Trend analysis to determine hazards related to climate change in the Andean agricultural areas of Cundinamarca and Boyacá

Análisis de tendencias para determinar amenazas relacionadas con el cambio del clima en zonas agrícolas altoandinas de Cundinamarca y Boyacá

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ABSTRACT

Recognizing the threat from climate change that is facing and will face agroecosystems is the first step in determining adaptation to climate change. One way is through Global Climate Models (GCMs), but their spatial resolution is not best suited for making decisions locally, further reducing scale, seen as a way to resolve the resolution problem, has not yielded the expected results. This study puts forth an exercise in which we study the climatic time series of precipitation and temperature to determine if there are effects of climate change on one of the most important national agricultural areas, using the Mann-Kendall analysis to determine the existence of statistically significant trends, i.e. signs of change in the variables analyzed. It was found that the variable that presents the most significant trends is the average maximum temperature, while precipitation and average minimum temperature do not.

Key words: mathematical models, climate observations, temperature, mountain farming.

RESUMEN

Reconocer la amenaza climática a la que se enfrentan y se enfrentaran los agroecosistemas es el primer paso para determinar las medidas de adaptación frente al cambio climático. Una forma de hacerlo es a través de los Modelos Climáticos Globales (MCG), sin embargo la resolución espacial de éstos no es la más indicada para tomar decisiones a escala local; además, la reducción de escala, vista como una forma de mejorar el problema de resolución, no ha dado los resultados esperados. Se plantea un ejercicio en el que se estudian las series de tiempo climáticas de precipitación y temperatura para determinar si hay efectos del cambio climático en una de las zonas agropecuarias de mayor importancia a nivel nacional. Se plantea el análisis de Mann-Kendall para determinar la existencia de tendencias estadísticamente significativas, es decir señales de cambio en las variables analizadas. Se encontró que la variable que presenta tendencias más significativas es la temperatura máxima media, mientras que la precipitación y la temperatura mínima media no.

Palabras clave: modelos matemáticos, observaciones del clima, temperatura, agricultura de montaña.

Introduction

According to the IPCC (2007), climate change is the variation (statistically significant) in average climatic conditions or in its variability over an extended period, typically decades or longer. Dry seasons becoming more frequent, higher temperatures than usual, very short rainy season in previous dry periods, droughts, floods, among other consequences, attributed to climate change, are considered the main threat to human development in our generation (UNDP, 2007). In addition to natural climate change, related to changes in obliquity, eccentricity and precession (Hays *et al*., 1976; Imbrie *et al*., 1984; Herbert and Fischer, 1986), more frequent cyclical phenomena (Pavia *et al*., 2009) and changes in vegetation cover (McGregor and Nieuwolt, 1998), the emission of greenhouse gases (GHGs), the product of human economic activity and its accumulation in the atmosphere have increased the radiative force (IPCC, 2007) impacting the current climate.

Furthermore, as the atmosphere has no limits or southern zone, GHGs are significant, determinative factors for the global climate and its effects can be modeled at the global level through Global Climate Models (GCMs), which can generate future climate scenarios, based on previously determined emission scenarios (IPCC, 1997). However,

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their low resolution (Molina *et al*., 2000) combined with methodological and operational difficulties arising from the reduction of scale (and statistics) has led to a need for assessing the presence of trends within the time series of climatic variables to understand what is happening locally and determine the level of threat and future climate risk.

This work takes into account the following five aspects: 1) current climate (2001-2008) measured at some stations located in the Colombian Andes is different to past climae (1970-1980) and the changes could modify the irrigation ... 2010), or accelerate life cycles of poikilothermic organisms, such as insects, weeds and crops, or determine cultivated species altitudinal migration in response to the search for optimal soil and climate (Jarvis and Ramirez, 2009). 2) Because the study area is a region of horticultural and livestock (dairy) importance (Madrid, 2006; ITC, 2009), the effect of climate change on the highlands of Cundinamarca and Boyacá can affect the country's food security. 3) The MCG have very low resolution and therefore do not detect local variations and/or the regional level. 4) Adaptation strategies to climate change should be prioritized by areas and production systems at regional and local levels. 5) It is important and necessary to review the time series of regional-scale climate variables to determine any trends in them. Those areas that recorded the most significant trends represent a major threat to agricultural production activities; therefore, there should be prioritized actions and strategies of adaptation. It is worth noting that, although in this paper we propose a qualitative scenario, as the product of an empirical (statistical) analysis, this does not ensure a reduction in uncertainty regarding the MCG, but because local settings are an important factor for decision makers (Alcamo *et al*., 2006) and can improve the identification of adaptation measures against these threats primarily by farmers.

Materials and methods

Study area

We analyzed the time series of the weather elements measured at weather stations located in the Cordillera Oriental, in the departments of Cundinamarca and Boyaca (Fig. 1).

