Chapter

Effects of Climate Change on Water Resources, Indices, and Related Activities in Colombia

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Abstract

In Colombia, a country with great climatic diversity, the water balance is affected in one way or another by climate change depending on the region. Thus, there may be increases and decreases in precipitation and, in all cases, a huge increase in temperature. This document presents some studies carried out in different areas of the country regarding the effects of climate change on water resources, including its influence on hydroelectric power generation, some changes in the water balance in arid areas, and the opportunity to ensemble climate change scenarios. Likewise, it outlines a possible future water supply-demand relationship, where supply is associated with a change in the water balance and demand with some crops, activities, and sectors that need water to survive. This allows to estimate some future status indices to see the overall picture of climate change in connection with the country's water resources.

Keywords: climate change, water resources, indices, water supply, water demand

1. Introduction

Colombia is a country located in South America within the Intertropical Convergence Zone (ITCZ), which is associated with east trade winds. And, in addition to its varied orography, it boasts a great diversity of climates and rainy and dry seasons, once or twice a year, depending on the area of interest [1]. The same happens to the influence of climate change in the country, that is, precipitation varies in different ways. Moreover, during Colombia's Third National Communication on Climate Change before the United Nations Framework Convention on Climate Change (UNFCCC), the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) said that there would be a reduction in precipitation between 10 and 30% for 27% of the country, specifically in the northern and southern areas of the Colombian territory. Conversely, the same variable is expected to increase in 14% of the territory, in the central and western areas of the country [2].

However, IDEAM studies cover a very large region of the country, which makes them a poor reference for making local or scale decisions regarding the watershed. Therefore, different studies have been carried out on that scale for different regions of the country, with different climatic and geographical conditions, some of which will be detailed throughout this chapter.

2. Models and scenarios

The Intergovernmental Panel on Climate Change (IPCC) has demonstrated—with 95% of certainty—that human beings and their activities are the leading cause of global warming, which has become evident for more than five decades due to the increase in the concentrations of greenhouse gases (GHG). This will produce future changes in extreme weather and climate events throughout the planet. Therefore, the temperature and frequency of extreme events associated with precipitation, both floods and droughts, are very likely to increase progressively [3].

In consequence, a range of future climate scenarios was created in order to establish the potential influence on climate change on the planet in the short, medium, and long term. The SRES scenarios (A1, A2, B1, and B2) [4] used for the fourth assessment report (AR4) depend on a combination of future prospects for economic and technological development, and population growth. And the RCP scenarios or Representative Concentration Pathways (2.6, 4.5, 6.0, and 8.5), used for the fifth assessment report (AR5), are associated with greenhouse gas emissions measured as carbon dioxide [3]. The scenarios mentioned are briefly described in **Table 1**.

The indicated table establishes the relationship between the SRES and RCP scenarios with a possible equivalence between them, which can be used as a reference to observe the possible future changes in each of the studies mentioned in this

Scenario	Description
SRES A1	It is a world with rapid economic growth, where the population grows to some extent in the middle of the century and with a rapid spread of efficient new technologies [5]
SRES A2	It is a self-sufficient world, with continuous population growth and economic development associated with technological changes [5]
SRES B1	It is a world with a rapid change in economic structures, where the population grows to some extent in the middle of the century and with the introduction of efficient resources and technologies [5]
SRES B2	It is a world with a local economic, social, and environmental emphasis, with sustainable development, progressive population growth, and economic development oriented toward environmental protection [5]
RCP 2.6	An increase in CO_2Eq emissions is expected for the year 2100 until reaching a concentration of 490 ppm, with a peak prior to that year and a subsequent decrease, which would increase temperature from 0.3 to 1.7°C [2]
RCP 4.5	An increase in CO_2Eq emissions is expected for the year 2100 until reaching a concentration of 650 ppm, with a subsequent stabilization, which would increase temperature from 1.1 to 2.6°C. It is equivalent to SRES B1 [2]
RCP 6.0	An increase in CO_2Eq emissions is expected for the year 2100 until reaching a concentration of 850 ppm, with a subsequent stabilization, which would increase temperature from 1.4 to 3.1°C. It is equivalent to SRES B2 [2]
RCP 8.5	An increase in CO_2Eq emissions is expected for the year 2100 until reaching a concentration of 1370 ppm, with subsequent growth, which would increase temperature from 2.6 to 4.8°C [2]

Table 1.
Description of climate change scenarios.

Models	Scenarios	Period	Location	Study
HadGem2-ES, GDFL-CM3	RCP 4.5 and RCP 8.5	2050-2070	Uribia, La Guajira	[6]
CCSRNIES-A21, CSIROMK2B-A21, CGCM2-A21, CGCM2-A22, CGCM2-A23, HadCM3-A21, HadCM3-A22, HadCM3-A23, HadCM3-A2-SDSM.	SRES A2 and B2	2010-2100	Sinú-Caribe Basin	[7–10]
BCCCM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, MIROC-ESM, MIROC5, MRI-CGCM3, NorESM1-M.	RCP 2.6, 4.5, 6.0 and 8.5	2050-2070	Nilo, Cundinamarca	[11, 12]
IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC 5	RCP 4.5 and RCP 8.5	2020-2050	Coello River Basin, Tolima	[13]

Table 2.
Models and scenarios according to the reviewed study.

