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Correlative analysis of climate impacts in an Andean municipality of Colombia

Análisis correlativo de los impactos del clima en una municipalidad Andina de Colombia

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ARTICLE DATA

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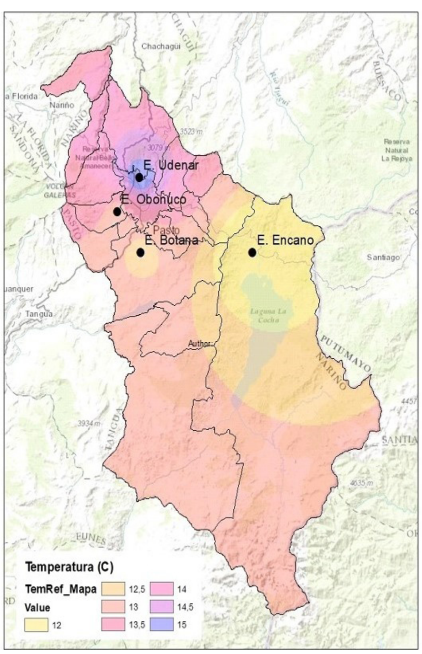

ABSTRACT

The municipality of Pasto (Colombia) is an intermediate, emerging city of the Colombian Andes, which is vulnerable to the impacts of climate change due to its environmental conditions, mountainous morphology, moderately humid climate, and socio-economic structure. This research aims at identifying the impacts of historical trends in climate variables on the main urban elements of the municipality of Pasto. The study uses the correlational method to determine the relationships between climate variables and some impacted urban elements between 2004 and 2019. The adjusted models allow identifying possible trajectories in the evolution of urban variables affected by climate change, population growth, and culture. Results show that climate variability produces negative quadratic trajectories in crop yields and flood events; positive quadratic patterns in landslides, forest fires, the prevalence of acute diarrheal diseases (ADD), and acute respiratory infections (ARI); and linear patterns in water availability, livestock production and food security. In general, the urban variables show a departure from equilibrium when exposed to higher temperatures and precipitation, which affect the reliability of crop yields, food security, water availability, natural disasters, and public health in the municipality of Pasto.

Keywords: climate variability; urban impacts; disaster risk; trajectories; urban elements.

RESUMEN

El municipio de Pasto (Colombia) es una de las principales ciudades intermedias y emergentes de los Andes. Sin embargo, en el contexto de la evolución del cambio climático, la magnitud de los impactos urbanos asociados a su ubicación geográfica, morfología montañosa y clima moderadamente húmedo es incierta. El objetivo principal de esta investigación es identificar los impactos del cambio climático en los principales elementos urbanos del municipio de Pasto. Este estudio utiliza el método correlacional para reconocer las relaciones entre la variabilidad climática y los elementos urbanos afectados entre 2004 y 2019. Los modelos ajustados permiten identificar posibles trayectorias en la evolución de las variables urbanas afectadas por la variabilidad climática, el crecimiento de la población y la cultura. En términos generales, la evolución de las relaciones causales entre el clima y las variables urbanas se aproxima mediante funciones cuadráticas positivas y negativas, es decir, que el aumento o la disminución de las condiciones iniciales de temperatura y precipitación influyen ligeramente en las variables urbanas, pero en la medida en que la alteración climática sea más significativa, la magnitud de las variables urbanas evolucionará exponencialmente hasta colapsar el sistema urbano. Se espera que esto ocurra con el rendimiento de los cultivos, la seguridad alimentaria, la disponibilidad de agua, el riesgo de desastres y la salud pública del municipio de Pasto.

Palabras clave: variabilidad climática; modelos correlacionales, impactos urbanos; riesgo de desastres; trayectorias; elementos urbanos.

INTRODUCTION

Climate change increases the frequency and intensity of extreme weather events (IPCC- Intergovernmental Panel on Climate Change, 2019a), and produces diverse impacts depending on the geographic, social, economic, and environmental conditions (IPCC - Intergovernmental Panel on Climate Change, 2013; IPCC, 2019b). These events affect the most vulnerable groups in terms of inequalities and exposure to climate change Masson-Delmotte *et al*., 2018 Especially, those living in the main cities of Latin America and the Caribbean will experience disruptions in agriculture, water, forests, biodiversity, infrastructure, droughts, floods, and therefore, increased poverty (Bárcena *et al*., 2020).

At the urban level, the incidence of infectious and non-infectious diseases is increasing (Li *et al*., 2021), including respiratory diseases, child malnutrition (Ebi *et al*., 2018), vector-borne diseases such as ticks and fleas (WHO - World Health Organization, 2019), especially dengue, chikungunya and zika in the Pacific region (Filho *et al*., 2019), as well as mental illnesses leading to suicides (Charlson *et al*., 2021).

At the rural level, Sheridan & Bicford (2011) identified positive relationships between plant growth and precipitation, and negative relationships with temperature, while livestock production is associated with temperature and at the same time with the Temperature and Humidity Index (THI), which defines animal comfort (Valdivia-Cruz *et al*., 2021; López *et al*., 2016) and the effects on food security (Bianchi & Szpak, 2016).

