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METHODOLOGY FOR STUDYING CLIMATIC CHARACTERISTICS AND FLOOD EVENTS IN A BASIN

Darwin Suárez Ariza[1]*, Dora Marcela Benítez Ramírez[2]

[1]*Pedagogical and Technological University of Colombia, Colombia. Email: darwin.suarez@uptc.edu.co*
[2]*Pedagogical and Technological University of Colombia, Colombia. Email: dora.benitez@uptc.edu.co*

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Corresponding Author: Darwin Suárez Ariza (darwin.suarez@uptc.edu.co)

ABSTRACT

The Upper Basin of the Chicamocha River (CARCh) is characterized by a length of 104 km and the incorporation of 24 municipalities. This region is of significant economic importance to Colombia. It is situated in the eastern Andes mountain range in the center of Boyacá. The region's climate and soil are shaped by the water supply, and it is the center of food security for the country. Consequently, as the climate undergoes changes, the basin also experiences alterations, influenced by human activities since the last century. The CARCh is situated within the equatorial zone, rendering it subjects to the influence of the Intertropical Confluence Zone (ITCZ). Climate variability due to ENSO is also a factor. The exacerbating factors of this variability include deforestation practices, increases in atmospheric emissions and artificialized territories, and changes in land use. This issue changes how meteorological variables affect the normal hydrological cycle in the region. The observed alterations, manifesting as elevated precipitation levels, have a pervasive impact on the entire region, giving rise to recurrent and substantial river flooding. This study analyzes the meteorological conditions of the last two decades and their correlation with floods in the CARCh. To this end, the study examines historical flood records from the Disaster Risk Management Unit of the Department of Boyacá and meteorological data from five stations operated by the Institute of Hydrology. Meteorology and Environmental Studies (IDEAM). What is the most effective approach to studying the meteorological phenomena and fluvial flooding within a river basin? The weather is highly unpredictable. The ambient temperature can vary significantly, ranging from extremely high to extremely low. In certain instances, the river's height is particularly pronounced, a phenomenon that is particularly evident during La Niña conditions. This phenomenon can occur in specific regions or across the entire basin. It serves as the primary conduit through which individuals, institutions, the government, and researchers access information. It is also a valuable resource that can be utilized in other basins.

KEYWORDS: Precipitation, Natural Hazard, Flood, Meteorology, Basin.

1. INTRODUCTION

The global climate is dynamic, worldwide they find a relationship between general or large-scale atmospheric processes and the generation of extreme weather phenomena. Large-scale atmospheric circulation generates heat waves or extreme precipitation that trigger flooding (Couto et al., 2024), the same effect has the climatic oscillations (Singh et al., 2025) typhoons and the monsoon especially in the presence of La Niña and El Niño (Kuo et al., 2016)

Small-scale and mesoscale phenomena also generate rainfall. Land and sea breezes or convective cells (Topouzelis & Kitsiou, 2015), atmospheric rivers (Blanchet et al., 2025) generate rainfall with flood potential, especially if they are 20-year returns (Raymond et al., 2019) being evidence of the relationship between rainfall and floods (Raymond et al., 2019) of the river type (Merz et al., 2021). These river levels vary from dry to wet periods in the presence of El Niño, the Southern Oscillation (ENSO), the Madden Julian Oscillation (MJO) and the Indian Ocean Dipole (IOD) (Rohmat et al., 2023).

In South America, the presence of El Niño, Southern Oscillation (ENSO) affects hydrology with regional differentiation. El Niño in northeastern South America and the Amazon is associated with drought and floods in the southwest (Cai et al., 2020). In Colombia, Poveda (1997) finds La Niña more developed than El Niño with significant precipitation discharges to the country's river channels (Poveda & Mesa, 1997) (Navarro-Monterroza et al., 2019)making each event unique; i.e., no two ENSO events are the same (Waylen & Poveda, 2002). This translates into a wetter and longer La Niña, and an aggravated El Niño due to changes in land cover and use (Poveda et al., 2011).

These variations are important due to their implications for the country's economic lines. An important commodity in the tropical Andes of Colombia is coffee, which depends on rainfall, soil moisture, and flows (Poveda et al., 2001; Poveda et al., 2011). In addition to the above variations, there is the orographic complexity, especially when the basins are made up of deep valleys surrounded by steep slopes in high mountains, which increases vulnerability to extreme weather events(Poveda et al., 2020) catalyzed by anthropogenic changes in land cover due to deforestation (Manciu et al., 2023).

The variation of the rainfall cycle defines dry and wet regional periods. Unimodal regionalization (one dry season and one rainy season) occurs in the Caribbean, the Pacific and the Amazon, while bimodal zones (two dry and two rainy seasons) are found in the Andes (Urrea et al., 2019). This is accentuated by the presence of ENSO: in the Andean, Pacific and Caribbean regions during El Niño, rainfall is reduced, leading to drier conditions, unlike in the eastern plains where there are no relevant changes (Giraldo-Osorio et al., 2022)

These variations have been drastic with various civilizations. There are records of climate crises in 1170 BC, when a drought causes the Hittite empire to disappear (Durusu-Tanriöver, 2023), another significant event is the Mayan drought (Lozano et al, 2015, as cited in López Aguilar, 2021) cause of the disappearance of the Mayans (Diamond & Perez, 2006). According to the "standard approach" of a warming climate, attributed to anthropogenic climate change, predictions indicate an intensified hydrological cycle that goes from dry to drier and from wet to wetter (Shaw & Stevens, 2025).

In the wet to wetter scenario, flooding due to extreme rainfall events produces significant and intensified impacts. Of the *Latin Inundatio-Onis* (Diez-Herrero et al., 2008) according to the WHO and the UNDRR, they are the most important disasters due to their frequency (McClean, 2020)(WHO, 2017). Overflows from normal water flow limits or water accumulation in areas that are not usually submerged (Matthews et al., 2023) due to heavy rains, melting ice or the presence of oceanic events connected to atmospheric events on the coasts (WHO, 2017).

However, civilizations have depended on floods. Like the Egyptian culture's link to the Nile River for agriculture(Diez-Herrero et al., 2008) especially in floodplains (Zalewski, 2008), for water supply or waste reception (Argudo, 2019): uses conditioned by technological capabilities (Habibbeh et al., 2021) and by the properties of the rivers (Wang & He, 2022). The above are examples of how rivers have served as a cradle and the history of civilizations develops in their course (Ruka Atuq, n.d.). In Colombia, the Zenú culture is an example of progress based on the development of hydraulic infrastructure such as canals and adapted constructions such as elevated platforms (IDEAM, 2017).

It is important to analyze floods no longer from the perspective of sustenance, but of interruption of sustenance or damage. According to the team of Diez-Herrero (2008), this perspective is influenced by: the depth, residence time of the water sheet, current speed, force or energy of the current and the solid charge (Diez-Herrero et al., 2008). This perspective is closely linked to climate extremes (Matthews et al., 2023).

The Intergovernmental Panel on Climate Change (IPCC) compiles evidence worldwide in the report

Climate Change 2021 – The Physical Science Basis, on the website: https://www.cambridge.org/core/books/climate-change-2021-the-physical-science-basis/415F29233B8BD19FB55F65E3DC67272B, on the relationship between global warming generated by human activities and how this phenomenon affects weather patterns and its repercussions in extreme events in the territories.