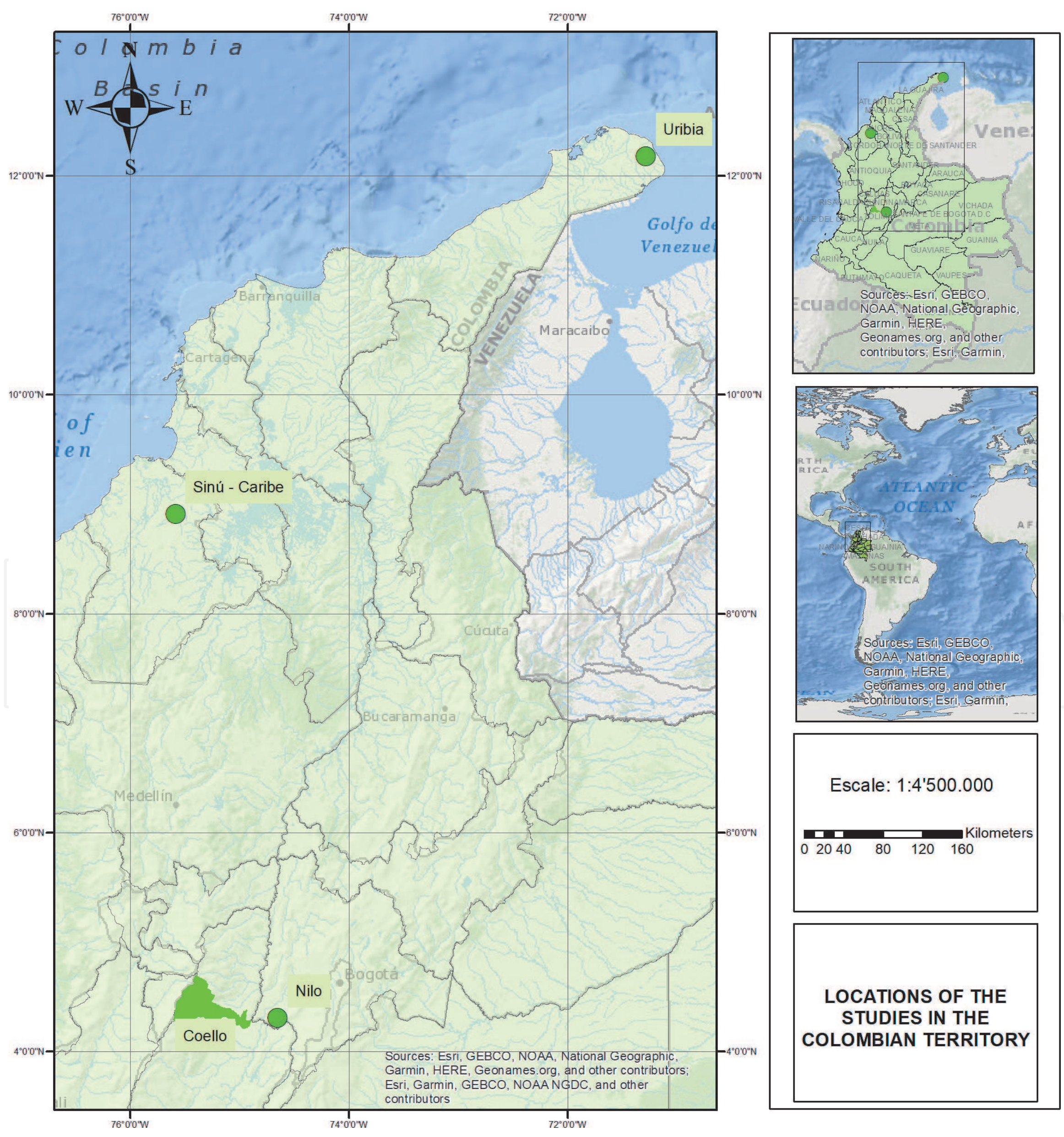

Figure 1.
Locations of the studies in the Colombian territory.

document. Given its broad temporal spectrum, **Table 2** shows the different scenarios over different periods of time.

The studies are located in different areas of the country, with different characteristics. The map illustrated in **Figure 1** shows their exact location within Colombia.

3. Effects of climate change on water resources, indices, and related activities in Colombia

This section introduces the studies carried out in different areas of the country, using different methodologies, which are explained in depth in each of the investigations. Additionally, it sets out the possible effects of climate change on the water resources in each location.

3.1 Effects of climate change on indices and climate zonification

3.1.1 Uribia, La Guajira

This study was carried out in Uribia, located in La Guajira, which corresponds to a desert area according to the Lang's Index (LI) and with little or no surplus water according to the Thornthwaite climate classification. It is an approximation of what may happen to the abovementioned classifications under climate change scenarios.

As shown in **Table 2**, this study considered two models and two scenarios. The HadGem2-ES model was the optimistic scenario for the RCP 4.5 scenario in 2050 and the GDFL-CM3 model was the pessimistic scenario for the RCP 8.5 scenario in 2070.

A hydrological balance was made both for the baseline (1976–2050) and for the previously mentioned scenarios, based on the meteorological data measured at the Nazareth station and its corresponding future change scenarios due to the influence of climate change. **Table 3** shows the annual average values for each variable considered in the water balance.

The climate change models were reviewed, obtaining an increase of 1.7°C and a 2.4% decrease in precipitation for the optimistic scenario, as well as an increase of 3.7°C and an 11% decrease in precipitation for the pessimistic scenario. This will have a direct effect on the provisional crops, as soil moisture will be reduced.

As an example, **Table 4** summarizes the changes in the variables resulting from the water balance and the implications that these changes may have on the water requirements of the corn, bean, and melon crops in the study area.

Variable	Baseline value
Maximum temperature (°C)	32.5
Average temperature (°C)	27.3
Minimum temperature (°C)	22.0
Precipitation (mm)	510.2
Evaporation (mm)	2044.5
Evapotranspiration (mm)	1521.1

Table 3.
Meteorological variables of Nazareth station [6].

DOI: http://dx.doi.org/10.5772/intechopen.90652

Water layer	Baseline	GDFL-ESM2G (GD) 4.52050			GDFL-ESM2G (HD) 6.02070			GDFL-ESM2G (HE) 8.52070		
		Value	Difference (mm)	Change (%)	Value	Difference (mm)	Change (%)	Value	Difference (mm)	Change (%)
Def (mm/year)	1060.6	1781.5	720.9	**68.0**	1816.1	755.5	**71.2**	1870.8	810.1	**76.4**
Pcp (mm/year)	510.2	446.2	−64.0	**−12.5**	445.2	−65	**−12.7**	446.2	−64.0	**−12.5**
ETo (mm/year)	1570.8	2227.7	656.9	**41.8**	2261.3	690.5	**44**	2317.0	746.1	**47.5**
ETa (mm/year)	510.2	446.2	−64	**−12.5**	445.2	−65	**−12.7**	446.2	−64	**−12.5**
Water requirements (mm/year)—Corn	257.5	426.9	169.4	**65.8**	426.2	168.7	**65.5**	433.7	176.2	**68.4**
Water requirements (mm/year)—Bean	195.9	363.1	167.2	**85.3**	356.6	160.7	**82.0**	370.2	174.3	**89.0**
Water requirements (mm/year)—Melon	223.9	403.8	179.9	**80.3**	394.1	170.2	**76.0**	412.5	188.6	**84.2**

The bold values highlight the percentage change.

Table 4.
Summary of water balance and requirements for the different scenarios and periods [14].

Once the water balance has been carried out with the new weather conditions, it is clear that none of the classifications mentioned at the beginning of this section have changed (Lang and Thornthwaite). However, the conditions of such classification are exacerbated since there is a reduction in the Moisture Index (Im), which may have a negative implication, both ecologically and socially, due to the lower availability and access to drinking water.

