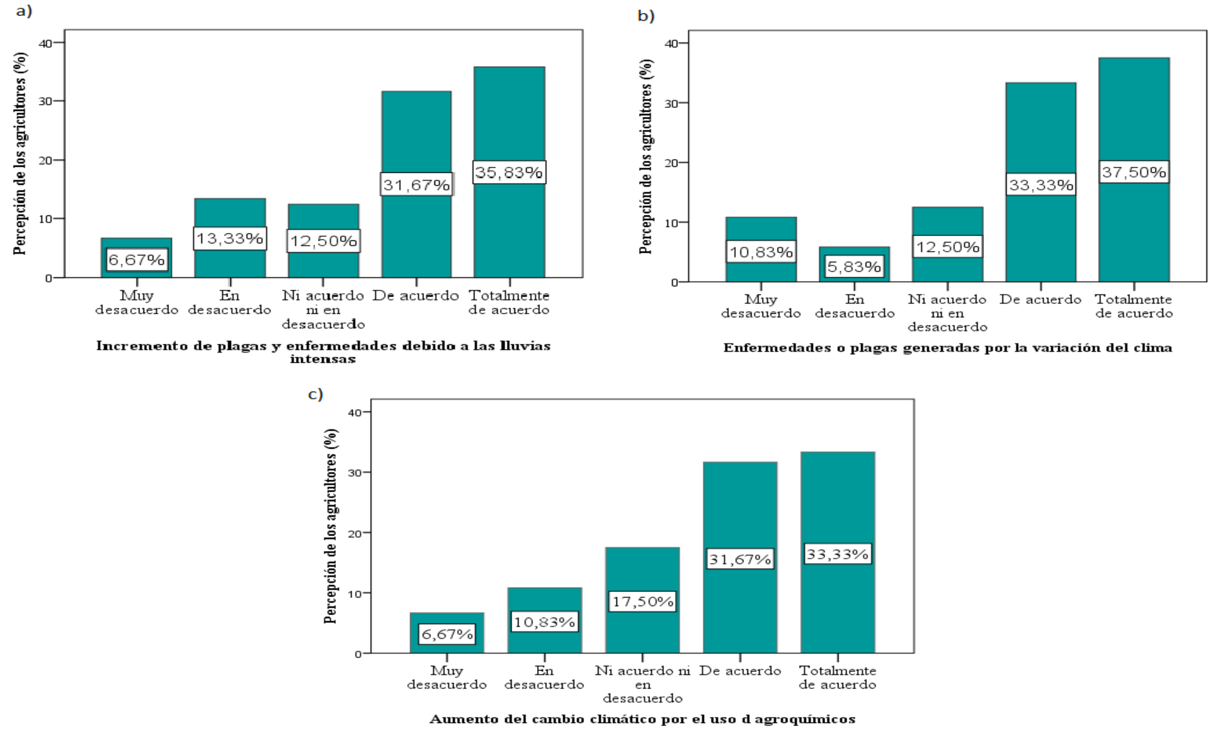

Figure 3. Effects of climate change on cocoa cultivation

Figure 4 shows a positive relationship with variables (a) and (b), with the highest percentages of 44.17% and 35% (a) stating that droughts and floods are the result of climate alterations due to high temperatures, intense rains and heat waves, which has caused climate change to increase drastically, affecting extensive hectares of crops, thus affecting the economy of the families that are exclusively dedicated to this activity. On the other hand, 10% (a) are undecided with the answer because they do not know exactly why droughts and floods occur. Similarly, 35.83% (b) revealed that they have been affected in the production of cocoa by drought, since it causes the fruit or cob not to develop fully, since it generates a low production and sometimes the plant may die due to lack of water resources. On the other hand, 10% and 15% (b) indicated that their crops have not been affected by droughts because they have an irrigation system that allows the growth and development of the plant to be optimal.