At the local level, there are many gaps in the understanding of impacts associated with climate change. Such gaps are consistent with those identified by Edward & Chao (2018), with respect to data management, interdisciplinary assessment of impacts, and the development of mechanisms for policy and market transformation. Other gaps relate to high-resolution modeling and the definition of the relationships between climate change, adaptability, air quality, health, energy, urban planning, government, water, agriculture, human processes, and management of government agency databases, among others (González *et al*., 2021).

In this research, the correlational method was applied to identify the trajectories arising from the dynamic relationships between urban variables and climate variables in the Andean municipality of Pasto (Colombia), for the period between 1976 and 2019. According to the information available at the local level, these relationships were established for the period 2004-2019.

MATERIALS AND METHODS

Location. The municipality of Pasto is the capital of the department of Nariño, located in the Andes in the southwest of Columbia. The municipality has an area of 109,555ha, of which 2.16% corresponds to the urban center and 97.84% is suburban and rural, with land dedicated to cultivating several crops and growing cattle. The city is an important economic hub of the border region with Ecuador and harbors small scale agroindustry, commerce, educative centers, and health centers that have influence over the Southern Colombian region.

Identification of variables. The bibliographic review was based on scientific articles, documents published by official agencies at the international, national, and local levels, and especially on the reports of the Intergovernmental Panel on Climate Change (IPCC).

The time series of the urban and climatic variables were obtained from the following institutions: Mayor's Office of Pasto, public utility companies, Governor's Office of Nariño, Regional Autonomous Corporation of Nariño (Corponariño), Departmental Health Institute of Nariño (IDSN), National Administrative Department of Statistics (DANE,), National Tax and Customs Directorate (DIAN), the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) and Disaster Risk Management Directorate (DGRD) of the Municipality of Pasto.

Evaluation period. To evaluate the evolution of climate in the short, medium, and long term, the IPCC (2013) defined two periods. The first corresponds to the reference period (1986-2005), from which the future climate evolution is compared, and the second corresponds to the projections where the Representative Concentration Pathway Scenarios (RCP Scenarios) were established for the periods 2016-2035, 2046-2065 and 2081-2100. At the national and local level, due to the greater availability of climate information, IDEAM *et al*. (2015), defined the reference period between 1976 and 2005, while the projections were established for the periods 2011-2040, 2041-2070, 2071-2100.

For the purpose of this research, the following periods were defined: i) reference climate period (1976-2005); ii) evidence climate period (2006-2019); and iii) impact period (2004-2019). In the evidence climate period, the alteration of temperature and precipitation variables with respect to the climate reference period was determined. In the impact period, the correlation models between urban variables and climate variables were formulated.

Since the urban variables are reported in different aggregations (i.e., annual population growth, semiannual agricultural production, weekly health events, and daily for disasters), the analysis considered the annual scale as a common basis for all the urban variables, which limits the results to inter-annual rather than intra-annual correlations.

The annual averages of precipitation and temperature within the municipality were calculated with isohyets and isotherms, using the inverse distance weighted interpolation (IDW) and polynomial function (Spline) methods of ArcMap 10.5, following the suggestion by Dias *et al*. (2021) for uneven morphologies.

Data collection for water availability. Water discharges in the municipality were obtained from the meteorological stations of Udenar and La Cocha, which record flows from the upper and middle part of the Pasto River basin, and from the upper part of the Guamúez river basin, respectively (Alcaldía de Pasto, 2014a). The surface runoff coefficient (Cs) was obtained through the equation used by Silva *et al*. (2021) Equation 1.

$$C_s = \frac{Flow}{Precipitation * Area} \qquad \text{Equation 1}$$

Data collection for agricultural production. In the agricultural sector, yields for different crops in the municipality (corn, cabbage, beans, fique, onion, potato, carrot, blackberry, wheat and cauliflower) were correlated with temperature (T), precipitation (P), and the ratio between rainfall and temperature (P/T). These crops represent the greatest contribution to the Gross Domestic Product (GDP) of the municipality (CEDRE, 2011).

The agricultural production database was obtained from the Secretary of Agriculture and Environment of the Governor's Office of Nariño, with records starting in 2004 for variables such as cultivated areas, yields, losses, and prices (the database does not report the varieties nor the places of origin of the produce).

Data collection for cattle production. The THI was used to determine the impact of climate change on cattle production, Equation 2.

$$THI = (1.8 * Ta + 32) - \left[\left(0.55 - 0.55 * \frac{HR}{100}\right) * (1.8 * Ta - 26)\right]$$

Equation 2

Where: HR= Relative humidity (%), and *Ta*= Air temperature (°C).

The THI associates animal comfort with climate variations on a scale of 1 to 100. The values of the index are interpreted as follows: (i) Normal or no production losses for THI < 72; (ii) Alert for losses equivalent to 5%, for 73<THI<78; (iii) Danger or losses equivalent to 10% for 78<THI<83; and (iv) Emergency or losses reaching 15% or more of production, for THI>83 (López *et al*., 2016).

Data collection for food security. Food security depends on how well the local production supplies the energy needs of the population. The dietary energy production was calculated as the product of agricultural production (tons) and the energy content per unit weight (kcal) of each food, which is obtained from the Food Composition Table suggested for Colombia by ICBF (2015).