This suggests that there is a growing need to investigate this area in order to develop an adequate plan that may include water harvesting projects or efficient crop irrigation systems that take into account the future demands and projected precipitation deficits, to serve as a climate change adaptation strategy.

3.2 Effects of climate change on related activities

3.2.1 Sinú-Caribe basin

The influence of climate change in this area of the country was analyzed, evaluating the supply-demand relationship. The activities related to hydroelectric power were taken into account in four investigations that will be briefly described in this section.

This area of the country is deserted due to the anthropic activity in the riverbed of the basin, in addition to the deforestation associated with different activities. It is a region of great importance for the country considering that approximately 66% of the electricity in Colombia is generated in hydroelectric plants [15] and that 3.7% of that value is a direct contribution of the Urra I system, located in the Sinú-Caribe basin. Moreover, it is susceptible to flooding; so the occurrence of extreme precipitation events is important for research related to climate change, considering that due to its influence the events will tend to be more frequent in the future [3].

For the first investigation carried out in 2009 [7], the precipitation and temperature data were initially obtained for two weather stations in the area. Then, some statistical regressions were performed to establish the relationship between the mentioned variables and the flow measured in the basin. Regarding the future projection of precipitation and temperature, some scenarios were generated taking into account the data of climate change models (deltas) and the series observed in the basin stations.

When reviewing the precipitation projected by each of the models, it was concluded that some projects have an increase and others a decrease, having a possible percentage change between −21 and 14. However, the flow tends to decrease between 2 and 35% regardless of whether precipitation increases or not, given its relationship with other variables.

Given the above, the intention was to establish the sensitivity and vulnerability of the hydroelectric power generation system, creating scenarios based on the supply and demand of the area and the aforementioned climate projections. The scenarios were entered in the "Water Evaluation and Planning System-WEAP 2.1" and it was found that hydropower generation tends to decrease in the future, between 15 and 46%, which can increase the production costs that could be transferred to the users of this service. The above is summarized in **Table 5**.

This study indicates that research should be carried out in order to establish the potential vulnerability of systems related to supply and demand in this area under the influence of climate change. Therefore, a subsequent investigation was carried out in which it was considered that the impact on water resources was not only the result of the change in its offer or its quality, but also the pressure on the said offer in which the population and planning processes influence significantly [8].

DOI: http://dx.doi.org/10.5772/intechopen.90652

Model/variable	Electricity generation		Flow
	Change %[1]	Change %[2]	Change %
CCSRNIES_A21	−0.7	−16.5	−5.9
CSIROMK2B_A21	−11.3	−25.4	−2.3
CGCM2_A21	−0.8	−16.5	−11.8
CGCM2_A22	−13.7	−27.4	−13.3
CGCM2_A23	−13.4	−27.1	−11.3
HadCM3_A21	−35.2	−45.5	−34.9
HadCM3_A22	−25.9	−37.7	−23.8
HadCM3_A23	−2.9	−18.3	−14.2
HadCM3_A2_SDSM	0.6	−15.4	−2.3
Statistic	−27.2	−38.8	

[1]*Reference scenario or baseline (1418.9 GWh/year).*
[2]*Maximum generation capacity (1687.2 GWh/year).*

Table 5.
Changes in hydroelectric power generation and its related variables [7].

A model was made using WEAP 2.1 software, to simulate hydrological processes in the scenarios concerning anthropogenic changes, land use, demands, and regulations among others. Its methodology is based on obtaining information on the daily consumption and activities in the study area, and their corresponding future increases based on projections. Then, it was contrasted with the reduction in supply due to environmental flow and quality considerations, as well as the possible variation in both temperature and precipitation and its consequent influence on the change in supply. Using WEAP, aspects of the supply-demand relationship were determined, such as unsatisfied demand, demand coverage, supply requirement, supply delivered, demand increase, and resource pressure indices. All scenarios are considered to be consistent with an increase in temperature and a positive or negative change in precipitation, as shown in Appendix 1, with a consequent decrease in the water flow or supply available.

As a result, it was concluded that in all scenarios it is not possible to supply the demand for water resources in all sectors and activities (commercial, industrial, rural, and urban areas), leading to a progressive growth of unsatisfied demand for the year 2039, as shown in **Figure 2**.

From this research, it is important to highlight the allocation of weights to climate change models based on their contribution to the flow, and their corresponding increase and decrease in temperature and precipitation respectively. Accordingly, a single weighted average scenario was proposed, where the worst possible scenarios are given a greater weight. Therefore, this scenario becomes a tool for planning water conservation strategies, such as the implementation of technologies for the reuse or efficient use of water, as well as the inclusion of vegetation conservation.

It was concluded that the proposed methodology and application of the WEAP tool allow to have a broader view of the resource in a region, allowing a better management of the water resource, with the possibility of planning strategies properly and taking into account adverse effects. This establishes the need to carry out a regionalization of climate change in order to develop tools that allow a detailed observation of its impact at local level. Finally, the inclusion of hydrological variables allows planning based on the water supply, reducing uncertainty in some way.

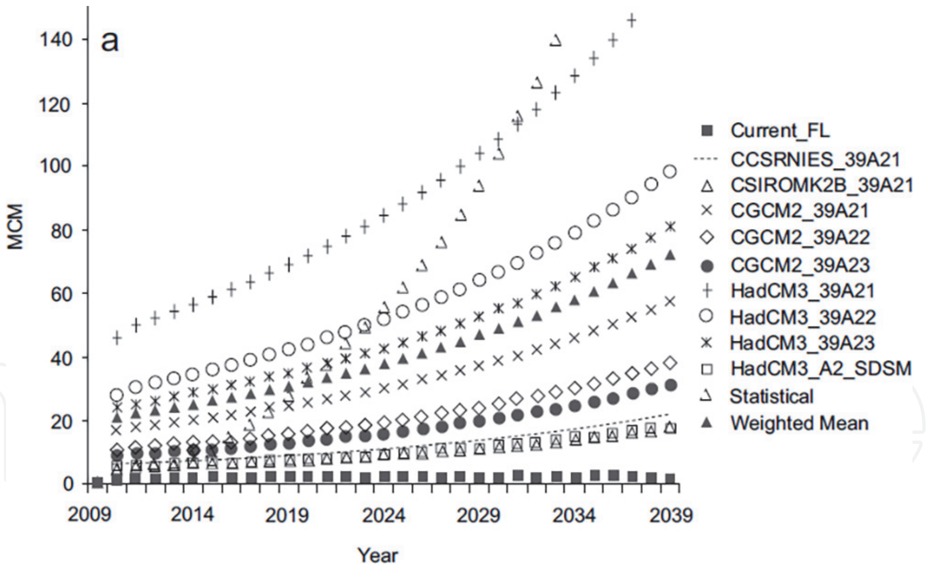

Figure 2.
Total unsatisfied demand, Sinú-Caribe basin [8].