These extreme events are associated with deviations of the values with respect to the historical average or annual average value. These anomalies occur at a specific time and place, characterized as positive if the value is higher than the historical average and otherwise negative (Yepes Palacio & Poveda Jaramillo, 2013). However, positive precipitation anomalies need to be studied in the case of floods, especially when they are intensified by factors such as urbanization(Xinxin Suia et al., 2024; Yang et al., 2024), the presence of ENSO (Agustina & Castro, 2020) or atmospheric instability combined with the positive thermal anomalies in the equatorial Pacific (Pacheco et al., 2019).

The relationship between extreme rainfall that triggers floods has been demonstrated. In the face of an amplified climate change scenario, both the intensity of extreme rainfall and floods increase with significant losses (Zhang et al., 2025) in the economic and social spheres (Li et al., 2024), especially for localized rain events that can generate flash flooding (Chen et al., 2025) aggravated by the presence of complex terrain and urban planning processes in floodplains (Geng et al., 2025)

There are a variety of methods, both advanced and simple, to relate extreme rainfall and flood events. Among the advanced are the application of hydrological models improves the ability to forecast and simulate floods (Li et al., 2024), including the distribution of constructions or buildings with respect to runoff processes improve the ability to determine resilience to these events (Geng et al., 2025), using machine learning to locate flash flood zones generated by extreme rainfall(Chowdhury et al., 2025) or the use of conventional neural networks (Wang et al., 2024).

The relationship between extreme rainfall and flood events has been proven. Due to the above relationship, we seek to study the climatic behavior of precipitation in the Upper Basin of the Chicamocha River with historical flood events between 2000 and 2020. This first study allows flood risk reduction to be managed to the extent that it provides basic information to avoid or reduce scenarios of impacts and losses generated by floods. This new knowledge is a useful tool for managing and improving resilience and reducing the overall vulnerability of the basin to a recurrent and intensified hydrometeorological threat according to the results obtained. The above scenario is aggravated by the fact that this basin does not have mechanisms that provide warning signals in the event of extreme precipitation events conditioned by the implications of climate change.

Overflow Of the Copa Dam- 2023. Photo: Dora Marcela Benitez Ramirez.

2. AREA OF STUDY

24 municipalities are part of the upper basin of the Chicamocha River located in the central area of the department of Boyacá in Colombia. See Figure 1. Of lacustrine and fluvio-lacustrine origin, this plateau surrounded by gently sloping mountain ranges is home to volcanic bodies in Paipa (Universidad Pedagógica y Tecnológica de Colombia et al., 2006). In the area, values of 13.1 °C, 20.7°C and 4.8°C are recorded for average, maximum and minimum temperatures with a bimodal regime according to the POMCA 2006(Universidad Pedagógica y Tecnológica de Colombia et al., 2006). The presence of drainage channels transforms the territory from a lake to an industrial corridor where the main cities of Tunja, Duitama, Paipa and Sogamoso are located, with growing populations that base their livelihoods on this basin (Universidad Pedagógica y Tecnológica

de Colombia et al., 2006).

Categorized between intermediate and large because it has a surface area of 214,770 hectares. Being of the exorheic type, it is not suitable for navigation but it can be used for irrigation and drinking water supply (Vásconez et al., 2019)

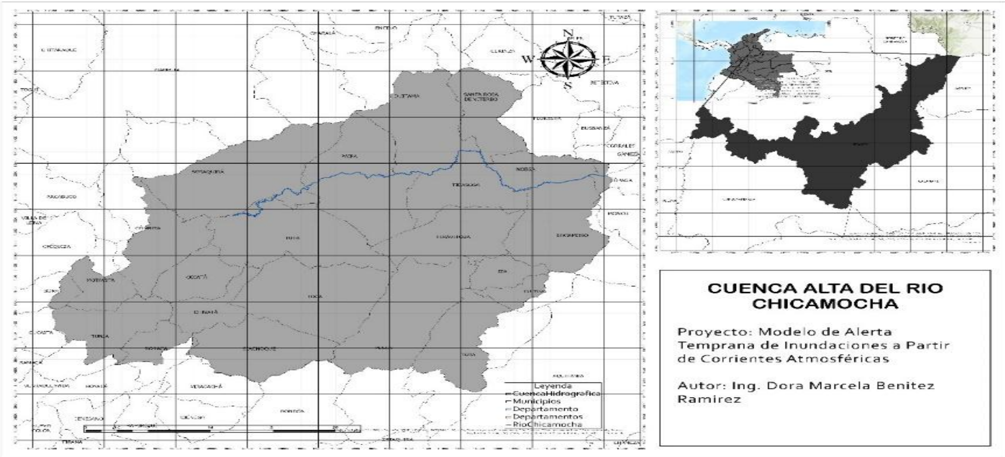

Figure 1: Geographical Location of The Upper Basin of The Chicamocha River.
Source: Dora Marcela Benitez R.

3. MATERIALS AND METHODS

The analysis of the influence of meteorological conditions on the generation of floods in the basin was based on 4 stages. Initially, for the period between 2000 and 2020, data are collected from the institutions: Institute of Hydrology, Meteorology and Environmental Studies-IDEAM (Colombia) in http://dhime.ideam.gov.co/atencionciudadano/, the Departmental Council for Risk Management of Boyacá and Corpoboyacá. The data are then processed and analyzed to continue with the identification of general flood-generating dynamics and finally the conclusions and recommendations (Figure 2).

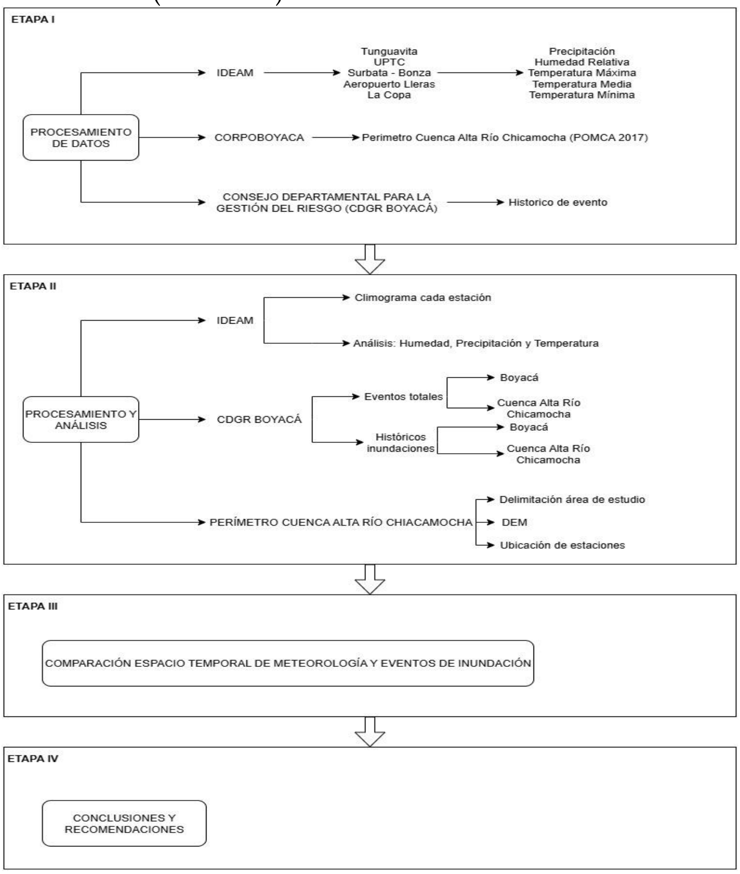

Figure 2: Methodological Development.