Data collection for disaster and public health risk assessment. Impacts on public health correspond to common diseases reported by IDEAM (2022) and IDSN (2020). Meanwhile, damages caused by disasters are presented in terms of people and property affected, according to records by the Disaster Risk Management Directorate (DGRD) of the Municipality of Pasto. Correlation models were established based on the T, P and P/T variables.

Statistical analysis. The F statistic was used to determine the significance of correlations between time series of climate and urban variables, while variations in temperature and precipitation time series between the reference period and the climatic evidence period were validated with the Mann-Kendall test. The statistical validation for the two cases was performed with a confidence level of 95%, commonly accepted in climate analysis (Güçlü, 2018).

RESULTS AND DISCUSSIONS

Identification of climate variability impacts. Climate impacts show linear and parabolic trends that negatively alter current conditions in water availability, agricultural production, natural disasters, public health, and the economy. The alteration in the availability of water may affect the growth of the industrial and commercial sectors. In agriculture, it is expected to alter the yield of the main crops produced locally, in livestock production the alteration of animal comfort. While, at the territorial level, the increase of natural disasters such as floods, landslides, forest fires, and in the incidence of some public health diseases, which together can destabilize the socioeconomic development of the municipality.

However, appropriate climate adaptation processes can generate positive effects on tourism, agriculture and the opening of new businesses related to renewable energies.

Local climate. The Mann-Kendall test shows an increasing trend between the reference climate period and the evidence climate period in both temperature (increase of 2.1%) and precipitation (increase of 11.8%). In particular, the impact period has seen the strongest climatic events on record. For example, the 2010-2011 La Niña and the 2015-2016 El Niño, with 2016 being the warmest year on record (Table 1). However, at least 30 years of consecutive data are required to confirm climate change (Gil-Guirado, 2019).

The municipality of Pasto lies within two climatic provinces, the Norandean province to the north and the Amazonian province to the east (Alcaldía de Pasto, 2014a). According to IDEAM (2020), the Norandean province, which harbors 84% of Pasto's population (DANE, 2019), has a rainfall regime between 600 and 1000 mm and temperatures between 13.5 and 15°C. The Amazonian province in contrast is more humid (precipitation between 1000 mm and 2000 mm) and colder (12 to 13.5°C) (Figure 1).

Table 1. Climate statistics of the reference and evidence periods.

Climatic characteristics	Reference climate period (1976-2005)		Evidence climate period (2006-2019)	
	Temperature (°C)	Precipitation (mm)	Temperature (°C)	Precipitation (mm)
Average	12.78	1338.3	13.05	1496.11
Standard deviation	0.35	267.77	0.33	146.89
Maximum	13.23	1789.2	13.47	1754.30
Minimum	12.16	719.82	12.23	1203.48
	Z-value	**Z-value**	**Z-value**	**Z-value**
Mann-Kendall test with $Z_{critical}$ = 1.96	0.1427	3.068	3.0155	-0.5447

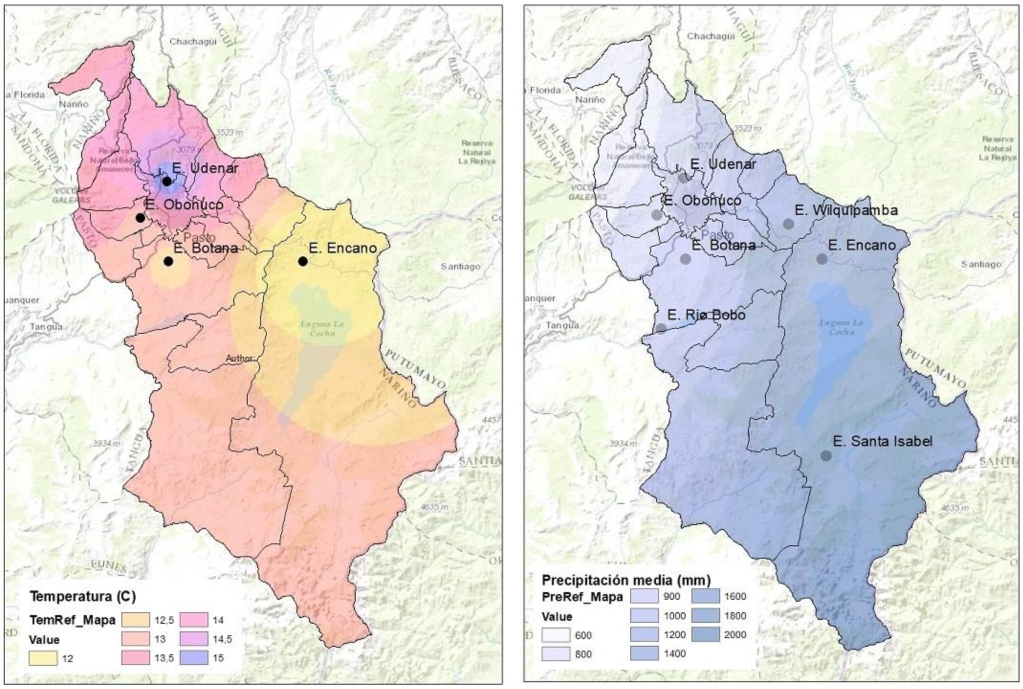

Figure 1. Climatic distribution

Influence on surface water availability. Between the reference climate period and the evidence climate period the mean runoff in the upper and middle Pasto River basin increased from 3.12 m^3/s to 3.82 m^3/s (22%), while the upper Guamuez River basin from 8.74 m^3/s to 8.86 m^3/s (1.35%) (IDEAM, 2020), due to the increase in precipitation (Figure 2). Although there is a significant water supply, conflicts are increasing due to population growth, urban expansion, over-dimensioning of water flows, and an increase in water concessions for agro-industrial, industrial and commercial use (Perugache, 2020).

