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EFFECTS OF CLIMATIC CHANGES ON CROPS, AREA OF SANTA ROSA DE CUSUBAMBA, CAYAMBE-PICHINCHA, ECUADOR

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ABSTRACT

This study was conducted in the zone of Santa Rosa de Cusubamba, Cantón Cayambe, Pichincha Province, In order to evaluate the effect of climatic changes on the crops. The Vulnerability Index (VI) was used for analyzing the exposure and sensitivity components as factors influencing the development of crops. Climatic projections were obtained according to exposure, which indicated that in the period 2020-2049, there would be a slight increment in temperature of 0.4 °C and in precipitation of 69-89%, while for the period 2040-2069 the temperature increment will be of 0.3°C and the precipitation increment will be of 149-157 %. With ECOCROP (data and the use of the DIVA-GIS software, climatic aptitude of the sensitivity of crops against weather conditions was determined. The results indicated that the aptitudes for cultivation of corn, potato, wheat and kidney bean were of 45%, 50%, 32% and 37% respectively. Adaptability was defined based on the Unsatisfied Basic Needs (UBN) indicator. The results for the study area and for Cantón Cayambe were of 80% and 63% respectively, which represents a high percentage compared to the average adaptability of Cayambe. In conclusion, the Vulnerability Index established for the study area indicated that corn, potato, kidney bean and wheat crops are vulnerable to precipitation at a low level, while to the temperature at a high level.

Keywords: climatic changes, vulnerability, exposure, sensitivity, adaptability, crops.

INTRODUCTION

Until the mid-twentieth century, the world population was about 2.5 billion but in the last 50 years, humanity has increased to 6.5 billion people. They eagerly expect for living and consumption standards similar to those delighted by developed countries. However, the demand for living and consumption standards for the fast growing population, in the coming years, will be much higher, as expected in 2050; the world population would be 8.9 billion people [1]. Weather conditions on the planet indicate that earth-ocean surface temperature showed a warming of 0.85 °C, over the period of 1880-2012, which was the averaged globally and calculated from a linear trend. The total increase between the mean values of 1850-1900 and 2003-2012 was 0.78º C [2].

According to Intergovernmental Panel on Climate Change (IPCC) [3], the global atmospheric concentrations of greenhouse gas (GHG) emissions estimated in 2005 were CO_2 (379 ppm) and CH_4 (1774 ppm), exceeding the natural range of values in the last 650,000 years. According to the World Meteorological Organization [4], CO_2 reached 389 ppm in 2010 (which means an increase of 39% compared to pre-industrial times), CH_4 reached 1808 ppm (158%) and the N_2O at 323.2 ppm (20%).

The global concentration of CO_2 is mainly due to the use of fossil fuels, followed by the change of soil use. It is most likely that the observed increase in CH_4 concentration is predominantly due to agriculture and the fossil fuels use, while the increase of N_2O concentration mainly comes from agriculture [3]. Global agriculture contributes a total emission of 17 - 32% of greenhouse gases (GHGs). Pollutant emissions by agriculture in developing countries increased from 32% in 1990 - 2005 and this trend is expected to continue to meet the demands of food products by a growing population. Especially if it is considered that the aggregate global potential to mitigate agricultural GHG emissions, the 74% lies in these countries [5].

According to the Second National Communication on Climatic Change of Ecuador [6], an increment in temperature and variations in frequency and intensity of precipitation were determined. In addition, losses in food production were presented due to the increased rainfall on the coast region and the prevalence and increased droughts in some parts of the Andean region. In addition, losses of cultivation lands, reduced availability of fresh water and crop and livestock losses by floods in the lowlands of Ecuador were presented. According to the above information and based on the emergency census developed by the MAGAP in 2012 [7], the main crops affected by flooding were rice, hard corn, cacao, banana, peanut, watermelon (in the coastal region) and bean, kidney tomato, potato, pea, wheat and barley (in the Andean region), which were directly affected by climatic changes. The deforestation process, which was estimated by the Ministry of Environment (the rate of forest loss is 0.66% in the period 2000-2008) [8], the agricultural losses in coastal areas and in the upper reaches; as well as pollution of coastal and marine ecosystems, makes the country highly vulnerable to climatic change.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with adverse effects of climatic change, including variability and climate extreme conditions. Vulnerability, therefore, is a function of the character, magnitude and speed of climatic change and the variation to which a system is exposed, its sensitivity and its adaptability [9, 10, 11, 12, and 13], and it is determined with the following function:

V *f* (E; S; A)

Where
V = Vulnerability is a function:
E = Exposure,
S = Sensitivity, and
A = Adaptability.

Vulnerability characteristics refer to sensitivity, exposure and adaptability. These features are nothing new, they have emerged from the risk of climatic variations on crops, from literature on food security, and in the last decade they have been expanded and integrated in the research community of global environmental change [14]. Vulnerability can be analyzed from various viewpoints or factors, which together make up a certain level of vulnerability. This level of vulnerability, results from the interaction of the specific conditions of an area and/or specific community. Furthermore, it is known that vulnerability itself is a dynamic system that emerges from the interaction between internal and external features that converge in time and space [15].

The vulnerability factors related to exposure and sensitivity are directly proportional, i.e., the higher the value of these coefficients, the greater the vulnerability of the analyzed crops, meanwhile, the rate of adaptability is inversely proportional, i.e., to a lower coefficient, the index of vulnerability is greater. Against this background, the present study was aimed to evaluate the effect of climatic changes using the vulnerability index of corn, potato, wheat and kidney bean crops produced in the rural zone of Santa Rosa de Cusubamba, which is determined by precipitation and temperature. The primary objective of the vulnerability analysis is to find the people, places or natural resources that are more susceptible to damage and identify actions to reduce vulnerability.

