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CLIMATE CHANGE SCENARIO AT SUBWATERSHED LEVEL HYDROGRAPHIC FOR THE YEAR 2050 OF THE CHIMBORAZO PROVINCE OF ECUADOR

ESCENARIO DE CAMBIO CLIMÁTICO A NIVEL DE SUBCUENCAS HIDROGRÁFICAS PARA EL AÑO 2050 DE LA PROVINCIA DE CHIMBORAZO-ECUADOR

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Abstract

The present study was realized in the Province of Chimborazo-equator by the intention of establishing a scene of climate change for the year 2050, in order to implement public policies in the Plan of Development and Territorial Classification that they help to reduce the vulnerability of the population before the climatic risks. For it, information was analyzed to level of hydrographic subbasins by a spatial resolution of 1 km2 in a scene of radiation of 2,6 RCP, it corresponds to a Global Model of Traffic (GCM) named MIROC-ESM-CHEM. In the definition of the scene, information was in use to a scale 1:4000000 more detailed generated by WorldClim since the climatic available information of models as PRECIS, TL959 generated for the Ecuador, they have a very low detail with a cricket of 50 km2, it climbs 1:282 800 000, which for the case of the province it is great bounding one considering that of the information obtained results for level of subbasins. On having compared the current scene and that of climate change for the year 2050, in the information climatic variations were observed principally reduction of the rainfall in the subbasins: Rio Namangoza, Rio Patate and Rio Chambo; as well as, an increase of the minimal and maximum temperature in the subbasin Rio Namangoza

Keywords: Climatic scenarios, vulnerability, Chimborazo, subbasin.

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Resumen

El presente estudio se realizó en la provincia de Chimborazo-Ecuador con el propósito de establecer un escenario de cambio climático para el año 2050, a fin de implementar políticas públicas en el Plan de Desarrollo y Ordenamiento Territorial que ayuden a reducir la vulnerabilidad de la población ante los riesgos climáticos. Para ello, se analizó información a nivel de subcuencas hidrográficas con una resolución espacial de 1 km2 en un escenario de radiación de 2,6 RCP, corresponde a un Modelo Global de Circulación (GCM) denominado MIROC-ESM-CHEM. En la definición del escenario, se utilizó información a una escala 1:4000000 más detallada generada por WorldClim ya que la información climática disponible de modelos como PRECIS, TL959 generados para el Ecuador, tienen un detalle muy bajo con una grilla de 50 km2, escala 1:282 800 000, que para el caso de la provincia es una gran limitante considerando que de la información se obtuvo resultados para nivel de subcuencas. Al comparar el escenario actual y el de cambio climático para el año 2050, en los datos se observó variaciones climáticas principalmente reducción de la precipitación en las subcuencas: río Namangoza, río Patate y río Chambo; así como, un incremento de la temperatura mínima y máxima en la subcuenca río Namangoza.
Palabras claves: Escenarios climáticos, vulnerabilidad, Chimborazo, subcuenca.

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1 Introduction

The province of Chimborazo is located in the center of Ecuador between the eastern and western mountain ranges. Its location allows the formation of 13 ecosystems (MAE, 2013) and a diversity of climatic floors that allow the development of productive activities based mainly in the central valley of the province. This climate diversity allows the cultivation of products from cold areas such as potatoes, wheat and barley, from temperate zones such as maize and beans, and from tropical areas such as sugar cane, bananas and cacao.

On the other hand, there is a scientific consensus regarding the alteration of the global climate, despite the uncertainty that characterizes these projections of computational models at global level (JimÃ©nez et al., 2012), and regional, as in the Andes (Cuesta Et al., 2009). According to the Second National Communication on Climate Change SCNCC of Ecuador and based on information from the National Institute of Meteorology and Hydrology INAMHI, there is an increase in average, maximum and minimum annual temperature throughout the national territory, with some exceptions in certain areas. From the information available from 39 stations analyzed between 1960 and 2006 the average annual temperature in Ecuador increased by 0.8 °C, the absolute maximum temperature by 1.4 °C and the absolute minimum temperature by 1.0 °C (MAE, 2011).

In the case of precipitation at the national level, the variation is differentiated by region of the country without a uniform pattern being observed. In the case of the mountain region the SCNCC reports an increase of 8 % in the precipitations between the years 1960 and 2006 (MAE, 2011).

However, for the province of Chimborazo there is a differentiated pattern between the north and the south central zone of the province. For the analyzed period based on the INAMHI reports, the northern area presents a slight increase in precipitation and in the south central zone a decrease in precipitation values. This local climate variability determines the production patterns, distribution of ecosystems and availability of water for local populations (Huettmann, 2006). Many of the agricultural products of the province depend entirely on the weather patterns as they develop under rainfed.