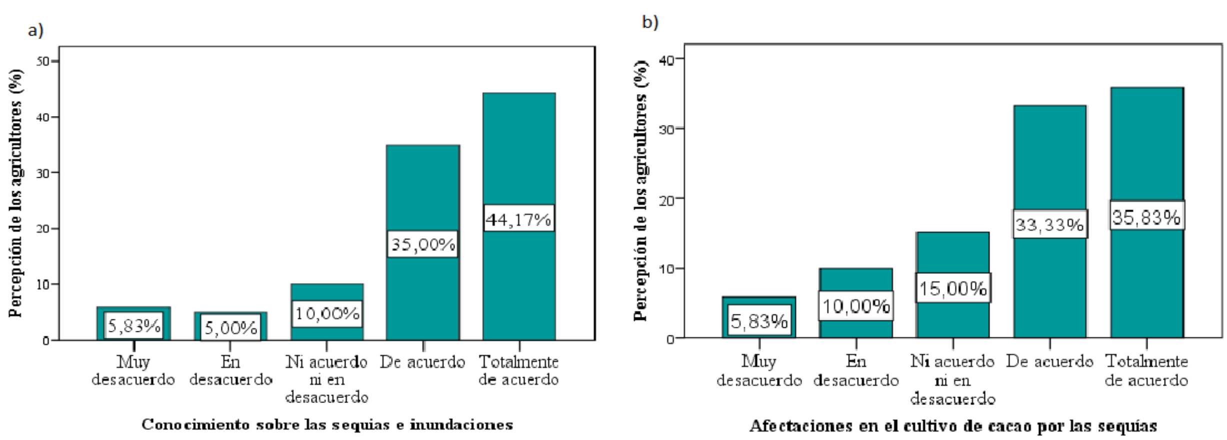

Figure 4. Citizen's perception of climate change

Agroecological zoning for cocoa cultivation under climate scenario SSP1 future projection 2041-2060

The future projection in the SSP1 scenario represents sustainability (Figure 5), obtaining considerable optimal areas of 76% (21,271 ha) for cocoa cultivation with temperatures of 25 to 26 ˚C and rainfall of 1912 to 2310 mm, which means that the crop tends to develop correctly, providing food and economic security to the population dedicated to this activity. Meanwhile, 23% (6,521 ha) corresponds to moderate areas with moderately deep soils, medium soil fertility and sandy loam texture.

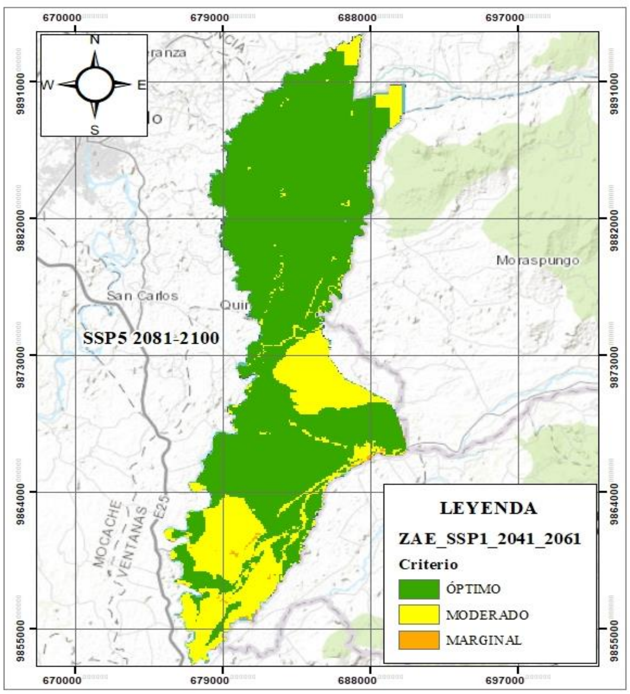

Figure 5. Agroecology zoning map for Quinsaloma canton SSP1 2041-2060

Agroecological zoning for cocoa cultivation under climate scenario SSP5 future projection 2041-2060