The Mann-Kendall test shows a stable Cs of 0.25 (Z critical=-1.45) since 1980, which can be explained by the compact, monocentric configuration of the city (FINDETER - Financiera de Desarrollo Territorial y Banco Interamericano de Desarrollo, 2015), that has kept the impermeability of the suburban and rural areas.

Influence on crop yields. Pasto dedicates 8,862.8ha to produce transitory and permanent crops (Alcaldia de Pasto, 2014b), which are highly dependent on climate (FAO - Food and Agriculture Organization of the United Nations, 2019). Crop yields vary with increasing temperatures, improving near the optimal values when soil moisture and CO_2 fertilization decrease (Vergara *et al*., 2014), and decreasing when temperature rises *2°C* above the average and when soil moisture decreases (IPCC, 2021).

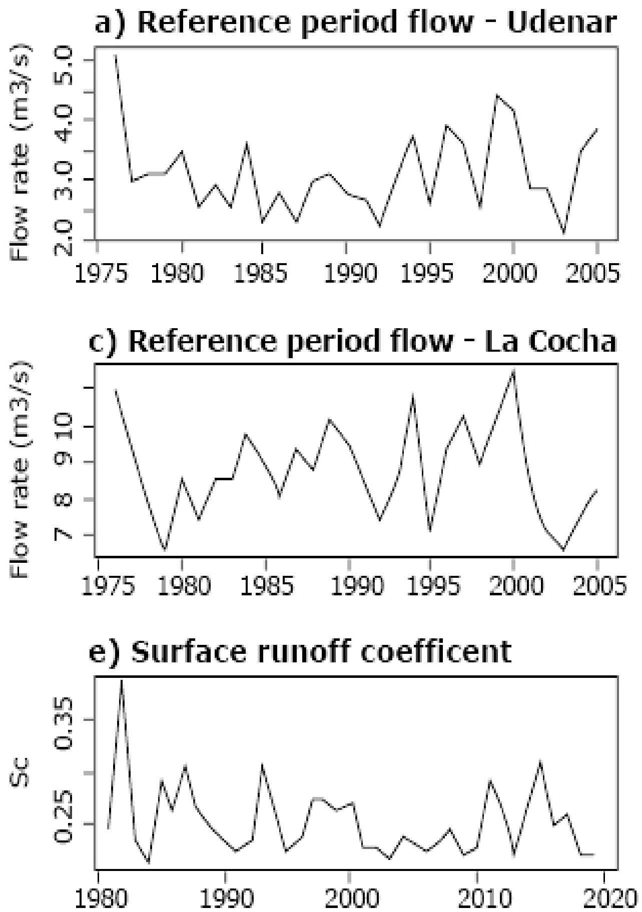

Figure 2. Water supply in Pasto. a) Reference climate period flow at Udenar meteorological station, b) Impact period flow at Udenar meteorological station, c) Reference climate period flow at La Cocha meteorological station, d) Impact period flow at La Cocha meteorological station, e) Surface Runoff coefficient.

In this sense, the correlations between the yield of the municipality's main crops and the climatic variables generated negative quadratic models, with an optimal crop yield in the apex of a parabola, with minor variations near the optimal value and strong reductions in yield when climatic conditions move away from the optimal performance. Strong impacts occur when several disturbances synergistically affect the crop. For instance, if rainfall increases, nitrogen leaching also increases, leading to soil erosion (Monterroso-Rivas & Gómez-Díaz, 2021) (Figure 3).

