

Vulnerability to climate change of smallholder cocoa producers in the province of Manabí, Ecuador

Vulnerabilidad al cambio climático de pequeños productores de cacao en la provincia de Manabí, Ecuador

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ABSTRACT

Keywords:

Coverage
Deforestation
Extreme weather events
Rainfall
Temperature
Theobroma cacao L.

The consequences of climate change in the agricultural sector worldwide expose the need to understand the scope of their impact in order to develop mitigation and adaptation strategies for them. Therefore, this research evaluated the alterations in the environmental conditions and their relation with the vulnerability of smallholder cocoa (*Theobroma cacao* L.) producers to climate change in the province of Manabí. A non-probabilistic sampling of 1,060 small farmers was made in five cantons of Manabí. The vulnerability was determined through indicators such as the normalized difference vegetation index (NDVI), deforestation data from 1990 to 2016, models of the changes in climate and extreme weather events, satellite images, records from the National Institute of Meteorology and Hydrology (INAMHI by its initials in Spanish), and numerical outputs of mathematical models calibrated for Ecuador climatic and environmental data. Each indicator was calculated in conventional units and then categorized into vulnerability levels: low, medium, high and very high. For the indicators' superposition, algebraic tools of the Geographic Information Systems' (GIS) maps were used. The results showed a very high incidence of extreme events, deforestation higher than 6,000 ha year⁻¹, an increase of 0.8 °C in temperature between 1960 and 2006, an increase in rainfall on the coastal zone close to 90% and a decrease of it of more than 20% on the agricultural area. Furthermore, coverage showed the following distribution of the determined vulnerability levels: low (13.30%), medium (34.74%), high (45.53%), and very high (6.43%).

RESUMEN

Palabras clave:

Cobertura
Deforestación
Eventos climáticos extremos
Precipitaciones
Temperatura
Theobroma cacao L.

Las consecuencias del cambio climático en el sector agrícola a nivel mundial dejan expuesta la necesidad de entender los alcances de su impacto para así desarrollar estrategias de mitigación y adaptación para las mismas. Por lo tanto, esta investigación evaluó las alteraciones en las condiciones ambientales y su relación con la vulnerabilidad que tienen los pequeños productores de cacao (*Theobroma cacao* L.) al cambio climático en la provincia de Manabí. Se hizo un muestreo no probabilístico de 1.060 pequeños agricultores en cinco cantones de Manabí. La vulnerabilidad se determinó mediante indicadores como el índice de vegetación de diferencia normalizada (NDVI por sus siglas en inglés), datos de deforestación de 1990 a 2016, modelos de los cambios en el clima y eventos climáticos extremos, imágenes de satélite, registros del Instituto Nacional de Meteorología e Hidrología (INAMHI) y salidas numéricas de modelos matemáticos calibrados para datos climáticos y ambientales del Ecuador. Cada indicador se calculó en unidades convencionales y luego se categorizó en niveles de vulnerabilidad: baja, media, alta y muy alta. Para la superposición de los indicadores se usó herramientas algebraicas de los mapas del Sistema de Información Geográfica (SIG). Los resultados muestran una incidencia muy alta de eventos extremos, deforestación superior a 6.000 ha año⁻¹, un incremento de la temperatura en 0,8 °C de 1960 a 2006, un aumento en las precipitaciones en la zona costera cercano al 90% y una disminución en las mismas superior al 20% en la zona agrícola. Además, la cobertura arrojó la siguiente distribución en los niveles de vulnerabilidad: baja (13,30%), media (34,74%), alta (45,53%), y muy alta (6,43%).

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According to the IPCC (2014), the temperature of the planet's surface has increased by approximately 0.2 °C per decade since the 1980s; however, this phenomenon has been accelerating since the end of 1990. Likewise, the projections of mathematical climate models show increases to 2 °C in 2050 and up to 3 °C at the end of the century.

The studies of the International Center for the Investigation of the El Niño Phenomenon CIIFEN (2014), and Thieelen *et al.* (2015), have determined that the changes will be gradual and will be accompanied by an increase in climatic variability and extreme events, which will generate more frequent episodes of droughts and floods, as well as an increase in the intensity of rainfall. In Ecuador, future scenarios show increases in temperature in the coastal region and reductions in the precipitation in the northern center of the Manabí province where precisely much of the agricultural activity takes place, and water sources play an important role because they are mainly used for irrigation, human consumption, and hydroelectric energy generation (Muñoz, 2010).