MATERIALS AND METHODS

This research was developed in the area of Santa Rosa de Cusubamba, Cantón Cayambe, and Pichincha Province-Ecuador with an area of 29.07 km^2. Its altitude ranges from 2000 to 3800 meters and its geographical position is 0°0’0’’ to 0°0’5’’ in South Latitude and from 78°15’ to 78°20’ in West Longitude. The area weather is tempered and the temperature varies between 10 °C and 25 °C, relative humidity is 30%. Regarding to precipitations, some years ago there was a marked rainy season from September to May, with two sub-periods of maximum rainfall; October to November and February to April. The driest period was from June to August, but now it varies constantly at any time of year.

To determine each of the coefficients, which establish the vulnerability, we proceeded as follows: For exposure analysis, the IPCC data with projections of future weather (19 climatic models) were obtained, and the average of these models, determined by the CIAT [16], i.e. a single value of precipitation and temperature projections were used. For the study area, the projections data regarding to Santa Rosa de Cusubamba were taken. These data were adjusted to the following scales:

Table-1. Categorization of climatic data regarding to temperature, precipitation, vulnerability.

Temperature		Precipitation		Vulnerability	
Categorization of climatic data: °C	**Scale**	**Categorization of climatic data, %**	**Scale**	**Categorization of climatic data, %**	**Scale**
1.89 - 1.52	Low	89-85	Low	89-85	Low
1.51 - 1.20	Medium	84-73	Medium	84-73	Medium
1.19 - 0.89	High	72-69	High	72-69	High

These data were used to determine the average increment in temperature and the average variation in precipitation in two future periods 2020-2049 and 2040-2069, and the results were categorized according to Table-1. For the Sensitivity analysis, the DIVA-GIS (version 7.5.0.) Software was used. This is a program for managing geographic information, which has an Ecocrop module, which allows modeling the climatic aptitude of crops using data of temperature and precipitation. The results of Ecocrop stablish the climatic aptitude of each crop with values ranging from 0 to 100.

With these results, maps were elaborated with the softwares: DIVA-GIS and ARC GIS. Referring to the adaptability analysis, the values of the Unsatisfied Basic Needs (UBN) were used, which also range on a scale from 0 to 100. The UBN are the number of people living together in "poverty", expressed as a percentage of the total population in a given year. It is considered as "poor" if a person belongs to a home that has persistent shortcomings in meeting their basic needs including housing, health, education and employment.

Once the factors of vulnerability were determined, the vulnerability index is calculated by the formula described above, i.e. the exposure and sensitivity factors are added and then the adaptability is subtracted for each crop. The methodology presented standardized vulnerability factors to 100, which is the maximum value of the vulnerability. The purpose was to obtain an index of crop vulnerability based on the threats that affect plants development. After obtaining the coefficients of exposure, sensitivity and adaptability, the Vulnerability Index of crops was calculated and then categorized based on the following criteria (Table-1).

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RESULTS AND DISCUSSIONS

Precipitation

The results of the rainfall analysis in the last 25 years (Table-2 and Figure-1) indicated that rainfall is highly variable in the area; there were dry months in the year, in which it rained 0.2 and 0.3 mm (August of the ano1993 and 1997). The maximum monthly precipitation reached 198.2 mm (April 1994). The overall results of the monthly precipitation occurred from 1990 to 2014 ranged from 289.7 mm to 2200 mm, corresponding to the months of August and April respectively within the period of 25 years.

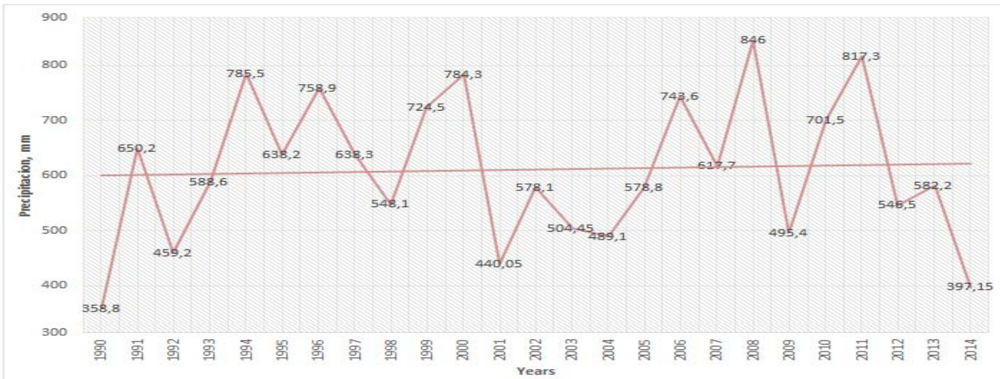

Figure-1. Distribution of precipitation. Tomalón Station. INAMHI, 2014.

Generally a dry period with less than 740 mm for the months of June to September was identified, and a wetter period, for the months of October (1575 mm) to April (2200 mm) followed by March (1883 mm) was identified. The monthly average in the period ranged from 12.1 to 88 mm, which represent lower amounts of rainfall. Analyzing the behavior of the precipitation values per year, according to Figure-1, we see that these were highly variable, the highest rainfall occurred in 2008 with 846 mm per year, while the driest year corresponded to 1990 with 358.8 mm annually. The variation coefficients were high (Table-2), indicating extreme variability of rainfall that occurs each month within the same year.

Table-2. Precipitation data (mm), period 1990-2014. Tomalón Station, INAMHI.