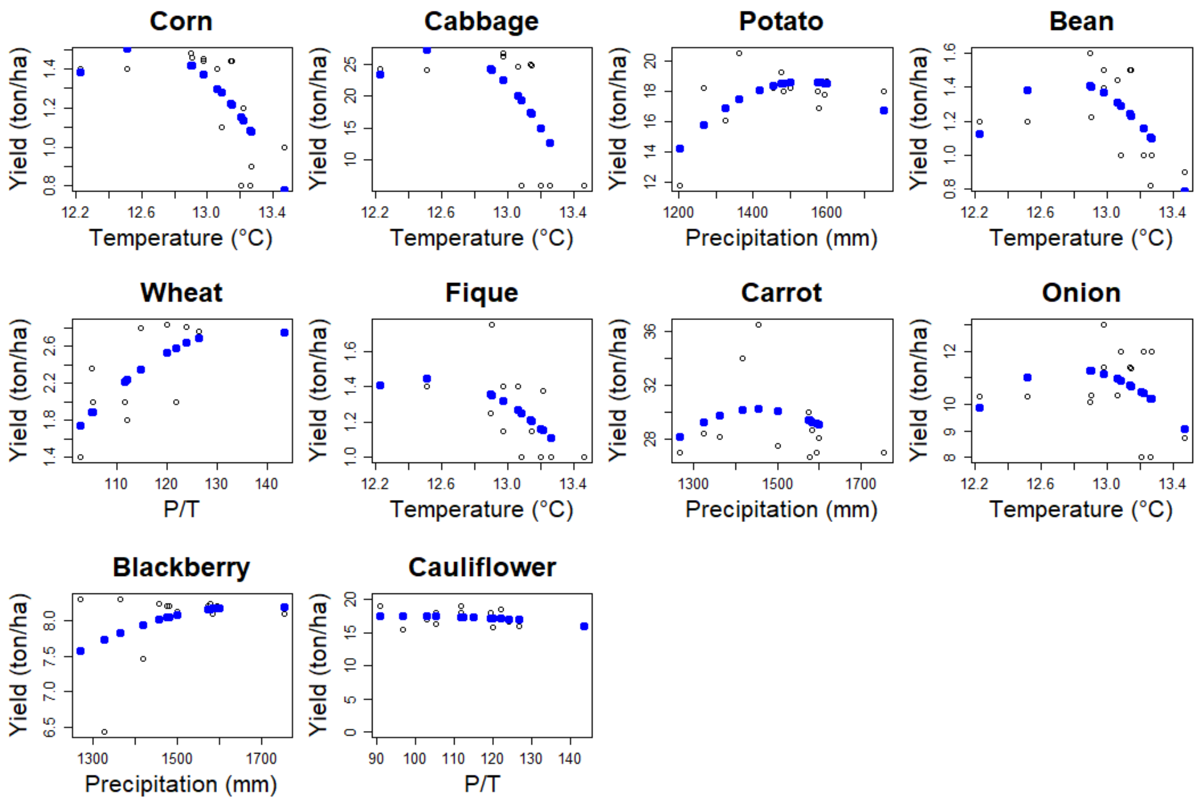

Figure 3. Crop yields in relation to climate.

Although not all the crop models were statistically significant (Table 2), their trajectories are consistent with the relationships between temperature, humidity, nutrient content and crop yields identified by Sheridan & Bicford (2011), as well as with the models defined by Vázquez *et al*. (2015), to identify the sensitivity of corn, bean and coffee crops to the effects of climate change.

Table 2. Statistical validation between crop yield and climate.

Crops	Climate	R^2	Equation	p-value
Corn	Temperature	0.51	$-0.95T^2+24.03T-149.77$	0.014
Cabbage	Temperature	0.50	$-32.2T^2+810.45T-5072.22$	0.029
Potato	Precipitation	0.45	$-0.00004e^{-5}P^2+0.12P-76.12$	0.027
Beans	Temperature	0.43	$-1.21T^2+30.72T-194.15$	0.045
Wheat	P/T	0.43	$-0.0006(P/T)^2+0.18P/T-10.6$	0.078
Fique	Temperature	0.38	$-0.56T^2+14.01T-86.09$	0.069
Carrot	Precipitation	0.20	$-0.000058P^2+0.17P-93.29$	0.367
Onion	Temperature	0.17	$-4.85T^2+123.91T-780.50$	0.334
Blackberry	Precipitation	0.14	$-0.0000036P^2+0.012P-1.96$	0.428
Cauliflower	P/T	0.11	$-0.0006(P/T)^2+0.13*P/T+11$	0.483

With respect to the statistically validated crops (corn, cabbage, potato, beans), it can be inferred that the impact of climate change under current conditions significantly influences their yields. For the non-validated models, it is inferred that the impact of climate change is not yet significant, so they turn out to be more resistant to climate variability.

Influence on livestock production. The municipality of Pasto produces several types of livestock (cattle, pigs, poultry, fish and guinea pigs), of which cattle is the main contributor to the local economy (CEDRE, 2011), with a dual-purpose production (meat and milk) (Alcaldía de Pasto, 2014b). According to the Secretary of Agriculture and Environment of the Government of Nariño, the average production is 25,811 Large Cattle Units (LCU), with an unsustainable carrying capacity of 0.92 animals/ha that threatens the sector. In addition, extreme weather events with temperatures above 26°C decreases animal comfort and is lethal above 37°C with relative humidity above 80% (Rodas-Trejo *et al*., 2017).

At the local level, THI was calculated at 55.8; therefore, climate is not affecting animal comfort. Nevertheless, this production is related to population growth by means of a positive linear function.

Influence on food security. The municipality of Pasto produces 150,320t/year of food, of which 75.18% comes from agriculture and 24.82% from livestock, equivalent to 767.52kcal/inhab/day, which supplies 30.3% of the food energy required by one person (2,500kcal/inhab/day). The remaining 69.7% (1,742.5kcal/inhab/day) is covered by imported products. However, data reported by the Secretary of Agriculture and Environment of the Government of Nariño indicate that food energy decreased from 767.91 to 516.62 kcal/inhab/day between 2004 and 2018, which is a progressive loss in local food security in response to population that continues to grow and agglomerate. Livestock production in turn maintains an increasing linear trend correlated with population growth.