According to Vergara *et al.* (2014), climate change has strong effects on agricultural activities. Considering that cocoa crops are susceptible to changes in environmental conditions, the occurrence of this variation has adverse effects on it. These extreme phenomena could cause an alteration in the development stages and rates of pests and diseases related to cocoa, a decrease in the incubation periods and development of harmful organisms, and high ease of introduction of invasive species as well as changes in their geographical distribution (Schroth *et al.*, 2016). Cocoa crops' productivity and all the socioeconomic variable related to it can be severely affected if those prone events happen; therefore, it is possible that 580,000 ha dedicated to the production of cocoa (*Theobroma cacao* L.) in Ecuador will be at risk. Approximately 60% of that agricultural area correspond to smallholder producers that have less than 3.5 ha each, and whose total cocoa production generate 820 million dollars of earnings to the country which equivalent to 0.6% of GDP (ANECACAO, 2015).

Recent research found tremendous effects on cocoa cultivation due to drought events, reporting losses in

production yields between 10 and 46% in Indonesia (Schwendenmann *et al.*, 2010). Gateau-Rey *et al.* (2018) found in farms, chosen randomly in Brazil, a high mortality of cocoa trees (15%) and a severe decrease in cocoa yield (89%), as well as an increase in the rate of infection of the chronic fungal disease *Moniliophthora perniciosa* after the environmental conditions imposed by the Niño phenomenon between 2015 and 2016. These findings, in the opinion of the authors, demonstrate that cocoa producers are at risk, and the increasing frequency of strong weather events will likely cause a decline in cocoa yields in the coming decades. Besides, cocoa and other crops can be the warning of the next important effects of the climate change on the natural and semi-natural vegetation.

Regarding the Ecuadorian outlook, the MAGAP (2015) reported that yields in cocoa production systematically had been increasing since 2002. Going from a national average of 0.17 to 0.60 t ha⁻¹. Only a shrinkage has been reported in 2012 that registered a 40% decrease in the total production (133 t) compared to 2011 (230 t), which undoubtedly is related to the occurrence of the La Niña Phenomenon in the South American coast between 2010 and 2011, generating strong droughts with a devastating effect on agricultural activities.

Although there are reports about annual cocoa yields, there are no studies that show the relationship between climate change and the alteration in the environmental conditions with the production of cocoa (*T. cacao* L.). Therefore, this research evaluated the alterations in the environmental conditions and their relation with the vulnerability of smallholder cocoa (*Theobroma cacao* L.) producers to climate change in the cantons of Chone, Tosagua, Bolívar, Junín, and Portoviejo in the province of Manabí. The vulnerability was determined based on the indicators such as the normalized difference vegetation index (NDVI), deforestation data from 1990 to 2016, models of the changes in climate and extreme events, satellite images, records from the National Institute of Meteorology and Hydrology (INAMHI by its initials in Spanish), and numerical outputs of mathematical models calibrated for Ecuador climatic and environmental data. Each indicator was calculated in conventional units and then categorized into vulnerability levels: low, medium, high and very high.

MATERIALS AND METHODS

The study was carried in a total area of 2,134.50 ha in the cocoa agricultural regions of Chone (0°37'59.5"S, 79°55'17.7"W), Bolívar (0°50'31"S, 80°09'43"W), Tosagua (0°47'02.2"S, 80°14'06.8"W), Junin (01°01'20.2792"S, 080°27'38.5844"W), and Portoviejo (1°01'20.3"S, 80°27'38.6"W) in the province of Manabí, Ecuador. A non-probabilistic sample of 1,060 smallholder farmers was used, these cocoa producers were selected because they have territory extensions of less than 5 ha and are certified as organic cocoa producers. Unstructured surveys and interviews were carried out to verify the information; the collected data was complemented with the direct observation on the premises and interviews of technicians of governmental institutions and advisers of rural producers.