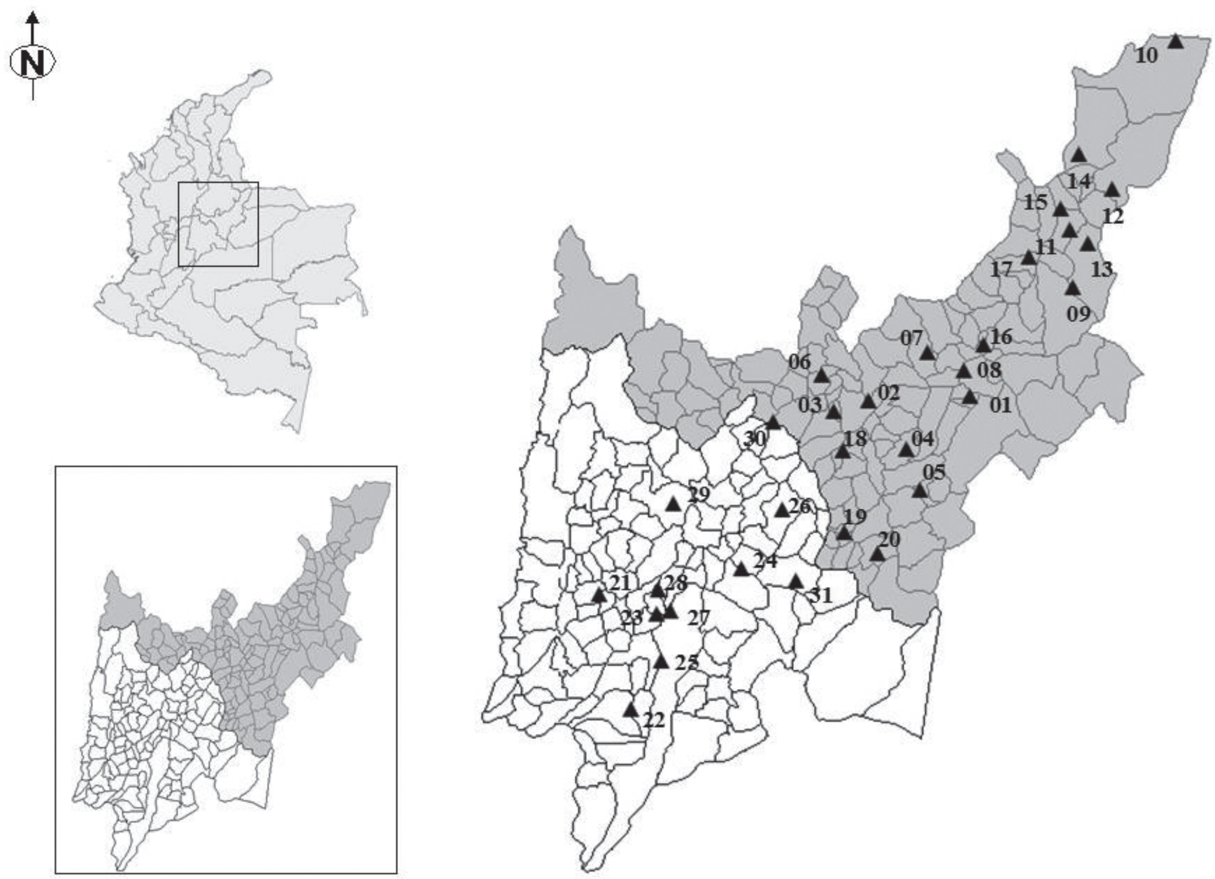

FIGURE 1. Location of weather stations in the Andean agricultural areas of Cundinamarca and Boyacá (Colombia).

Most of these are in the highlands of Cundinamarca and Boyaca, which comprises a set of high-altitude basins, along with the upper parts of the rivers Chicamocha, Bogota and Suarez (Valencia, 2002). The plateau of this area is comprised of a set of mesas that are located between 2,500 and 2,600 m a.s.l., surrounded by mountains up to 4,000 m. Climatically, it is considered a dry island, compared with its surroundings; the precipitation has a strong spatial variation, since the annual rainfall ranges from 600 to 1,500 mm. The temperatures are determined by the height above sea level (Valencia, 2002).

In this region, intra-annual temporal variation in precipitation and temperature is marked by the double pass of intertropical convergence zone (ITCZ). The first three months of the year are dry (January-March), forming the first dry season of the year (FDSY), the three subsequent months are rainy (April-June), especially in April and May, the first rainy season of the year (FRSY). July, August and September are dry, but in September, depending on the area can be characterized as a transitional month and comprise the second dry season of the year (SDSY), whereas the last three months of the year are rainy and form the second rainy season (SRS) (Boshell, 2009). According to Boshell, during the SDSY and FDSY average temperature tends to decrease as the result of radiative loss, associated with clear skies at night, while in the FRSY and SRS it tends to increase for the opposite reason.

Climatic time series

Information for average annual maximum temperature (Tmax) and minimum temperature (Tmin) and the cumulative annual rainfall (Prec) was used from 31 meteorological stations located in the Andean highlands in the departments of Cundinamarca and Boyacá, for a total of 87 time series (Tab. 1), with a minimum length of 23 years.