YEAR	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	Total	Mean	Standard deviation	Variation coefficient
1990			36,4	58,2	32,1	19,4	9,4	4,4	10,9	134,7	25,9	27,4	358,8	35,9	38,06	106,1
1991	99,4	15,5	111,3	56,6	88,3	14,3	18	10,4	46	38,3	82,7	69,4	650,2	54,2	35,87	66,2
1992	27,7	69,7	46,5	86,5	51,7	14,6	5,7	6,7	39,4	44,3	41,5	24,9	459,2	38,3	24,34	63,6
1993	35,3	96,2	108,6	81,5	59,8	6,9	8,7	0,2	29,8	14,2	93,5	53,85	588,55	49,0	38,73	79,0
1994	98,6	53,4	112,4	198,2	43,8	2,4	9,5	9,8	17,7	55,6	129	55,1	785,5	65,5	58,98	90,1
1995	18,8	27,3	85,4	62,2	49,4	24,5	30	41,8	11,7	76,7	153,1	57,3	638,2	53,2	39,02	73,4
1996	90,2	74	101	85,5	123,5	71,7	4,3	19,4	19,3	89,7	22	58,3	758,9	63,2	38,40	60,7
1997	116,5	31,6	106,4	70,4	35,1	27,8	26,3	0,3	52,3	36,7	88,3	46,6	638,3	53,2	35,22	66,2
1998	20,9	68,1	79,6	73	85,1	14,7	26,8	4,9	22,1	55,7	61,8	35,4	548,1	45,7	27,91	61,1
1999	76,4	116,9	68,1	84	56,5	34,3	8,9	9,6	79,6	55,3	32,8	102,1	724,5	60,4	34,23	56,7
2000	78,5	99	72	93,7	167,1	61,5	6,2	4,2	99,4	35,5	32,4	34,8	784,3	65,4	46,54	71,2
2001	50,1	37,8	59	43,4	33,6	13	25,1	30,55	36	28,8	45,3	37,4	440,05	36,7	12,08	32,9
2002	23,9	33,1	26,7	109,2	32,9	41,3	1,4	6,3	9,9	114,3	80,7	98,4	578,1	48,2	41,17	85,5
2003	38,8	54,3	32,5	75,7	14,4	35,3	24,6	22,55	20,5	83,7	63,4	38,7	504,45	42,0	22,45	53,4
2004	38,6	20,5	16,3	84,3	63,6	1,5	4,5	0,6	50,3	48	54,4	106,5	489,1	40,8	33,78	82,9
2005	38,3	63,2	68,2	54,8	30,2	21,8	7,6	6,6	40,3	45,1	33,6	169,1	578,8	48,2	42,71	88,6
2006	41,2	83,4	108,6	88,2	38,5	62,3	3,5	4,9	4,6	72,7	134,2	101,5	743,6	62,0	43,87	70,8
2007	18,8	18,5	84,8	140,1	41,6	31,8	5	12,3	8,6	102,7	81,5	72	617,7	51,5	43,78	85,1
2008	73,8	82	145,9	108,4	91,7	37,8	9,5	22,8	39,4	123	57,8	53,9	**846**	**70,5**	41,49	58,9
2009	75,2	43,5	105	37,7	26,5	48,5	1,7	1,3	14,6	42,6	31,4	67,4	495,4	41,3	30,39	73,6
2010	22,6	39,1	23,3	108,5	60,2	48,6	63,1	10,2	47,6	57,7	115,5	105,1	701,5	58,5	34,90	59,7
2011	56	109	88,4	170,8	39,7	26,2	58,8	31,4	14,9	77,1	59	86	**817,3**	**68,1**	42,73	62,7
2012	86	69,3	52,7	112,7	6,7	7,7	3,2	5,6	9,5	59,8	113,9	19,4	546,5	45,5	42,59	93,5
2013	31,7	99,6	69,2	75	124,5	2,5	3,8	22,9	4,8	82,3	23,5	42,4	582,2	48,5	40,77	84,0
2014	72,9	39,6	75,1	41,1	98,6	69,85							397,15	66,2	22,47	33,9
Total	1330,2	1444,6	**1883**	**2200**	1495,1	740,25	365,6	289,7	729,2	1574,5	1657,2	1563				
Mean	55,4	60,2	**75,3**	**88,0**	59,8	29,6	15,2	12,1	30,4	65,6	69,1	65,1	**610,89**			
Standard deviation	29,81	30,27	33,18	38,15	38,20	21,29	16,68	11,22	23,97	30,86	38,36	34,98				
Variation coefficient	53,793	50,293	44,037	43,364	63,8828	71,914	109,48	92,978	78,89	47,042	55,558	53,719				

Bold: high values; **Underline**: low values

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If the monthly average of the period is divided to the number of days of the month, you get to the driest month (August: 12.1/30) 0.4 mm/day of rain and the rainiest month (April: 88/30) 2.9 mm/day. These value corresponding to the sheet of water. With the sheet of water of 2.9 mm/day can be covered the water requirement of crops of beans, corn, and wheat. However, with the value of 0.4 mm/day, does not cover the water requirement that the plant needs for growth and productivity [22], so irrigation systems should be implemented.

In general, the data of total precipitation per year and the average (610.9 mm), indicate features variations, which identify with a temperate zone, in a sub-humid montane altitudinal, adapted or recommended floor to the cultivation of maize whose water needs are between 500 - 700 mm per year, the cultivation of beans and wheat with 550 mm. Without however, for potatoes you need about 700-1200 mm, these annual values of precipitation they not cover the hydric necessities, so it would have to compensate the sheet of water with irrigation, to achieve greater production of the crop [18, 22].

Temperature

Temperature data (Table 3), an annual average in the period from 1990 to 2014, according to database of INMAHI [17], recorded temperatures of 14.16 °C as the lowest (1999) and 15.44 °C (1998) as the highest temperature. These data indicate that the temperature varied little with an increase of 1.28 °C. The variation coefficients of monthly average temperature were between 1.69 to 5.71 %, indicating that there was little inter-annual variability in the temperature in the zone. The average values in the period under review indicated that August is the hottest month with 15.35 °C, followed by September with 15.27 °C, while February and December are the coldest months, with 14.60 and 14.61 °C. In general terms, there is a hot season from June to September and the cooler months were seen from October to May. The highest variation coefficients are for January (6.16 %) and February (5.11 %), while the lowest coefficients were calculated for April (3.41 %) and November (3.27 %), which represents a low variability between those months.