Stage I: Data Preparation

The information is consolidated from the citizen service web portal of the Institute of Hydrology, Meteorology and Environmental Studies-IDEAM (Colombia) in http://dhime.ideam.gov.co/atencionciudadano/. The data of the 5 climatological stations present in the basin listed in Table 1 are downloaded for the variables: precipitation, temperature (maximum, average and minimum) and relative humidity. At the same time, data are obtained from the Departmental Council for Risk Management CDGR_Boyacá. The perimeter of the POMCA basin (2017) and the Digital Elevation Model (DEM) are downloaded from the https://earthexplorer.usgs.gov/ website specifically SRTM 1 Arc – Second Global for Path 7 and Row 56.

Weather stations implemented in the study.

The meteorological stations used in this study are all active and located in the department of Boyacá within the perimeter of the basin. They correspond to the categories of main, ordinary and agro-meteorological climatic. They implement conventional and automatic technologies with telemetry, located in the municipalities of Tunja, Sogamoso, Duitama, Paipa and Toca, along an altitudinal gradient between 2,470 and 3,265 meters above sea level. Distributed in such a way that they allow data to be recorded that represent the climate variability of the CARCh as closely as possible to reality. Through the records in the IDEAM, the base time series for the analysis of precipitation, temperature and relative humidity in the region are consolidated (Table 1).

Table 1: Spatial Data of The Stations Included in the Study for The Period 2000-2020.

Código	Nombre	Categoría	Tecnología	Municipio	Ubicación	Altitud (msnm)	Fecha instalación
24035040	LA COPA	Climática Ordinaria	Convencional	Toca	(5.57919444, -73.20877778)	2.700	15/12/1991
24035120	SURBATA BONZA	Agrometeorológica	Convencional	Duitama	(5.80244444, -73.07447222)	2.485	15/03/1944
24035130	U P T C	Climática Principal	Convencional	Tunja	(5.5430775, -73.36081306)	2.690	15/02/1962
24035340	AEROPUERTO A LLERAS	Climática Principal	Convencional	Sogamoso	(5.67694444, -72.96791667)	2.500	15/01/1974
24035430	TUNGUAVITA - AUT	Agrometeorológica	Automática con Telemetría	Paipa	(5.74591667, -73.11636111)	2.470	15/12/2004
24035350	ANDALUCIA	Climática Principal	Convencional	Duitama	(5.90113889, -73.05833333)	3.265	15/09/1996

Source: Consolidated IDEAM stations

Stage II: Processing And Analysis

The time series of the data obtained from IDEAM and CDGR_Boyacá are formed. The shape file is prepared where the information of the SRTM of Path 7 and Row 56 is left as a base and the perimeter of the basin is superimposed to obtain the DEM of the study area. The IDEAM stations are located within the perimeter of the basin

Then, based on the IDEAM data, the analysis of the variables of each of the 5 station stations is carried out through climograms. With the CDGR-Boyacá records, all the events that occurred in Boyacá, in the basin, are recorded and those corresponding to floods are filtered

Stage III. Spatiotemporal Comparison of Meteorology and Flood Events

Based on the information obtained from stage II, the periods of greatest spatial and temporal impact of floods are determined and the information represented in the climograms is analyzed.

Stage IV. Conclusions And Recommendations.

Through a comprehensive analysis of the results obtained, the contributions of the study are evidenced and possible mechanisms for the continuation of the research are projected.

4. RESULTS

The spatiotemporal analysis of meteorology and floods in the basin identified weather patterns with flood-generating events during the period 2000 and 2023. On a large scale, the basin is made up of a valley that collects water from the flanks of the mountains that surround it. The CARCh, high Andean, belongs to the Chicamocha River basin that is part of the Caribbean slope, which classifies it as endorheic. The lowest point of elevation is in the municipality of Sogamoso with 2471 meters above sea level and the highest point in the mountain system northeast of the basin between the municipalities of Duitama and Santa Rosa de Viterbo at 3964 meters above sea level. See Figure 3.

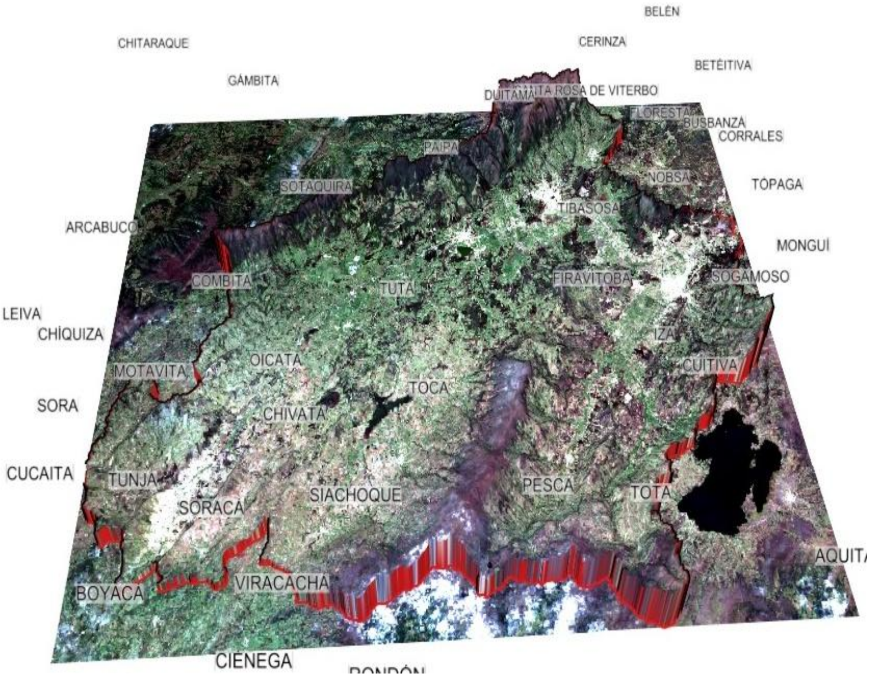

Figure 3: Digital Elevation Model of The Upper Chicamocha River Basin.
Source: Jonathan Panimbosa D And Dora Marcela Benitez R.

With respect to the altitudinal distribution of the CARCh, the vast majority is part of the valley. 55.2% with 11,867.1 ha, are in the lowest altitudinal range, between 2471 and 2850 meters above sea level, which represents the plain areas of the river. 31.6% of the basin is located in the intermediate range, between the values of 2851 to 3200 meters above sea level associated with the middle slope sector, and the third range between 3201 to 3964 meters above sea level with 2809.2 ha is made up of 25.1% of the basin are the high mountain areas where the different moorland complexes are located whose summits together trace the watershed line of the basin, as illustrated in Table 2 and Figure 1.