Under these conditions, changes in temperature and precipitation affect agricultural yields, resulting in changes in harvesting times and thus affecting both food security and the income that rural communities receive from the sale of agricultural products (Serrano Et al., 2012) (Laderach et al., 2010).

Given the above, it is necessary to establish a climate change scenario at the hydrographic subbasin level by 2050 in the province of Chimborazo, Ecuador, in order to contribute to the generation of new agricultural and productive policies that allow the population to face the climatic changes in the province.

2 Materials and Method

2.1 Description of the study area

The province of Chimborazo, is a province of Ecuador, located in the middle of the inter-Andean region of the country, known as the Sultana de los Andes, due to the fact it is surrounded by great summits: Chimborazo volcano, Carihuayrazo, El Altar, The Igualata, the Tungurahua, the Sangay, several of these summits share with other provinces. Administratively it has 10 cantons (AlausÃ, Chambo, CumandÃ¡, Penipe, Colta, Riobamba, Guamote, Chunchi, Pallatanga and Guano) and 45 rural parishes. Access to the province can be done by the first route, the Pan-American route, through the inter-Andean region or the highlands, from the city of Quito and Balbanera, by the Coastal region, and, from the city of Guayaquil.

2.2 Physical aspects

In Chimborazo the high mountain equatorial climate predominates in approximately 58.73 % of the territorial extension, in which they are the parochial headers of Tixán, Palmira, Cebadas, Pangor, Licto, Pungalá, Chazo, Guanando, Ilapo, Santa Fe de GalÃ¡n and the Penipe canton and all its parishes.

2.2.1 Hydrology

The natural water supply is directly associated with the availability of water that the hydrological cycle provides in a period and place. Its estimation and variability can be obtained by means of multiple in situ observations, or by means of calibrated hydrological models.

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In the province of Chimborazo, August and September are the months of greatest demand for water in the year, requiring 1 663.87 l/s for watering 2 040 ha. The supply is 2 524 l/s, whose irrigated area increase factor is 1.51 (relation supply demand), thus indicating that the availability of water will increase the irrigation coverage.

2.2.2 Precipitation

Due to the orography of the territory, precipitation has a variation throughout the province. In general, the rainy season has its maximums in March (60-90mm) and October (50-70mm) with a bimodal distribution, with the maximum peak in March and the minimum in August (10-20mm).

The mean values of monthly precipitation observed in areas with the highest precipitation exceed 200 mm (Pallatanga, Cailimbe), while the region with the lowest mean precipitation is Guano with 57 mm corresponding to the month of March (GADPCH, 2014).

2.2.3 Temperature

The average temperatures are varied, the maximum values usually occur in November and the minimum values of average temperature in July.

In Chimborazo, the populated areas cover the central strip of the territory, located in valleys formed by a graben, to the left side is the Central Mountain Range and to the right the Oriental. In this context, the average annual temperature decreases from the central valley to the mountain ranges. The lowest registers are located in populated areas, the Pangor parishes, Villa la Union of the Colta and San Juan of the Riobamba canton, Achupallas of the AlausÃ Canton, Palmira Guamote canton, with average temperatures that oscillate 9-10 °C, while the highest registers are located in the parish of the AlausÃ canton with 20 °C and the CumandÃ¡ canton with temperatures close to 24 °C. The ambient temperature varies according to the height or climatic floor (GADPCH, 2014).

The variation of the temperature is quite wide, since from the highest points in the Chimborazo and Tungurahua volcanoes to the lowest point, annual average temperatures vary from -4 to 0 °C for heights>5,000 meters, up to 25 °C in the Canton CumandÃ¡ with a height that goes from the 300 to 1 900 masl approximately (GADPCH, 2014).

2.2.4 Hydrographic demarcation

The provincial hydrographic system is made up of three hydrographic basins: Guayas, Pastaza and Santiago and four hydrographical sub basins: Yaguachi, Patate, Chambo and Namangoza. The most extensive demarcation corresponds to the Pastaza Basin with 54 % of the total area (Figure 1).

2.3 Climate change in Chimborazo

In the province of Chimborazo, there are no specific studies on the problem of climate change.

However, there is evidence that in the province in recent years there has been a large number of fires, mainly in the highlands and primary forests (GADPCH, 2014).

Fires caused in natural ecosystems do not allow adequate adaptation to climate change, causing animal and plant species to migrate to higher climatic floors to ensure their survival (Feeley and Silman, 2010).