Table-3. Temperature data, period from 1990 to 2014. Tomalón Station, INAMHI.

YEAR	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	Total	Mean	Standard deviation	Variation coefficient
1990			15,4	14,8	14,7	15,1	15,1	15,5	16,1	14,4	15,4	15	151,50	15,15	0,48	3,16
1991	15,1	15,6	15,3	14,9	15,4	15,3	15,1	15	15,3	15,2	14,6	15,2	182,00	15,17	0,26	1,69
1992	15,6	15,3	15,8	15,5	14,7	16,3	15	15,2	14,7	15	14,9	15,2	183,20	15,27	0,47	3,09
1993	14,3	14,1	14	14,5	14,6	16,3	15,3	15,5	15	15,8	14,8	14,6	178,80	14,90	0,70	4,73
1994	14,4	14,3	14,1	14,6	15,1	15,4	15,3	15,3	15,6	15	14,1	15	178,20	14,85	0,53	3,56
1995	15,4	15,2	15	15,5	14,9	15,5	15	15,3	15,8	15,1	14,2	14	180,90	15,08	0,52	3,48
1996	13,7	13,9	14,1	14,3	14,2	14,5	14,7	15,2	15,9	14,2	14,7	14,8	174,20	14,52	0,60	4,15
1997	13,9	14,7	15,3	14,8	15,5	14,8	15,8	16,4	16	15,9	14,8	16	183,90	15,33	0,73	4,78
1998	16,9	16,2	15,8	15,5	15,8	15,2	14,7	15,2	15,3	15,2	14,7	14,8	185,30	15,44	0,65	4,22
1999	14,2	13,5	14,1	14,4	14,1	13,7	14,9	14,9	13,7	14,3	14,5	13,6	169,90	14,16	0,47	3,35
2000	13,5	13,5	13,5	14	13,7	14,1	14,4	14,9	13,8	15,6	14,6	14,5	170,10	14,18	0,65	4,59
2001	13,8	14,8	14,3	14,9	14,9	15,1	15,1	16,1	14,6	16,3	14,9	15,3	180,10	15,01	0,69	4,57
2002	15,6	15	15	14,4	15,7	15	15,6	15,6	15,7	15,3	14,6	14,8	182,30	15,19	0,45	2,99
2003	15,1	15,4	14,4	14,9	14,8	14,3	15,1	15,7	15	14,5	14,6	14,5	178,30	14,86	0,43	2,86
2004	14,6	14,3	15,8	14,8	14,9	15,2	14,4	16	14,9	14,9	15,2	14,6	179,60	14,97	0,52	3,46
2005	14,7	15	14,4	14,9	15	15,1	15,5	16	15,7	14,8	15,1	13,8	180,00	15,00	0,58	3,87
2006	14,1	14,5	14,4	14,3	15,2	15	16,1	16,1	15,4	15	13,7	14,3	178,10	14,84	0,76	5,14
2007	15,6	14,9	14,6	13,9	14,9	14,8	15,5	15,1	15,6	14,5	14,2	13,3	176,90	14,74	0,70	4,75
2008	14,2	13,6	13,6	14	14,1	14,5	14,3	14,3	14,9	14	14,3	14,3	170,10	14,18	0,36	2,54
2009	13,7	13,6	14,4	14,6	14,4	14,8	15,1	15,2	16,2	15,8	15,9	15	178,70	14,89	0,82	5,50
2010	15,5	15,7	15,6	15	16,2	14,7	14,3	14,5	14,6	14,8	14,1	13,7	178,70	14,89	0,73	4,93
2011	13,9	14,3	13,9	13,8	15,2	14,6	14,3	14,8	15	14,4	14,8	14	173,00	14,42	0,47	3,24
2012	13,3	13,9	15,2	14,2	14,6	15,5	16,1	15,6	16,1	15,2	14,9	15,2	179,80	14,98	0,86	5,71
2013	15,9	14,3	15,3	15,3	14,1	15,6	14,8	14,9	15,6	14,5	15,3	15,1	180,70	15,06	0,55	3,68
2014	14,8	14,9	14,8													
Total	351,8	350,5	368,1	351,8	356,7	360,4	361,5	368,3	366,5	359,7	352,9	350,6				
Mean	**14,66**	**14,60**	**14,72**	**14,66**	**14,86**	**15,02**	**15,06**	**15,35**	**15,27**	**14,99**	**14,70**	**14,61**		**14,88**		
Standard deviation	**0,90**	**0,75**	**0,70**	**0,50**	**0,60**	**0,61**	**0,53**	**0,53**	**0,68**	**0,59**	**0,48**	**0,64**				
Variation coefficient	**6,16**	**5,11**	**4,77**	**3,41**	**4,05**	**4,04**	**3,52**	**3,43**	**4,43**	**3,95**	**3,27**	**4,39**				

Temperature range from 14.16 to 15.44 °C, found in the area indicate that it may be suitable for the growth of most short-cycle crops, unless for soil conditions. These values indicate that many crops will need less time to complete their phenological cycle, relative to corn, bean and wheat crops. Although in the case of potato crop, problems could be found at the time of tuber development, as it requires cooler temperatures to promote growth and tuber production as seen in Table-4.

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Table-4. Temperature and annual precipitation requirements in the crop cycle [18].

Type of crop	Temperature, °C	Precipitation, mm
Pea	12-18	400 a 700
Bush kidney bean	15-25	350-600
Voluble kidney bean	12-18	600-900
Corn	10-20 máx. 32	600-900
Potato	13-18	700-1000 (1200)
Bean	7-14	500-800
Barley	8-15	400-600
Wheat	8-14	500-700
Lupinus	7-14	300-600
Quinoa	9-16	600-900
Amaranth	> 15	400-600

Projections

Figure-2 shows the projection of changes in precipitation, three ranges are observed, the first in green color (high) comprises 89-85%, the second (yellow color) of 84-73% and the third (red color) 72-69%, which means that the study area will be exposed to changes in rainfall in the years 2020-2049.