In the SSP5 scenario for the period 2041-2060 (Figure 6), it was found that there are no optimal areas for the development of cocoa cultivation, because with high consumption of fossil fuels, GDP growth, agriculture with a rapid increase in productivity, among others, the soil tends to be damaged and the areas are increasingly reduced. For this reason, 62% (17,417 ha) corresponds to moderate areas for cocoa cultivation with a temperature of 27 ˚C and rainfall of 2165 to 2622 mm, with more intense rainfall expected in the future. On the other hand, marginal zones correspond to 34% (9599) areas that do not meet agroecological requirements (Table 3) due to the constant climate changes generated by human activities, industrialization and inequality. Considering that for the 2041-2060 period in the SSP5 scenario represents a high contamination for the environment and society.

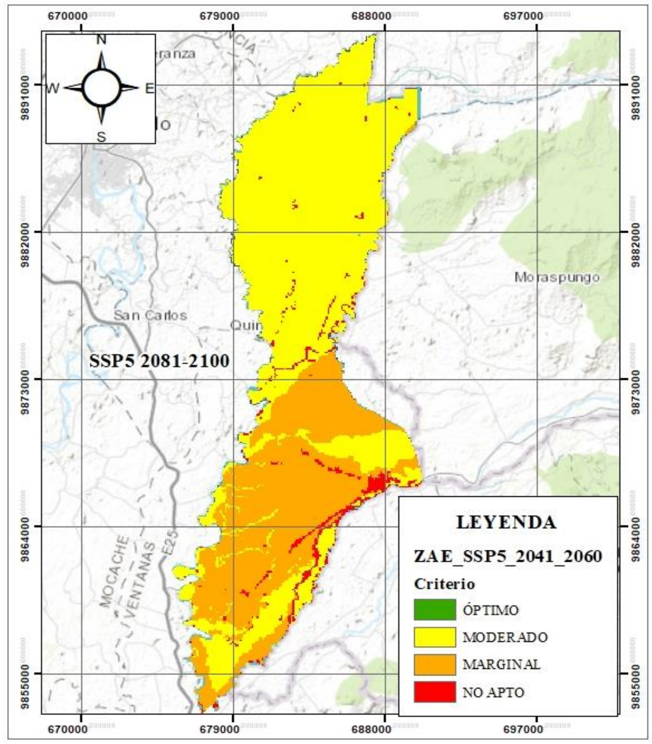

Figure 6. Agroecological zoning map for Quinsaloma canton SSP5 2041-206

DISCUSSION

The climatic conditions that negatively influence cocoa crop development are drought and rainfall results that are consistent with that reported by Gateau-Rey et al. (2018) indicating that drought caused high cocoa tree mortality (15%) and severe decrease in cocoa yield (89%); drought also increased the infection rate of the chronic fungal disease witches' broom. Furthermore, Lawal & Omonona (2014) revealed that excessive rainfall leads to low crop yields, while increases in temperature and relative humidity drive some physiological processes for pod production in cocoa.

The constant changes in climate also depend on the practice of cocoa farmers, as too many chemical inputs, inadequate washing of container tanks, leaks in storage tanks, discharged residues and accidental spills cause environmental pollution (Asela et al., 2014). Similarly, Tudi et al. (2021) mention that the use of pesticides can prove to be highly toxic to other non-target organisms (flora and fauna) as well as water resources and air quality; moreover, pesticides are toxic and expose farmers to risks due to the hazardous effects of these chemicals (Denkyirah et al., 2016). Most farmers do not handle pesticides carefully, reporting inadequate storage (Okoffo et al., 2016).

The strategies to be complied with by cocoa farmers is the application of organic fertilizers, cultural labors and an adequate destination for hazardous solid waste, criteria that contrast with Afriyie-Kraft et al. (2020) who report the strategy of irrigation of young cocoa farms, mulching to reduce the direct impact of heat on cocoa, felling of old cocoa and replanting with hybrid chemical spraying. On the other hand, Utomo et al. (2016) demonstrated that cocoa and coconut agroforestry represent an excellent strategy to conserve soil organic matter favoring the growth and activity of microbiota.