For the chosen cocoa agricultural areas, their vulnerability to climate change was determined through several climatic and environmental indicators such as the Normalized Difference Vegetation Index (NDVI), the deforestation coverage, the occurrence of extreme weather events, the models of climate changes as well as the superposition of the digital information of the same. Besides, the vulnerability was classified into four levels: very high, high, medium and low.

Generation of indicators based on satellite data

The satellite information and its geometric corrections were made according to the methodology proposed by Montilla Pacheco and Pacheco Gil (2017) in order to process the image of the Landsat 8 sensor, LC80110612016332LGN00, from November 2016. The objective of this procedure is to orient the pixel positions regarding Ecuador's cartographic reference system through control points (GCP).

Radiometric corrections

The methods that tend to eliminate dispersion by subtraction were applied in order to approximate the response received by the sensor with the real object observed on the earth's surface. The method used in this phase was the minimum histogram. According to Hum *et al.* (2014), it is limited to subtract in each band the minimum value observed since it assumes that in a scene there can be some pixels in total shadow, which in the absence of atmosphere would and should not reflect

any solar energy. With these procedures, more accurate data were obtained than previous versions of Landsat, incorporating substantial improvements in geometrical and radiometric aspects, according to the studies of Mishra *et al.* (2016), Sousa and Small (2017), and Roy *et al.* (2016).

Calculation of the Normalized Difference Vegetation Index (NDVI)

This index was determined according to the approaches of Baihua and Burgher (2015), to determine the characteristics of the vegetation in semi-arid zones in ecological conditions similar to those present in the studied places. The NDVI is obtained with the equation:

$$NDVI = \frac{(NIR - VISR)}{(NIR + VISR)}$$

Where:

NIR: Near-infrared band.

VISR: Red band

With the application of the above equation, an image with normalized magnitudes between -1 and 1 was generated, where the negative values and close to 0 indicate zones devoid of vegetation, and those leading to 1 indicate areas with very dense cover vegetation. This coverage was reclassified into four vulnerability levels through a spatial distribution analysis (Table 1).

Coverage of deforestation

The historical deforestation information of the MAE (2017) was used for the periods 1990-2000, 2000-2008, 2008-2014, and 2014-2016. With the Geographic Information Systems (GIS) the four coverages (bare soil, dry forest, transition forest, and humid forest) were united in a single map, which was reclassified in a Boolean image with low and very high vulnerability levels for the zones without deforestation and with deforestation, respectively.

Extreme weather events and models of climate changes

The historical data of the INAMHI were used to define the affectation due to extreme weather events, considering as extreme the cases above the last quartile and below the first one of the series of data for the period 1970-2016. On the other hand, the proposal of

Schroth *et al.* (2016) was considered for the models of climate changes, processing the numerical outputs generated by the MAE (2017) and INAMHI (2017) with the ETA and TL959 models, these models presented the best correlations with the historical records for precipitation and temperature, respectively. Shapefiles were constructed with the information obtained from these models, with the coverage of changes in precipitation and temperature for the province of Manabí; categorizing the vulnerability into four levels according to the climate elements in very high, high, medium and low.

RESULTS AND DISCUSSION

The Normalized Difference Vegetation Index (NDVI) reported values ranging from -0.278 to 0.549, with an average of 0.212. Coverage of transition and dry forest comprised about 70.35% of the territory studied and had a medium and high vulnerability, respectively (Table 1). Although the humid forest presented a low vulnerability when the experiment was carried out, it is an area that must be monitored since it could be potentially used for agriculture expansions to sow cocoa and other crops. It is notable that this area represented more than 25% of the studied zone.

Table 1. Categorization of vulnerability according to the normalized difference vegetation index.

NDVI	Surface		Vulnerability level	Type of coverage
	(km ²)	(%)		
0.00-0.10	99.24	3.25	Very high	Bare soil
0.10-0.18	904.09	29.58	High	Dry forest
0.18-0.27	1,246.23	40.77	Medium	Transition forest
>0.27	779.175	25.49	Low	Humid forest
<0.00	279.504	0.91	Null	Water bodies

The search for new sites suitable for producing cocoa could trigger the clearing of forests and natural protected areas, which are important for flora and fauna habitats (Ruf *et al.*, 2015). In this sense, Turbay *et al.* (2014) recommend adequate shade management in crops, renewal with disease-resistant varieties, crop association, plant cover, stepped

sowing, and reforestation as strategies to reduce vulnerability to climate change. As Figure 1 shows, the vulnerability levels very high and high are mostly located in areas close to the coast, where dry forest coverage predominated; while low vulnerability was distributed in the central western mountainous area with predominance of the humid forest coverage.

