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Temporary Climate Variability for the Period 1965-2016 in the Pedro Moncayo Canton, Ecuador

ORIGINAL ARTICLE

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***Abstract* - The objective of the study was to determine the climatic variability of Pedro Moncayo canton, to establish methodologies for planning and adaptation of the agricultural production systems of the canton. Meteorological data in the period 1965-2016, various aspects of climate variability and the occurrence of extreme events such as the ENSO phenomenon were analyzed, and how they have influenced the air pressure, precipitation and the temperatures of the canton. The Standardized Precipitation Index and the equation created by Fournier were applied. The results show that the average thermal amplitude was 2.46 ° C, the average temperature increase of 0.5 ° C in the whole-time series analyzed. The period of drought corresponds to the months of May to September and to the rainy season of October to April; and the annual average value is 618 mm per year, with a minimum of 409 mm for 2001 and a maximum of 846 mm for 2008. The characterization of the climate variability of the canton will allow corrective measures of territorial planning and formulate a sustainable management plan of the territory.**

Keywords: *ENSO, meteorology, precipitation, temperature, climate extreme*

I. INTRODUCTION

Ecuador is highly vulnerable to the impacts of climate change, because of its geographical location, the country varied topography and the occurrence of El Niño and La Niña (ENSO El Niño South Oscillation) [1]. It is expected that rising temperatures, floods and recurrent droughts, melting of glaciers and the intensification and changes in precipitation patterns, may cause several impacts in the country [2].

The area of study is Pedro Moncayo canton located north of the province of Pichincha, ranging from 1730-4300 meters above sea level, has an annual average temperature of 13.7 °C and an average annual rainfall of 400-1300 mm [3]. One of the main threats to the productive areas of the canton Pedro Moncayo is climate change. Most of the canton has an average vulnerability to high [4]. The impacts caused by droughts and windstorms in major crops (beans, corn, vegetables, potatoes) Canton worsen the problems of malnutrition and malnutrition in the population, leading to a situation of social risk [3]. Another threat is the removal of vegetation cover which is the factor that initiates the process of erosion, this is the sum inadequate management and agricultural land use which reduces production capacity, because of this soil is unprotected against the intensity of the rain and the trawl runoff [3]. For this reason, it is important to determine the climatic aggressiveness of the canton to propose its sustainable use, zoning canton according to its erosive potential and plan the proper use must have for any soil depending on their risk to erosion [5].

Analysis of the conditions affecting the environment of Pedro Moncayo Canton seeking to determine climate and hydrometeorological behaviour over time the study of climate variability is necessary, which can modify the structure, ecosystem function, their interactions with the atmosphere and the time [1]. In addition, it can have effects on agricultural activities that generate changes in the use of land and impact their performance, droughts and floods that affect the land planted and housing, the decrease in accessibility to drinking water and the provision of energy, the displacement and disappearance of plants and animals, among others [6]. Knowing about the climatic variability of a place is essential to understand how natural systems and human activities work [7].

The present study considers the changes of the climatological variables affect the climatic variability, both monthly and annual, and, consequently, determine the inter-annual variability in periods of time, for which it is this case temperature and precipitation as they are affected by weather phenomena. [8].

On a global and interannual scale, climate variability is strongly influenced by the cyclical phenomenon ENSO that begins with changes in the temperatures of the Tropical Pacific Ocean, influences air pressure, precipitation totals and temperatures throughout the year world, which can be both above and below normal [1]. The ENSO phenomenon has two phases: 1) that of El Niño which is the warm phase and 2) that of La Niña, which is the cold phase of the ENSO [9].

In this study, the Standardized Precipitation Index (SPI) was used, which was developed by [10], index recognized for its ease of use at different time scales and for providing better results than other indices in terms of explaining the impacts of the drought [11]. The results obtained with the SPI will contribute to the adaptation and planning of the agricultural production systems of the canton [12].

In Ecuador there are some studies on climate variability, one of them is applied to Quito, the capital of Ecuador, which due to its climatic complexity due to the existence of microclimates is a challenge to study it. The research work is based on the analysis of anomalies of precipitation and temperature with the events of El Niño and La Niña to relate the extreme events with these phenomena and as conclusions we obtained an increase in temperature of 0.13 ° C each decade and with 11 extreme events in a period of 100 years of study with periods of drought and extreme rainfall [13] Another of the studies carried out in Cayambe, Ecuador, shows the development of crop resilience in the face of climate change with an increase of 0.4 ° C by 2029, indicating an aptitude for the cultivation of 45% corn, 50% potato, wheat 32%, and for beans 37% [14].