TABLE 1. Time series used in the Andean agricultural areas of Cundinamarca and Boyacá (Colombia).

No.	Code	Municipality	Department	M a.s.l.	Longitude	Latitude	Tmax		Tmin		Precipitation	
							Initial	Final	Initial	Final	Initial	Final
1	509503	Cuítiva	Boyacá	3000	-72.943	5.572	1983	2008	1978	2008	1971	2008
2	403513	Tunja	Boyacá	2690	-73.355	5.553	1979	2008	1979	2008	1969	2008
3	401522	Samacá	Boyacá	2600	-73.495	5.511	1978	2008	1978	2008	1969	2008
4	508502	Rondón	Boyacá	2120	-73.203	5.358	1978	2008	1978	2008	1971	2008
5	508504	Miraflores	Boyacá	1640	-73.144	5.192	1984	2008	1984	2008		2008
6	401530	V. de Leyva	Boyacá	2215	-73.543	5.655	1980	2008	1980	2008	1978	2008
7	403517	Paipa	Boyacá	1470	-73.116	5.745	1978	2008	1980	2008	1969	2008
8	403534	Sogamoso	Boyacá	2500	-72.967	5.676	1983	2008	1983	2008	1982	2008
9	523501	Socotá	Boyacá	3590	-72.529	6.011	1978	2008	1978	2008	1974	2008
10	703501	Cubará	Boyacá	370	-72.115	7.006	1979	2007	1978	2006	1972	2005
11	403501	La Uvita	Boyacá	2950	-72.545	6.245			1986	2008	1986	2008
12	403524	Guicán	Boyacá	3716	-72.731	6.407	1978	2008	1978	2008	1974	2008
13	403525	Chita	Boyacá	2888	-72.466	6.188	1980	2008	1980	2008	1972	2008
14	403531	Chiscas	Boyacá	2350	-72.504	6.549	1978	2008	1978	2008	1974	2008
15	403533	Boavita	Boyacá	2150	-72.578	6.326	1983	2008	1981	2008	1978	2008
16	403515	Nobsa	Boyacá	2530	-72.890	5.778			1977	2008	1969	2008
17	403532	Sativanorte	Boyacá	2594	-72.704	6.133					1975	2008
18	507501	Nuevo Colón	Boyacá	2438	-73.456	5.353	1978	2008	1978	2008	1971	2008
19	507502	Satatenza	Boyacá	1930	-73.449	5.022	1978	2008			1970	2008
20	507504	Macanal	Boyacá	1300	-73.316	4.941	1986	2008			1982	2008
21	120567	Anolaima	Cundinamarca	1915	-74.437	4.770	1979	2008	1979	2008	1971	2008
22	119507	Pasca	Cundinamarca	2256	-74.311	4.310	1980	2008	1979	2008	1969	2008
23	120542	Mosquera	Cundinamarca	2543	-74.209	4.691	1978	2008	1978	2008	1970	2008
24	120570	Guasca	Cundinamarca	2750	-73.868	4.879	1978	2008	1978	2008	1974	2008
25	120572	Soacha	Cundinamarca	2900	-74.189	4.505	1978	2008	1978	2008	1973	2008
26	120574	Chocontá	Cundinamarca	2709	-73.701	5.117	1976	2008	1976	2008	1974	2008
27	120579	Bogotá	Cundinamarca	2547	-74.150	4.705	1977	2008	1977	2008	1972	2008
28	120598	Tenjo	Cundinamarca	2560	-74.200	4.792	1986	2008	1986	2008	1983	2008
29	306512	Pacho	Cundinamarca	2000	-74.139	5.141	1978	2008	1978	2008	1974	2008
30	401512	Fúquene	Cundinamarca	2580	-73.734	5.467	1978	2008	1978	2008	1970	2008
31	506501	Gachetá	Cundinamarca	1752	-73.646	4.830	1980	2008	1980	2008	1972	2008

TABLE 2. Example of calculation of the trend of a series using Mann-Kendall.

Year	1	2	3	4	5	+	-
Dates	23.8	23.5	22.7	22.9	22.4		
.	.	-0.3	-1.1	-0.9	-1.4	0	4
.	.	.	-0.8	-0.6	-1.1	0	3
.	.	.	.	0.2	-0.5	1	1
.	.	.	.	.	-0.5	0	1
Sum	.	.	.	.	.	1	9
Value - S							-8

Each variable was analyzed on a multi-year time scale, for which annual series were satisfied with the average values (temperatures) and cumulative values (rain) for each season (FDSY, FRSY, SDSY, SRS).