Chimborazo, considered as a purely agricultural province, provided with prodigious territories for agricultural labor, over time has been losing their fertility and yields necessary for their profitability, which has caused the agricultural strips to gain space invading areas of natural cover.

The loss of natural cover is mainly reflected in the change in the agricultural calendar, increasing the number of rainy days and reducing the number of dry days, causing farmers to feel uneasy due to crop losses due to excess or lack of precipitation.

In addition, the Chimborazo colossus, located at the western end of the province, the snowed peak of 6 310 masl, whose thaws gives rise to important streams for the inhabitants of the provinces of Tungurahua and Chimborazo, has suffered in recent years the loss of a part of the glaciers, which is experienced in the water supply (La Frenierre, 2010).

2.4 Method

2.4.1 Current weather

The current climatic scenario for the province was built based on the bioclimatic information generated by the Ministry of the Environment of Ecuador (MAE, 2013). This information corresponds to information available worldwide from the WorldClim model (Hijmans et al., 2005a, 2005b) and information from the INAMHI Institute. Based on this

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Table 1. Hydrographic basins of the province of Chimborazo, with their extension in ha and % present in the territory. Source: SENAGUA

Basin (River)	Province	Area (Ha)	Area (%)
Guayas	Chimborazo	240 555,01	37
Pastaza	Chimborazo	349 161,64	53,71
Santiago	Chimborazo	60 345,47	9,28
Total		**650 062,12**	**100**

Table 2. Hydrographic subbasins. Source: SENAGUA

Basin (River)	Subbasin (River)	Province	Area (Ha)	Area (%)
Guayas	Yaguachi	Chimborazo	240 555,01	37
Pastaza	Patate	Chimborazo	1 944,69	0,3
Pastaza	Chambo	Chimborazo	347 216,95	53,41
Santiago	Namangoza	Chimborazo	60 345,47	9,28
TOTAL			**650 062,12**	**100**

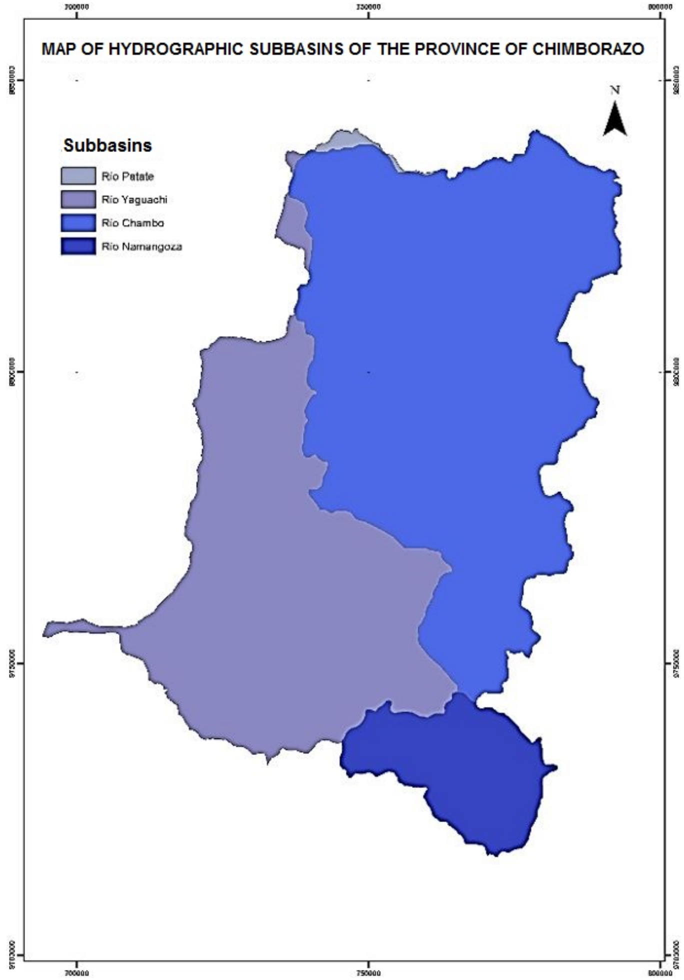

Figure 1. Hydrographic subbasins in the province of Chimborazo

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information, the climatic conditions of the current scenario were determined for the period between 1971 and 2000 at a resolution of 1 km^2. The document Bioclimatic Model for Ecuador (MAE, 2013) describes the methodological details for obtaining the results that were used in this document as baseline of precipitation and maximum and minimum monthly temperature.

This information is the baseline on which comparisons of climate change scenarios will be made.