Singh et al. (2021) indicated that a large proportion of 80% of current cocoa orchards are in highly and exceptionally suitable classes; as well as the sustainable climate scenario of the period 2041-2060 show advantages in the area of the crop with 76% of optimal agroclimatic and biophysical conditions. On the contrary, Arcentales (2019) established that the future climatic suitability for cocoa cultivation in 2050 will dramatically reduce the area available for this crop, affecting the cocoa market and the provinces of the Coastal region will cease to be a cocoa producing area, which implies economic and social effects.

Given this problem, the province of Los Ríos will have an average temperature in the period 2019-2050 of 26.93 °C, with a progressive increase of 1.07 °C (González et al., 2020). Likewise, Igawa et al. (2022) identified a trend of increasing temperature and decreasing precipitation in areas with soils suitable for cocoa planting. This coincides to a certain extent with the data obtained in this research, since for the period 2041-2060 under the SSP5 scenario, temperature and precipitation tend to increase; both climatic variations generate heat waves, intense rains, droughts, among others, which are caused by unconscious human activities.

Within the canton Quinsaloma, there are areas already occupied with other activities which further reduces the land for cocoa production. The same states (Schroth et al., 2017) that climatic suitability refers to the probability that cocoa can be grown profitably on a site, revealing that not all areas identified as climatically suitable actually grow cocoa, as in some may be occupied by human settlements or different crops. Similarly, Ten Hoopen et al. (2019) report that by 2050 land use increases for food crop production will negatively impact global production by reducing optimal areas due to the massive consumption of natural resources.

Climate change, in addition to reducing cultivated land, also causes indirect impacts on the population and natural resources, as water, air and soil (Paitan & Verburg, 2022).

For this reason, it is estimated that for the period 2041-2060 in the SSP5 scenario, natural resources will be more limited and the edaphic conditions of soil texture, drainage, organic matter, and relief tend to decrease their potential, results that are related to Merchán-Benavides et al. (2019) stating that the lack of irrigation, poor drainage, shallow soil depth and salinity negatively influence cocoa cultivation. Similarly, Younis et al. (2021) states that through an optimistic trajectory (SSP1) up to 14Mha of land could be available until 2050, but higher that the soil could be more destroyed, due to higher productivity of land use(González Osorio et al., 2022).

CONCLUSION

The climatic conditions present in the canton of Quinsaloma are intense rains and high temperatures that generate droughts, which cause a decrease in crop yields and, therefore, the economy of farmers. Agroclimatic conditions also cause adverse effects such as diseases, pests, eroded soils, frequent use of biocides, runoff causing pollution to the environment and the health of the population. Agroecological zoning in the cocoa crop period 2041-2060 presented optimal areas under the sustainability scenario (SSP1) for production and the scenario (SSP5) the forecast is moderate and marginal based on the problems of soil fertility, organic matter, unsuitable soil texture and heavy rainfall.