Trend analysis

For the analysis we used the Mann Kendall nonparametric test that is considered one of the most robust for determining the existence of seasonal trends in series (Hamed, 2008) of length equal to or greater than 10 data, even with missing data (Buffoni *et al.*, 1999). According to Hamed (2008), test results may be erroneous in auto-correlated series, so this study uses annual data and multi-annual seasons. The statistical basis of this test was proposed by Mann in 1945 and as the null hypothesis (H_0) proposes that the data series come from a population where the measurements are independent and identically distributed (Hipel and McLeod, 2005). The alternative hypothesis (H_1) is that the data follow a trend, "monotonic" in time. Given H_0, the Mann-Kendall statistic (S) is:

$$S = \sum_{j<k} a_{jk}$$

Where

$$a_{jk} = sign(X_k - X_j) = \begin{bmatrix} +1, & X_j < X_k \\ 0, & X_j = X_k \\ -1, & X_j > X_k \end{bmatrix}$$

While, *j* and *k* are two positions in the time series, where *j* is antecedent of *k* for any following position, satisfying *j* < *k*, so that the greatest difference (*k* - *j*) is equal to n-1, where n is the size of time series. In that sense, when the value of S is positive an increasing trend is indicated, meaning that the variable takes on higher values over time, on the contrary, when it has a negative value, negative trends. For example, assume the following hypothetical series of annual average temperature: 23.8, 23.5, 22.7, 22.9, 22.4, calculation of S (S Mann Kendall) determines whether the trend is incremental or decremental as shown in Tab. 2. In 1975, Kendall showed that the distribution of S was normal and found a fix for when there are "ties" (xj = xk) (Hipel and McLeod, 2005), so you can determine if the trend of the series is significant and accept the null hypothesis or the alternative based on the probability of z (Onoz and Bayazit, 2003). To perform this analysis in the present study, we used the "MannKendall trend test {Kendall}" in the statistical program "R" (R Development Core Team, 2008).

Results

Average maximum temperature (Tmax)

Most Tmax annual series have a positive trend (Fig. 2), specifically, with 95% confidence we can say that over 65% of these have a positive trend, with 99% confidence we can say that 55% of the 28 series have an incremental tendency. About 20% of the annual series analyzed had no trend,

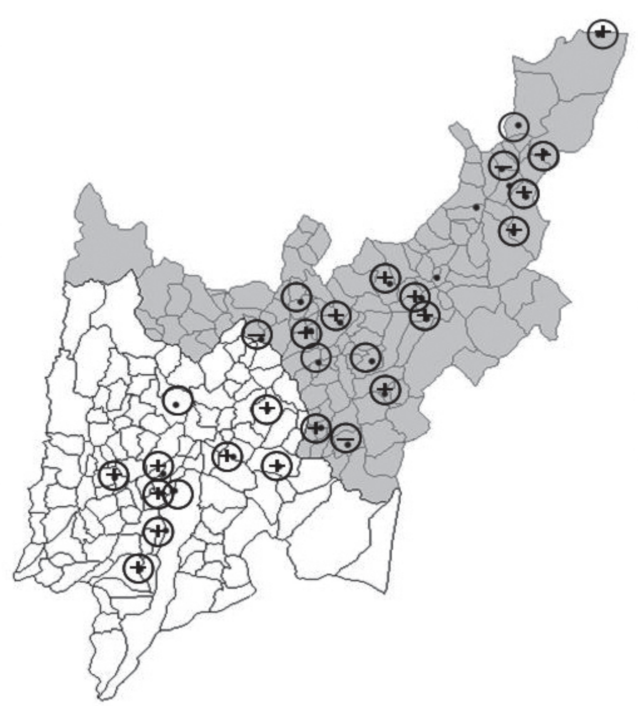

FIGURE 2. Trends in annual maximum temperature (significant $P \leq 0.05$) in areas of Cundinamarca and Boyacá (Colombia).

while only 10% of the series under analysis have a negative trend (99% confidence) (Tab. 3). In this study, unlike that found by Pavia *et al*. (2009) in Mexico, usually when there is a significant trend in the annual values of mean maximum temperature, there is a tendency in the same direction (same direction of the slope) and similar degree of significance in the multi-year series of seasons, i.e. if the annual Tmax values are highly significant negative trends, it is expected that each year, each of the seasons weather (FDSY, FRSY, SDSY, SRS) will have lower Tmax values. In turn, when there is no significant trend in the annual series of the climate element, multi-year trends in the seasonal series are not expected (Tab. 3).

TABLE 3. Trend of the average maximum temperature, annual and multi-year in areas of Cundinamarca and Boyacá (Colombia).