2.4.2 Future weather

For the future scenario, the information available on the WorldClim (2013) page was used to collect information from different worldwide climate research centers. For this analysis the information of the global circulation model denominated MIROC-ESM-CHEM was used for the year 2050 with a resolution of 1 km^2 considering a CO_2 gas concentration of RCP 2.6. The available data are climate projections of reduced and calibrated GCMs (corrected diagonals) using WorldClim 1.4 as the "current"base climate. WorldClim is a set of global climate layers (weather data with grid). Monthly information was obtained in raster format of maximum temperature, minimum temperature and precipitation.

2.4.3 Global circulation models

The GMC is a computational model that calculates and predicts future weather patterns. GCMs use the fluid dynamics movement equations in a Numerical Weather Prediction (NWP), for the purpose of weather as a result of slow changes in some initial and boundary conditions or physical parameters (Such as the solar constant and the concentration of greenhouse gases). The model focuses on each cell and the energy transfer between them. Once the simulation is calculated, a series of weather patterns and scenarios can be determined. GCMs are made in a number of specialized computer labs around the world.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was based on the results of 21 global climate models (GCMs), data are available through an IPCC interface, or directly from the institutions that developed each of the models. Thus, in small-scale maps, the level of detail is small and large-scale maps, the detail of the mapped elements is greater. Scaling down is therefore necessary to provide higher resolution surfaces of the expected future climates so that the likely impacts of climate change on agriculture are predicted more accurately. In the present study, the raster files with spatial resolution of 50 km^2 were replaced by those of 1km^2, reducing the scale of the information.

Spatial resolution data of 1 km^2 were produced using a method that can be easily applied for climate models. It begins with the projected change in a meteorological variable (for example, the minimum temperature in June). This is calculated as the absolute difference between GCM production for the reference years (1970-2000) and for the target years (2041-2060). These changes are interpolated to a grid with a high resolution (1 km). The assumption made is that the change in climate is relatively stable over space, high spatial autocorrelation. These high-resolution changes are then applied to the high-resolution interpolated weather data for the çurrent period"(in this case the WorldClim dataset), by means of a calibration of the model. Calibration is necessary because GCMs do not accurately predict the current climate in all places. For that reason, it is not possible to directly compare the current climate observed with the predicted future climate. It is also problematic to compare the response to simulated current conditions with a response to simulated future conditions because simulated current conditions could be far from reality (WorldClim, 2013).

With the help of these established methodologies and with the necessary computer data generated for both current and future models, the GIS tool, "Zonal statistics as table", which allows results to be generated at subbasin levels, is the subject of the present research.

2.4.4 Spatial analysis

For the analysis of the information, the boundaries of the subbasins described in Table 2 were taken as the spatial unit. The results were obtained from the raster layers for each month of the analyzed variables. For the analysis of the information the current and future scenarios were compared and according to the methodology established by the IPCC (2007), it was considered that the greater variation between the average of the baseline variables with the future scenario would have a greater impact. To obtain the average values of each variable at the subbasin level, the "Zonal statistics as table"tool of the Spatial

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Analyst tool of ArcMap version 10.2 was used.

The average monthly differences for each canton between 2050 and the current baseline were calculated.

These variations are shown as the percentage of variation between the baseline conditions and the climate change scenario 2050. In addition, the value of variation is shown either degrees Celsius in the case of temperature and millimeters of rain for the case of precipitation. In the case of the percentage, increase or decrease values are shown as the case may be (Serrano et al., 2017).

3 Results and Discussion

3.1 Temperature

The results observed for the province of Chimborazo, as a function of temperature, coincide with all worldwide forecasts indicating a generalized increase. For the province, the monthly average minimum temperature would increase approximately between 1.61 and 1.66 °C by 2050, while the monthly maximum temperature would increase approximately between 0.94 and 2.43 °C. The highest minimum temperatures are recorded in July: 2.01, 2.05 and 2.09 °C and the coldest in September: 1.39 and 1.38 °C. Coinciding with information generated for the province at the canton level (GADPCH, 2014).

In subbasin analyzes, the highest monthly minimum temperature increase is recorded for the Patate and Chambo river subbasins with 2.05 °C in July. The lowest variation in this parameter corresponds to the subbasins of the river Yaguachi and Chambo river in the month of September. The average annual minimum temperature increase varies between 1.61 and 1.66 (Table 3).

When analyzing the information at the hydrographic subbasin level, the subbasin of the Namangoza River registers the highest increase of the monthly maximum temperature with 2.40; 2.41 and 2.49 °C in May and July respectively. The lowest variation in this parameter corresponds to the subbasins of the Yaguachi River and Chambo River in February (Table 4).