In Figure-3, the projections for the period from 2040 to 2069 indicate values between 169 and 176% in the high range (green color), while for the second (yellow color), it shows values between 157 and 168 %, and for the low range (red color), the values ranged from 157 to 149%. When comparing the two periods, it is observed (green color) that the study area will be exposed to a higher percentage, as it increases in the second period in the study area.

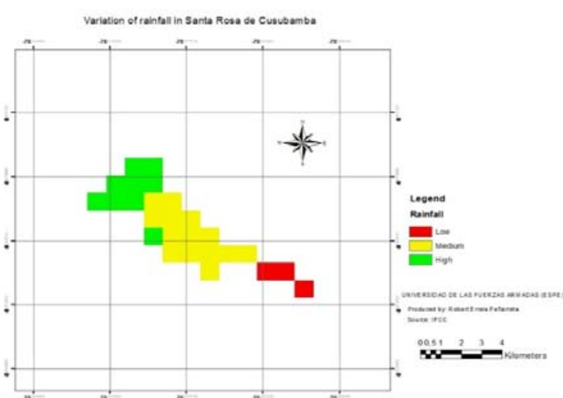

Figure-2. Changes in precipitation for the period 2020-2049.

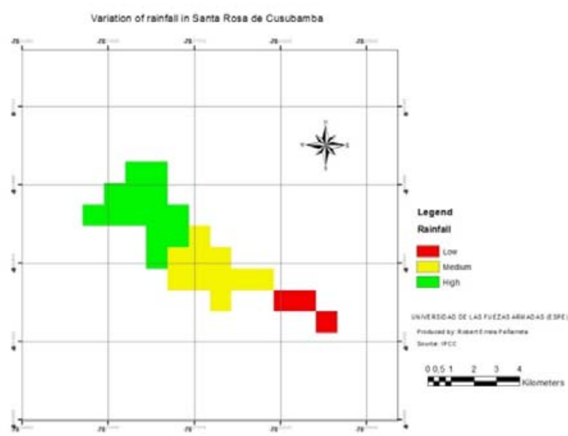

Figure-3. Changes in precipitation for the period 2040-2069.

For the temperature analysis, in Figure-4, three ranges are presented in order to represent the mean of temperature increment: the high in green: 10.9-10.5, the medium in yellow: 10.5-10.2 and the low in red: 10.2-9.9. For 2020 - 2049, there are future changes in the area of Santa Rosa de Cusubamba, with increases of 0.4 °C in the high range (green): and of 0.3 °C in the low range (red) (Figure-4).

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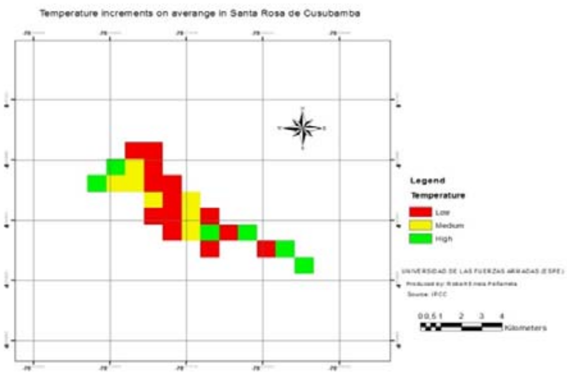

Figure-4. Temperature increments on average in 2020-2049.

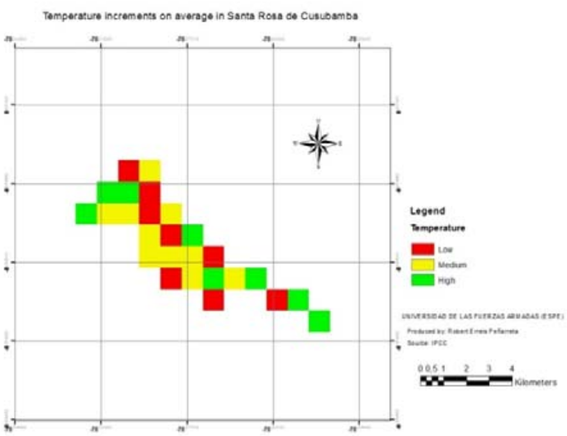

Figure-5. Temperature increments on average in 2040-2069.

In Figure-5, three ranges are presented in order to represent the mean of temperature increment: the high in green: 18.9-18.7, the medium in yellow: 18.7-18.4 and the low in red: 18.4-18. An average increase of 0.2 °C is shown for the high range and of 0.4 °C for the low range. So a slight variation was determined in the temperature between the periods established for the area of Santa Rosa de Cusubamba.

Sensitivity

These results were obtained with the DIVA-GIS software, which is a tool for modeling the climatic aptitude of crops through projections of temperature and precipitation.

Corn *(Zea mays)* crops

According to the results of climate aptitude presented in Figure-6, the study area presents a favorable projection of 80% for cultivation of corn by 2030, with 27% of the lands. While 20% is within the average conditions for farming (yellow).

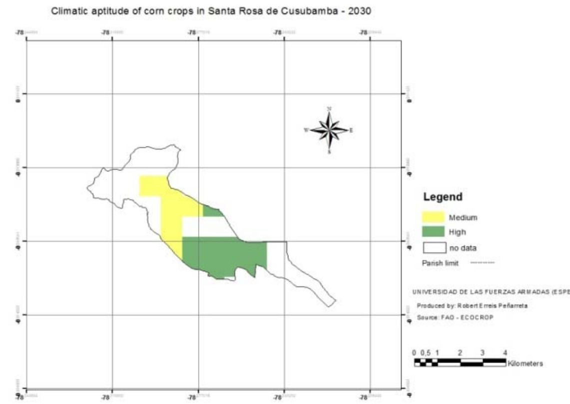

Figure-6. Climatic aptitude of corn crops - 2030. Santa Rosa de Cusubamba.

