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URBAN GROWTH AND VULNERABILITY TO CLIMATE CHANGE OF CALDERÓN IN THE METROPOLITAN DISTRICT OF QUITO, ECUARDOR [1]

CRECIMIENTO URBANO Y VULNERABILIDAD AL CAMBIO CLIMÁTICO DE CALDERÓN EN EL DISTRITO METROPOLITANO DE QUITO, ECUADOR

JOHANNA ELIZABETH VILLAVICENCIO-ORDÓÑEZ 2
DIANA RAQUEL LÓPEZ-GUZMÁN 3
ÁNGEL PATRICIO VELÁSQUEZ-CAJAS 4

1 This work is part of the Curriculum Integration Project

2 Magíster en Investigación en Estudios Urbanos
Estudiante de la Tecnología en Gestión Territorial del Cambio Climático
Instituto Superior Universitario Cotopaxi, Latacunga, Ecuador
https://orcid.org/0000-0002-0033-7282
jevillavicencioo@istx.edu.ec

3 Magíster en Dirección y Administración de Empresas
Docente de la Tecnología en Gestión Territorial del Cambio Climático
Instituto Superior Universitario Cotopaxi, Latacunga, Ecuador
https://orcid.org/0000-0003-3507-4766
drlopezg@istx.edu.ec

4 Magíster en Creación de Guiones Audiovisuales
Docente de la Tecnología en Gestión Territorial del Cambio Climático
Instituto Superior Universitario Cotopaxi, Latacunga, Ecuador
https://orcid.org/0000-0002-1814-1691
apvelasquezc@istx.edu.ec

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La parroquia Calderón, ubicada en el Distrito Metropolitano de la ciudad de Quito, presenta una dinámica espacial característica de los procesos de expansión con un crecimiento poblacional notable, pérdida de suelo agrícola y asentamientos en áreas vulnerables. Esta investigación tuvo como objetivo identificar la vulnerabilidad al cambio climático mediante análisis del crecimiento urbano de la parroquia Calderón para definir medidas de adaptación al mismo. Se utilizó la metodología de enfoque mixto a través de tres etapas: análisis histórico y espacial del crecimiento urbano, relación entre el crecimiento urbano y vulnerabilidad al cambio climático y medidas de adaptación al cambio climático en la parroquia Calderón. Los trece indicadores analizados demuestran en sus componentes de exposición y sensibilidad un nivel medio bajo de riesgo, sin embargo, sucede lo contrario en el componente de capacidad adaptativa donde la vulnerabilidad es alta. La relación entre el crecimiento urbano de la parroquia y la vulnerabilidad al cambio climático no es directa. Por una parte, los procesos de expansión afectan al territorio y a la población, originando conflictos ambientales y sociales y, por otra, se evidencian factores que están inmersos en la propia dinámica espacial de la expansión urbana.

Palabras clave: cambio climático, crecimiento urbano, exposición, sensibilidad, vulnerabilidad

The parish of Calderón, located in the Metropolitan District of Quito, has a spatial dynamic characteristic of the expansion processes, with notable population growth, loss of agricultural land, and settlements in vulnerable areas. This research aimed to identify the vulnerability to climate change by analyzing urban growth in this parish to define measures for its climate change adaptation. A three-stage mixed approach methodology was used: the historical and spatial analysis of urban growth, the relationship between urban growth and vulnerability to climate change, and climate change adaptation measures in the parish of Calderón. The thirteen indicators analyzed show a medium-low risk level in their exposure and sensitivity components. However, the opposite is true for the adaptive capacity component, where vulnerability is high. The relationship between the parish's urban growth and vulnerability to climate change is not direct. On the one hand, the expansion processes affect the territory and the population, causing environmental and social conflicts. On the other hand, factors immersed in urban expansion's spatial dynamics are revealed.

Keywords: Climate change, urban growth, exposure, sensitivity, vulnerability.

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I. INTRODUCTION

In Latin America, urban growth occurs in an accelerated and disorderly way, reflecting "deep causes of an economic and social origin, along with a lack of adequate urban planning" (Herrera & Pecht, 1976, p. 18). Consequently, problems such as regional and urban network imbalance, marginality, unemployment, absence of essential services, and increased urbanization in the peripheries are revealed (Vilela & Moschella, 2017). However, climate change has become one of the current narratives that influence the political, economic, territorial, and cultural spheres, and this, accompanied by accelerated urbanization processes, is a significant challenge. Firstly, urbanization in developing countries is related to being less prepared for environmental challenges. Secondly, large cities are vulnerable to climate change risks such as losing natural resources or even natural disasters. Thirdly, cities produce the highest level of greenhouse gases and energy consumption (Duque & Montoya, 2021). Similarly, urban expansion causes variations in air temperature that can affect the residents' well-being (Ferrelli et al., 2016).

According to the UN (2011), understanding urban area growth is essential to mitigating climate change. These areas have obvious risks from weather patterns that have become the daily realities of the most vulnerable population. The analysis of climate and environmental change in the context of Latin America and the Caribbean is particularly relevant, given that it is a primarily urban region. Cities are home to more than 80% of the population and most economic activities, which generates a high demand for land, public services, drinking water, and energy. This, in turn, seriously impacts air quality and greenhouse gas emissions (Duque & Montoya, 2021). Therefore, urban growth has replaced forests, wetlands, and agricultural fields, as can be seen in the study by Mendes et al. (2020), who note that "the homogeneity of hot and humid areas eliminates the thermal contrasts needed to generate local breezes and winds" (p. 192), which explains the high levels of pollution in medium-sized and large cities.