Having reviewed the supply-demand relationship in this area for different activities and considering the importance of hydroelectric power generation for the country, the need to propose a vulnerability index for this activity was established [9]. Based on the observed and projected data from the previous investigations, both for precipitation and temperature and for flow, as well as on the supply and demand data of the water resource, the WEAP tool was used again to perform a water balance that includes the data mentioned and the operating policies, technical problems, bathymetries, and evaporation in the basin.

Given the above, there is a direct relationship between the flow and the volume of the basin with changes in precipitation and temperature. Therefore, the vulnerability index will depend directly on these two variables, its lowest value being the result of a 10% increase in precipitation and a 0.5°C increase in temperature and the highest value the result of a 10% decrease in precipitation and a 3°C increase in temperature.

Given the cost overruns in energy production, research similar to the previous one supposes the possibility for decision-makers to establish the vulnerability of their systems to climate change, as well as to implement projects to adapt to and mitigate the effects.

Finally, it was intended to establish if the availability of water can act as an optimization factor in the generation of hydroelectric power [10]; so, an investigation focused on this topic was carried out. To do so, using both current and future supply and demand values, an adapted scenario was established in which demand decreases by 20% due to the efficient use of water. This makes the critical point at which demand equals supply more distant, having a difference of 5 years on average.

As for hydroelectric generation, some system optimization scenarios were established, including pumping from a downstream point of the basin to an upstream point, which regulates the basin and can be used to mitigate events of flood that, as mentioned, are very likely to occur. The optimization scenarios are contingent on pumping with different start dates and the amount of water extracted. It was established that pumping must begin before the critical point established for each demand scenario to avoid regional conflicts over the use of water.

However, from this latest investigation it was concluded that the critical point with measures such as pumping only takes a little longer to occur. Therefore, it is crucial to make changes in demand such as establishing appropriate water management and regulation strategies, optimizing water delivery infrastructure, and establishing priorities. This study and the previous ones encourage decision-makers to carry out adaptation projects that take into account all the issues addressed in this section and the changes in the meteorological variables indicated in Appendix 1.

3.3 Effects of climate change on water resources, indices, and related activities

3.3.1 Nilo, Cundinamarca

The municipality of Nilo, located in the department of Cundinamarca, is an important region for the production of Cocoa in Colombia. This study seeks to evaluate the water requirements for growing this product in current and future scenarios with climate changes [11].

For this purpose, a baseline was initially established in the period 1975–2005. Then, using variables such as precipitation, temperature, evapotranspiration, among others, a water balance was performed to recognize and characterize the study area, establishing adequate water availability, according to the water resource indices in **Table 6**. This procedure was repeated again considering the change in the projected meteorological variables for the years 2050 and 2070.

Additionally, the water requirements of the crop were established using CropWat software, climatic variables of the baseline and future scenarios, as well as some parameters related to soil, which were established based on fieldwork performed in the study area.

Consequently, crops were delimited due to water deficiency in soil, as a result of an increase in temperature (T) and a decrease in precipitation (PCP). The aforementioned will involve drought stress, a possible increase in pests, and a drastic reduction in crop yield. In addition, there will be a possible increase in the water deficit (Def) in both the pessimistic and optimistic scenarios, changing the Hydric Availability Index (HAI) in the area from optimal to semiarid, as shown in **Table 7**. According to the values in **Table 7**, in terms of the water requirements of the reference crop, a value of 359 mm for the baseline and a consequent increase up to 535 mm were established as a result of climate change.

This study opens up the possibility of planning the use of the land, depending on the water requirements of both current and future crops, in order to make sustainable use of the water resource and can serve as a reference for new studies on this subject. This investigation measured the arithmetic average of the results obtained from the different models and scenarios. However, it does not allow observing the effect of each model, which may differ from each other, either in the magnitude of the change in temperature or in the increase or decrease in precipitation.

Index	Description	Value
LI	The Lang's index describes the humidity conditions in the area as the ratio between average annual precipitation and average annual temperature [16]	VH: Very humid H: Humid MH: Moderately humid ML: Semiarid L: Arid VL: Desert
HAI	The Hydric availability index allows to identify surpluses or deficiencies of water in specific areas or periods. It is a function of the relationship between the sum of the actual evapotranspiration and a quarter of the surpluses with the potential evapotranspiration [17]	VH: Very humid H: Humid MH: Moderately humid M: Optimal ML: Semiarid L: Arid VL: Desert

Table 6.
Description and assessment of the calculated indices.

Therefore, the scenarios were grouped into four clusters or groups of similar results, in which the centroid value of each of the variables was obtained, as shown in **Table 8**. It was decided to assemble a scenario by assigning weight factors to each cluster, in order to generate a unique scenario with the most adverse effects. Since the municipality of Nilo is mainly engaged in agriculture, it was concluded that the most negative effect in this area is the reduction of precipitation and the increase in temperature. Therefore, the clusters in which this occurs will have a greater value at the time of assigning the weight factor (WF) for each of variable [12].

Accordingly, a unique scenario (WA) for precipitation and average, minimum and maximum temperatures were established based on the previously assigned weights. This scenario differs from the arithmetic average (AA) of all the scenarios calculated; they were compared with the established baseline (BL), as shown in **Figure 3**.

Climate variable/scenario	**Tmin (°C)**	**Tmax (°C)**	**Tavg (°C)**	**PCP (mm)**	**Def (mm)**	**LI**	**HAI**
Current	21.4	23.4	22.4	1292.0	124.5	M-L	M
Change in climate variable/ scenario	**ΔTmin (°C)**	**ΔTmax (°C)**	**ΔTmed (°C)**	**ΔPCP (%)**	**ΔDef (%)**	**LI**	**HAI**
Pessimistic 2050	2.0	2.1	2.1	−39.8	396.4	L	L
Optimistic 2050	1.3	2.3	1.8	3.2	31.1	M-L	M
Average 2050	1.6	2.1	1.8	−15.8	152.8	L	M-L
Pessimistic 2070	2.5	3.5	3.0	−36.5	382.8	L	L
Optimistic 2070	2.5	3.7	3.1	14.3	13.9	M-L	M
Average 2070	2.1	2.6	2.3	−14.0	150.1	L	M-L

Table 7.
Summary of the variation of climatic variables and associated indices [11].