No.	Code	Municipality	Significance and slope					P-Value				
			Year	FDSY	FRSY	SDSY	SRS	Year	FDSY	FRSY	SDSY	SRS
1	509503	Cuítiva	+++	---	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
2	403513	Tunja	+++	.	+++	+++	+++	0.00	0.23	0.00	0.00	0.00
3	401522	Samacá	++	.	---	+++	+	0.05	0.37	0.00	0.00	0.10
4	508502	Rondón	.	.	.	.	+++	0.21	0.39	0.95	0.18	0.00
5	508504	Miraflores	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
6	401530	V. de Leyva	.	+++	+++	+++	+++	0.20	0.00	0.00	0.00	0.00
7	403517	Paipa	++	++	+++	+++	++++	0.03	0.01	0.00	0.00	0.00
8	403534	Sogamoso	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
9	523501	Socotá	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
10	703501	Cubará	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
11	403501	La Uvita										
12	403524	Guicán	+++	++	+++	+++	+++	0.00	0.01	0.00	0.00	0.00
13	403525	Chita	+++	+	+++	+++	+++	0.00	0.07	0.00	0.00	0.00
14	403531	Chiscas	.	.	.	.	.	0.28	0.66	0.56	0.13	0.34
15	403533	Boavita	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
16	403515	Nobsa										
17	403532	Sativanorte										
18	507501	Nuevo Colón	.	.	.	.	.	0.28	0.52	0.47	0.20	0.91
19	507502	Satatenza	+++	+++	+++	+++	+++	0.00	0.00	0.21	0.00	0.00
20	507504	Macanal	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
21	120567	Anolaima	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
22	119507	Pasca	+++	++	+++	+++	++	0.00	0.02	0.00	0.00	0.02
23	120542	Mosquera	+++	+++	+++	+++	+++	0.00	0.10	0.00	0.00	0.00
24	120570	Guasca	+++	+++	+++	+++	++	0.00	0.00	0.00	0.00	0.03
25	120572	Soacha	++	.	.	+++	+++	0.00	0.64	0.38	0.00	0.00
26	120574	Chocontá	+++	.	+++	+++	+++	0.00	0.62	0.00	0.00	0.00
27	120579	Bogotá	.	.	.	.	.	0.48	0.32	0.58	0.97	0.37
28	120598	Tenjo	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
29	306512	Pacho	.	.	.	.	.	0.45	0.33	0.36	0.15	0.59
30	401512	Fúquene	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
31	506501	Gachetá	++	.	+++	+++	+++	0.04	0.38	0.00	0.00	0.00

FDSY, first dry season of the year; FRSY, first rainy season of the year; SDSY, second dry season of the year; SRS, second rainy season.

+ + + Positive trend (increase) highly significant (99% confidence), + + positive trend (increase) significant (95% confidence), + positive trend (increase) not significant (90% confidence), . without trend, --- negative trend (decrease) highly significant, - negative trend (decrease) significant, negative trend (decrease) insignificant.

Average minimum temperature (Tmin)

Unlike what happens with the Tmax, this variable is not as widespread on the behavior of the trend (Tab. 4, Fig. 3), 28% of the annual series of Tmin under analysis have a significant positive trend (90% confidence) 32% do not have any trend and about 40% a decremental tend (90% confidence). The temporal multi-year behavior is equal to T max.

Accumulated precipitation (Prec)

Over 70% of the analyzed seasons have no trend in annual rainfall accumulated values, however, 29% have a tendency with some degree of significance, predominantly positive (20%), i.e. sites in which each year it is raining more, as reported by Peña *et al.* (2010) for the station of El Espinal, located in the Magdalena valley, meanwhile

TABLE 4. Trend of the average minimum temperature, annual and multi-year in areas of Cundinamarca and Boyacá (Colombia).

No.	Code	Municipality	Significance and slope					P-Value				
			Year	FDSY	FRSY	SDSY	SRS	Year	FDSY	FRSY	SDSY	SRS
1	509503	Cuítiva	--	---	---	---	--	0.03	0.00	0.00	0.00	0.01
2	403513	Tunja	+	.	+++	+++	.	0.09	0.15	0.00	0.00	0.10
3	401522	Samacá	.	.	---	---	---	0.95	0.53	0.00	0.00	0.00
4	508502	Rondón	-	--	.	.	--	0.07	0.05	0.50	0.67	0.03
5	508504	Miraflores	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
6	401530	V. de Leyva	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
7	403517	Paipa	---	.	---	---	---	0.00	0.46	0.00	0.00	0.00
8	403534	Sogamoso	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
9	523501	Socotá	--	.	---	---	.	0.03	0.23	0.01	0.00	0.15
10	703501	Cubará	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
11	403501	La Uvita	+++	---	---	+++	+++	0.00	0.00	0.00	0.00	0.00
12	403524	Guicán	---	---	---	---	---	0.00	0.00	0.00	0.00	0.02
13	403525	Chita	.	--	+++	+++	+++	0.13	0.50	0.00	0.00	0.00
14	403531	Chiscas	.	.	.	.	.	0.32	0.25	0.27	0.77	0.64
15	403533	Boavita	---	---	---	+++	+++	0.00	0.00	0.00	0.00	0.00
16	403515	Nobsa	.	.	.	.	.	0.31	0.36	0.28	0.14	0.14
17	403532	Sativanorte										
18	507501	Nuevo Colón	.	.	.	+	+	0.44	0.27	0.81	0.09	0.14
19	507502	Satatenza										
20	507504	Macanal										
21	120567	Anolaima	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
22	119507	Pasca	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
23	120542	Mosquera	+++	.	+++	+++	+++	0.00	0.13	0.01	0.00	0.00
24	120570	Guasca	---	---	---	--	--	0.00	0.00	0.00	0.03	0.01
25	120572	Soacha	+	.	.	+++	+++	0.06	0.39	0.22	0.00	0.04
26	120574	Chocontá	.	++	.	-	.	0.18	0.04	0.41	0.07	0.78
27	120579	Bogotá	+++	+++	+++	+++	+++	0.00	0.00	0.01	0.00	0.01
28	120598	Tenjo	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
29	306512	Pacho	.	.	--	-	--	0.28	0.43	0.03	0.08	0.02
30	401512	Fúquene	.	.	.	.	.	0.31	0.75	0.08	0.31	0.14
31	506501	Gachetá	+++	+++	+++	+++	+++	0.78	0.84	0.00	0.00	0.00