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References

1. Afriyie-Kraft, L., Zabel, A., & Damnyag, L. (2020). Adaptation strategies of Ghanaian cocoa farmers under a changing climate. Forest Policy and Economics, 113(February), 102115. https://doi.org/10.1016/j.forpol.2020.102115
2. Agbongiarhuoyi, A., Abdulkarim, I., Fawole, O., Obatolu, B., Famuyiwa, B., & Oloyede, A. (2013). Análisis de los agricultores' estrategias de adaptación al cambio climático en la producción de cacao en Kwara Estado. Revista de Extension Agricola, 17(1), 10–22. https://doi.org/10.4314/jae.v17i1.2
3. Aidoo, E. N., Appiah, S. K., Awashie, G. E., Boateng, A., & Darko, G. (2021). Geographically weighted principal component analysis for characterising the spatial heterogeneity and connectivity of soil heavy metals in Kumasi, Ghana. Heliyon, 7(9), e08039. https://doi.org/10.1016/J.HELIYON.2021.E08039
4. Arcentales, E. (2019). Variación en la potencial distribución del cultivo de cacao en la Región Costa del Ecuador para el año 2050, debido al cambio climático. Pontificia Universidad Catolica Del Ecuador, 1–19.
5. Arias, P. A., Ortega, G., Villegas, L. D., & Martínez, J. A. (2021). La climatología colombiana en modelos CMIP5/CMIP6: Sesgos persistentes y mejoras. Revista Facultad de Ingeniería Universidad de Antioquia, 100, 75–96. https://doi.org/10.17533/UDEA.REDIN.20210525
6. Asela, D., Del Puerto Rodríguez, M., Susana, D., Tamayo, S., Daniel, L., & Palacio Estrada, E. (2014). Efectos de los plaguicidas sobre el ambiente y la salud. Revista Cubana de Higiene y Epidemiología, 52(3), 372–387.
7. Bustamante, D. P. (2017). Escenario De Cambio Climático a Nivel De Subcuencas Hidrográficas Para El Año 2050 De La Provincia De Chimborazo- Ecuador. La Granja, 26(2), 15. https://doi.org/10.17163/lgr.n26.2017.02
8. CAF. (2020). CACAO FINO Y DE AROMA PARA AMÉRICA LATINA Proyecto de investigación regional sobre producción de cacao sostenible adaptado al clima y cadmio. 1–15.
9. Cinar, Z. Ö., Atanassova, M., Tumer, T. B., Caruso, G., Antika, G., Sharma, S., Sharifi-Rad, J., & Pezzani, R. (2021). Cocoa and cocoa bean shells role in human health: An updated review. Journal of Food Composition and Analysis, 103, 104115. https://doi.org/10.1016/J.JFCA.2021.104115
10. Denkyirah, E. K., Okoffo, E. D., Adu, D. T., Aziz, A. A., Ofori, A., & Denkyirah, E. K. (2016). Modeling Ghanaian cocoa farmers' decision to use pesticide and frequency of application: the case of Brong Ahafo Region. SpringerPlus, 5(1), 1-17. https://doi.org/10.1186/S40064-016-2779-Z/TABLES/6
11. Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development, 9(5), 1937–1958. https://doi.org/10.5194/GMD-9-1937-2016
12. Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology, 37(12), 4302–4315. https://doi.org/10.1002/JOC.5086
13. Gateau-Rey, L., Tanner, E. V. J., Rapidel, B., Marelli, J. P., & Royaert, S. (2018). Climate change could threaten cocoa production: Effects of 2015-16 El Niño-related drought on cocoa agroforests in Bahia, Brazil. PLoS ONE, 13(7). https://doi.org/10.1371/JOURNAL.PONE.0200454
14. González, B., Barragán, R., Simba, L., & Rivero, M. (2020). Influencia de las variables climáticas en el rendimiento de cultivos transitorios en la provincia Los Ríos, Ecuador. Centro de Investigaciones Agropecuarias, 47(4), 54–64.
15. González Osorio, B., Enriquez Viteri, L., & Vlassova, L. (2022.). Ecosystem services of urban green spaces: Multicriteria spatial analysis model. https://doi.org/10.14704/nq.2022.20.6.NQ22165
16. Grupo de Petrología Aplicada. (2001). Análisis Multivariante con SPSS. Reducción de Datos: Análisis de Componentes Principales y Factorial. Universidad de Alixante. https://web.ua.es/es/lpa/docencia/practicas-analisis-exploratorio-de-datos-con-spss/practica-5-analisis-multivariante-con-spss-reduccion-de-datos-analisis-de-componentes-principales-y-factorial.html
17. Huang, J., Cang, J., Zhou, Z., & Gholinia, F. (2021). Evaluation effect climate parameters change on hydropower production and energy demand by RCPs scenarios and the Developed Pathfinder (DPA) algorithm. Energy Reports, 7, 5455–5466. https://doi.org/10.1016/j.egyr.2021.08.136