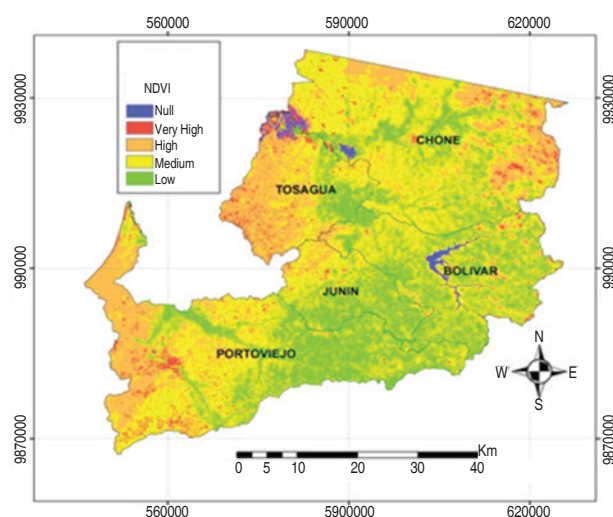


Figure 1. Spatial distribution of vulnerability in response to the normalized difference vegetation index (NDVI).

Deforestation

Table 2 and Figure 2 show the concentration of the deforested areas in the northern part of the studied zone which belong to Chone and Bolívar cities, encompassing a total deforested area of 392.06 km² (12.8% of the studied area) between 1990 and 2016, with a deforestation rate higher than 1,500 ha year⁻¹.

High deforestation is attributed to changes in land use, generally for agricultural activities such as mainly extensive cattle-breeding and short-cycle crops. The practice of these activities with technologies that are not friendly to the environment increases vulnerability to climate change because it favors the emission of greenhouse gases and the loss of forest and soil

Table 2. Deforestation during the period 1990-2016.

Deforestation Period (1990-2016)	Surface		Vulnerability Level
	(km ²)	%	
Forested area	2,661.18	87.16	Low
Deforested area	392.06	12.84	Very high

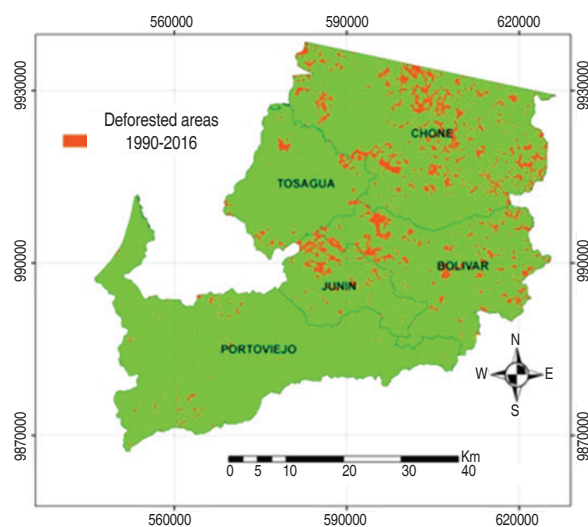


Figure 2. Spatial distribution of deforestation due to agricultural activities between 1990 and 2016.

resources (MAE, 2017). This information is consistent with studies conducted in West Africa, reported by Ruf *et al.* (2015), where cocoa cultivation is indicated as an important deforestation driver. On-site detection for replanting old plantations, farmers usually migrated to the forest borders to establish new cocoa farms in order to find more humid areas to sow it.

Deforestation has a direct relation to climate change. Forest degradation leads to the loss of carbon dioxide repositories. The carbon storage compartments in trees are aerial biomass, mainly in the trunks of woody

plants and leaves; there is also underground biomass that stores it in the root tree network. The carbon accumulated by trees, and hence by the forest, can move and be stored in the soil due to the necromass and plant litter.