Changes in temperature will have a direct effect on the distribution of remaining natural ecosystems, crop productivity and distribution patterns of species that transmit tropical diseases, which in the new conditions may increase their altitudinal distribution. The scenario for the year 2050 coincides in the generalized increase of the temperature in all the subbasins of the province of Chimborazo in ranges superior to the 2,4 °C in some cases.

4 Precipitation. Provincial level

The wide altitudinal variation, has defined the precipitation patterns in the interior of the province of Chimborazo. The climate of the province also has influence of the humid masses coming from the Amazon basin and the humidity coming from the Pacific Ocean. Under these conditions the province presents a series of microclimates and conditions, ranging from very humid in Sangay National Park to dry areas such as those found in the city of Riobamba or Palmira (Figure 2).

In Figure 3, like a climogram, it shows, in a synthetic form and with monthly values, how the average monthly rainfall accumulated in two scenarios, the current and the future, to 2050. The results at the provincial level show a variation in monthly precipitation average in the province, especially in the period April to December, where current precipitation reaches opposite values, in the climate change scenario there is a reduction of rainfall for this period. In addition, between the months of January to April there are no abrupt changes at the provincial level.

When analyzing the results obtained at the level of hydrographic subbasins, the conditions are very diverse. Subbasins are recorded in which no significant change is observed in relation to the current conditions, while in other cases the variation can reach tens of millimeters of monthly rainfall (Table 5).

Of the four subbasins that exist for the province of Chimborazo, the Chambo River and Namangoza River present a reduction in the values of average monthly precipitation in all months of the year. The Yaguachi River subbasin presents a reduction in precipitation in the year 2050 in 7 of the 12 months of the year, with an increase in precipitation in February, March, May, June and July. The subbasin of the Patate River presents a reduction of precipitation in 11 of the 12 months, and on the other hand an increase of precipitation of 23.1 mm for the month of June (Table No. 5). The subbasin of the Yaguachi river with a value of -1.3 in relation to the ba-

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Table 3. Change in average values of minimum temperature (Celsius) at basin level between the baseline and the climate change scenario by the year 2050

Subbasin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Promedio
Río Yaguachi	1,5	1,4	1,54	1,6	1,8	2	2	1,7	1,4	1,5	1,5	1,4	1,61
Río Chambo	1,5	1,4	1,54	1,6	1,8	2	2,1	1,7	1,4	1,5	1,5	1,4	1,62
Río Namangoza	1,5	1,4	1,6	1,7	1,8	2	2,1	1,7	1,4	1,5	1,5	1,4	1,64
Río Patate	1,6	1,5	1,55	1,6	1,85	2,1	2,1	1,8	1,5	1,6	1,6	1,5	1,66

Table 4. Change in average values of maximum temperature (Celsius) at basin level between baseline and climate change scenario by year 2050

Subbasin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Promedio
Río Yaguachi	1,5	1,4	1,54	1,6	1,8	2	2	1,7	1,4	1,5	1,5	1,4	1,61
Río Chambo	1,5	1,4	1,54	1,6	1,8	2	2,1	1,7	1,4	1,5	1,5	1,4	1,62
Río Namangoza	1,5	1,4	1,6	1,7	1,8	2	2,1	1,7	1,4	1,5	1,5	1,4	1,64
Río Patate	1,6	1,5	1,55	1,6	1,85	2,1	2,1	1,8	1,5	1,6	1,6	1,5	1,66