FDSY, first dry season of the year; FRSY, first rainy season of the year; SDSY, second dry season of the year; SRS, second rainy season.

+ + + Positive trend (increase) highly significant (99% confidence), + + positive trend (increase) significant (95% confidence), + positive trend (increase) not significant (90% confidence), . without trend, --- negative trend (decrease) highly significant, - negative trend (decrease) significant, negative trend (decrease) insignificant.

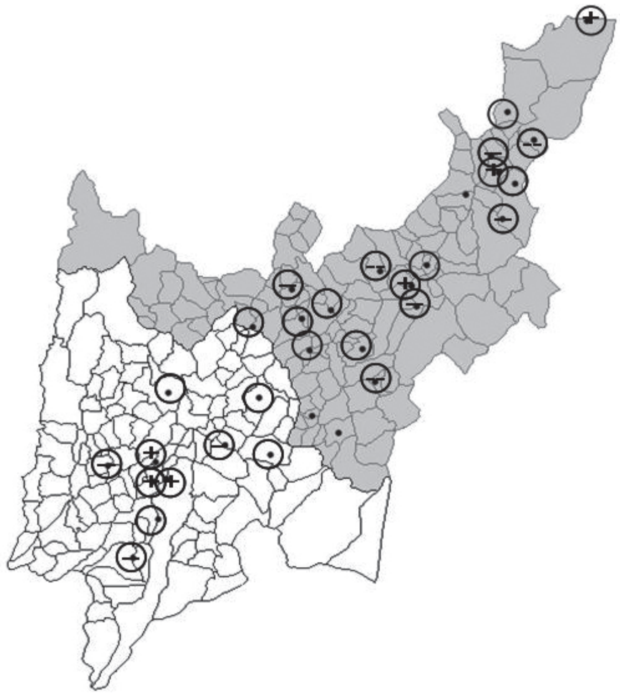

FIGURE 3. Trends in annual minimum temperature (significant $P\leq0.05$) in areas of Cundinamarca and Boyacá (Colombia).

in a few stations there tends to be less rain (Tab. 5 and Fig. 4). The temporal behavior of rainfall is similar to the annual scale, which means that if there are trends in annual rainfall values, neither in the series will have multi-year periods (Tab. 5).

Discussion

Temperatures (Tmax and Tmin)

According to the outputs of the GCMs (IPCC, 2007), in the region which is located in the study area, the main effect of climate change is the increase of temperature. The trends analyzed in this study show a general increase in Tmax, but not in Tmin, because the latter is less sensitive to the overall effect and long term is more related to local conditions and daily cycles. At the station in the municipality of Bogota (27), annual mean maximum temperatures showed no trend, but a significant increase in the average minimum temperature from year to year is seen, which could be linked to the increased presence of gases like CO_2 in the layer closest to the ground, reducing terrestrial radiation (IR) that escapes at night to the upper layers of the

TABLE 5. Trend of precipitation , annual and multi-year in areas of Cundinamarca and Boyacá (Colombia).

No.	Code	Municipality	Significance and slope					P-Value				
			Year	FDSY	FRSY	SDSY	SRS	Year	FDSY	FRSY	SDSY	SRS
1	509503	Cuítiva	.	+	.	.	.	0.52	0.06	0.88	0.17	0.34
2	403513	Tunja	.	.	.	.	.	0.81	0.49	0.87	0.68	0.46
3	401522	Samacá	.	.	.	.	.	0.84	0.23	0.17	0.48	0.88
4	508502	Rondón	.	.	.	.	.	0.73	0.41	0.65	0.70	0.21
5	508504	Miraflores										
6	401530	V. de Leyva	+++	---	+++	.	++	0.00	0.00	0.00	0.62	0.02
7	403517	Paipa	.	.	.	.	.	0.47	0.94	0.38	0.74	0.38
8	403534	Sogamoso	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
9	523501	Socotá	-	.	.	.	.	0.12	0.27	0.16	0.32	0.91
10	703501	Cubará	.	.	.	+	.	0.84	0.25	0.61	0.11	0.99
11	403501	La Uvita	---	---	+++	---	---	0.00	0.00	0.00	0.00	0.00
12	403524	Guicán	.	.	---	++	-	0.00	0.37	0.00	0.05	0.11
13	403525	Chita	.	.	.	++	.	0.31	0.43	0.63	0.04	0.80
14	403531	Chiscas	.	+	.	.	.	0.51	0.03	0.58	0.39	0.53
15	403533	Boavita	.	.	-	.	.	0.41	0.23	0.10	0.50	0.50
16	403515	Nobsa	.	.	.	.	.	0.22	0.33	0.42	0.41	0.79
17	403532	Sativanorte	--	.	-	-	.	0.02	0.30	0.12	0.13	0.18
18	507501	Nuevo Colón	.	.	.	.	.	0.35	0.61	1.00	0.44	0.51
19	507502	Satatenza	+++	+	++	++	.	0.00	0.10	0.02	0.01	0.48
20	507504	Macanal	+++	+++	+++	---	+++	0.00	0.00	0.00	0.00	0.00
21	120567	Anolaima	.	.	.	.	.	0.78	0.48	0.25	0.61	0.98
22	119507	Pasca	.	.	.	.	.	0.25	0.83	0.87	0.90	0.55
23	120542	Mosquera	.	.	.	.	.	0.81	0.50	0.17	0.56	0.68