18. Igawa, T. K., de Toledo, P. M., & Anjos, L. J. S. (2022). Climate change could reduce and spatially reconfigure cocoa cultivation in the Brazilian Amazon by 2050. PLOS ONE, 17(1), e0262729. https://doi.org/10.1371/JOURNAL.PONE.0262729
19. INEC. (2021). Muestreo ESPAC 2020. Encuesta de Superficie y Producción Agropecuaria Continua.
20. INIAP. (2014). Cacao. Instituto Nacional de Investigación Agropecuarias. http://tecnologia.iniap.gob.ec/index.php/explore-2/mcafec/rcacao
21. Instituto Geográfico Militar. (2017). Cartografía de Libre Acceso Escala 50k – Geoportal Ecuador. Geoportal. http://www.geoportaligm.gob.ec/portal/index.php/cartografia-de-libre-acceso-escala-50k/
22. IPCC. (2021). El cambio climático es generalizado, rápido y se está intensificando. Grupo Intergubernamental de Expertos Sobre El Cambio Climático (IPCC).
23. Kumar, S., & Sable, K. (2019). Cocoa Products Market by Product Type and Application: Global Opportunity Analysis and Industry Forecast, 2019-2026. Cacao Products Markt. https://www.researchandmarkets.com/reports/4828620/cocoa-products-market-by-product-type-and
24. Lawal, J. O., & Omonona, B. T. (2014). The effects of rainfall and other weather parameters on cocoa production in Nigeria. Comunicata Scientiae, 5(4), 518–523.
25. MAGAP. (2020). Zonificación agroecológica del cultivo de cacao. Sistema de Informacion Publica Agropecuaria.
26. Maney, C., Sassen, M., & Hill, S. L. L. (2022). Modelling biodiversity responses to land use in areas of cocoa cultivation. Agriculture, Ecosystems and Environment, 324(September 2021), 107712. https://doi.org/10.1016/j.agee.2021.107712
27. Martínez Ques, Á. A., Braña Marcos, B., Martín Arribas, C., Vázquez Campo, M., Rumbo Prieto, J. M., López Castro, J., Herrero Olivera, L., & Gómez Salgado, J. (2022). Diseño y validación de un instrumento sobre calidad de la planificación anticipada de decisiones para profesionales. Gaceta Sanitaria. https://doi.org/10.1016/J.GACETA.2021.11.002
28. Merchán-Benavides, S., Delgado-Vera, C., Aguirre-Munizaga, M., Vergara-Lozano, V., Lagos-Ortiz, K., & Martínez-Carriel, T. (2019). Agro-Ecological Zoning of Cacao Cultivation Through Spatial Analysis Methods: A Case Study Taura, Naranjal. Advances in Intelligent Systems and Computing, 901, 88–98. https://doi.org/10.1007/978-3-030-10728-4_10/COVER
29. Nabati, J., Nezami, A., Neamatollahi, E., & Akbari, M. (2020). GIS-based agro-ecological zoning for crop suitability using fuzzy inference system in semi-arid regions. Ecological Indicators, 117, 106646. https://doi.org/10.1016/J.ECOLIND.2020.106646
30. Ochoa, F., González, B., Navarrete, D., & Sevillano, A. (2018). Las ONGs y su impacto en la adopción de tecnologías: Caso productores de cacao del cantón Quinsaloma, Ecuador. Revista Amazónica Ciencia y Tecnología, 7(3), 158–171.
31. Okoffo, E. D., Mensah, M., & Fosu-Mensah, B. Y. (2016). Pesticides exposure and the use of personal protective equipment by cocoa farmers in Ghana. Environmental Systems Research 2016 5:1, 5(1), 1–15. https://doi.org/10.1186/S40068-016-0068-Z
32. Paitan, C. P., & Verburg, P. H. (2022). Accounting for land use changes beyond the farm-level in sustainability assessments: The impact of cocoa production. Science of The Total Environment, 825, 154032. https://doi.org/10.1016/J.SCITOTENV.2022.154032
33. Perez Neira, D. (2016). Energy sustainability of Ecuadorian cacao export and its contribution to climate change. A case study through product life cycle assessment. Journal of Cleaner Production, 112, 2560–2568. https://doi.org/10.1016/j.jclepro.2015.11.003
34. Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change, 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009
35. Samaniego, J. L., Galindo, L. M., Mostacedo, S. J., Ferrer, J., Alatorre, J. E., & Reyes, O. (2017). Síntesis de políticas públicas sobre cambio climático. 4–5.
36. Schroth, G., Läderach, P., Martinez-Valle, A. I., & Bunn, C. (2017). From site-level to regional adaptation planning for tropical commodities: cocoa in West Africa. Mitigation and Adaptation Strategies for Global Change, 22(6), 903–927. https://doi.org/10.1007/s11027-016-9707-y
37. Singh, K., Fuentes, I., Fidelis, C., Yinil, D., Sanderson, T., Snoeck, D., Minasny, B., & Field, D. J. (2021). Cocoa suitability mapping using multi-criteria decision making: An agile step towards soil security. Soil Security, 5, 100019. https://doi.org/10.1016/J.SOISEC.2021.100019
38. Suárez, G. M., Florido, B. R., Soto, C. F., & Caballero, N. A. (2013). Bases para la zonificación agroecológica en el cultivo del cacao (Theobroma cacao, Lin) por medio del criterio de expertos. Cultivos Tropicales, 34(2), 30–37.
39. Ten Hoopen, G. M., Motilal, L. A., & Bekele, F. L. (2019). The role of agroforestry systems in reconciling food and cocoa (Theobroma cacao l.) and coffee (coffea spp. l.) production in a changing environment. Tropical Agriculture, 96(95), 98–109. https://doi.org/10.37234/TA96012019/00009601011
40. Tudi, M., Ruan, H. D., Wang, L., Lyu, J., Sadler, R., Connell, D., Chu, C., & Phung, D. T. (2021). Agriculture Development, Pesticide Application and Its Impact on the Environment. International Journal