Variable/cluster	**1**	**2**	**3**	**4**
Members	22	7	7	8
Percentage	50	15.91	15.91	18.18
Tmin (°C)	23.08	**24.61**	23.4	23.39
Tmax (°C)	33.89	**35.43**	34.06	34.1
Tavg (°C)	28.49	**30.03**	28.74	28.73
PCP (mm)	1101.25	1149.27	**874.74**	1314.08
Def (mm)	294.52	287.76	525.86	191.01
LI	L	L	L	M-L
HAI	M-L	M-L	M-L	M-L
PCP WF	0.26	0.68	**4.34**	0.38
Tmax WF	0.36	**2.46**	1.35	1.17
Tmin WF	0.34	**2.44**	1.39	1.23
Tavg WF	0.34	**2.45**	1.38	1.22

The bold values highlight the greater temperature values on the cluster 2 and so the greatest weighting factor for this variables correspond to the scenarios which are part of that cluster. While the minor precipitation value is in the cluster 3, giving it a greater weighting factor to this variable in the scenarios belonging to this cluster.

Table 8.
Summary of climatic variables, their associated indices and weights for each cluster [12].

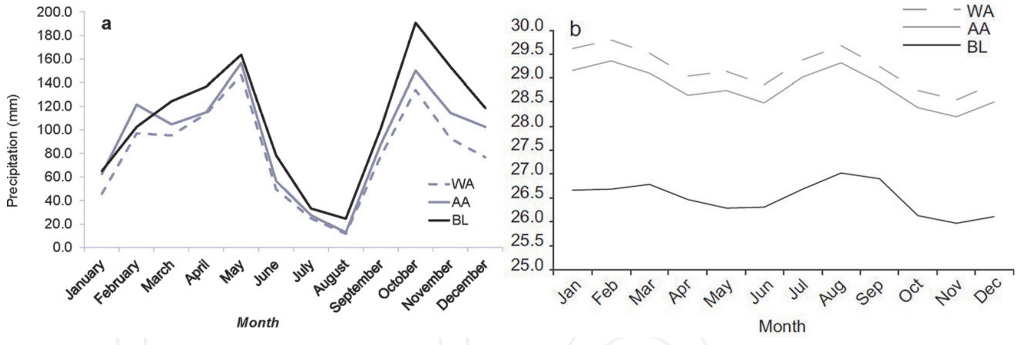

Figure 3.
Monthly behavior of (a) precipitation (b) average temperature [12].

Establishing a unique scenario as indicated in this investigation allows decision-makers to establish adaptation measures for that single scenario, focusing efforts on preventing or mitigating the most adverse effects for the area of interest, which is of vital importance for the proper management of water resources in an unfavorable future.

3.3.2 Coello River basin

The Coello River basin is located in the department of Tolima. It covers a large percentage of its territory and is of great importance for the region since it supplies the municipalities settled there, as well as their economic activities, mainly agricultural. Likewise, it supplies one of the most important irrigation districts in the region due to its large rice and cotton production.

An investigation was conducted in this basin, focused on assessing the implications of climate change on the supply, demand, and indicators of water resource status, namely, indices of aridity, water use, vulnerability to water shortage, and water retention. Its methodology was based on the development of a hydrological model using the Soil and Water Assessment Tool (SWAT), both for the baseline (1976–2005) and for the future period (2020–2050), in which daily precipitation and monthly temperature were entered as input variables.

In the case of temperature, the Delta Method was used as a methodology for the reduction of the geographic scale of the General Circulation Models (GCM) implemented, which consists in establishing the variation of the temperature per month taking as reference the historical data of the GCMs mentioned in **Table 2**. In the case of precipitation, since a daily resolution was required, it was decided to combine the Delta Method for the monthly scale reduction with the Maximum Entropy Method for the disaggregation of said value on a daily basis, depending on the observed behavior of said variable in each station studied [13].

As a result, a potential increase in annual precipitation was determined as shown in **Figure 4**. However, there was a sharp decrease in its value at daily resolution as illustrated in **Figure 5**, which suggests a possible increase in extreme events since large amounts of precipitation are concentrated on specific day(s).

In the case of the maximum temperature, its value increased progressively as illustrated in **Figure 6**.

Once the input variables for the hydrological model have been established, the flow values were obtained throughout the basin, thus establishing the water supply in each of the microbasins. Subsequently, the flows were characterized using flow duration curves, which, compared with the observed value, indicate an increase in the probability of extreme events and a decrease in the average flow that flows through the channel most of the time (**Figure 7**).

In the case of demand, having a projection of the meteorological variables and the crop areas, as well as the type of product grown, the water demand was established in terms of the irrigation requirement of said crops using the CropWat tool, as shown in **Table 9**.

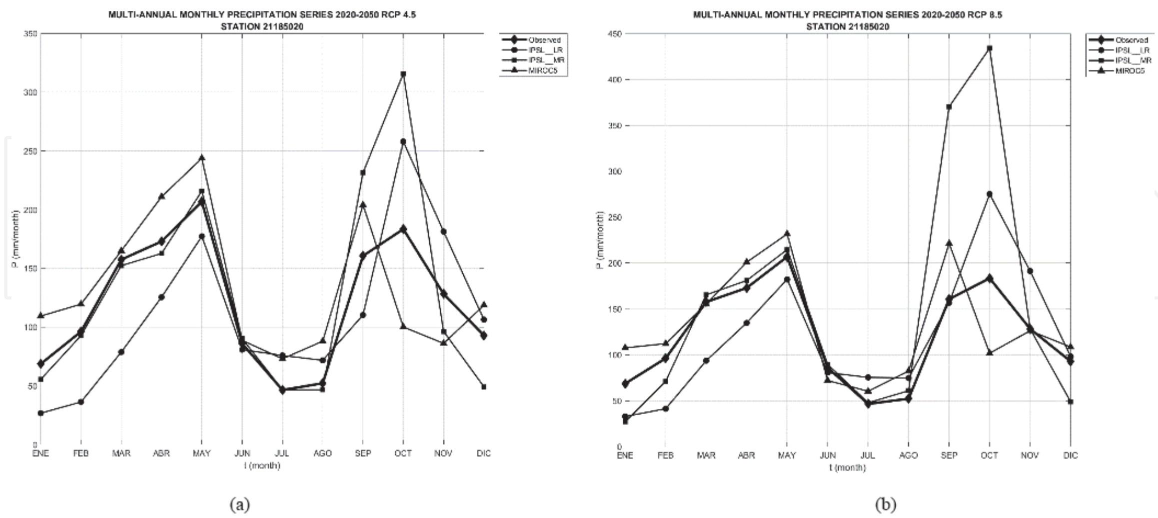

Figure 4.
Monthly behavior of precipitation. (a) RCP 4.5 (b) RCP 8.5 [13].