Figure-7 shows the projection of climatic aptitude for 2050. It is encouraging for cultivation since the factors of rainfall and temperature are favorable, for example, there will be more rainfall, which means that the water needs could be covered and new crops will be adapted. The current crops' water needs are 600-800 mm [18]; therefore, corn production in the area will not be affected.

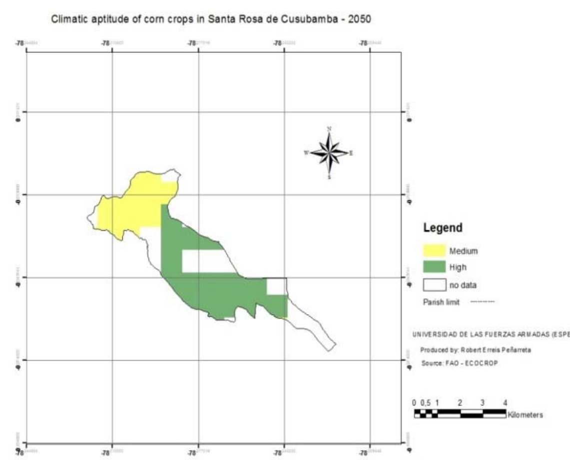

Figure-7. Climatic aptitude of corn crops - 2050. Santa Rosa de Cusubamba.

Potato (*Solanum tuberosum*) crops

In Figure-8, it can be observed the climatic aptitude for 2030 and according to the results, 73% of the lands will present high conditions for cultivation. Climatic aptitude for potato cultivation projected for 2050, showed that the same conditions are maintained (73% of the lands) (Figure-9). This means an improvement of abiotic parameters for crop development with water needs between 700 and 1200 mm [18, 22].

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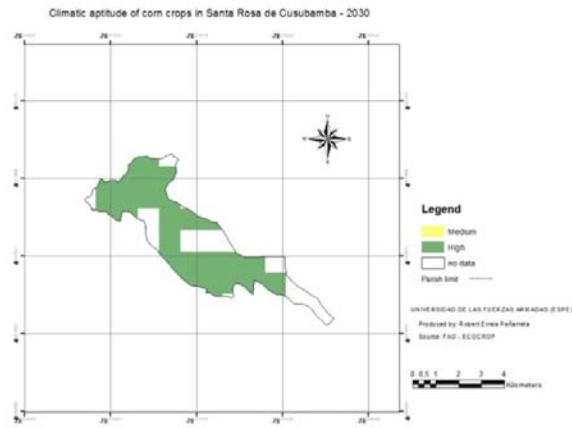

Figure-8. Climatic aptitude of potato crops - 2030. Santa Rosa de Cusubamba.

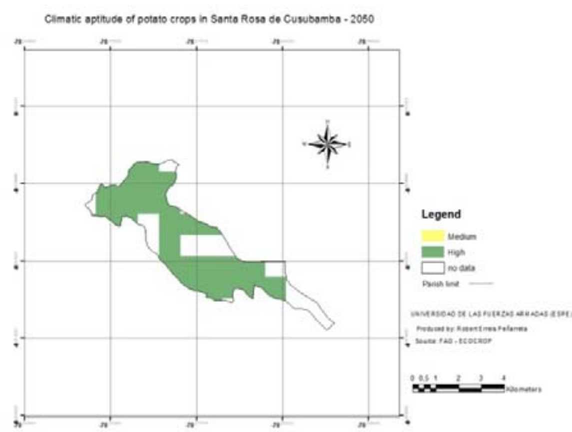

Figure-9. Climatic aptitude of potato crops - 2050. Santa Rosa de Cusubamba.

Wheat (*Triticum vulgare*) crops

Climate aptitude shown in Figure-10 indicates that wheat crops in 2030 present optimal weather conditions for the development of the plant with 57% of the lands. Projections for 2050 show an increase in the optimal lands for wheat cultivation, representing 62%. Besides, average conditions of 11% were presented for the area of Santa Rosa (Figure-11).

Climatic aptitude will increase from 87 to 89% regarding to the high range for wheat crops. Meanwhile, the medium range will rise to 62% with regard to aptitude in 2050.

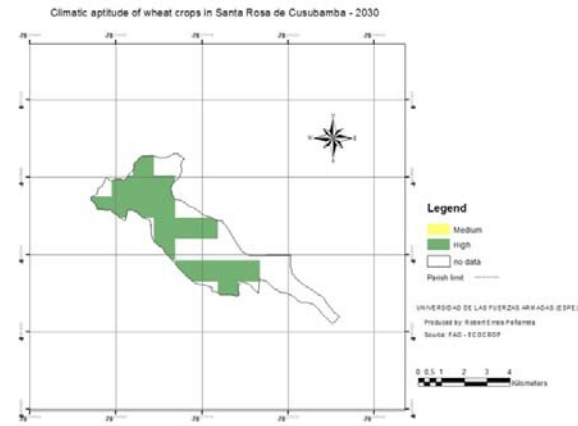

Figure-10. Climatic aptitude of wheat crops - 2030. Santa Rosa de Cusubamba.

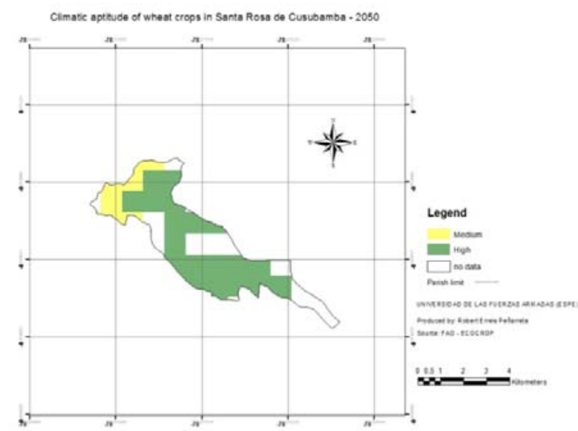

Figure-11. Climatic aptitude of wheat crops - 2050. Santa Rosa de Cusubamba.