Food security depends not only on the availability (local production or imports), but also on access (food acquisition), use, conservation, and the permanent existence of food (Bianchi & Szpak, 2016). Of these factors, local agricultural production is perhaps the most sensitive due to the discouragement of the agricultural sector, related to the lack of government support, and the continuous increase in food imports, which generate new economic dynamics of unemployment, poverty and migration. The impact on local agricultural production weakens food sovereignty, which is the right of communities to decide their food system (Micarelli, 2018). For example, in 2021, Colombia imported 9848 tons of milk powder (Forbes Staff, 2021) during the economic recovery process associated with the Covid-19 pandemic.

Promoting food imports increases local vulnerability in the food supply since no habitable place on the planet is exempt from climate change impacts (IPCC, 2021). Hence the importance of promoting local production to strengthen food security in the municipality.

Influence on disaster risks. At the local level, the most common weather-related risks are floods, landslides, and forest fires, which have been reported since 2004, based on the number of people and property affected, as well as the aid provided (remittances, rent subsidies, mattresses, and blankets).

According to Corponariño (2011), the floods that occurred in Nariño between 2010-2011 were associated with both the La Niña phenomenon and anthropogenic actions (invasion of riverbeds with legal and illegal constructions and lack of maintenance of sanitation infrastructure). In this period, the DGRD reported 2,479 people and 2,823 properties affected with an average rainfall of 211.5mm/month.

However, starting in 2015, reports began to decrease, even with more intense rainfall than in the reference period. This occurred due to the construction of 16 km of sewers and the rehabilitation of another 41km, between 2016 and 2018 (Empopasto, 2018), which changed the linear trend of affected population towards a negative parabolic function. For instance, in December 2019, with rainfall of 218.5mm/month (IDEAM, 2020), no damages were reported. Consequently, the relationship between population and affected properties was adjusted with a positive parabolic function, associated with population growth (Figure 4).

The stats did not validate the parabolic function between precipitation and affected population (p-value=0.52), because flooding also depends on the inadequate disposal of solid waste in the streets that obstructs water flow (Molina-Prieto, 2016). However, the relationship between population and affected properties was statistically validated (p-value=1.552e-06).

Landslides of low magnitude occur throughout the year, with the worst records occurred in the periods of La Niña (2010) and El Niño (2014), reaching the highest records of 40 people and more than 150 properties affected, especially in the urban area, due to the alteration of the groundwater regime, the mountainous relief with slopes greater than 45º, and significant topographic differences (Alcaldía de Pasto, 2014c). At the national level, landslides are caused by the humid tropical climate, the La Niña phenomenon, and the activity of glacial volcanoes; which mainly affect large cities due to the expansion of human settlements in mountainous zones (Mergili *et al*., 2015).

While the relationship between population and affected properties follows an increasing linear function, possibly due to the lower exposure of the population (Figure 4).

The relationship between temperature and affected population by landslides could not be validated (p-value of 0.3103), due to the time delay between the onset of rainfall and the occurrence of landslides, i.e., the time required for soil saturation (Martínez *et al*., 2010). On the other hand, the time series shows a decreasing number of events, possibly associated with the identification of risk zones in the municipality's Land Management Plan.

As for forest fires, the records started in 2015 due to the major catastrophe during El Niño (more than 300 properties affected). Thereafter, the data decreased following a trajectory fitted to a positive quadratic function, limited to the right in P/T equal to 120.53, and statistically validated (p-value = 0.0046) (Figure 4). This means that, if temperature increases and humidity decreases, plants become stressed, generating conditions conducive to a forest fire (Farfán *et al*., 2021). Although 99% of forest fires in Nariño are caused by burning crop residues (Alcaldía de Pasto, 2014c).