Table 2: Altitudinal Classification of The Basin

Altitudinal range (masl)	% of watershed area	Area (ha)
2500 – 2675	25,5	5.479,80
2675 – 2850	29,7	6.387,30
2850 – 3025	18,8	4.044,40
3025 – 3200	12,8	2.756,70
3200 – 3375	5,8	1.244,30
3375 – 3550	4,4	944,4
3550 – 3725	2,1	450,8
3725 – 3900	0,8	169,7
Total	**100**	**21.477,40**

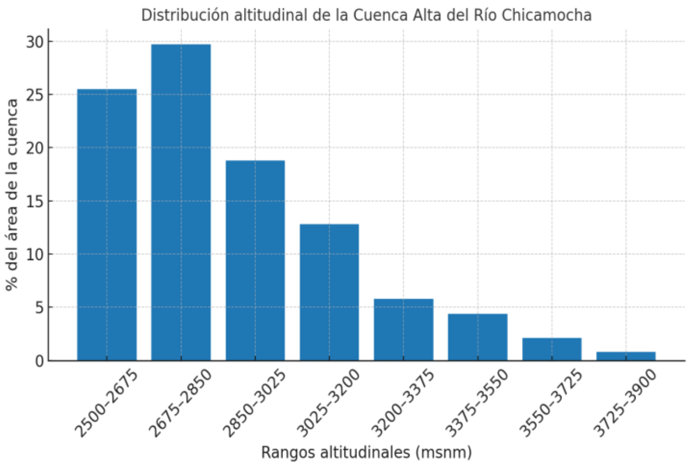

Figure 1: Altitudinal Distribution of The Basin.
Source: USGS DEM With Carch Perimeter

Before detailing the historical analyses, the types of floods are consolidated in Table 3. It is a summary of the main characterizations of floods based on three significant institutions of the world order: The Geological and Mining Institute of Spain, and the Institute of Hydrology, Meteorology and Environmental Studies-IDEAM and the National Center for Modeling-CNM with the most recent classification generated by the United Nations Office for Disaster Risk Reduction, & International Science Council (2025)

Table 3. Flood Classification.

<table>
<tr><th colspan="5">TIPOS DE INUNDACIONES</th></tr>
<tr><th colspan="4">Instituto Geológico y Minero de España (Diez-Herrero et al., 2008),
Instituto de Hidrología, Meteorología y Estudios Ambientales y Centro Nacional de Modelación (2017)</th><th>United Nations Office for Disaster Risk Reduction, & International Science Council (2025)</th></tr>
<tr><td rowspan="10">Naturales</td><td rowspan="6">Terrestres (inland)</td><td rowspan="4">Vinculadas a la red fluvial (avenidas y riadas)</td><td>Torrenciales (avenídas súbitas o relámpago)</td><td>Inundación costera</td></tr>
<tr><td>Crecidas fluviales (aumento lento del nivel del agua)</td><td>Inundación estuarina (costera)</td></tr>
<tr><td>Rotura de presas naturales(lagos, represamientos naturales</td><td>Inundación repentina</td></tr>
<tr><td>Obstrucción de cauces)movimientos de terreno, otros aportes</td><td>Inundación fluvial (ribereña)</td></tr>
<tr><td rowspan="2">No vinculadas a la red fluvial</td><td>Endorreismos (percipitación in situ, aportes a lagos o a zonas artificiales</td><td>Inundación de agua subterránea</td></tr>
<tr><td>Hidrogeológicas: A. Surgencias y B. Variaciones del nivel freatico</td><td>Inundación proveniente de hielo con escombros</td></tr>
<tr><td rowspan="4">Litorales (costeras)</td><td rowspan="2">Mereales</td><td>Pleamar y mareas vivas</td><td>Estanque (drenaje) inundación</td></tr>
<tr><td>Bores (zonas muy llanas contracorriente en ríos)</td><td>Inundación del deshielo</td></tr>
<tr><td rowspan="2">Olas y ondas</td><td>Tormentas, ciclones (meteorológico)</td><td>Inundación de agua superficial</td></tr>
<tr><td>Tsunamis(sismogenéticos; volcanogenéticos; movimientos en masa)</td><td>Inundación de estallido del lago glacial</td></tr>
<tr><td>Inducidas o agravadas</td><td colspan="3">(obstáculos al flujo, impermeabilizaciones del suelo, deforestación)</td><td rowspan="4"></td></tr>
<tr><td rowspan="3">Antrópicas</td><td colspan="3">Gestión inadecuada de obras hidráulicas</td></tr>
<tr><td rowspan="2">Roturas y fugas</td><td colspan="2">Almacenamientos (balsas, embalses)</td></tr>
<tr><td colspan="2">Conducciones (acueductos y saneamiento)</td></tr>
</table>

Source: Adapted by Dora Marcela Benitez and Darwin Ariza, from: Geological and Mining Institute of Spain, Institute of Hydrology, Meteorology and Environmental Studies-IDEAM and National Modeling Center-CNM, United Nations Office for Disaster Risk Reduction, & International Science Council (2025)

Regarding the historical analysis of the emergencies presented in the two decades, it is found that, between 2000 and 2020, 74% of the events that occur in Boyacá (19106 events) occur in the CARCh (14129 events) of which 610 correspond to floods. This means that 4.3% of what happens in the basin is caused by fluvial floods following the recent UNDRR characterization of 2025 (UNDRR–ISC, 2025). The detail of the events compared to the Oceanic Niño Index (ONI) (Climate Prediction Center, 2024) It is recorded in Table 4.

Table 4: Historical Flood Events in the Department of Boyacá and In the Upper Basin of the Chicamocha River (2000-2020) Related to the Oceanic Niño Index (ONI).

Eventos registrados en Boyacá y CARCh					Índice de Niño Oceánico (ONI)											
AÑO	Total Boyacá	Total CARCh	Inundaciones Boyacá	Inundaciones cuenca	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2000	1157	1017	96	82	-1,7	-1,4	-1.1	-0,8	-0,7	-0,6	-0,6	-0,5	-0,5	-0,6	-0,7	-0,7
2001	2287	2052	77	64	-0,7	-0,5	-0,4	-0,3	-0,3	-0,1	-0,1	-0,1	-0,2	-0,3	-0,3	-0,3
2002	558	466	0	0	-0,1	0	0,1	0,2	0,4	0,7	0,8	0,9	1.0	1.2	1.3	1.1
2003	389	358	0	0	0,9	0,6	0,4	0	-0,3	-0,2	0,1	0,2	0,3	0,3	0,4	0,4
2004	446	394	0	0	0,4	0,3	0,2	0,2	0,2	0,3	0,5	0,6	0,7	0,7	0,7	0,7
2005	389	244	0	0	0,6	0,6	0,4	0,4	0,3	0,1	-0,1	-0,1	-0,1	-0,3	-0,6	-0,8
2006	2583	2374	120	99	-0,9	-0,8	-0,6	-0,4	-0,1	0	0,1	0,3	0,5	0,8	0,9	0,9
2007	2862	2022	49	41	0,7	0,2	-0,1	-0,3	-0,4	-0,5	-0,6	-0,8	-1.1	-1.3	-1,5	-1,6
2008	1241	1020	78	63	-1,6	-1,5	-1.3	-1.0	-0,8	-0,6	-0,4	-0,2	-0,2	-0,4	-0,6	-0,7
2009	1140	952	58	43	-0,8	-0,8	-0,6	-0,3	0	0,3	0,5	0,6	0,7	1.0	1.4	1.6
2010	386	126	37	27	1.5	1.2	0,8	0,4	-0,2	-0,7	-1.0	-1.3	-1,6	-1,6	-1,6	-1,6
2011	446	227	210	54	-1,4	-1.2	-0,9	-0,7	-0,6	-0,4	-0,5	-0,6	-0,8	-1.0	-1.1	-1.0
2012	195	47	44	11	-0,9	-0,7	-0,6	-0,5	-0,3	0	0,2	0,4	0,4	0,3	0,1	-0,2
2013	282	141	24	15	-0,4	-0,4	-0,3	-0,3	-0,4	-0,4	-0,4	-0,3	-0,3	-0,2	-0,2	-0,3
2014	410	200	0	0	-0,4	-0,5	-0,3	0	0,2	0,2	0	0,1	0,2	0,5	0,6	0,7
2015	267	71	10	0	0,5	0,5	0,5	0,7	0,9	1.2	1.5	1.9	2.2	2.4	2.6	2.6
2016	337	99	32	12	2.5	2.1	1.6	0,9	0,4	-0,1	-0,4	-0,5	-0,6	-0,7	-0,7	-0,6
2017	263	89	52	22	-0,3	-0,2	0,1	0,2	0,3	0,3	0,1	-0,1	-0,4	-0,7	-0,8	-1.0
2018	725	476	32	24	-0,9	-0,9	-0,7	-0,5	-0,2	0	0,1	0,2	0,5	0,8	0,9	0,8
2019	589	365	9	5	0,7	0,7	0,7	0,7	0,5	0,5	0,3	0,1	0,2	0,3	0,5	0,5
2020*	1050	722	14	12	0,5	0,5	0,4	0,2	-0,1	-0,3	-0,4	-0,6	-0,9	-1.2	-1.3	-1.2