In this context, the studies reviewed on urban expansion in Calderón confirm the parish's situation in terms of territorial and environmental conflicts. For example, Altamirano's (2016) research shows that urban expansion is related to the environment. He points out that demographic growth has been generated by diverse factors such as the location of residential, industrial, and equipment areas. This presents an environmental impact due to high levels of pollution as a result of the increase in population, industries, and automobile fleet, among other aspects. Another study by Vásquez (2007) mentions that population growth and the need for territory to urbanize the land with an agricultural vocation have disappeared. Therefore, urban development affects protection and conservation areas. It should be noted that no research has been carried out regarding the relationship of urban growth with climate change in the studied territory beyond the environmental issue, reorganization, and proposal of urban models for the parish. Therefore, analyzing this case is relevant to understanding how unplanned urban expansion and territorial conflicts exacerbate the parish's vulnerability to the adverse effects of climate change, such as temperature increases, extreme weather events, and the alteration of rainfall patterns. These effects threaten the natural environment and the quality of life of its inhabitants.

In this way, it is proposed to identify the vulnerability of Calderón parish, considering that accelerated growth has affected it socially, economically, and environmentally. In this sense, the general objective of this work is to identify the vulnerability to climate change by analyzing the urban growth of Calderón to define climate change adaptation measures. Three specific objectives were raised: analyzing urban growth historically and spatially, determining the relationship between urban growth and vulnerability, and establishing climate change adaptation measures. The research was based on a mixed approach study, combining quantitative, qualitative, and spatial methods over three stages: 1) historical and spatial analysis of urban growth, 2) evaluation of the relationship between urban growth and vulnerability to climate change, and 3) proposals for adaptation measures. For this, thirteen indicators were used to measure exposure, sensitivity, and adaptive capacity. This paper proposes guidelines on climate change based on the governance and absence of adaptation measures in the Territorial Organization and Development Plans (PDOT, in Spanish) and the recent Climate Change Adaptation Plan (2023).

II. THEORETICAL FRAMEWORK

The research is carried out in three categories: urban growth, climate change, and vulnerability. Urban growth is understood from three processes: expansion, consolidation, and densification. The term *expansion* "refers to the change of land use, i.e., when spaces used for rural activities are used in city-related activities" (Ramírez & Pértile, 2013, p. 196). On the other hand, *consolidation* is related to the set of services, infrastructure, and densification. It includes the increase in population and housing per unit area. Small cities have a concentric urban expansion trend. However, there is gradual demographic growth with a change in the development

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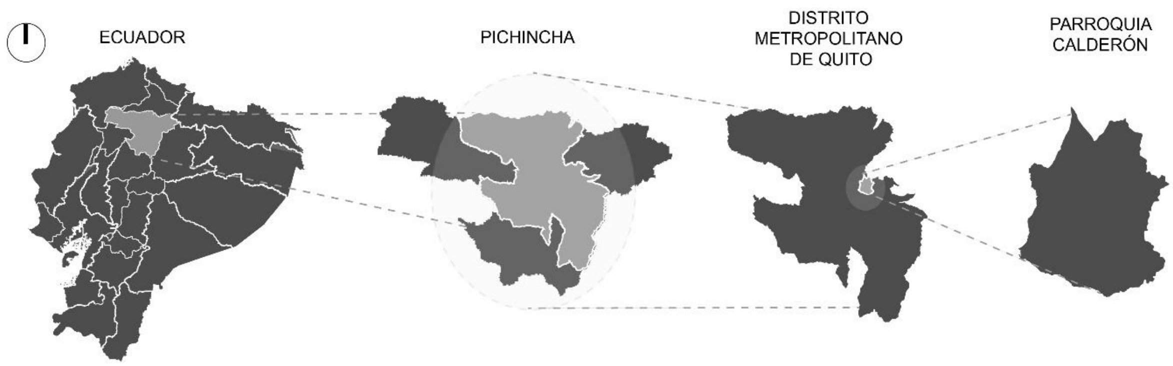

Figure 1. Location of the parish of Calderón. Source: Preparation by the authors based on information from the Military Geographical Institute.

model, which implies urbanization processes. Therefore, city expansion begins to be evident in the peripheries and rural areas. (Bazant, 2008).

Thus, urbanization processes alter the climate at local and regional levels, and urban areas tend to have higher temperatures and more precipitation than rural ones. Urbanization influences the climate because it hinders the flow of winds, causing a hotter and less ventilated environment. Automobiles, industries, and human activity generate heat emissions, and pavements retain heat, contributing to an increase in urban temperature (Vásquez, 2007). Therefore, urbanization processes are a fundamental part and consequence of urban growth, directly related to climate change and its challenges. Developing countries are the most exposed to climate threats and other environmental challenges, where net CO_2 emissions come from using and changing land use (IPCC, 2020). The IPCC (2019) defines climate change as the "variation of the climate's state identifiable in the variations of the average value (...), which persists for prolonged periods, usually decades or longer, and that climate change may be due to internal natural processes or external ones" (p. 75).