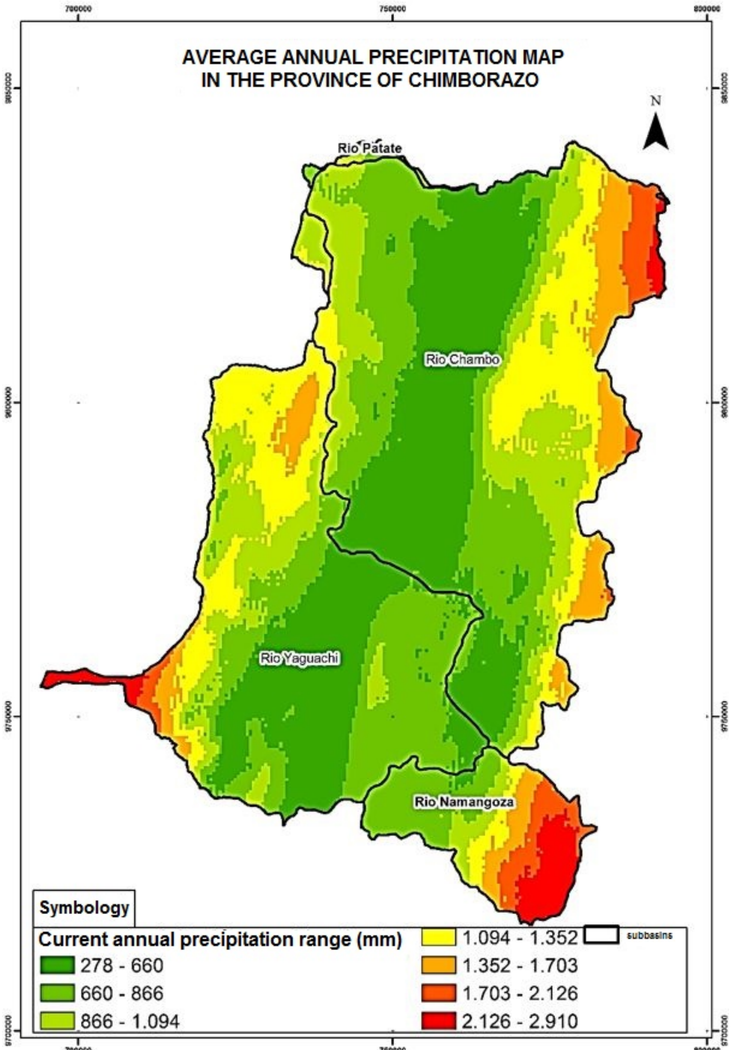

Figure 2. Average annual precipitation (mm) in the province of Chimborazo

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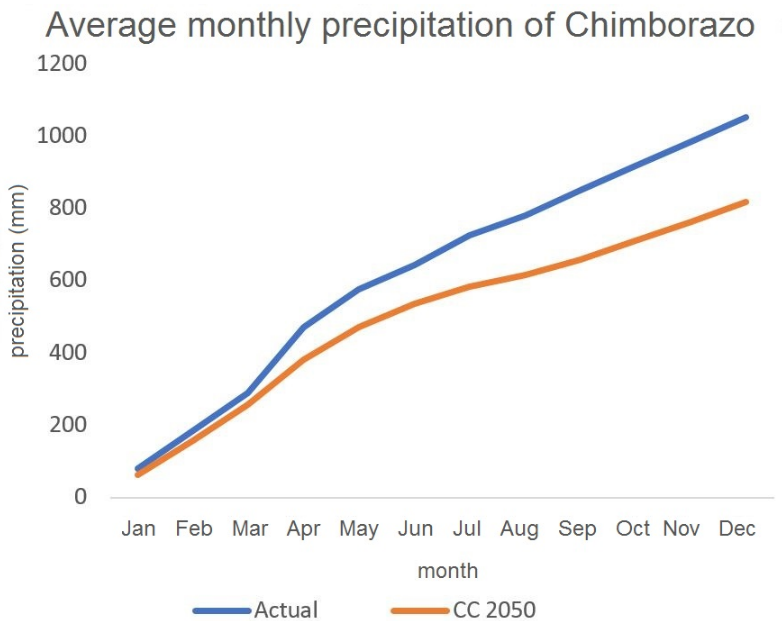

Figure 3. Average accumulated monthly precipitation (mm) for the province of Chimborazo under current conditions and climate change.

seline value, going from the current 671.38 mm to 670.08 mm. The subbasin that will show the greatest annual net precipitation variation will be the Namangoza river with a value of -417,78 mm annually, going from the current 1,435.1 mm to the annual 1,117.32 mm.

The values of accumulated precipitation by level of hydrographic subbasins is important when considering the type of crop that can be developed with present precipitation conditions, this data is critical for rain-fed crops. In 3 of the 4 subbasins, there would be a reduction in cumulative precipitation, including the Chambo River subbasin covering more than 50% of the province's territory (See Figure 4b, 4c and 4d). The subbasin of the Yaguachi River (Figure 4a) presents a scenario where current and future precipitations have similar values. (Figures 5 and 6).

The net and percentage changes of rainfall will have effects on the availability of water in all the ecosystems of the province. The highlands become key ecosystems to partially reduce the effects related to climate change in both precipitation and temperature. A gJanralized temperature increase for the province and reduced rainfall will have an adverse effect on local communities, as this will mean higher rates of evapotranspiration in crops, especially in rainfed crops (GADPCH, 2014).

To counteract changes that undermine the people's food sovereignty and affect the well-being of their people, it is necessary to establish real policies that help protect natural ecosystems, work on agricultural practices that help adapt to climate change and, especially its mitigation.