The objective of this study is to determine the meteorological conditions of the Pedro Moncayo canton to determine the climatic variability over the period 1965-2016 whose results are an important source to establish methodologies for planning and adaptation of agricultural production systems in area.

II. MATERIALS AND METHODS

A. Determination of the study area

The study was carried out in the Pedro Moncayo canton located northeast of the province of Pichincha, 51 km north of the city of Quito (0° 2′ 37.31″ N, 78° 20′ 57.26″ W) [3]
It as an extension 335 Km^2, corresponding to 2% of the Province; Tabacundo is cantonal head and largest city. Pedro Moncayo canton limits the north to the Otavalo canton of Imbabura province, south of Cayambe and Quito cantons; on the east by Cayambe canton and west to Quito canton.[3]
The elevation of Pedro Moncayo canton fluctuates between 1730 to 4300 m.a.s.l, it has an average temperature of 13.7 ° C, with minimum values of 3 ° C and 25.6 ° C maximum. The annual rainfall is 400 to 1300 mm, with a dry period between the months July to October, which have a water deficit of 0 to 330 mm.[15]

TABLE I WEATHER STATIONS LOCATED IN THE STUDY AREA

Station	Coordinates		Altitude	Average Annual Rainfall	Average annual Temperature
	East	North	(m)	(mm)	°C
Tabacundo H. Mojanda	807571	1000568	2940	71,4	12,7
Malchingui Inamhi	796186	1000655	2840	47,9	14,3
Hda. Jerusalem	794144	9999312	2300	41,3	No data
Cochasqui - Hda. Inamhi	799023	1000582	2960	62,3	12,5
Tomalon - Tabacundo	804969	1000324	2790	51,1	14,9
Vindobona	788991	9999694	2250	34,8	17.8

B. Analysis and adjustment of meteorological series

The meteorological data were obtained from 5 stations provided by INAMHI [16]. Table 1 shows temperature and rainfall data between 1965 to 2016
Table 1. Weather stations located in the study area

It should be mentioned that the stations did not have enough information, so the calculation was performed statistically to obtain temperature and rainfall data, This calculation was carried out until obtaining complete series according to the methodology of [17]. The equations for interpolation are presented in table 2

TABLE 2. SHOWS THE STATISTICAL DATA FOR TEMPERATURE INTERPOLATION

Station	Equation	Error
Malchingui	y = 0,9324x + 1,8736	R^2 = 0,9863.
Tomalón-Tabacundo	y = 6,1687e^{0,0632x}	R^2 = 0,9995
Tabacundo-Mojanda	y = 1,0679x - 1,9463	R^2 = 0,9957

C. Standardized Precipitation Index – SPI

The calculation of SPI index was based on the probability with a normal distribution adjusted to 0 and characterized according to [18], [19] and equation (1).

$$SPI=\frac{x_{i,j}-\bar{x}}{\sigma} \qquad (1)$$

Where, x = the seasonal precipitation at the i the rain gauge and j the observation, x¯ = the long-term seasonal mean and σ = standard deviation, SPI = Standardised Precipitation Index. The rainfall events according to the same author were characterized [10]. Table 3 refers to the characterization according to the SPI value.

TABLE 3. SHOWS THE CRITERIA FOR CLASSIFICATION

SPI	*Characterization of the period*
> 2	Extremely Humid
Among 1,5 and 2	Very Humid
among 1 and 1,5	Damp
among 1 and -1	Normal
among -1 and -1,5	Dry
among -1,5 and -2	Very dry
<-2	Extremely Dry

For the processing Excel software was used in an annual time range (SPI-12)

D. Thermal amplitude (TA)

One of the important variables related to the temperature is the thermal amplitude that according to [20] the equation (2) explain how to calculate the variable. For the case study, it was conducted annually for the analyzed time series

$$TA=1/b\sum_{j-1}^{b} Tmax-Tmin \qquad (2)$$

b means de number of years of the series; j means each year and Tmax and Tmin is the maximum and minimum temperature respectively

E. El Niño-Southern Oscillation (ENSO)

ENSO occurrence information was obtained from the National Oceanic and Atmospheric Administration / Climate Prediction Center - NOAA / CPC database [21] El Niño, La Niña and Neutral years are classified as hot (red) and cold (blue) based on a limit of +/- 0.5°C of the equatorial Pacific sea Surface temperature (SST) in region El Niño 3.4 [22]. ENSO events were classified as follows, according to the methodology proposed by [23] as shown in table 4.