It is also essential to introduce the concept of *vulnerability* and the situations and effects of climate change to which informal settlements are exposed. *Vulnerability* is the "propensity or predisposition to be negatively affected. Vulnerability comprises a variety of concepts, including sensitivity or susceptibility to harm and lack of responsiveness and adaptation" (IPCC, 2019, p. 92). Meanwhile, *exposure* is "the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social or cultural assets in places and environments that could be negatively affected" (IPPC, 2019, p. 11). *Sensitivity* is the "degree to which a system is affected, positively or negatively, by climate variability or change. The effects can be direct (...) or indirect" (IPCC, 2007, p. 113), and the *adaptive capacity* is the "ability of systems, institutions, human beings, and other organisms to adapt to potential damage, to take advantage of opportunities or cope with the consequences" (IPCC, 2019, p. 76).

III. CASE STUDY

The parish of Calderón is located 15 km northeast of the Quito Metropolitan District (QMD). It sits on the Guangüiltagua plateau and has an area of 79.17 Km^2. It is one of 33 rural parishes (Figure 1). It is bordered to the north by the parish of San Antonio, to the South by Llano Chico, to the East by Guayllabamba, and to the West by Pomasqui (GAD Calderón, 2023). Calderón has been part of the expansion process that the QMD has experienced (Farinango, 2017) through four mechanisms, as pointed out by Loachamín (2017): "socio-economic and residential segregation, migration, economic crisis, and land speculation" (p. 5).

Historical-spatial analysis of the urban growth of the Calderón parish

Calderón has seen an urban growth model starting from land subdivision and the start of agricultural activities in the 1960s and 1970s. The population settled in the consolidated area, and households with family incomes below the minimum wage did so in the periphery, forming new nuclei in the parish. The division of haciendas and land donation was the starting point for "building amenities and population

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Year	1950	1962	1974	1982	1990	2001	2010	2020
Inhab.	6.931	8.854	13.358	18.059	36.297	84.848	152.242	243.587

Table 1. Evolution of the population in the parish of Calderón. Source: Prepared by the authors based on historical data from the National Institute of Statistics and Censuses (INEC).

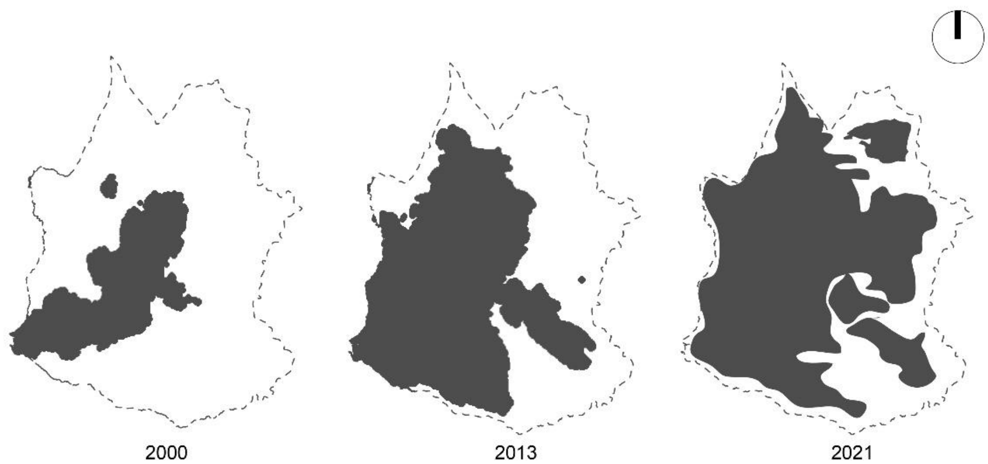

Figure 2. Variation of the urban sprawl in Calderón parish (2000-2021). Source: Preparation by the authors based on GIS (2016) files of UN Habitat, NYU, and Lincoln Institute of Land Policy (2016).

increase, which drove the growth and development of the parish" (Ron, 2017, p. 79). In addition, real estate companies were interested in large plots for building closed housing complexes or for industrial use.

As a result of population growth, the peri-urbanization processes have shaped Calderón spatially with greater emphasis after the 1990s (Álvarez, 2021; Farinango, 2017). This was because "the excessive rise in population in a very short period drastically impacted how the space was used" (Álvarez, 2021, p. 105). If the growth of Calderón is considered in terms of migratory processes and increased commercial activity due to its spatial location (Farinango, 2017), it is necessary to point out that population growth was evidenced from the first national census in 1950. The growth up to 1982 was in line with that of a rural parish; however, between 1950 and 1974, it doubled (Farinango, 2017; Ron, 2017), and between 1974 and 1990, it tripled (Table 1). The population growth rate from 1982 to 1990 was 7.76%, 7.72% from 1990 to 2001, and 6.50% from 2001 to 2010 (Loachamín, 2017; GAD Calderón, 2023). Calderón is also considered the parish with the highest population density since, according to the 2010 census, it reaches a density of 1.9245 hab/Km^2, the highest among other rural parishes of the QMD (GAD Calderón, 2023; Farinango, 2017).