Current irrigation systems, investment in production systems, and citizens should consider future variations and availability of water in climate change scenarios.

Figure 5 and 6 show two scenarios, the current conditions and the climate change scenario. Here is a clear reduction of wet conditions in the eastern foothills which is the most evident effect within the province of the effects of climate change (GADPCH, 2014).

This work allows to visualize the changes of precipitation and temperature that will have the province and its implication in the subbasins that constitute a natural limit, which will be affected if similar practices against the increase of CO_2 emissions are not followed, aggravating the climatic conditions, producing the much-feared climate change.

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Table 5. Change in average precipitation values (mm) at basin level between the baseline and the climate change scenario by the year 2050

Subbasin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rio Yaguachi	-8,6	11	7,4	-43	2	28	3,8	-1,3	-7	-14	-14	-18
Rio Chambo	-18	-2,9	-11	-72	-18	-7,1	-11	-16	-17	-15	-11	-23
Rio Namangoza	-29	-22	-19	-57	-34	-21	-83	-60	-56	-37	-25	-36
Rio Patate	-33	-2,2	-3,1	-88	-17	23	-17	-15	-15	-14	-6,9	-26

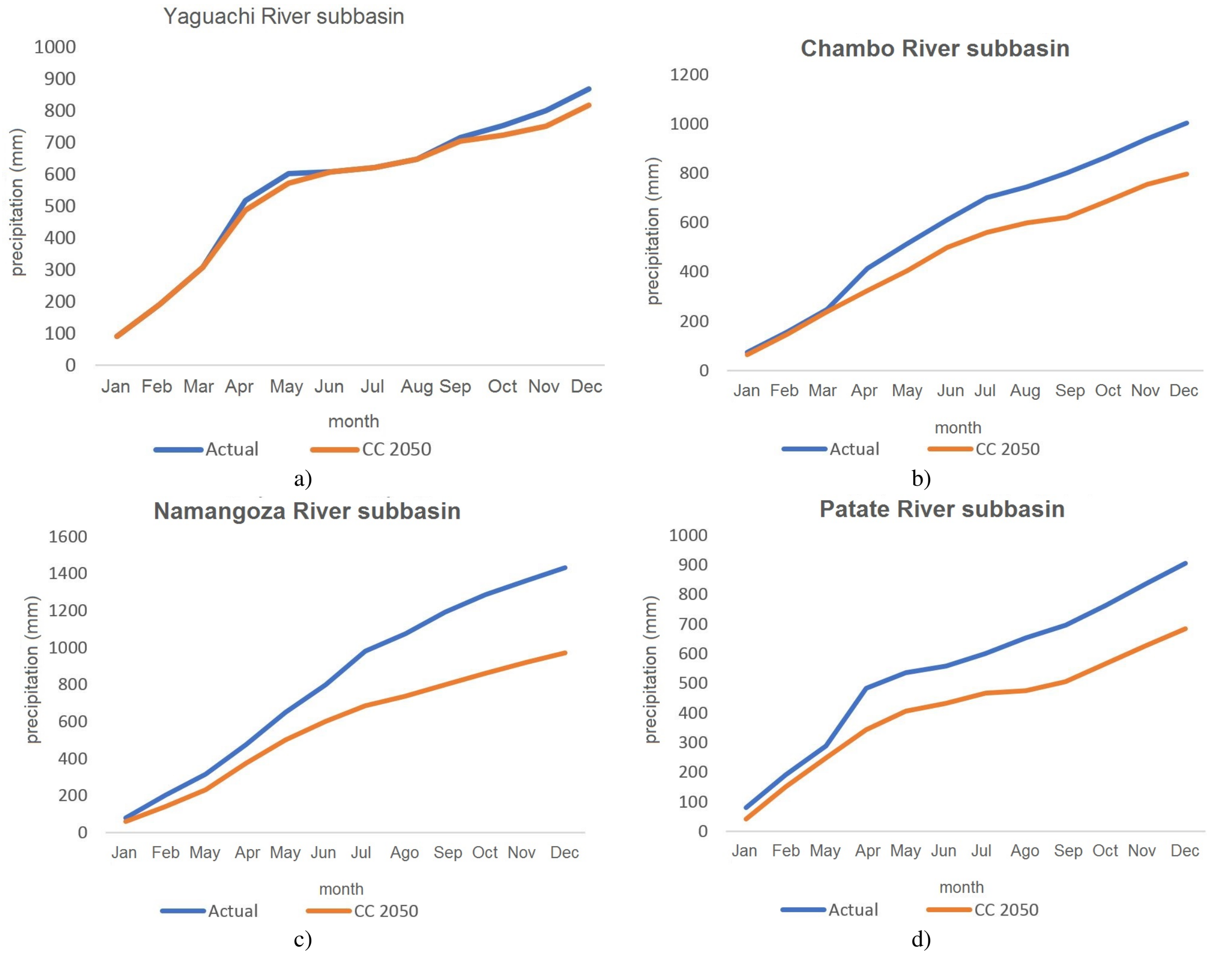

Figure 4. Cumulative precipitation (mm) by subbasin

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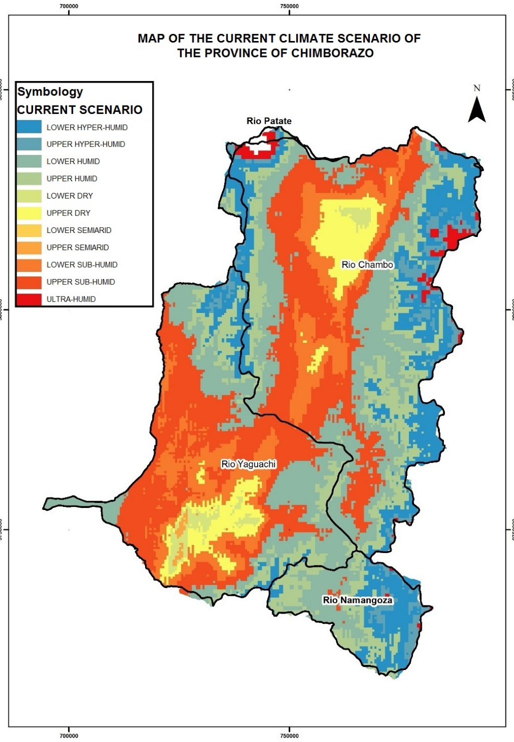

Figure 5. Scenario of current conditions for the province of Chimborazo

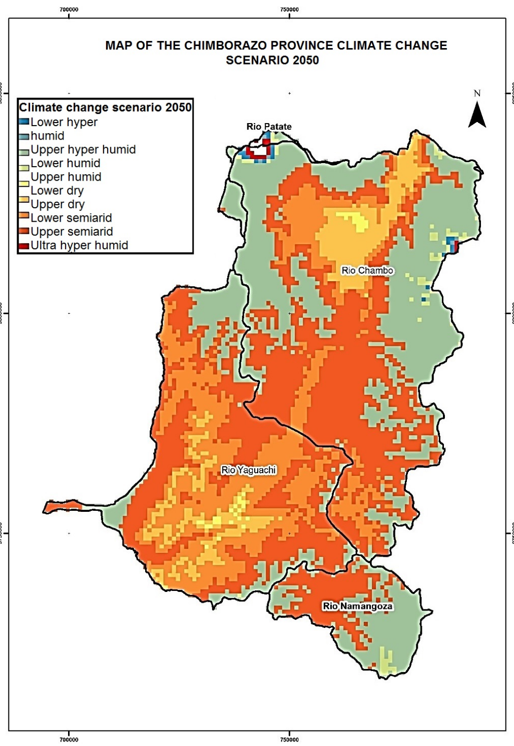

Figure 6. Climate change scenario by 2050 for the province of Chimborazo

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5 Conclusions