Kidney bean (*Phaseolus vulgaris*) crops

The climate aptitude shown for kidney bean in the Figure-12, indicate that for 2030, the kidney bean shows 34% of the lands with high conditions and 39% of the lands with medium conditions will be presented for cultivation of kidney beans.

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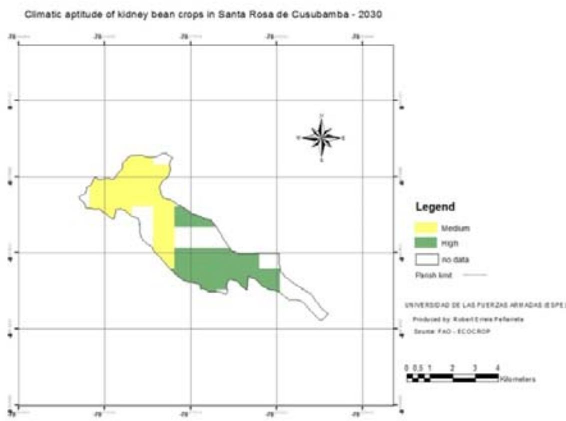

Figure-12.Climatic aptitude of kidney bean crops - 2030. Santa Rosa de Cusubamba.

In Figure-13, it is shown that 51 % and 22 % of the lands will present high and medium climatic conditions respectively for plant development.

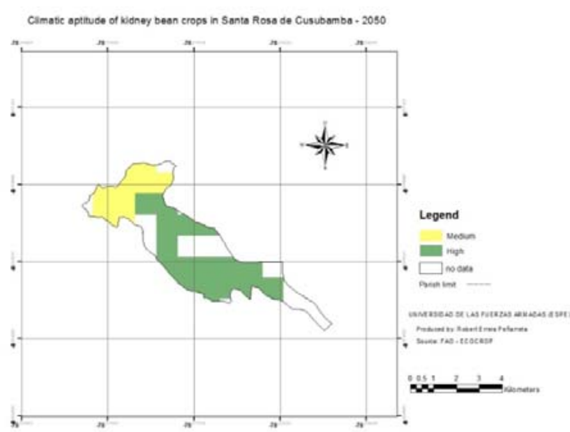

Figure-13.Climatic aptitude of kidney bean crops - 2050. Santa Rosa de Cusubamba.

Climatic aptitude

For the crops analyzed, it is determined that by 2030 the potato and wheat crops will present the high range of climatic aptitude, while all crops except wheat will present the medium range (Figure-14).

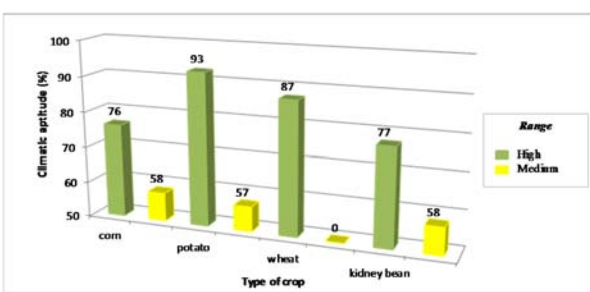

Figure-14. Climatic aptitude data of crops, 2040.

For 2050, potato and wheat crops will be found in the high range of climatic aptitude. Although, with a slight reduction in the aptitude relative to 2030 (Figure-15).

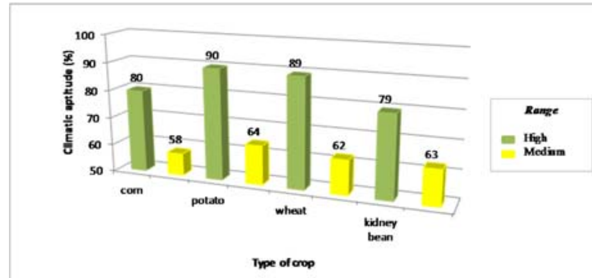

Figure-15. Climatic aptitude data of crops, 2050.

Adaptability

The information on the percentage of Unsatisfied Basic Needs (UBN) for households and population employed in agriculture, forestry, hunting and fishing in the rural part of Pichincha province is 29.98 % and 17.60 % respectively. Whereas, for Cayambe is 63.20 % and 54.75 % respectively [19].

For the rural area of Santa Rosa de Cusubamba, the information showed that 80.55% of households are in poverty due to unsatisfied basic needs, which represents a high range (Figure-15), while the population in Cayambe canton were determined in the low range, since most of the population lacks basic services and therefore it does not meet their needs.

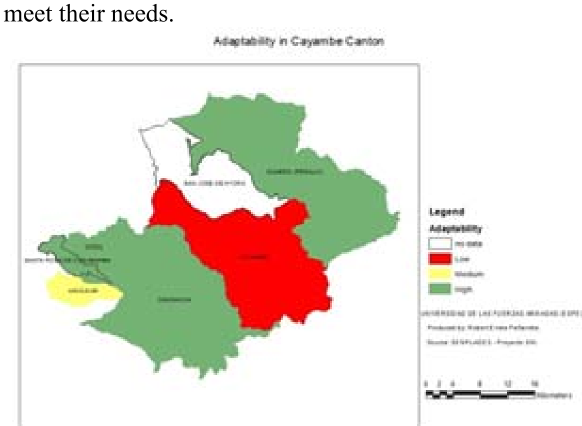

Figure-16. Adaptability of the area of Santa Rosa de Cusubamba.