The urban sprawl of Quito spread to the periphery, and one of the most affected areas was the northeast after 2000 (Figure 2). The consolidated land, as stated by Farinango (2017), increased from 3.79% in 1996 to 35% in 2010, denoting that growth "has occupied all the flat spaces for development and has started to occupy irregular topographic spaces" (p. 22). Therefore, with urban growth and environmental and social conditions, the land use in the parish has changed. Between 2005 and 2015, there was evidence of a decrease in residential and agricultural use and ecological protection and an increase in industrial and residential surface use (Loachamín, 2017).

The following aspects were considered to analyze the exposure, sensitivity, and adaptability variables: Calderón is located in the Esmeraldas River basin and the Guayllabamba River sub-basin, consisting of six micro-basins and six gorges, the most extensive being the Tumahuco gorge with 24.69 km^2 (Mora, 2017; Loachamín, 2017; GAD Calderón, 2023). It is located in the plains of a valley and has slopes of less than 25% in the urban area. Conversely, where the slope is more significant, this area has been destined for residential and protective agricultural use (Loachamín, 2017). The Calderón parish has a warm mesothermal dry climate (Loachamín, 2017),

Variable	Indicator	Source
Exposure	Flood risk in urban habitat	QMD Municipality Geoportal
	Risk of heat waves in urban habitat	
	Risk due to landslides in urban habitat	
	Wildfires hazard	
Sensitivity	Population density	Military Geographical Institute Geoportal
	Access to basic services	
	Socioeconomic level	
	Conflict over land use in the Expansion area	
	Plant cover	
Ability to adapt	Level of education	Military Geographical Institute Geoportal
	Access to IESS Social Security	Population and Housing Census 2010
	Actions and projects on climate change	QMD Council
	Local plans for climate change and disaster risk management	

Table 2. Variables analysis model. Source: Preparation by the authors.

with an average annual rainfall of 519.0 mm between February and April with intense rains (Mora, 2017). The average temperature varies from 14 to 18°C; however, temperatures of 13 to 15°C predominate in the consolidated area (GAD Calderón, 2023).

IV. METHODOLOGY

The following research was based on a study with an experimental design and mixed approach (quantitative, qualitative, and spatial). A deductive method was used to obtain guidelines and propose adaptation measures. An in-depth applied and exploratory research was carried out since the relationship between urban growth and vulnerability to climate change in Calderón parish was analyzed through two stages.

Stage 1: Relationship between urban growth and vulnerability to climate change

A documentary review of secondary information on climate change and vulnerability in previous studies, plans, and reports, among other sources, was proposed as a research technique for which an information matrix was used. The spatial analysis was performed with GIS software to make thematic vulnerability maps. The operationalization of this component was worked out using an analysis model (Table 2) that collected three variables and thirteen indicators.

The thirteen indicators were chosen based on the proposals of three research projects: *the vulnerability index to climate change and adaptation plan for the city of Loja* (FIC and Universidad Técnica Particular de Loja, 2021), *The book of vulnerability. Concept and guidelines for standardized vulnerability assessment* (GIZ, 2017) and *Vulnerability and adaptation to climate change in Guayaquil* (CAF, 2018). A comparative matrix was made for their analysis, and each variable was represented; in addition, the availability of information regarding the Geoportals of the Municipality of the QMD and the Military Geographical Institute was considered. Each of the indicators had a scale of 1 to 5, and three had to be modified to adapt to this scale: the conflict for land use in the expansion zone, because they were classified as adequate use, over light, over moderate, over severe, underutilized, and the non-expansion area does not apply. The plant cover indicator was classified into agricultural, mixed agricultural, anthropic, conservation and production, conservation and protection, and extraction of non-renewable natural resources, with livestock, protection or production, and unproductive lands not applicable. These were grouped to represent the scale, assigning level 5 to conservation coverage. As for the indicator of access to IESS Social Security, the data were grouped into five levels according to access. For the result of the vulnerability scale, the ratio of total hectares and hectares with a high or low level was considered depending on the indicator. Finally, for the indicators of actions and projects on climate change and local plans, a search was made for actions and

Indicator	Total Inhab.	High/low value	Scale
Exposure			
Flood risk in urban habitat	3136.53	11.12	0.35
Risk of heat waves in urban habitat	3132.91	111.74	3.57
Risk due to landslides in urban habitat	3127.71	782.98	25.03
Wildfires hazard	7919.63	1453.79	18.36
Sensitivity			
Population density	6225.33	52.95	0.85
Access to services	6225.33	177.88	2.86
Socioeconomic level	6225.33	1749.09	28.05
Conflict over land use in expansion areas	6241.02	275.24	4.41
Plant cover for conservation and protection	6241.02	1137.69	18.23
Ability to adapt			
Level of education	6225.39	5285.33	84.90
Population enrolled in Social Security	7919.69	4693.16	59.26
Departments/heads that include climate change (municipality)			75.00
Actions/projects on climate change			80.00

Table 3. Vulnerability results, scale from 0 to 100%. Source: Preparation by the authors.