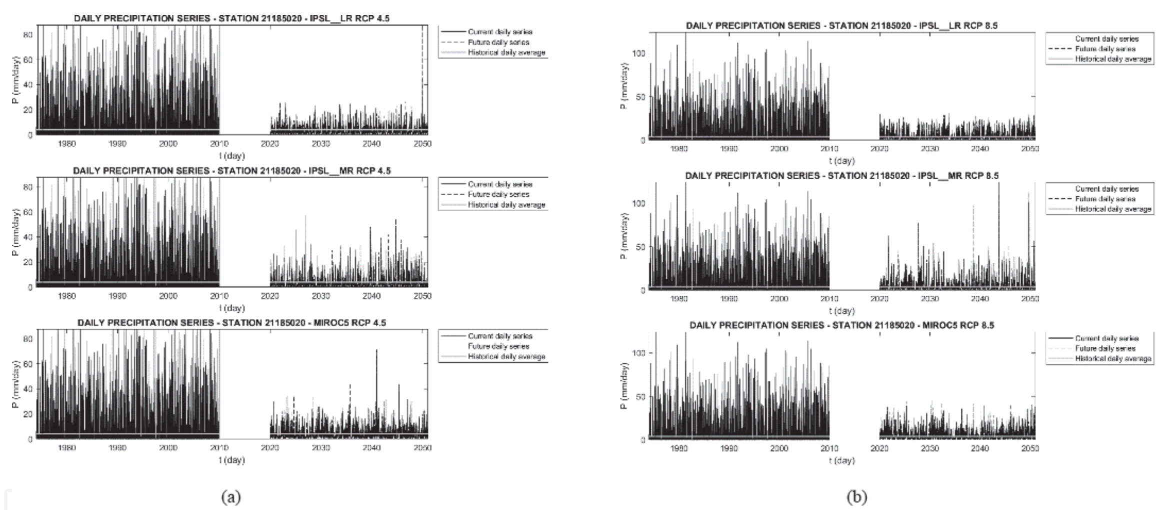

Figure 5.
Daily behavior of precipitation. (a) RCP 4.5 (b) RCP 8.5 [13].

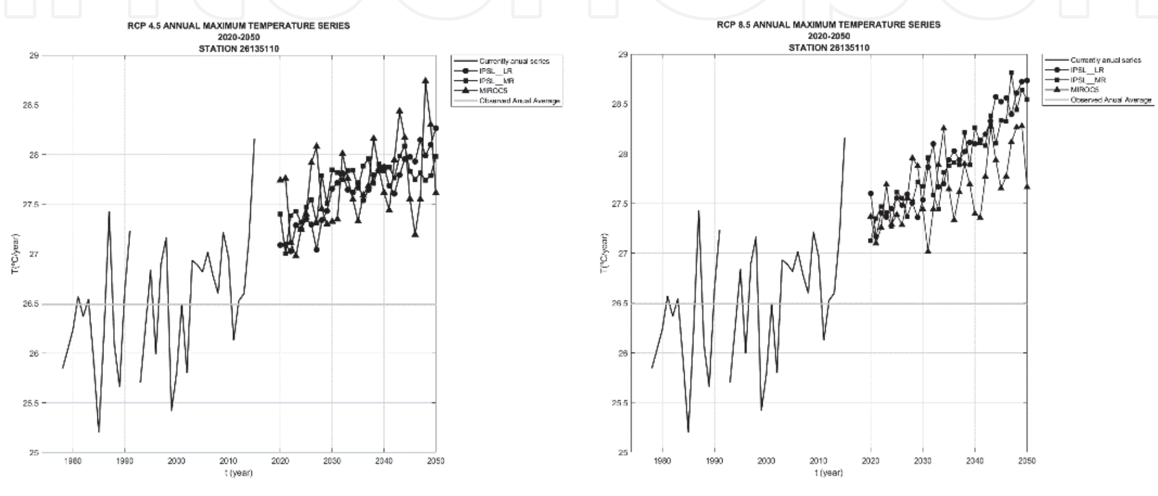

Figure 6.
Annual behavior of temperature. (a) RCP 4.5 (b) RCP 8.5 [13].

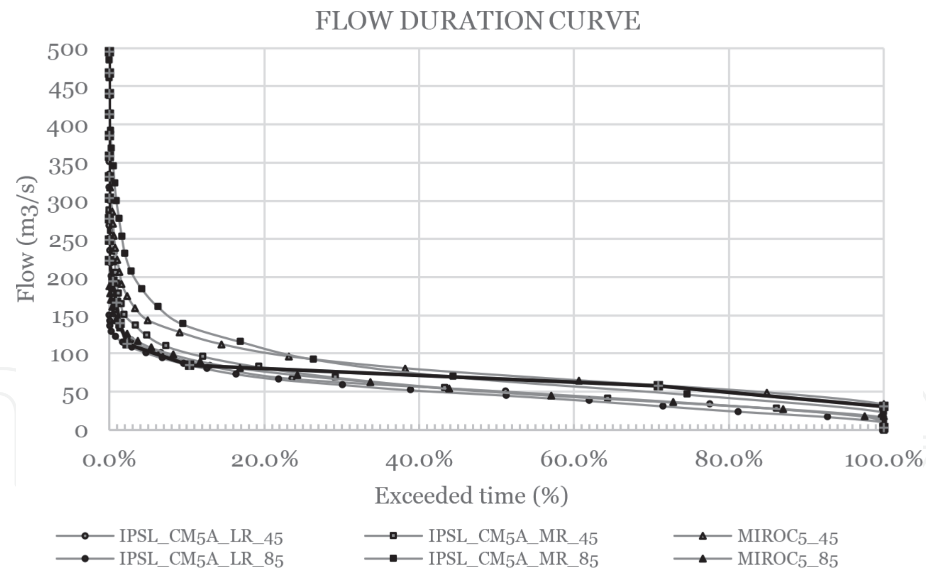

Figure 7.
Flow duration curve for all the models and RCPs selected, year 2050 [13].