Vulnerability index, VI

The vulnerability index is obtained for each of the crops by calculating the variables of exposure, sensitivity and adaptability, the result indicates that the crops will be more affected by the temperature in 2050.

The Vulnerability index-VI is represented with a high scale (in red) of 100-67; a medium scale (in yellow) of 66-34 and a low scale (in green) of 0-33 [20; 21]. In Table 5, the VI is presented for corn, potato, wheat and kidney bean crops with temperature projections for 2030 and 2050. It was determined that the crops had a high vulnerability between 89% and 91% in the second period of analysis in relation to the climatic threat. However all crops obtained a medium vulnerability for 2050.

Table-5. Vulnerability index of crops, considering temperature projections.

Type of Crop	Exposure	Sensitivity	Adaptability	Vi %	Year
CORN	50	67	80	37	2030
	100	69	80	89	2050
POTATO	50	75	80	45	2030
	100	77	80	97	2050
WHEAT	50	87	80	57	2030
	100	76	80	96	2050
KIDNEY BEAN	50	68	80	38	2030
	100	71	80	91	2050

Regarding to precipitation, the vulnerability of crops presented a different dynamic (Table-6), since the crops obtained a medium range in the second period and were less vulnerable for the first period. The projections indicated an increment of rain, which will benefit the crops because their water needs would be covered during the growing period.

Table-6. Vulnerability index of crops, considering precipitation projections.

Type of crop	Exposure	Sensitivity	Adaptability	Vi %	Year
Corn	23	67	80	10	2030
	66	69	80	55	2050
Potato	23	75	80	18	2030
	66	77	80	63	2050
Wheat	23	87	80	30	2030
	66	76	80	62	2050
Kidney Bean	23	68	80	11	2030
	66	71	80	57	2050

Adaptation measures

After analyzing vulnerability, some measures can be defined for the adaptation to climatic change for the area of Santa Rosa de Cusubamba.

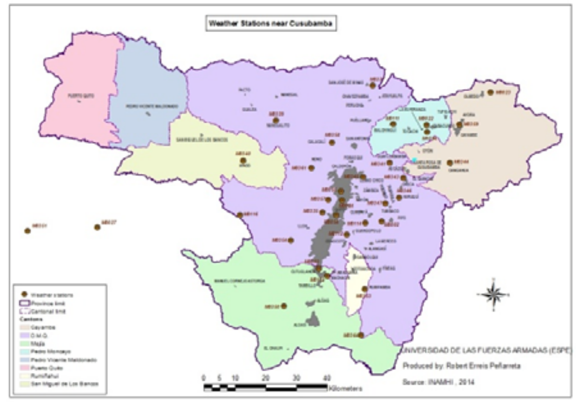

Figure -17. Current location of the INAMHI Stations.

There is a lack of climate information, not only in the parish of Santa Rosa, but also in the Cayambe Canton. This information is needed to determine the influence of precipitation and temperature on crops, which evidenced the need to improve the network of meteorological stations for the monitoring climate throughout the territory, and thus make the best decisions about territorial planning related to the improvement of the productivity of crops and the reduction of losses due to weather conditions.

Building reservoirs to store water during dry seasons could be considered for the middle and lower areas of Santa Rosa de Cusubamba, due to the changes that have occurred in recent years in terms of the amount of rainfall, according to local producers.

On the other hand and according to the projections developed in this study, increments in water would have serious consequences for food production. Training for farmers must be implemented in order to foster a culture of prevention against potential climatic risks through village schools (CCS) and local agricultural research committees (LARC). These organizations should revalue the ancestral practices.

CONCLUSIONS

With historical data of precipitation, it was determined that the water needs for the cultivation of corn, kidney bean and wheat are covered in the study periods; however, for potato crops, there is a need to incorporate irrigation systems in order to meet the water needs and improve production conditions. The results indicate that the temperature on average will increase 0.4 °C for the period 2020-2049 and 0.3 °C in the period 2040 - 2069. These scenarios do not benefit the potato cultivation due to its phenological stage of tuber, which needs more hours of cold. Hence, its production would be affected. The precipitation showed an increment of 79% in the first period and 164% in the second period, which generally will benefit the crops. However, these results indicate possible floods in the area, where silty loam and sandy soils predominate, which implies a strong base compounds washing. This will lead to an increment in soil acidity and mineralization of organic matter with the consequent loss of aggregates. In the case of the sensitivity of crops, corn crops presented a climatic aptitude of 45% in the first period (2020-2049) and of 52% in the second period (2040 to 2069), which projects an increment of favorable conditions to meet the water needs. For potato crops, 50% and 51% of aptitude for the respective periods was found and it was considered that the conditions would improve for its cultivation without the need for irrigation. Regarding to wheat crops, 35% and 30% of aptitude for the respective periods were obtained. Finally, kidney bean crops obtained an aptitude of 40% and 35% in the periods defined for this study.

The values of the Unsatisfied Basic Needs (UBN) per household were used as an indicator in order to determine the adaptability for the rural area of Santa Rosa de Cusubamba. The results indicated 80% for the study area, 63% for Cayambe Canton, and 29% for the Pichincha Province.

The results of the vulnerability index (VI) of crops were presented generally in the medium range; for corn crops, a VI of 66 for temperature was determined, while for precipitation, the VI was 60. For potato crops, a VI of 71 was determined; representing a high range in the case of temperature, while the VI for precipitation for these crops was of 66, which corresponds to the medium range. In the cultivation of wheat, the VI for temperature and precipitation were of 71 and 65 respectively. Finally, considering the temperature, a vulnerability index of 65 was obtained, and for precipitation, the VI was of 59 for the kidney bean cultivation. Given that climatic changes are affecting crops, the development of adaptation measures with the Vulnerability Index proposed in this study as a guide, is a contribution to the land planning in the agricultural sector because important variables are incorporated in this study, such as temperature and rainfall.

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