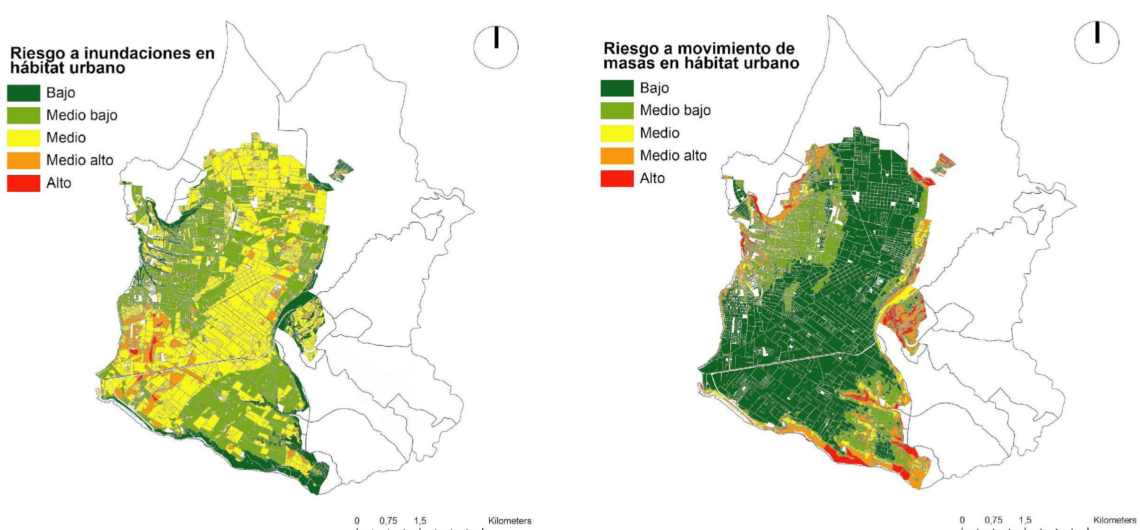

Figure 3. a) Flood risk. (b) landslides in urban habitats. Source: Preparation by the authors based on data in the shape format of 2020 of the QMD Municipality Geoportal (2023).

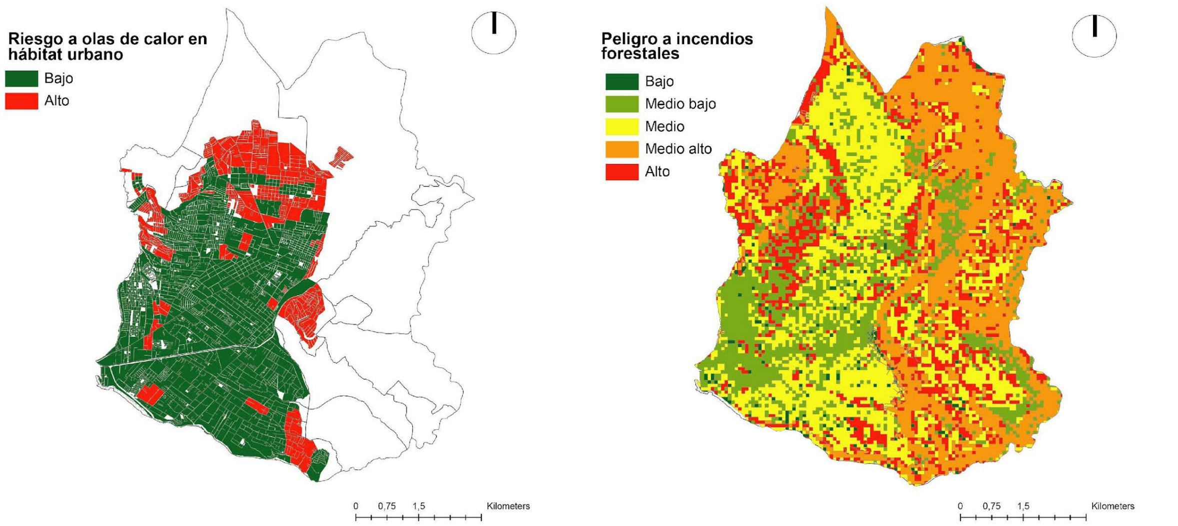

Figure 4. a) Risk of heat waves in urban habitat. b) Wildfires. Source: Preparation by the authors based on data on the shape format of 2020 from the QMD Municipal Geoportal (2023).

projects implemented by the municipality and the Calderón Zonal Administration, as well as the availability of local plans concerning climate change and disaster risk management. Therefore, instruments such as the 2022 Accountability and the 2022 Annual Operating Plan were analyzed. Thus, 25 departments/heads at the municipal level who work on climate change were determined, and 20 actions were developed on this topic; a difference ratio was made with 100% for managing the vulnerability scale in these two indicators.

Stage 2: Adaptation measures to climate change in Calderón Parish

In the second stage of the research, the bibliographic review technique of regulatory documents in force in the country and the QMD, as well as international parameters on adaptation measures, was used. The municipality has 25 areas that work on environmental issues, including climate change, within the projects and 20 actions that include the QMD PDOT. In this case, this was subtracted from 100% to determine the vulnerability regarding the absence.

V. RESULTS

Vulnerability analysis

According to the Ministry of the Environment, Water and Ecological Transition, Calderón has a vulnerability index to climate change of 90.48%, a high value on the proposed measurement scale (Ministry of the Environment, Water and Ecological Transition, 2023). According to the research results, the parish's vulnerability is low to medium (0-60%) concerning the first nine indicators (Table 3). However, the adaptive capacity of the parish has high levels of vulnerability (60-100%). In this context, implementing planning instruments regarding climate change can improve adaptation capacity and allow it to face its negative impacts.