***COVID Registrations Are Not Included In 2020**

Source: Data from CDGR-Boyacá and NOAA: National Oceanic and Atmospheric Administration in https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

For two decades, records show that the years of greatest events coincide with the ONI Niña periods. The year with the lowest record is 2012 with 47 events that although it presented 4 periods of La Niña the neutral phase is significant in the decrease of the figure, in 2001 with 2052 events it is the final part of a cold period of La Niña. A magnitude of 2005 events shows a marked recurrence of floods in the area.

CARCh is active in emergencies. The analysis of historical events of emergencies in the department of Boyacá and the CARCh shows significant correspondence in their behaviors, see graph 2-A. With respect to flooding, the period from 2010 to 2012 is identified as the most affected in the department with a second peak in the records for the period from 2005 to 2007 with a third increase between 2016 and 2017, see Figure 2 -B).

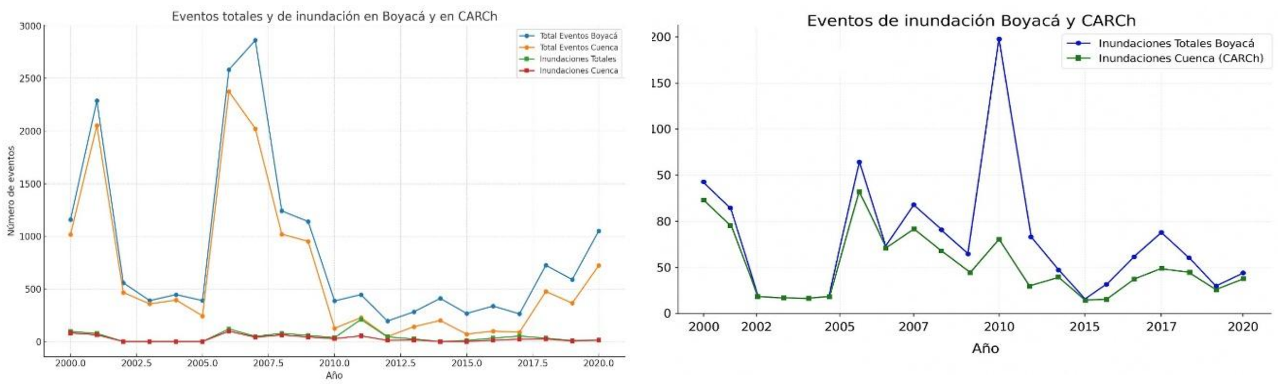

Figure 2: Historical Events Of Emergencies In The Department Of Boyacá And The Carch. A, Event Totals, B. Floods.

Source: Own Elaboration With Data From The Departmental Management Unit Of The Riesgo_ Boyacá.

There are frequent periods with flood records in Tunja, Paipa, Duitama and Sogamoso during 2000 and 2020, especially in the months of April, May, October and November. However, between 2010 and 2011, under La Niña conditions, there were significant effects on the 24 municipalities of the basin (Figure 4). The overflows cause losses in crops and livestock, damage to infrastructure and basic sanitation services, interruption in educational activities, tourism, transportation (rail) and other economic lines due to non-attendance at work due to the effects on workers' properties.

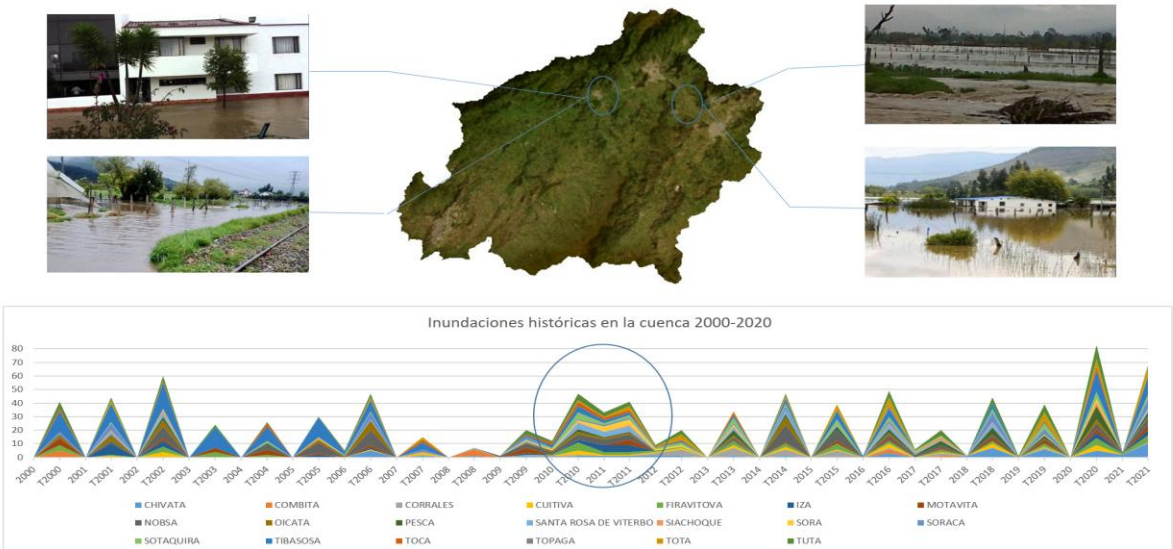

Figure 4: Historical Records And Evidence Of Flooding In The Upper Chicamocha River Basin Carch.

Source: Own Elaboration With Data From The Departmental Unit For The Management Of The Boyacá Riesgo_, Photographic Records From Online Information Sources And YOUTUBE Videos.

The basin presents a plain where floods occur in greater number, in this area are located the municipalities of Duitama, Paipa. Even in dry seasons, there is land with vegetation of lake origin.