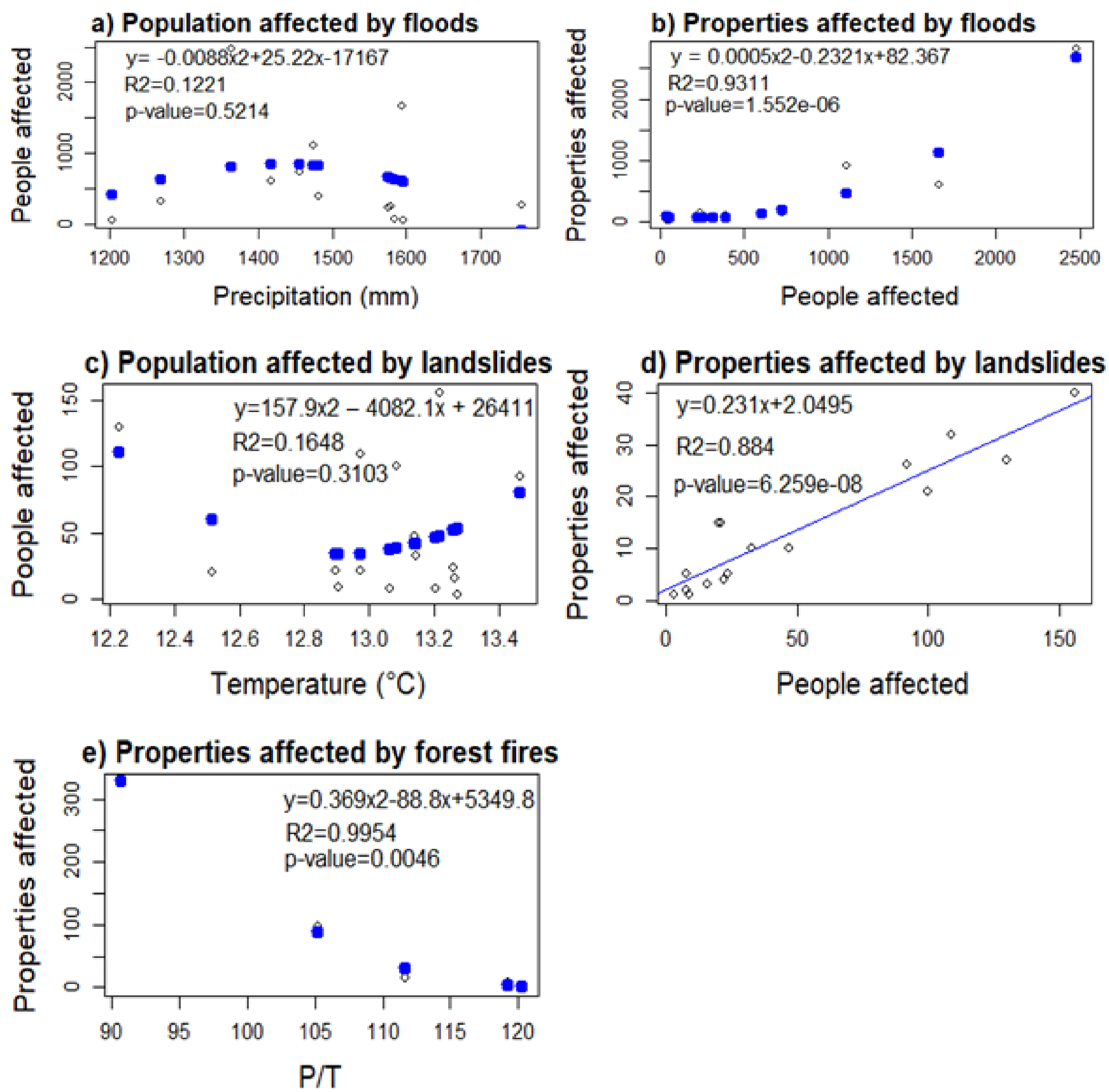

Figure 4. Disaster risks. a) Population affected by floods, b) Properties affected by floods, c) Population affected by landslides, d) Properties affected by landslides, e) Properties affected by forest fires.

Influence on human health. According to WHO (2018), the impacts of climate change on human health are direct and indirect. The direct impacts include psychological effects; an increase in non-communicable diseases such as respiratory diseases, cardiovascular diseases, injuries and even death; the last two associated with droughts, floods, heat waves, storms and forest fires. The indirect impacts include food security, availability of water for human consumption, and the spread of infectious diseases. The latter is associated with population displacement and reduced access to health services for the poorest.

At the local level, there are no reports of climate-associated diseases, so in order to identify possible conditions, the national reports of the Climate and Public Health Bulletin (IDEAM, 2022) were compared with local health reports (IDSN, 2020). This established relationships with ADD, ARI, and child malnutrition (MNT), which especially affect children under 5 years of age.

Regarding ARI, D'Amato *et al*. (2016) state that climate disturbance causes allergic respiratory and obstructive lung diseases that decrease lung function and can lead to death. According to Mehdi *et al*. (2016), these diseases increase with extreme meteorological changes, such as heat waves, floods, storms, droughts, and forest fires. On the other hand, Ebi *et al*. (2018) and Santos *et al*. (2021) state that heat increases mortality from respiratory system diseases and malnutrition.

The incidence of ADD also increases after heavy rains or floods (Levy *et al*., 2016) because they agitate the water and disperse fecal pathogens that may reach contact with humans, with the child population being the most vulnerable (Wu *et al*., 2015). Similarly, Rodríguez-Pacheco *et al*. (2019) state that elevated temperatures and droughts increase the incidence of ADD. In addition, unhealthy water supply, inadequate sanitation and hygiene deficits are responsible for 88% of ADD (Escalona *et al*., 2018).

In accordance with the above and with the information available at the local level, the impacts of climate variability on the incidence of diseases related to ADD and ARI follow trajectories marked by positive quadratic functions with respect to the P/T variable. This allows modeling the increase in the incidence of these diseases, both by an increase or decrease in the temperature and precipitation variables. In addition, the vertex of the parabola represents the lowest impact when climatic conditions are adequate, and the concavity of the function represents the exponential increase of the impact when climatic conditions become adverse (drier and warmer or wetter and colder) (Figure 5).

The correlational models adjusted at the local level do not show trends because other variables, such as economic conditions and health care, influence them. Therefore, it is possible to affirm that the current climatic conditions do not yet represent a strong impact on the incidence of these diseases. But as climate change worsens, it is possible that health impacts will follow the identified trajectories or similar ones. Regarding MNT, many authors such as Mehdi *et al*. (2016) relate climate change as a precursor of this disease. Despite this, with local records dating back to 2016, it is not possible to identify trajectories with respect to climatic variables. However, at the national level, Hodson de Jaramillo *et al*. (2017), Forero *et al*. (2014), and Elum *et al*. (2017) relate this disease to poverty conditions of the population.