continues

CONTINUES TABLE 5. Trend of precipitation , annual and multi-year in areas of Cundinamarca and Boyacá (Colombia).

No.	Code	Municipality	Significance and slope					P-Value				
			Year	FDSY	FRSY	SDSY	SRS	Year	FDSY	FRSY	SDSY	SRS
24	120570	Guasca	.	.	.	.	.	0.30	0.85	0.37	0.30	0.19
25	120572	Soacha	.	+	.	.	.	0.82	0.07	0.86	0.18	0.36
26	120574	Chocontá	.	.	.	.	+	0.24	0.23	0.28	0.73	0.15
27	120579	Bogotá	.	.	.	.	.	0.20	0.33	0.18	1.00	0.62
28	120598	Tenjo	+++	+++	+++	+++	+++	0.00	0.00	0.00	0.00	0.00
29	306512	Pacho	.	.	.	.	.	0.86	0.99	0.68	0.79	0.91
30	401512	Fúquene	.	.	.	.	+	0.80	0.21	0.45	0.53	0.13
31	506501	Gachetá	++	+	.	.	++	0.03	0.11	0.33	0.41	0.01

FDSY, first dry season of the year; FRSY, first rainy season of the year; SDSY, second dry season of the year; SRS, second rainy season.

+ + + Positive trend (increase) highly significant (99% confidence), + + positive trend (increase) significant (95% confidence), + positive trend (increase) not significant (90% confidence), . without trend, --- negative trend (decrease) highly significant, - negative trend (decrease) significant, negative trend (decrease) insignificant.

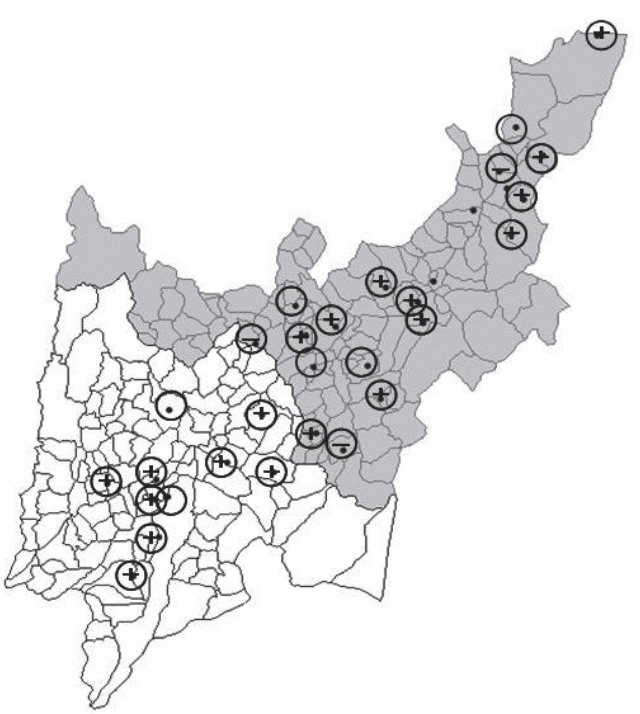

FIGURE 4. Trends in annual precipitation (significant $P \leq 0.05$) in areas of Cundinamarca and Boyacá (Colombia).

atmosphere and thus generates increases in temperature at night. As raised by Yunling and Yiping (2005), climate change has regional peculiarities that are not consistent with the patterns found on a global scale, especially in mountainous regions, where the topography means greater influence of local circulation. In fact, as found by Pavia *et al*. (2009) in Mexico, very few stations show significant increases in both temperature variables analyzed, which does not mean that this area is outside the global warming effect, but that the threats must be detected locally. For example, if the GCMs were used to identify the threats of climate change on economic activities in the region, one would think that frost would not be a problem for crops grown in the highlands of Cundinamarca and Boyaca, when indeed, in some places, the decremental trend of Tmin may result in a higher incidence of frost, causing great losses to farmers.