The main tool to prepare agricultural land is the burning of green areas and forest; this practice leads to increase deforestation. Besides, scorched vegetation releases CO₂, CH₄, N₂O, ozone precursors, and aerosols (including black carbon) to the atmosphere. The vegetation that develops after a fire is going to absorb and consume

atmospheric CO₂ and nitrogen. Anthropogenic land management or land transformation through fire leads to an increase in the levels of disturbance or permanent clearance of forest. This action results in net emissions to the atmosphere over time. Satellite detection of fire occurrence and persistence has been used to estimate fire emissions. However, it is hard to separate the source of fire as natural or anthropogenic. These conditions are intensified in the studied area due to an average of 400 kg of nitrogen fertilizer is used per extension and livestock is produced with a loading capacity of only 1 head ha⁻¹, wherewith the great influence of deforestation on the land of smallholder cocoa producers in the Province of Manabí was determined.

Fieldwork carried out in the studied area, and the use of dated satellite images interception updated how is the processes of continuous deforestation with current trends – an estimation of 4,000 ha year⁻¹ in the rural territory, which represents approximately 20.00 km². However, these data do not represent facts. The Ecuadorian government ratified the commitments made in the Paris agreement and presented a zero deforestation goal for the year 2025. Public policies and citizen training must be implemented to achieve the objectives, which

imply significant changes in the current technologies production and incorporation of sustainable mechanisms economically and environmentally speaking.

Extreme weather events

The thermal and rainfall regimes in the central region of the Manabí province are characterized by a high seasonality, related to the seasonal warming of the equatorial Pacific and the displacement of the intertropical convergence zone (Thielen *et al.*, 2015). During this seasonality, anomalies with a high incidence of extreme weather events such as La Niña and El Niño phenomenon occur. These phenomena produce two extreme conditions such as intense periods of drought or rainfall, the occurrence of one of them depending on the geographical zone that they occur. Therefore, cocoa crops are susceptible to these both weather extreme event (Ojo and Sadiq, 2010).

The analysis of climate data shows that the frequency of positive and negative thermal anomalies (El Niño and La Niña), which generate extraordinary rainfall and drought is very high in the equatorial Pacific. Therefore, the entire coastal area of Ecuador has a very high vulnerability to extreme events of this type (Figure 3).

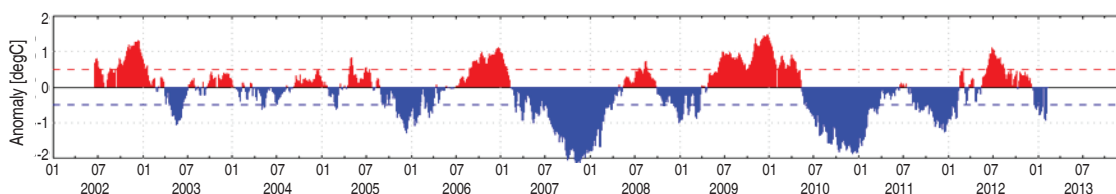


Figure 3. Thermal anomalies in the sea surface temperature of the Equatorial Pacific Ocean between 2002 and 2012.

During 2015, 2016, and 2017 the extraordinary rains, related to the anomalous warming of the sea surface in the equatorial Pacific coast, altered the historical averages in the precipitations, the solar brightness, and the environmental temperature causing severe impacts in the flowering, the ears' development, and the growth of the cacao trees (MAGAP, 2015). The rainfall in the Ecuadorian coastal area has exceeded, in some cases, more than 500% of the historical averages (INAMHI, 2017).

Regarding the incidence of these climatic alterations in cocoa cultivation, Schrot *et al.* (2016) report that

the cocoa fruit does not develop completely during the droughts, and very intense rains diminish the flowering and the fruit set; hence, both events reduce cocoa productivity. On the other hand, in response to the increase in temperature, the cacao trees restrict the development of pods to get the most water for growth. MAGAP reported the increasing incidence of the monk because of the El Niño phenomenon in 2017. It is known this pest occurs in rainy seasons, where the temperature and humidity conditions are favorable for the growth of the fungus *Moniliophthora roreri* which causes watery cocoa rot (INIAP, 2015).