The climate change scenario for 2050 for the province of Chimborazo shows a gJanralized reduction of precipitation in the hydrographic subbasins, information obtained in contrast to the current climate of the province. The subbasins with a greater percentage of reduction of precipitation in the province are: river Namangoza, river Patate and river Chambo. The subbasin of the Yaguachi River, which feeds the Guayas basin, in 7 of the 12 months shows an almost imperceptible change in precipitation, current values as for climate change are relatively similar. On the other hand, the increase of the minimum temperature and maximum temperature occurs mainly in the Namangoza River basin in the month of July. In this subbasin is located the Sangay Wildlife Reserve.

6 Recomendations

There is a need to strengthen programs to conserve the natural cover because the reduction of natural ecosystems will increase the impacts due to the absence of the remaining habitats. Thus, it is necessary to implement policies that help to strengthen the processes of the efficient use of water, to be prepared in front of an almost gJanralized reduction of the availability of water.

To reduce vulnerability to climate change in scenarios, where temperature increases and precipitation reduction are evident, the efficiency of land and water use must be strengthJand and integrated into an integrated climate-ecosystem management.

While it is true that the administrative political division helps the authorities to exercise their powers in relation to the development objectives, it is necessary to start working together by considering the hydrographic units as new elements of leadership for the work for the reduction of effects of climate change.

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