Due to extraordinary rainfall, negative impacts are generated on crops and structures (Pacheco et al., 2019). In the CARCh, the records of these rains coincide in the periods where floods occur. A flood calendar presented in Figure 3 is prepared, with the records of IDEAM, showing climatic conditions with bimodal regime in the basin according to the preliminary analysis of the data from 5 meteorological stations located in the study area; UPTC, Tunguavita, Surbata_Bonza, La Copa, Lleras Airport. Specifically, atypical data are identified with correspondence to torrential flood events that trigger floods.

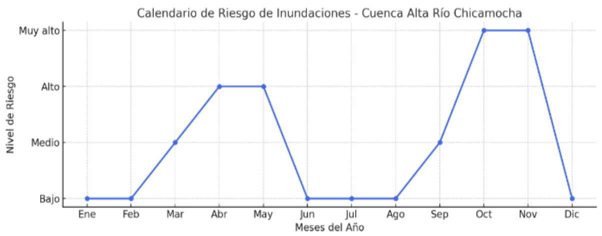

Figure 3: Bimodal Conditions with Flooding Potential.
Source: Own Elaboration With Data From IDEAM.

MES	ESCALA DE VALORACIÓN DEL RIESGO
Octubre–noviembre	**Muy alto** (máximo anual).
Abril–mayo	**Alto.**
Marzo y septiembre	**Medio** por lluvias de transición.
El resto del año	**Bajo**

April–May: high **risk**.
October–November: very high **risk** (annual maximum).
March and September: medium **risk** for transitional rains.
The rest of the year, **low risk**

Table 5 summarizes the preliminary meteorological analysis of the stations included in the study. According to the values of the variables, the stations show similar regional behaviors in the values of the records with some coincidences in the temporalities. In terms of maximum rainfall, they are above 70 mm/day in the valley stations, while the UPTC at higher altitude presents a reduction of 20 mm/day with respect to Tunguavita and with respect to Lleras Airport the difference is 28.8 mm.

Maximum temperatures are between the ranges of 25.4 in UPTC and Andalusia with respect to 29 C in Tunguavita. Minimum temperatures range from -9.8 C in the Copa del Rey to 0.4 C in Andalusia. 100% relative humidity means that the air in the station area is saturated with water vapor at the temperature of the place at the time. There is a regional convergence of cold and warm periods, which means that during the first quarter of the year the highest and lowest temperatures are recorded

Table 5: Consolidation Of The Preliminary Meteorological Analysis Of The Stations Included In The Study.

CONDITION		STATIONS					
		THE CUP	SURBATA BONZA	UPTC	TUNGUAVITA	AIRPORT TO LLERAS C	ANDALUSIA
Precipitation	**Maximum (mm)**	71.4	76.0	56.4	77.0	48.2	73.2
	Maximum month-year	09/02/2003	19/09/2012	21/04/2012	04/04/2015	12/11/2020	09/02/2003
Maximum temperature C	Maxim	25.9	27.6	25.4	29.0	27.2	25.4
	Maximum month-year	22/02/2007	23/03/2010	01/03/2016	12/03/2016	09/03/2016	27/02/2016
Minimum Temperature C	Maxim	-9.8	-8.0	-0.6	-5.2	-8.6	0.4
	Maximum month-year	02/02/2007	04/02/2007	03/01/2010	04/02/2007	03/02/2007	02/01/2006
Relative humidity	Maximum (%)	100	100	100	100	100	100
	Maximum month-year	10/09/2000	08/01/2000	09/09/2004	01/01/2000	11/05/2000	15/01/2000
Hot and cold periods	Warm months	February (2007)	March (2010)	February (2016)	March (2016)	March (2016)	February (2016)
	Cold months	February (2007)	February (2007)	January (2010)	February (2007)	February (2007)	January (2006)
Dry and rainy periods	More months Rainy	November (2018)	September (2012)	April (2012)	April (2015)	November (2020)	February (2003)
	Less rainy months	January (2005)	July (2013)	January (2010)	July (2009)	January (2011)	January (2008)

Source: Prepared By The Author With Data From IDEAM

Figure 7 then consolidates the results of the climatic analyses of the Universidad Pedagógica y Tecnológica de Clombia-UPTC, Tunguavita, Aeropuerto Lleras, Surbata-Bonza and Copa stations with the DEM of the basin. A common denominator is the bimodal regime presented in the quarters of

April, May and June for the first peak of rainfall and the second during September, October and November

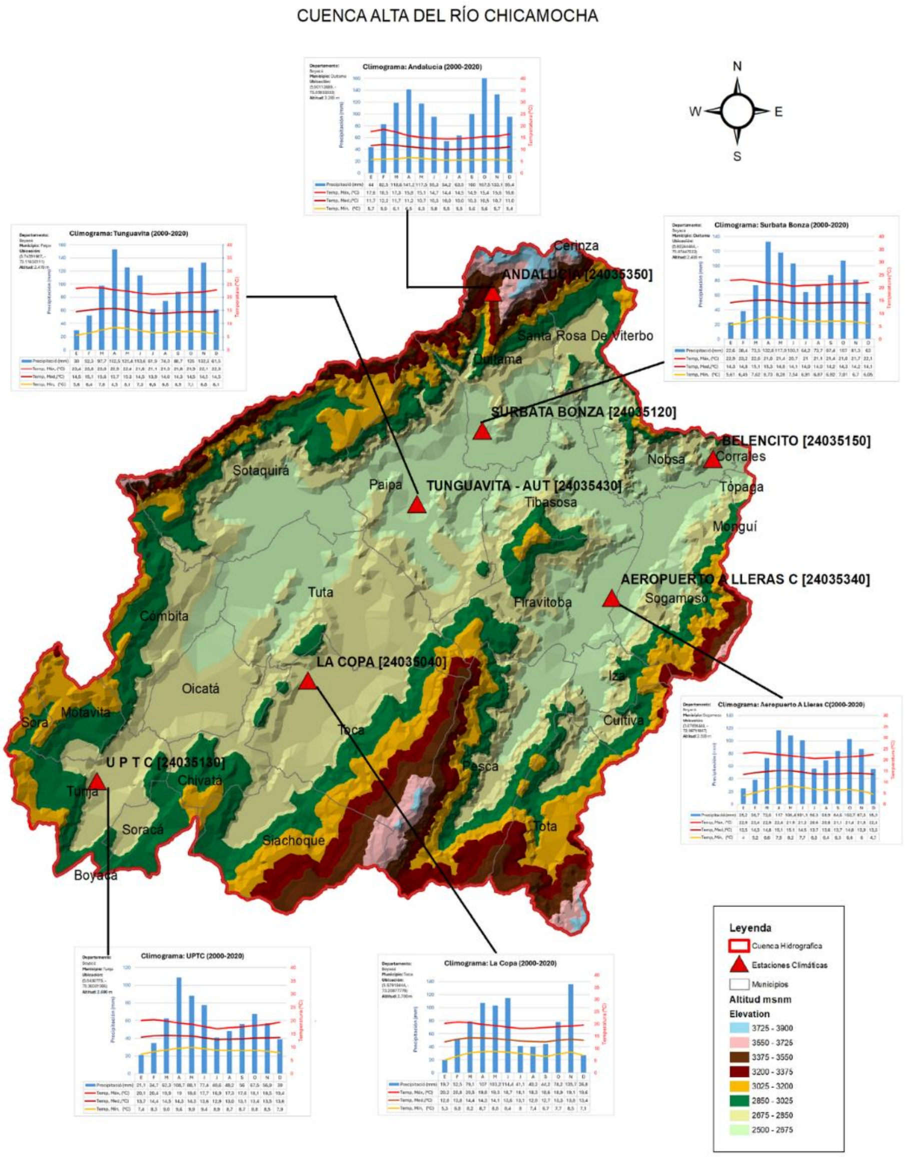

Figure 7: Climate Analysis And Altitudinal Distribution.
Source: Prepared By The Author With Data From IDEAM.