Demand/crop	Pane cane	Banana	Plantain	Arracacha	Rice
Model	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**
Current	13.5	10.6	5.4	2.0	296.3
IPSL_LR45	20.8	12.4	6.4	1.8	393.1
IPSL_MR45	16.3	14.2	7.3	2.2	367.5
MIROC5_45	20.4	10.3	5.3	1.7	314.4
IPSL_LR85	19.1	19.5	10.0	1.7	390.8
IPSL_MR85	21.2	14.1	7.2	2.2	362.9
MIROC5_85	13.1	10.2	5.2	1.9	322.2
Demand/crop	**Bean**	**Corn**	**Yucca**	**Cocoa**	**Coffee**
Model	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**
Current	1.2	1.1	0.7	36.7	183.5
IPSL_LR45	1.6	1.3	0.98	50.7	245.5
IPSL_MR45	1.7	1.4	0.96	45.6	234.4
MIROC5_45	1.7	1.3	0.89	42.7	210.4
IPSL_LR85	1.5	1.3	0.94	49.8	243.6
IPSL_MR85	1.6	1.4	0.97	44	227.3
MIROC5_85	1.7	1.3	0.9	43.4	211.4
Demand/crop	**Mango**	**Avocado**	**Soursop**	**Lemon**	**Cotton**
Model	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**	**(Mm^3/year)**
Current	2.6	0.042	0.014	0.33	12.3
IPSL_LR45	3.6	0.064	0.018	0.53	16.3
IPSL_MR45	3.2	0.054	0.018	0.47	14.7
MIROC5_45	3.0	0.042	0.018	0.38	12.2
IPSL_LR85	3.5	0.063	0.018	0.51	16.1
IPSL_MR85	3.1	0.055	0.017	0.47	14.8
MIROC5_85	3.09	0.046	0.018	0.39	13.1

Table 9.
Irrigation requirement for the crops in the study area [13].

Furthermore, growth projections were defined for both population and other economic activities such as livestock and industry. In this way, the supply that each of them will require in the future was established, noting that no demand for another activity is comparable with that established for the agricultural sector as shown in **Table 10**.

Finally, the water resource status indices were established, which are a function of both the previously calculated supply and demand. This evidenced a strong increase in the Aridity Index (AI) and Water Use Index (WUI), as well as a scenario of improvement with respect to the Index of Vulnerability to Water Shortages

Scenario	Agricultural sector demand (m^3/s)	Domestic sector demand (m^3/s)	Industrial sector demand (m^3/s)	Total demand (m^3/s)
Current	17.73	0.888	0.310	19
IPSL_CM5A LR RCP 4.5	27.55	1.579	1.790	31
IPSL_CM5A MR RCP 4.5	26.12	1.579	1.790	30
MIROC5 RCP 4.5	23.42	1.579	1.790	27
IPSL_CM5A LR RCP 8.5	27.67	1.579	1.790	31
IPSL_CM5A MR RCP 8.5	25.84	1.579	1.790	29
MIROC5 RCP 8.5	23.52	1.579	1.790	27

Table 10.
Water demand in the scenarios selected. Adapted from [13].

Index	Description	Value
AI	It describes the degree of surplus or deficiency of precipitation to sustain ecosystems based on potential and actual evapotranspiration, qualifying it from water deficit to water surplus [1]	VH: High surplus H: Surplus MH: Moderate to surplus M: Moderate ML: Moderate to deficient L: Deficit VL: Highly deficient
WRI	It establishes the ability to retain and regulate humidity in the basin, according to a relationship between the values extracted from the flow duration curve [13]	VH: Very high H: High M: Medium L: Low VL: Very low
WUI	It describes the pressure of the demand with respect to the supply [13]	VH: Very high H: High M: Medium L: Low VL: Very low
IVWS	It describes the vulnerability of the water system to the shortage of the resource for different users [1]	VH: Very high H: High M: Medium L: Low VL: Very low

Table 11.
Description and assessment of the calculated indices.

DOI: http://dx.doi.org/10.5772/intechopen.90652

(IVWS), Water Retention Index (WRI), and/or the same indices calculated for the baseline. **Table 11** shows a brief explanation of these indices.

Based on the average values of each index, **Table 12** shows the total values of the basin.

Scenario	IA	WRI	WUI	IVWS
Baseline	M	H	H	M
IPSL-CM5A-LR – RCP 4.5	M	M	VH	H
IPSL-CM5A-MR – RCP 4.5	M	M	VH	H
MIROC 5 – RCP 4.5	M-H	M	VH	H
IPSL-CM5A-LR – RCP 8.5	M	H	VH	M
IPSL-CM5A-MR – RCP 8.5	M	M	VH	H
MIROC 5 – RCP 8.5	M-H	H	VH	M

Table 12.
Average values of each index for the baseline and each projected scenario. Adapted from [13].