TABLE 4. CLASSIFICATION OF ENSO EVENTS

ENSO	Characterization of the period
≥ 1.70	El Niño Strong
1.69> El Niño Moderate > 0.90	El Niño Moderate
0.89 > El Niño Weak > 0.50	El Niño Weak
0.49 > Neutral > -0.49	Neutral
-0.49> La Niña Weak> -1.49	La Niña Weak
1.49> La Niña Moderate> -1.69	La Niña Moderate
≤ -1.70.	La Niña Strong

F. *Climate Aggression*

The calculation of climatic aggressiveness was made by means of equation (3) being the Modified Fournier Index (1960) where the MFI was obtained for each year with the monthly and annual total rainfall data [24]:

$$MFI=\frac{\sum_{I=1}^{12} Pij^2}{Pm} \quad (3)$$

MFI (Modified Index of Fournier) is sum of the monthly rainfall of month i in (mm) of year j and Pm is the average annual rainfall in mm

Then, the sum of the estimated MFIs over the number of years analyzed [24] was averaged using the equation (4):

$$MFI=1/b \sum_{j-1}^{b} MFI \quad (4)$$

b means de number of years of the series

III. RESULTS AND DISCUSSION

G. *Temperature*

The variations that have existed in the series of years 1965-2016 in terms of temperature are directly influenced by El Niño and La Niña phenomenon causing very high peaks of high and low temperatures maintaining an annual average of 13.9 as seen in Figure 1. According to the statistical analysis of the data obtained in INAMHI, the month with the highest temperature is August in each of the meteorological stations and the month with the lowest temperature is the month of January showing the months with the highest incidence in the rainy season and drought as seen in Figure 2.

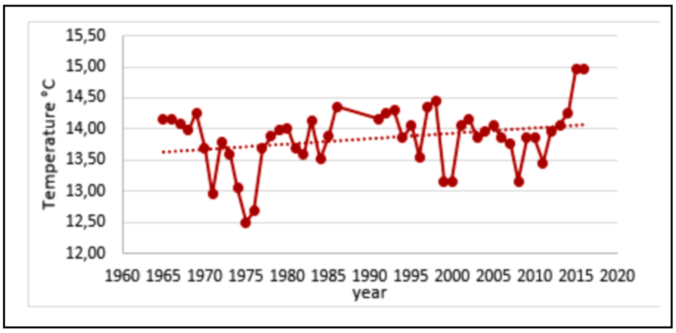

Fig 1. Average annual air temperature for the period 1965-2016

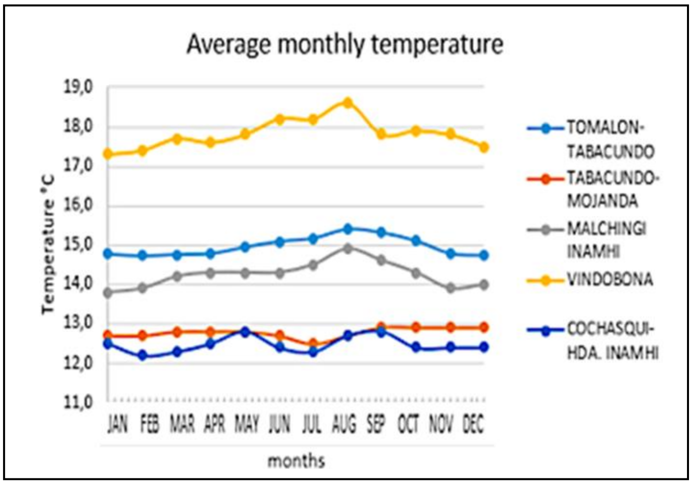

Fig 2. Average monthly air temperature

The average air temperature increased 0.5 ° C for the entire study period fluctuating between 14 ° C, the cold periods were 1970-1975, 1998-200 and 2008-2011, while the warm season occurred in 1985-1990, and from 2014-2016 having a maximum historical temperature value last year as shown in Figure 1.