In general, two marked behaviors are observed with respect to the annual thermal amplitude during the 20 years of the study, due to the fact that the ranges are between 10 and 20 C, which categorizes it in the medium and high levels in specific regions. Greater amplitudes in the quarters of December, January and February and reduction in the months of July and August throughout the basin with a transition zone in the other months of the year (Table 6).

Table 6: Thermal Amplitude Of The Basin.

	Estación	**LA COPA**	**SURBATA BONZA**	**UPTC**	**TUNGUAVITA**	**AEROPUERTO LLERAS C**	**ANDALUCIA**
Amplitud térmica (°C)	Periodo frío	5,3	5,61	7,4	5,6	4	5,4
	Periodo cálido	20,08	14,73	21,1	23,8	23,4	18,5
	Amplitud	14,78	9,12	13,7	18,2	19,4	13,1

Source: Own Elaboration With Data From IDEAM

The highest thermal amplitudes (C) are between 19.4 and 18.2 in the stations of Lleras Airport and Tunguavita and the lowest in Surbata-Bonza and La Copa with 9.12 and 14.78 with similar intermediate behaviors between UPTC and Andalusia with 13.7 and 13.1, between the areas of greater and lesser thermal amplitude there are rains and floods.

In the middle of the year, a regional decrease in the maximum temperature is noted after starting during the first quarter with high values without exceeding 25 C, with the UPTC registering the lowest values for this variable throughout the basin. In graph 4, the behavior of the maximum relative humidity and the maximum temperature is consolidated where the humidity is between the ranges of 80% in La Copa and 97% in Surbata-Bonza. It does not present significant variation, maintaining its values in the Surbata – Bonza and Tunguavita stations, where variation is found in the Copa.

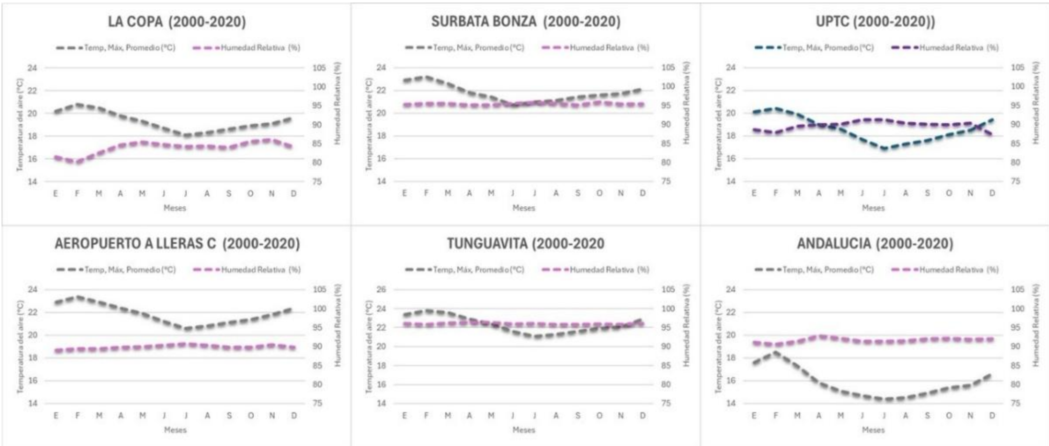

Figure 4: Behavior Of Maximum Relative Humidity And Maximum Temperature In The Upper Basin Of The Chicamocha River For The Period 2000-2020.
Source: Prepared By The Author With Data From IDEAM

Historical data on climatic information on precipitation and maximum temperature show a relatively homogeneous behavior of the trends in the stations located in the upper basin of the Chicamocha River (Figure 5).

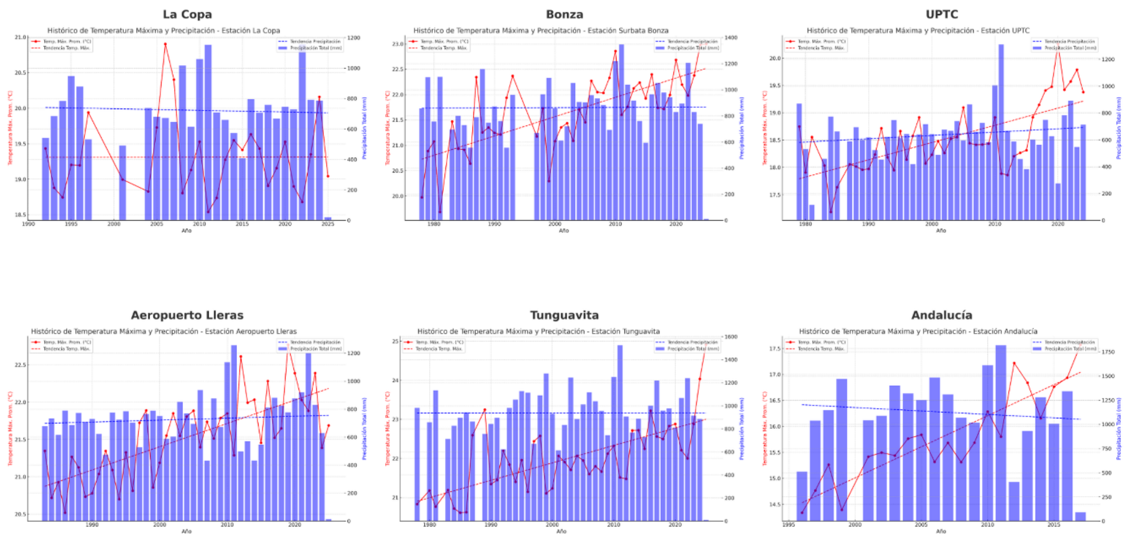

Figure 5: Historical Trends Of Precipitation And Maximum Temperature In The Stations Of The Upper Basin Of The Chicamocha-Carch River.
Source: Own Elaboration With Data From IDEAM.

At the UPTC station (Tunja), a gradual and sustained increase in the maximum temperature is observed, accompanied by a progressive decrease in precipitation. The Tunguavita station presents a marked increase in maximum temperature, with the presence of extreme events in recent years, while precipitation reflects a decrease with high interannual variability.

At the Surbatá Bonza station, the thermal rise translates into a greater frequency of warm days, while precipitation shows a slightly negative trend with significant oscillations, which shows its high vulnerability to climate variability phenomena such as El Niño and La Niña.

The La Copa station confirms a sustained rise in the maximum temperature and a gradual decrease in the accumulated precipitation. At the Andalucía station, there has been a notable increase in the maximum temperature in the last two decades, accompanied by a progressive decrease in rainfall, a pattern that is repeated at the Aeropuerto Lleras station, where the maximum temperature rises consistently while the precipitation shows a downward trend.