Exposure

Figure 3a shows the flood risk in 5 levels. It is observed that the South-west has a high level of risk, covering an area of 11.12 ha, and an average level, on the other hand, is evident in the North and South with an area of 1121.81 ha exposed to floods, representing 35.70% of the urban surface area. On the other hand, the urban area is located on a semi-flat relief with low slopes, as indicated in Figure 3b, where the risk of landslides is high (111.75 ha). Only in the eastern sector of the parish is the risk medium-high, where the transition from the natural to the urban area occurs and where the slopes are greater than 40% (GAD Calderón, 2023). It can be seen that the low level corresponds to 63.27% of the urban area.

Figure 4a shows a high level of risk in the North and Northeast sectors in an area of 782.92 ha, close to natural

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and protection areas, representing 24.95% of the urban area. Very high temperatures produce droughts, which increases the events related to wildfires. The North Eastern sector is next to ecological protection areas; the conservation and protection ground cover predominates with forest, shrub, herbaceous vegetation, grasslands, and paramo. Figure 4b indicates the very high level of wildfire danger that is spread throughout the territory. The average level, equivalent to 2506.3 ha, occupies a large continuous area on the East side.

Sensitivity

The expansion sectors close to protection and conservation areas had low densities, unlike those in the southwest of the parish, where high densities are seen in an area of 52.96 ha and high averages of 56.19 ha, as evidenced in Figure 5a. On the other hand, Figure 5b shows that the parish has a high level of access to essential services (drinking water, sewerage, and garbage collection), that is, 2882.80 ha, representing 46.31% of the surface, as opposed to 177.88 ha that have a low level in the Northern sector.

The socioeconomic level indicator (Figure 5c) considered high to low socioeconomic level values, obtaining that the high socioeconomic level covers only 58.83 ha, with low and medium-low levels predominating with 1746.09 ha and 2580.21 ha, respectively.

Regarding the conflict indicator of land use in the expansion zone (Figure 6a), 275.24 ha belong to the highest level; there is a conflict concerning underutilization "where the demand or requirement of the activity exceeded the supply provided by the land" (CIIFEN, 2012, p. 22). In addition, the land cover was analyzed (Figure 6b), and the presence of conservation and protection land in the parish was highlighted. Therefore, 1137.69 ha are from the use of conservation and protection. It should be considered that this use is essential because anthropic activities reduce the sensitivity of these areas and the population (CAF Development Bank of Latin America, 2018).

Ability to adapt

Calderón reveals a low average level of education (Figure 7a), with an area of 5285.33 ha. In the access to social security indicator, information from the Population and Housing Census 2010 (INEC, 2010) was used to obtain five population ranges of access to social security from the IESS, which, in this case, represents 473,086 inhabitants. The low level corresponds to 4693.16 ha (Figure 7b). This zone considers the expansion areas, use of ecological protection, and those scattered in the consolidated area. The high level represents only 115.38 ha of the entire territory.

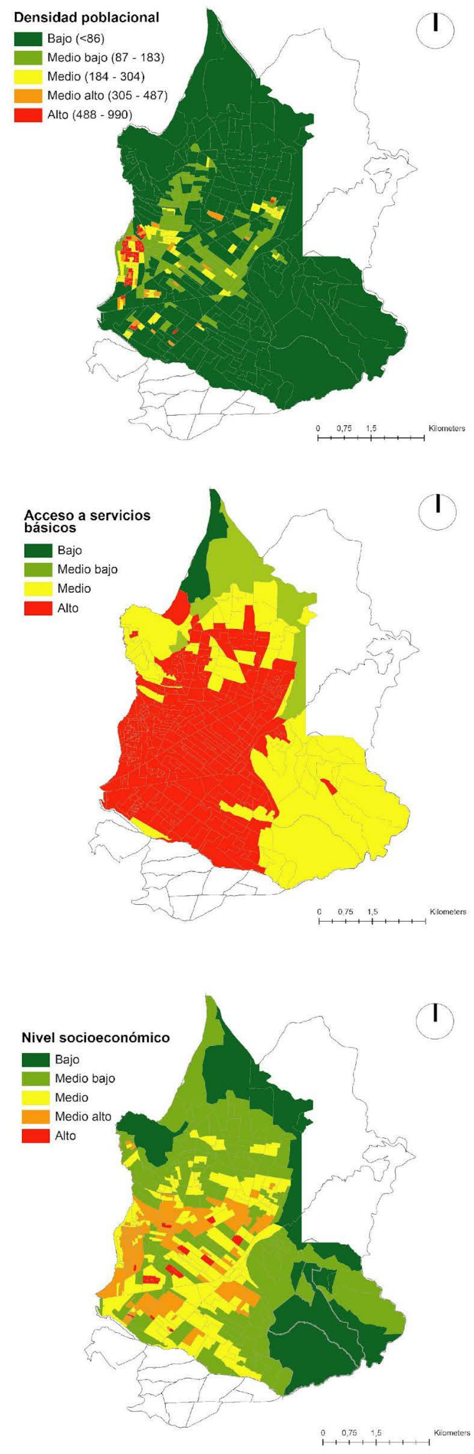

Figure 5. a) Population density (inhab/ha). b) Access to essential services. c) Socio-economic level. Source: Preparation by the authors based on data in the shape format of 2019 from the Military Geographical Institute Geoportal (2019).