Considering environmental conditions for the criteria the normal development of cocoa cultivation occur at temperatures between 18 and 34 °C and precipitations per cycle from 1200 to 3000 mm are required (INIAP, 2015). The average monthly precipitation range required for cocoa cultivation is 125 mm. When rainfall does not cover water needs, farmers must use irrigation (in areas with water availability) to compensate the deficit and avoid production losses. The entire province was categorized in a very high vulnerability to cocoa cultivation considering the high frequency in the occurrence of extreme events.

Gateau-Rey *et al.* (2018) reported severe decreases in the soil's water content, because of the extreme weather

events caused by the El Niño phenomenon in Brazil from 2015 to 2016. The water deficit of the soil has a great influence on the yield decrease of the cocoa crop.

Model of the climate changes

The decrease in precipitation is located precisely in the mountainous zones recognized as water-producing areas (Figure 4); therefore, this decrease has a direct effect on the availability of water for future irrigation systems in cocoa areas since the monthly rainfall average in them barely exceeds the amount required by the crop (125 mm year⁻¹). On the other hand, the increase in temperature would affect the availability of water due to the increase in evapotranspiration although it would not surpass the optimal temperature limits of cocoa crops (Muñoz, 2010).

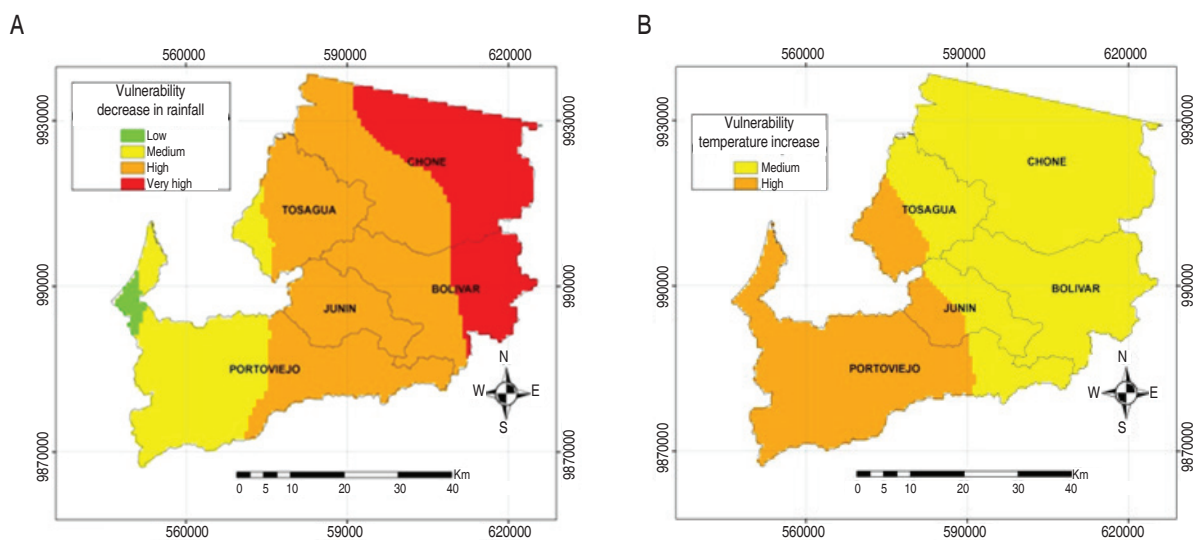


Figure 4. Vulnerability according to A. Decrease in rainfall; B. Temperature increase.

The effects related to extreme events in the climate could generate great consequences for the global production of cocoa, not only because of the physiology of the plant but also because of the increase of diseases and pests (Ruf *et al.*, 2015).

The categorization of vulnerability due to climatic events showed that 34.69% of the studied area has a high vulnerability to temperature variations, with increases of up to 0.8 °C (Table 3). On the other hand, 54.51% of the territory is highly vulnerable to the decrease in rainfall levels, with negative values between 40 and 50% of the total annual rainfall; that variation means that the crop

could be affected since the lack of water affects the floral development.