The global average thermal amplitude presents a value of 2.47 ° C and according to the National Geographic Institute of Spain, a negligible thermal amplitude is presented. According to [25] shows a classification according to the temperature has a temperate climate. Table 5 shows the number of cases for the cold and hot seasons of each season and the percentage that represents in the time series analyzed.

TABLE 5. ENSO SUMMARY CHART IN PEDRO MONCAYO

Stations	Temperature Oscillation (°C)	Number of Cases	%	Average (°C)
Tomalón Tabacundo	Heating	22	46,81	0,38
	Cooling	21	44,68	-0,36
	Constant	4	8,51	0,00
Tabacundo Mojanda	Heating	23	48,94	0,43
	Cooling	20	42,55	-0,45
	Constant	4	8,51	0,00
Malchingui	Heating	22	46,81	0,39
	Cooling	21	44,68	-0,37
	Constant	4	8,51	0,00

The cooling or heating trend of the study period analyzed for the three seasons shows that in 22 years (46.81%) the temperature increased; in 21 years (44.68%) the temperature dropped; while, in 4 years (8.51%) the temperature did not change. The results shown indicate an average annual temperature rise trend with average heating of 0.4 ° C; while, the cooling was -0.39 ° C. In the Figure 3 the oscillation of the temperature in relation to the ENSO is observed.

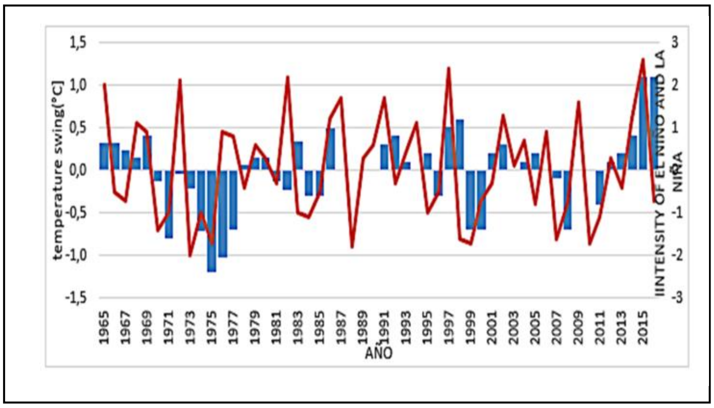

Fig 3. Intensity of El Niño and La Niña, and Oscillation of global average air temperature

During the El Niño phenomenon, 66.67% of the cases (1969-70, 1972-73, 1976-78, 1979-80, 1986-87, 1991-92, 1997-98, 2004-05, 2009-10 and 2014-16) the temperature rose, while 33.33% (1968-69, 1982-83, 1987-88, 1994-95, 2002-03 and 2006-07) the temperature dropped. While for La Niña, 22.22% of the cases (1983-84, 1995-96, 1998-99 and 2005-06) the temperature rose, 22.22% (1988-89, 2000-01, 2010-11 and 2016-17) the temperature you suffered no change and 55.56% of the cases (1970-72, 1973-76, 1984-85, 1999-00, 2007-09 and 2011-12) the temperature decreased by the link to this phenomenon.

H. Determination of Climatic Aggressiveness

The stations evaluated consider MALCHINGUI INAMHI because it presents a very high IFM, indicates a probable erosion by rain and soil degradation. It can contribute to desertification and being semi-arid its resilience is at risk and with anthropogenic incidence it can be generated high soil deterioration. Table 6 shows the IFM values for each station

TABLE 6. RESULTS OF CLIMATIC AGGRESSIVENESS

Code	Station	IFM	Classification
M109	Tomalon-Tabacundo	76,67	Low
M022	Tabacundo-Mojanda	108,90	Moderate
M0111	Malchingi Inamhi	181,63	very high
M210	Vindobona	57,32	very low
M605	Cochasqui-Hda, Inamhi	89,81	low (moderate)
M0574	Jerusalén	72,33	Low

In the years 1973-1977, 1997-1999 and 2014-2016, the that the Niño and La Niña phenomena directly affect the change in temperature, especially in recent years with an increase in temperature since 2011.