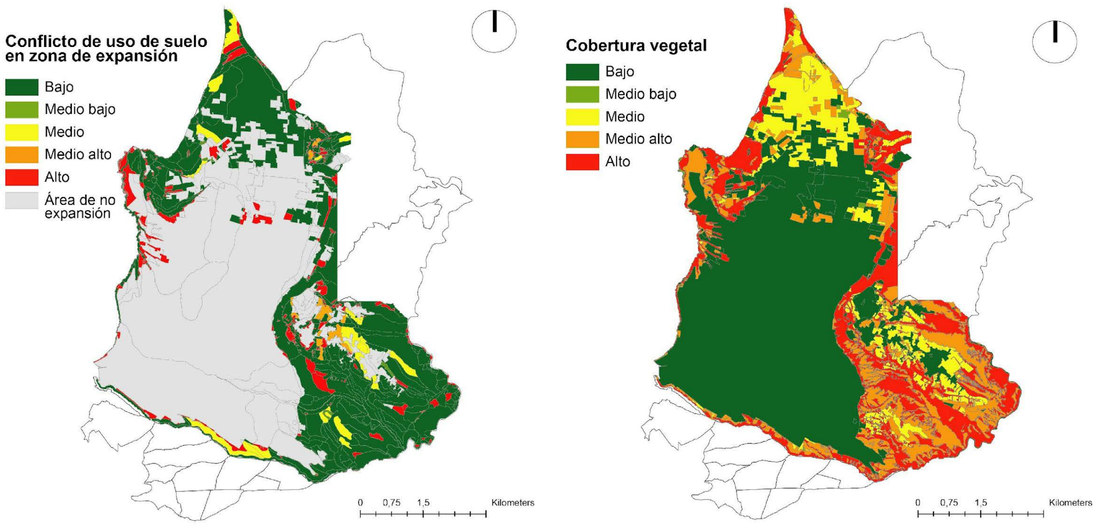

Figure 6. a) Conflict over land use in expansion areas. b) Plant cover. Source: Preparation by the authors based on data in the shape format of 2019 from the Military Geographical Institute Geoportal (2019).

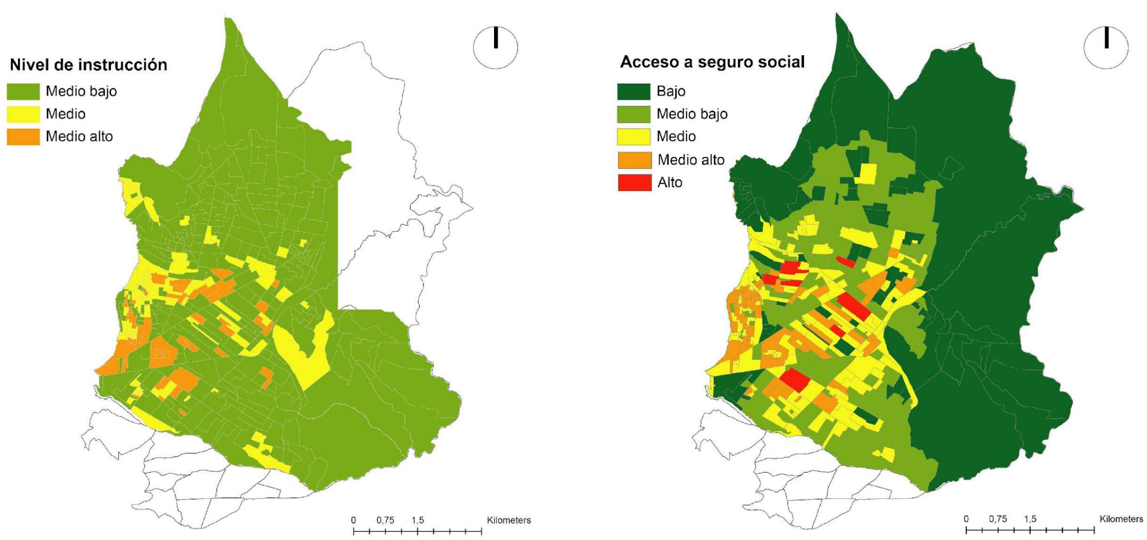

Figure 7. a) Education level. b) Access to IESS social security. Source: Preparation by the authors based on data in the shape format of 2019 of the Military Geographical Institute Geoportal (2019) and the Population and Housing Census (INEC 2010).

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Actions and projects		Plans
Recovery of plant cover	5 ha of plant cover with collective reforestation actions in ecological protection areas and ravines	Territorial Organization and Development Plan GAD Calderón 2021 (update 2023)
Revision of 100% of the risk analysis reports	22 reports to locate anthropogenic activities that cause risk	Metropolitan Organization and Development Plan 2021-2033
Implementation of 22 actions to mitigate minor risks	15 collective actions for disaster risk mitigation 6 training processes on risk issues in neighborhoods	Quito PACQ 2020 Climate Change Action Plan

Table 4. Actions and projects implemented, and plans related to climate change and risk management. Source: Preparation by authors based on secondary information matrices and Municipality of Quito (2022).

Also, in this component, the adaptive capacity was assessed using two factors (Table 4): actions and projects implemented by the municipality and the Calderón Zonal Administration and the availability of local plans related to climate change and disaster risk management.