of Environmental Research and Public Health 2021, Vol. 18, Page 1112, 18(3), 1112. https://doi.org/10.3390/IJERPH18031112
41. Tuesca-Molina, R., Rodríguez-Ávila, N., & Moreno-Castro, C. (2021). Escala de percepción ante crisis y pandemias: desarrollo y validación de una escala pedagógica. Educación Médica, 22(4), 199–205. https://doi.org/10.1016/J.EDUMED.2021.01.005
42. UCLA. (2021). Principal Components (PCA) and Exploratory Factor Analysis (EFA) with SPSS. Advanced Research Computing. https://stats.oarc.ucla.edu/spss/seminars/efa-spss/
43. Utomo, B., Prawoto, A. A., Bonnet, S., Bangviwat, A., & Gheewala, S. H. (2016). Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia. Journal of Cleaner Production, 134(Part B), 583–591. https://doi.org/10.1016/J.JCLEPRO.2015.08.102
44. Wongnaa, C. A., & Babu, S. (2020). Building resilience to shocks of climate change in Ghana's cocoa production and its effect on productivity and incomes. Technology in Society, 62(December 2019), 101288. https://doi.org/10.1016/j.techsoc.2020.101288
45. Younis, A., Trujillo, Y., Benders, R., & Faaij, A. (2021). Regionalized cost supply potential of bioenergy crops and residues in Colombia: A hybrid statistical balance and land suitability allocation scenario analysis. Biomass and Bioenergy, 150, 106096. https://doi.org/10.1016/J.BIOMBIOE.2021.106096