The results of the model of climate changes suggest the loss of environmental capacity for the cocoa cultivation in the coast, the increase of the temperature would displace the crop areas to higher altitudes. This situation is contrary to the results found by the CIAT (2014) for Ecuador's Andean region, where cocoa crops move to lower areas.

As a strategy to face the problem, it is necessary to update the information with research on irrigation

systems suitable for cultivation. Parallel to it, there should be formulated government policies to help farmers and the cocoa industry to prepare for facing and adapting to climate change.

Table 3. Vulnerability categorization according to thermal and rainfall anomalies.

Thermal elevation (°C)	Surface		Decrease in rainfall (%)	Surface		Vulnerability level
	(km ²)	(%)		(km ²)	(%)	
>0.8	0	0	>50	724.24	23.81	Very high
0.4-0.8	1,058.6	34.69	40-50	1,658.26	54.51	High
0.2-0.4	1,994.1	65.31	30-40	627.78	20.64	Medium
<0.2	0	0	<30	31.63	1.04	Low

Vulnerability summary

The overlapping of the indicators reflects the total vulnerability in four levels (Table 4), where most of the areas evaluated are categorized into a high and very

high vulnerability, they together account for more than 50% of the territory. This result implies urgent needs to implement mitigation and adaptation measures to climate change.

Table 4. Categorization of the total vulnerability.

Surface		Vulnerability level
(km ²)	(%)	
190.53	6.43	Very high
1,349.29	45.53	High
1,029.64	34.74	Medium
394.05	13.30	Low

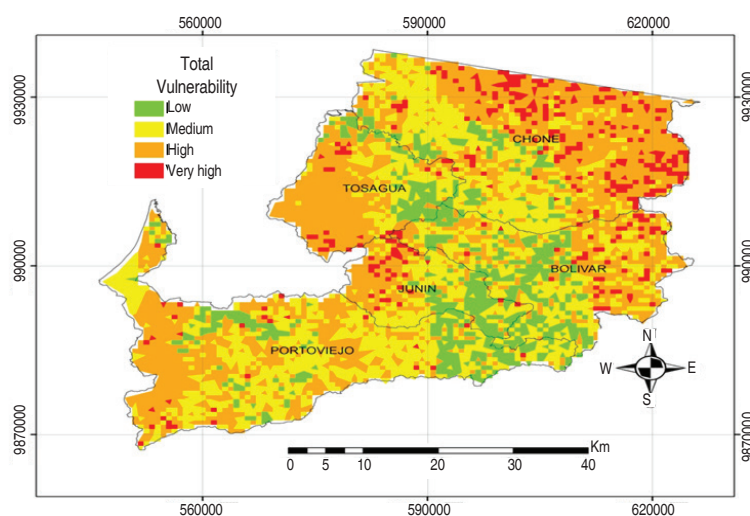


Figure 5. Spatial distribution of the total vulnerability.

This study also specified the particularly vulnerable areas (Figure 5) to lead decision making by cocoa producers in these areas. They need to implement strategies for the adaptation and mitigation to bear the climate change, which will allow them to enrich or maintain the productivity of the cocoa crops. Apply those measures is not possible if they do not possess the knowledge, the tools, and the support of governmental and institutional entities. Nowadays, several alternatives can be implemented such as agro-tourism, the integration of family labor, community and union associations, day labor, and marketing strategies; the latter alternative encompasses fair markets and product certifications that help to improve sales prices and withstand the moments of crisis. These strategies can be adapted to the cultivation of cocoa in the studied area.

CONCLUSIONS

The indicators analyzed yielded that the normalized vegetation difference index groups 34% of the studied territory into high and very high vulnerability to climate change. Besides, 12% of the territory presents deforestation, going from forest cover to agricultural mosaic, due to unsustainable agricultural practices regarding the climate effects. The province of Manabí is exposed to frequent extreme weather events such as droughts and floods which is evidenced by the anomalies of the sea surface temperature; actually, 77% of its territory presented high and very high vulnerability to the models of the climate changes. The combined action of all the studied indicators generates high and very high vulnerability in 52% of the territory analyzed. These results suggest the need to consider scenarios for the implementation of adaptation and mitigation measures that increase the resilience of populations and ecosystems to the effects of climate change.

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