I. Rainfall

Determination is important to note that there are two marked periods of rain and drought as shown in Figure 4.

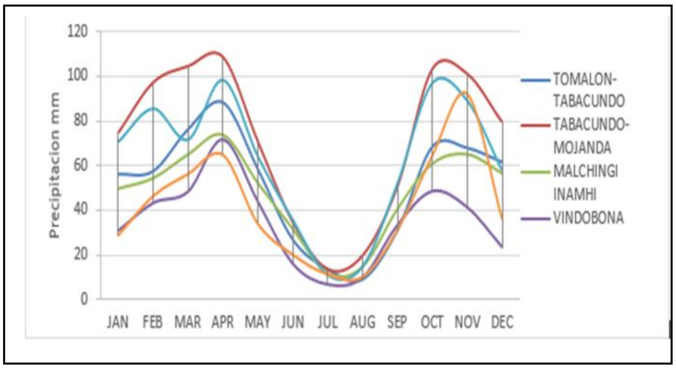

Fig 4. Average monthly rainfall

The period of drought corresponds to the months of May to September and for the rainy season it goes from October to April. The annual average value for the study period is 618 mm per year and with a minimum of 409 mm for the year of 2001 and a maximum of 846 mm for the year 2008. Figure 4 shows the result of the SPI in the time series 1965-2016 together with the ENSO data.

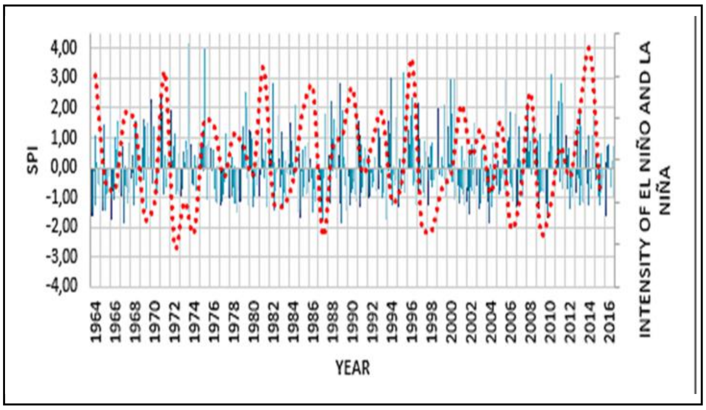

Fig 5. SPI index and Intensity of El Niño and La Niña

The monthly precipitation index represented in Figure 5 has the highest amount of data comprised between -1.5 and 2.5, having high positive peaks of up to 4.16 and negative ones of up to -1.99 which are shown as extreme events. There is a greater number of positive high values and a greater accumulation of negative values. The historical average is -0.01 showing a low variability of precipitation in the study area.

The SPI is directly related to the intensity of the El Niño and La Niña phenomena, with the peaks for the years 19780, 1996 and 2008 showing high amounts of rain and drier periods in the years 1964,1978 without having a greater influence of the dry seasons.

IV. CONCLUSIONS

The climatic variability for the Pedro Moncayo canton presents a variation depending on the periods of drought or rain. The pluviometry and air temperature fluctuations vary between extremely dry and humid years that maintained a relationship with La Niña and El Niño events contributing to climate variability with drastic changes in climate. According to the analyzed period, the increase in temperature is given in 0.5 ° C with a tendency to increase although it does not show a marked thermal oscillation but with the passage of time it could be affected, for which it is important to improve the resilience of the cities before this imminent change. The main activity affected is agriculture, especially flower production, which is the main economic activity in the canton, which is why it would be affected soon. Climatic aggressiveness is an indicator that helps to take preventive measures against erosion and desertification, so the areas of Malchingui and Tabacundo are at risk due to being at a very high climate aggressiveness value of 182 and 109 respectively, which is why the landscape is highly vulnerable and if corrective measures of territorial planning are not taken in the future, there will be problems with land use. In future research this information can be incorporated mainly for the evaluation of local crops against climate change and provides farmers the possibility to make decisions regarding agricultural practices and creating a resilience plan to climate change and development of a sustainable agriculture.

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DECLARATION

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