Climate change adaptation measures

Factors such as vulnerability and exposure were considered for climate threats. In this sense, it is vital that the PDOT management model establishes mechanisms to implement climate adaptation measures. This considers the key players, current mechanisms, engagement times, and whether a unit within each GADM is responsible for monitoring and execution. In this context, implementing climate change planning instruments can improve adaptation capacity and face the negative impacts that lead to climate change.

For its part, the Quito PACQ 2020 Climate Action Plan (Secretary of Environment of the Metropolitan District of Quito and C40, 2020), in its adaptation component, prioritized some dimensions that facilitated the design of actions with the identification of the most significant territorial impact and benefits. This PACQ highlights some actions: (1) the proposal of climate compatible planning standards using guidelines for climate change adaptation in urban expansion and agricultural areas, which includes the zoning and standards for land conservation area; (2) the land occupation conditions for climate neutrality, which involved areas that contribute to the land bank to reduce the risk, provided that there is available land to cover the lack of green areas, public space and housing; (3) early warning water adaptive management to reduce flood risks, i.e., the implementation of extreme rainfall event notifications; (4) a sustainable urban drainage infrastructure proposal that controls surface runoff in urban areas, to increase the resilience to climate change; (5) training and capacity building regarding wildfires to reduce the impact of fire by human causes; and finally, (6) to engage in sustainable and climate compatible agriculture, through sustainable agriculture land use management, which contributes to food security and sovereignty (Secretariat of Environment of the Metropolitan District of Quito and C40, 2020).

VI. DISCUSSION

The UN (2011) notes that the combustion of flammable fossil elements, extensive industrial pollution, the destruction of forests, and changes in land use have led to an accumulation of greenhouse gases in the atmosphere, decreasing the ability of oceans and vegetation to absorb these gases, which has caused temperatures changes in cities. Understanding urban growth becomes crucial for mitigating climate change, especially in Latin America and the Caribbean, where most of the population resides in urban areas and economic activities are concentrated in cities. This concentration generates a high demand for resources and services, contributing to environmental pollution. In addition, the transformation of the urban landscape, with the replacement of natural areas by infrastructures, alters local weather patterns, exacerbating city pollution levels (Duque & Montoya, 2021).

In this way, the research findings on Calderón Parish highlight the interconnection between urban growth, climate change, and vulnerability. Historically, population growth has driven urban expansion, especially towards peripheral areas, significantly increasing housing density. This uncontrolled growth exacerbated climate risks such as landslides, floods, and heat waves, unevenly affecting the territory and population and creating environmental and social conflicts. This relationship aligns with the theoretical framework, which describes how urban expansion alters the local and regional climate, contributing to a hotter and less ventilated environment due to heat retention on urban surfaces. Vulnerability, defined as the predisposition to be negatively affected by climate change, manifests itself in peripheral urban areas where exposure to climate risks is combined with an increasing sensitivity and a limited adaptive capacity. Taken together, these findings underscore the importance of sustainably addressing urban growth and implementing climate change adaptation measures to reduce the vulnerability of urban communities to emerging environmental challenges.

Consequently, "the urban growth model effectively represents a factor of vulnerability to the effects of climate change" (Cerda, 2020, p. 48). Climatic, social, and environmental factors have become a fundamental focus for the population's vulnerability; i.e., an urban growth model can reduce ecosystem resources, increasing vulnerability (Cerda, 2020). Thus, "the urbanization process, understood as a concentration of inhabitants, expansion of urban limits or creation of new cities, has a high impact on the environment and social dynamics" (Rosales, 2013, p. 1).

VII. CONCLUSIONS

This research proposes to identify the vulnerability to climate change by analyzing the urban growth of the Calderón parish to define climate change adaptation measures. To do this, thirteen indicators were used to determine the vulnerability conditions in the parish and develop the exposure, sensitivity, and adaptive capacity variables in the territory.

Population growth in the Calderón parish has been one of the main factors in the expansion process. It has led to the implementation of new residential, industrial, and commercial areas. However, this area has unfavorable geomorphological and geological conditions and is prone to natural hazards such as floods, landslides, and ash falls, with a high risk in the East of the parish. In the adaptive capacity variable, a high vulnerability is observed due to the few actions and projects aimed directly at climate change adaptation by the Municipality of the QMD and the Calderón Parish GAD. The lack of legal instruments prevents climate-related actions from being coordinated, as well as the lack of initiatives to engage with the private sector and develop actions that start from research and innovation towards the advancement of mechanisms that ensure efficient measures in the face of climate change vulnerability.

In conclusion, the research reveals the intimate relationship between uncontrolled growth and its vulnerability to climate change. The population increase has driven the expansion of residential, industrial, and commercial areas, which has exposed the parish to natural hazards such as floods and landslides, especially in the Eastern area. The municipal and parish authorities' lack of specific actions and projects to adapt to climate change has left the community vulnerable. The research highlights the urgency of integrating adaptation measures into Territorial Organization and Development Plans (PDOT) with the participation of key actors and the need to have risk management units in each municipality. The action proposals presented are based on existing instruments, such as the Quito 2020 Climate Action Plan, which offers a framework for effectively addressing climate vulnerability in Calderón Parish.

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