Together, the six stations confirm a regional pattern of sustained increase in maximum temperature and reduction in total annual precipitation during the different periods of information issued by IDEAM, a trend that is consistent with the climate change scenarios projected for the Andean region. This scenario reinforces the need to strengthen integrated water resource management, territorial planning and the protection of strategic ecosystems that guarantee resilience in the face of these climate transformations.

5. DISCUSSION

The importance of this research lies in the fact that it shows the preponderant trends in the upper basin of the Chicamocha River in terms of the significant recurrence of flood events mainly in the municipalities of Tunja, Tuta, Paipa, Duitama, Tibasosa, Sogamoso and Nobsa according to UDGR-Boyacá records. Diez-Herreo (2008) indicates the importance of analyzing aspects such as depth, permanence, and velocity for these events, it is not possible to do so, because these records do not exist in the institutions present in the basin. This recurrence of events is aggravated by the orographic complexity similar to that described by Poveda in 2020, since the CARCh is located in the high mountains, made up of a valley surrounded by mountains with promotion of vulnerability due to urban construction dynamics in the floodplain, as occurs in China (Geng et al., 2025).

During the two decades covered by the study, a period defined in terms of the fact that there are emergency records in Boyacá since the year 2000, it is found that the years with the highest number of fluvial floods occur in the presence of La Niña, coinciding with the studies of (Kuo et al., 2016), (Merz et al., 2021). According to the results, it is a basin that presents two dry and wet periods. The results obtained allow us to characterize the basin as a territory with a bimodal climatic regime, in accordance with the atmospheric dynamics of the Colombian Andean region according to (Giraldo-Osorio et al., 2022) which impacts on river flows, which is affirmed in a global context by (Rohmat et al., 2023) and already planned for Colombia by (Poveda & Mesa, 1997).

Maximum rainfall was identified in the months of April–May and October–November, associated with the passage of the Intertropical Confluence Zone, and dry periods between December–February and June–August, which shows a marked seasonality. The above information is important in project planning, for scheduling crops and even for health institutions in terms of periods where seasonal diseases such as those related to the respiratory system are generated.

The La Copa and Tunguavita stations recorded the highest rainfall volumes, exceeding 1,200 mm/year, while at the UPTC (Tunja) and Lleras Airport (Sogamoso) the averages ranged between 800 and 1,000 mm/year. Taken together, the climodiagrams confirm the regional coherence of the climate, the local variations induced by altitude and the inverse relationship between temperature and elevation, as well as the synchronicity in precipitation peaks throughout the Andes basin as found (Urrea et al., 2019).

The floods that occur in the basin are slow, generated by the rainfall that falls in the watershed areas and in the Chicamocha River valley itself. According to the slope of the river shown in Figure 5, both pluvial floods (accumulation of water for hours or days due to saturation of the land capacity, preventing its drainage), and fluvial floods (all the water that remains on the surface near the rivers after their overflow) occur in the valley (Civil, 2013). These scenarios are complicated when there are no efficient drainage structures designed to foresee maximum rainfall events and especially when a part of the territory depends for its operation on the Large-Scale Irrigation and Drainage District of Alto Chicamocha and Firavitoba "USOCHICAMOCHA" (Pastor Muñoz, 1986).

The information found for the thermal amplitdes allows programming agricultural activities, water resource management strategies for dry seasons, improving water storage infrastructure in both rural and urban areas, foreseeing maintenance processes for the municipal sewerage system and managing resources, all of the above within the framework of strengthening risk knowledge.

Overall, the results show that the periods of greatest risk of flooding in the basin are concentrated in April-May, with a high threat level; in October-November, with a very high threat level due to the maximum annual rainfall; and in March and September, with a variable risk conditioned by the occurrence of atmospheric anomalies that enhance rainfall.

In the CARCh as in the China Basin (Yuan et al., 2024) transformations generated by the growth of artificial territories are identified, and predispose the communities located there to the flood threats generated by extreme precipitation events and the increase in the frequency, intensity and duration of rainfall recorded in the existing meteorological and rainfall stations in the region.

6. CONCLUSIONS

Due to historical emergency events, the basin is classified as active, which makes the intervention of organizations and institutions a priority to strengthen their capacities in knowledge and reduce the flood threat. It is recommended for the region to establish an early warning system (SAT) that allows for advance reporting on the flood scenarios that are developing in the basin. It is necessary to rethink urban planning processes accompanied by processes of administration and management of changes in land cover and use, taking into account water resources, especially in the face of the scenario of climate change exaggerated by all anthropic activities.

In short, the region covered by the Tunguavita station rains more and is hotter than the others. The stations located in the valley register lower temperatures, which can qualify them as cold; likewise, they are the ones that receive the highest amount of rainfall. There are high thermal amplitudes throughout the basin.

It is a basin where low to medium slopes predominate and to a lesser extent the high mountain or water recharge sectors of the CARCh. This conditions that the populations are in flat areas and close to the river due to the availability of water supply. This factor encourages the exposure of communities to flooding when building on the floodplain and exacerbates vulnerability due to the characteristics of the infrastructure, the economic conditions of the growing population, food security, basic sanitation and even epidemiologically affected by frequent periods of flooding

Among the socioeconomic factors that drive vulnerability to flood or drought events are: in the face of precarious ancestral traditions, both environmental and agricultural, and population growth, poverty and social inequality are generated; it also increases formal and informal housing facilities and the need for quality support infrastructure (public services)(Camilloni et al., 2020). Due to climate change, the impacts of floods are exacerbated, where the urban sector is the one with the greatest impact due to the population increase, for which the implementation of both structural and non-structural measures is recommended (Osés-eraso & Foudi, 2020).

The analysis of climate dynamics is essential to understand the interaction between atmospheric factors and hydrological processes that affect territorial planning and risk management. The comparative analysis of stations in Boyacá confirms the vulnerability of the region to flooding, especially in periods of heavy rainfall. Climate diagrams are a practical tool to synthesize climate information and support decision-making in territorial planning. It is recommended to strengthen the meteorological monitoring network, implement community education programs in risk management, and develop early local warning systems.

7. RECOMMENDATIONS

Since the basin has been an important area for the region since pre-Columbian times in terms of food security, determine the probabilities of destruction of cultivated areas due to floods (Fenoglio, 2019) as well as its impact on public health (Pedrozo et al., 2018). It is a responsibility for the authorities and their research the legacy of the universities of the region for a community with a widely established agricultural vocation.

The Chicamocha River basin is of vital importance as a source of agricultural supply and ecosystem services, especially water for the region and for the country, but its vulnerability to the threats of frequent floods is also underlined. It is important that flood threat scenarios are identified to foresee loss of human lives, as well as to anticipate the effects and impacts on the productive and economic systems of the basin.

Interventions for the implementation, expansion, updating, and improvement of infrastructure is an urgent need to be addressed, with conventional and alternative elements and systems that allow the improvement of early warning systems through the improvement of climate services in the basin. Authorities with preparation and experience in the field is a priority to improve governance, the organization of the territory, the resilience of the communities and the development of the basin.

Finally, it is important to consider feedback within the human-water system when assessing changes in flooding over decades or centuries. It is argued that an integrated approach to flood risk management is needed to address the risk of future floods, focusing on reducing the vulnerability of the social system (Blöschl et al., 2015).

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