Despite the above, in recent years, the local incidence of mortality from ADD and MNT is zero, except for ARI, which remains constant (Figure 5). Such reduction in the rates of ADD and MNT can be related to the progress and good management of the municipality's health system, which is considered one of the best in Colombia (Salud, 2016). However, ARI, as an airborne transmitted disease, is the most sensitive to climate variability.

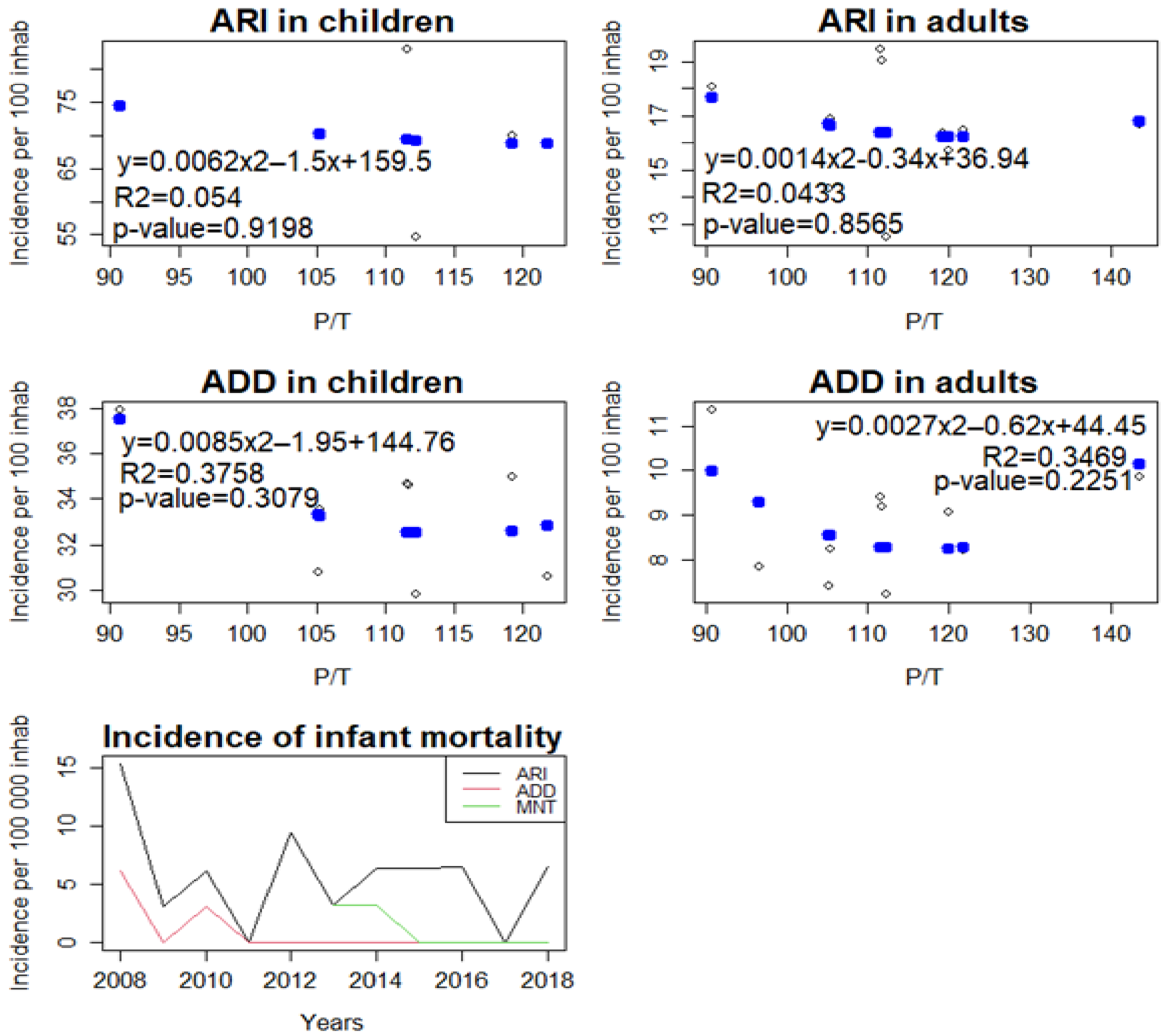

Figure 5. Incidence of climate change on morbidity and mortality.

Since there are no reports of heat waves in the municipality (IDEAM, 2020), it is unlikely that these events may influence mental, cardiovascular, and skin conditions, as they do occur in other places (Cheng *et al*., 2021; Goshua *et al*., 2021). In this regard, it is more likely that these health conditions may be related to a more prolonged exposure to ultraviolet radiation in the high Andean mountains. Similarly, there is no evidence of insect-borne diseases (dengue, chikungunya, Zika, and others) because of the cold climate.

CONCLUSIONS

The average annual temperature and precipitation in Pasto increased between the reference (1976-2005) and the evidence climate period (2006-2019), impacting crop yields, food security, number of natural disasters, and incidence of some public health diseases.

Hazards associated with temperature and precipitation in Pasto increased in both intensity and severity, although the effects are somehow dampened by improvements in basic urban planning and infrastructure.

Relationships between climate and urban variables fit positive and negative quadratic functions that offer a basis for predicting urban risks associated with global climate policies and local city management.

Conflict of interests: The authors declare that there are no conflicts of interest.

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