Although some stations have a trend in which Tmax is positive and Tmin is negative, this should not be confused with a compensatory effect to indicate that the average temperature is not growing. The methodology used in this study determined the threat in a qualitative way, using a nonparametric statistical analysis that determines the existence of trends, so that in these localities, the threat is determined by a higher probability of occurrence of frost at higher altitudes a general increase in evaporation and insect pests, an increase in the number of cohorts (egg-adult cycle) by increasing daytime temperatures. On the other hand, although several authors have determined that these effects (Tmax increasing and Tmin decreasing) are related to deforestation and land use change (Gross, 1987; Gash *et al*., 1996; Giambelluca, 1996; McGregor and Nieuwolt, 1998; Adams, 2007), they cannot be attributed solely to this factor, to determine the change, you must think about the wider effect of increasing greenhouse gases in the atmosphere and climate variability over long and medium periods (Tourre *et al*., 2001; Pavia *et al*., 2009).

Precipitation

Most series analyzed showed no rain trend, possibly because in mountainous regions, precipitation is a local type phenomenon, related to circulation systems on a scale of a few kilometers, catalyzed by processes on a larger scale (Montoya and Palomino, 2005), where the main factor involved in rainfall-genesis is the terrain, so the phenomena in these regions induces variability and climate change appears to have less effect than on sites free of the orographic effect (Peña, 2000).

The stations that show a marked tendency to increased precipitation also show a marked increase in the maximum temperature, however, in those places where positive trends in maximum temperature are found do not always record an incremental annual accumulated rainfall, and which the incremental effect cannot be attributed to increased evaporation and/or evapotranspiration, caused by the increase in maximum temperature. In addition, station 12 (Guice), where there is a tendency to reduce the amount of annual rainfall, a highly significant increase in Tmax is also present. These results are consistent with those reported by Poveda et al. (1998), who noted that even without significant changes in precipitation amounts; the changes that occur in the temperature can affect the water balance.

In this regard, Peña *et al*. (2008) found that in the high plains of Colombia, the response of field water to possible climate change depended on the type of soil, showing the importance of the local approach when defining measures for adaptation to climate change.

Conclusions

- There is a widespread climate threat in the Andean highlands of Cundinamarca and Boyaca, and in most stations evaporative and evapotranspiration rates of crops are expected to increase annually due to increasing T max. In turn, this increase in Tmax is widespread throughout the year, i.e., the effect is not concentrated in some seasons, as in other parts of the world, which could result in an increase in the number of insect cohorts (Tab. 6).

TABLE 6. Related climate threat of climate change in each season in the Andean agricultural areas of Cundinamarca and Boyacá (Colombia).

No.		Threat	
1	Further increase evaporation	Increased risk of frost	
2	Further increase evaporation		
3	Further increase evaporation		
4	Further increase evaporation		
5	Further increase evaporation		
6	Further increase evaporation	Increased risk of frost	Further increase humidity
7	Further increase evaporation	Increased risk of frost	
8	Further increase evaporation	Further increase humidity	
9	Further increase evaporation	Increased risk of frost	Further increase humidity
10	Further increase evaporation		
11	Further increase evaporation		
12	Further increase evaporation	Increased risk of frost	Less precipitation
13	Further increase evaporation		
14	Further increase evaporation		
15	Increased risk of frost		
16			
17	Less precipitation		
18	Further increase evaporation		
19	Further increase evaporation		
20	Further increase humidity		
21	Further increase evaporation		
22	Further increase evaporation	Increased risk of frost	
23	Further increase evaporation		
24	Further increase evaporation	Increased risk of frost	
25	Further increase evaporation		
26	Further increase evaporation		
27	Further increase evaporation		
28	Further increase evaporation	Further increase humidity	
29	Further increase evaporation		
30			
31	Further increase evaporation	Further increase humidity	

- Stations with significant trends of increasing Tmax do not necessarily show an increase in Tmin, as opposed to middle and high latitudes, the absolute minimum and average minimum annual temperature in the tropics are more related to the daily cycle, cold nights and warm days, and not with the annual cycle; also local conditions (topography, land cover) have a great influence on minimum temperatures. Several authors have found that increasing the difference between Tmax and Tmin is related to changes in land use, which must be taken into account, not to mention the overall effects. This condition is important in higher areas, because this means that even with a warming, we must continue to anticipate frost affecting crops in the driest seasons of the year.
- No significant trend was found in the annual accumulated precipitation data from most stations analyzed. Some stations have an increasing trend, however, it cannot be assured that the cause of this are the increases in evaporation or evapotranspiration, associated with positive trends in the Tmax. Also, there are cases in which the precipitation trend is negative, showing that precipitation is a variable difficult to predict.
- Unlike parametric tests for analysis of trends in time series (eg. Regression analysis), whose effect is reduced when the series comes from data with skewed distribution, statistical tests that do not depend on distribution (nonparametric) have the advantage that their effect and significance are not affected by the current distribution of the data.

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