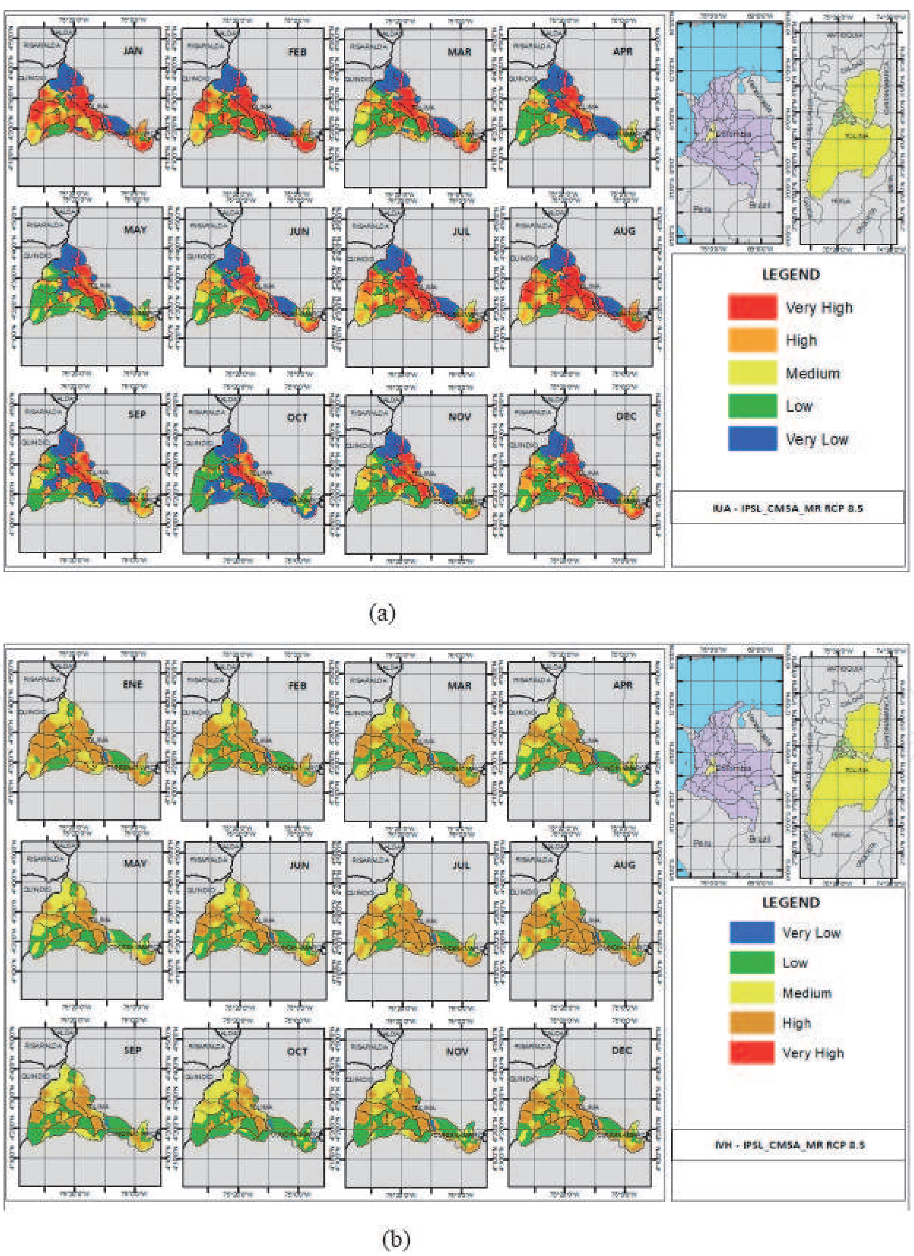

Figure 8.
Spatialized values for the IPSL-CM5A-MR RCP 8.5 model for (a) water use and (b) vulnerability to water shortages [13].

It is worth noting that these indices were calculated with a spatial distribution defined by the microbasins of the hydrological model, for each month of the year, so the research includes maps of each index such as those illustrated in **Figure 8**.

However, despite obtaining an optimistic future scenario unlike other regions of the country, this should be used with caution given the uncertainty that it entails; for example, there was an increase in the amount of monthly precipitation but a decrease in the daily average, indicating an increase in the intensities concentrated on specific days. The foregoing has a direct influence on the water retention index, which may give an unsuccessful perspective on the optimism of the scenario.

Finally, studies such as the one mentioned above may be of great interest to decision-makers, since they broaden their spectrum of possible future scenarios, in order to adopt measures that mitigate the possible impacts of climate change.

4. Conclusions

It was concluded that the effects of climate change throughout the country are very varied in contrast to its current state. These changes are summarized in Appendix 1, where there is mostly a decrease in the amount of precipitation in the future under climate change scenarios, with the exception of the Coello River basin area where there is an increment. It should be noted that in the latter case this increase occurs at monthly resolution and that on a daily scale there is a decrease in this variable with possible concentrations on specific days. This suggests a possible increase in precipitation intensity and consequently a possible increase in extreme events.

In the case of temperature, all studies agree that there will be an increase from 0.5 °C in the period 2011–2040 to almost 4 °C in the period 2071–2100 in different scenarios and areas as detailed in Appendix 1. The foregoing has a direct implication in related activities as explained in this chapter. A possible decrease in hydroelectric generation is expected given both the increase in temperature and the variation in precipitation. In addition, in the case of agricultural activities, the increase in temperature has a direct effect on evapotranspiration and consequently on the irrigation requirements of the crop, which will also depend on changes in precipitation.

In turn, the change in the variables, added to other anthropic activities expressed in terms of water demand, can exert significant pressure on the water resource. This could represent an increase in the vulnerability to shortages and unsatisfied demands, generating a risk associated with food security and water use for the population in the country. This, in addition to the potential risks associated with the increase in extreme events, that is, floods or droughts, has a direct impact on the inhabitants and their economic activities.

The latter stresses the need to conduct studies with a finer resolution both geographically and temporally in order to determine the potential impacts of climate change more accurately, serving as a tool for decision-makers. Using these tools, it is possible to establish strategies for the proper management of water resources, management plans that take into account future scenarios, as well as the importance of water availability to avoid regional conflicts.

Appendix 1

Changes in temperature and precipitation for the different studies in this chapter.

Site	Baseline		Scenarios	2011–2040		2041–2070		2071–2100		
	$\overline{T}$ (°C)	PCP_y (mm)		ΔT (°C)	ΔPCP_y (%)	ΔT (°C)	ΔPCP_y (%)	ΔT (°C)	ΔPCP_y (%)	
Nilo	26.5	1292	Arithmetic average			1.8	−16	2.3	−14	[11]
			Weighted average					2.7	−25.3	[12]
Uribia	27.3	510.2	HadGem – RCP 4.5			1.7	−2.4			[6]
			GDFL–CM3 - RCP 8.5					3.7	−11	
Sinú	28.2	2212	Had-CM3 - A2	1.3	7.5	2.0	19.7	2.5	30.4	[7]
			Had-CM3- B2	0.9	10.9	1.3	17.4	1.7	25.9	
			CCSRNIES_A21	0.5	−5.9					
			CSIROMK2B_A21	0.7	−2.3					
			CGCM2_A21	0.7	−11.8					
			CGCM2_A22	0.9	−13.3					
			CGCM2_A23	0.8	−11.3					
			HadCM3_A21	1.9	−34.9					
			HadCM3_A22	1.6	−23.8					
			HadCM3_A23	1.4	−14.2					
			HadCM3_A2_SDSM	0.5	−2.3					
Coello	18.8	1520	IPSL-CM5A-LR – RCP 4.5			1.1	−4.3			[13]
			IPSL-CM5A-MR – RCP 4.5			1.2	5.6			
			MIROC 5 – RCP 4.5			1.1	11.9			
			IPSL-CM5A-LR – RCP 8.5			1.4	2.5			
			IPSL-CM5A-MR – RCP 8.5			1.4	23.8			
			MIROC 5 – RCP 8.5			1.1	10.4			

DOI: http://dx.doi.org/10.5772/intechopen.90652

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