Estimation of water supply and demand, using meteorological parameters from 1990 to 2020, in the micro-basin of the Chibunga river - Ecuador

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Article

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ABSTRACT

The objective is to prove the climatological state of the Chibunga River micro-basin through a water balance based on hydro-meteorological information. Historical records of rainfall and temperature were used from 1990 to 2020 (30 years). By processing these data, it was possible to determine the catchment flow of the basin, which is reflected in the water supply, and to calculate the demand for water in the area, using population and endowment data. These two parameters are key to determining the scarcity index in the basin and thus to estimating the amount of water in the area. The meteorological station records were provided by the National Institute of Meteorology and Hydrology.

Statistical and mathematical operations were carried out using the R programming language and ArcGis10x software. The weather patterns of the micro-basin are well defined and did not show temporal changes in any of the calculated parameters, the amounts varied between periods, and therefore the water supply, demand, and scarcity index. From the first to the second period, the scarcity index went from insignificant to moderate, closing the third period also with a moderate index, so that its value between periods was from 8.81 to 16.79%.

KEY-WORDS: water balance, Chibunga micro basin, Ecuador.

INTRODUCTION

Increasing atmospheric concentrations of carbon dioxide and other trace gases are causing climatic changes with important implications for the hydrological balance and water resources. These "greenhouse gases" are expected to alter the equilibrium of the atmosphere, leading to temperature increases and changes in many other climate variables (Iglesias et al., 2005). Recent hydrological research strongly suggests that this so-called "greenhouse effect" will alter the timing and magnitude of runoff and soil moisture, change lake levels, and affect water quality (Vuille, 2013). Such changes increase the potential for environmental and socio-economic dislocations and have important implications for future water resources planning and management.

Hydrological studies determine the quantity and quality of water available (Ahmadi & Moradkhani, 2019), information that in turn can be used as a tool for environmental education (Shammi et al., 2022), function as a basis to support remediation projects, irrigation plans, water purification projects, (Urama & Hodge, 2006). The water catchment of the land is directly related to the climatological behaviour of the area, (Zscheischler., 2020) so the spatial and temporal variability of the various climatic factors in a given territory must be established (Hu et al., 2019).

The absence of hydrological research studies, and the scarce funding for research by governmental authorities and private entities hampers decision making by authorities in integrated water management (Marston et al., 2022).

Ecuador is one of the countries in Latin America in which access to various water sources is poorly managed (Pérez & Arias, 2018), which is why it should be studied. In the province of Chimborazo is the micro-basin of the Chibunga River, stretches for 38 km, runs northwest to southeast and is the main tributary of the Chambo River, which is a tributary of the Pastaza; several studies have determined its low water quality index in its main river. (Mayorga & Carbonel, 2018).

Glaciers supply water resources to over six hundred million people worldwide (Messerli et al., 2004). The tropical Andes are an exemplar of the potential vulnerability nexus of increasing water demand and decreasing glacial coverage (Frenierre & David, 2014).

The Chibunga river basin has scarce and unreliable information on water use and production and basic climatic indices (MAE, 2013).

Previous studies show the perceived changes in precipitation, for example (Perez & Arias, 2018), showed that rainfall from 1990 to 1998 in the sub-basin of the Chambo river varied considerably, the paramo present in the area occupies large areas functioning as an ecosystem that retains large amounts of water (Mendoza et al., 2021), a factor that has been affected by its reduction from 2012 to 2020 equal to 9% of its total area (Pazmiño et al., 2021), Most land use transformations have occurred at lower elevations, in an average range between 3500-5000 m.a.s.l. (Ross et al., 2017) All these factors considerably affect the recharge of the aquifer, knowing that this acquires water to a large extent from the melting of the Chimborazo snowmelt (Chidichimo et al., 2018).

The water balance is a study method that allows determining the hydrological behaviour of a given area based on its climatic patterns (Pandey et al., 2022). Our objective was to estimate the water balance in the micro-basin of the Chibunga river with data obtained from 11 meteorological stations and 30 years of data, to verify the pattern that occurred in that time range.

METHODS

The present research has a quantitative approach because climatic data were obtained for the different variables (precipitation, evapotranspiration, temperature, water supply and demand and scarcity index) necessary to carry out the water balance. It also has a descriptive character since it seeks to refer to the most important climatic characteristics of the micro-basin of the Chibunga River. It is a non-experimental study, as these variables will not be intentionally manipulated, but the phenomenon of interest will be observed in its natural form. Finally, it will be a longitudinal study because it is intended to collect and analyse information over 30 years to demonstrate the changes in climate and water availability in the micro-basin.

STUDY AREA

The Chibunga River micro-basin is located in the province of Chimborazo and is part of the Chambo River sub-basin. The water body contributes part of its flow within the Chambo aquifer, particularly on the southern side, as indicated by (Tenelema, 2017). The surface area of this basin is approximately as follows 522 km^2. The main river has a length of about 24km. According to the National Institute of Meteorology and Hydrology (INAMHI, 2021), the study area has an average temperature between 10 and 14°C, an average altitude of 3600 metres above sea level, the rainy season in the micro-basin is from December to May and the dry season from June to October. According to information provided by the Ministry of Agriculture, Aquaculture and Fisheries (MAGAP, 2020), most of the land in the micro-basin is used for agricultural purposes, with the predominant presence of shrub and herbaceous vegetation, with a mainly sandy soil texture. In general, the study area is affected by moderate water erosion as shown by the research work of (Llamatumbi & Chitalogro, 2021) in which the area is rated with 46.17% erosive damage (see Fig. 1). In the study by (Saberi et al., 2019) the authors present the respective insights obtained with three methods used for the study of the Chimborazo glacier, on the temporal relationship between meltwater, groundwater and discharge. These plots show that, even though hydrochemical conditions vary over the different periods, groundwater samples, which geochemically interact with soil and rocks, consistently contain much higher ion concentrations than meltwater samples.

By means of the DEM of the area, obtained from the US Geological Survey website, using ArcGIS 10x (Reyes Pozo et al., 2020) and HecGeo, the area of interest was delimited, and the hydrological components provided by the program were obtained, in the following order.

- Fil Sinks
- Flow Direction
- Flow Accumulation
- Stream Link
- Stream order
- Stream to Feature
- Feature vertices to points.
- Basin

OBTAINING METEOROLOGICAL DATA

We used 11 meteorological stations with 30 years of each, from 1990 to 2020 (see Tab. 1) from the official database of the National Institute of Meteorology and Hydrology of Ecuador (INAMHI, 2021).

Table 1 - Weather stations under consideration in study. Source: INAMHI., 2021.

CODE	WEATHER STATION	X	Y	HEIGHT
M030	SAN SIMÓN	723679	9817973	2530
MI33	GUASLAN	760216	9809636	2850
M376	PILAHUIN	752358	9856011	3314
M393	SAN JUAN-CHIMBORAZO	746623	9820099	3220
M395	CEBADAS	762446	9788953	2930
M407	LICTO	767007	9800255	2865
M408	GUANO	764839	9822414	2620
M409	PAN GOR-J.DE VELASCO	735652	9797775	3109
MI036	RIOBAMBA-ESPOCH	757545	9817389	2850
M1069	CALAMACA	742705	9858860	3437
M5186	CAJABANIBA	749091	9810476	3226

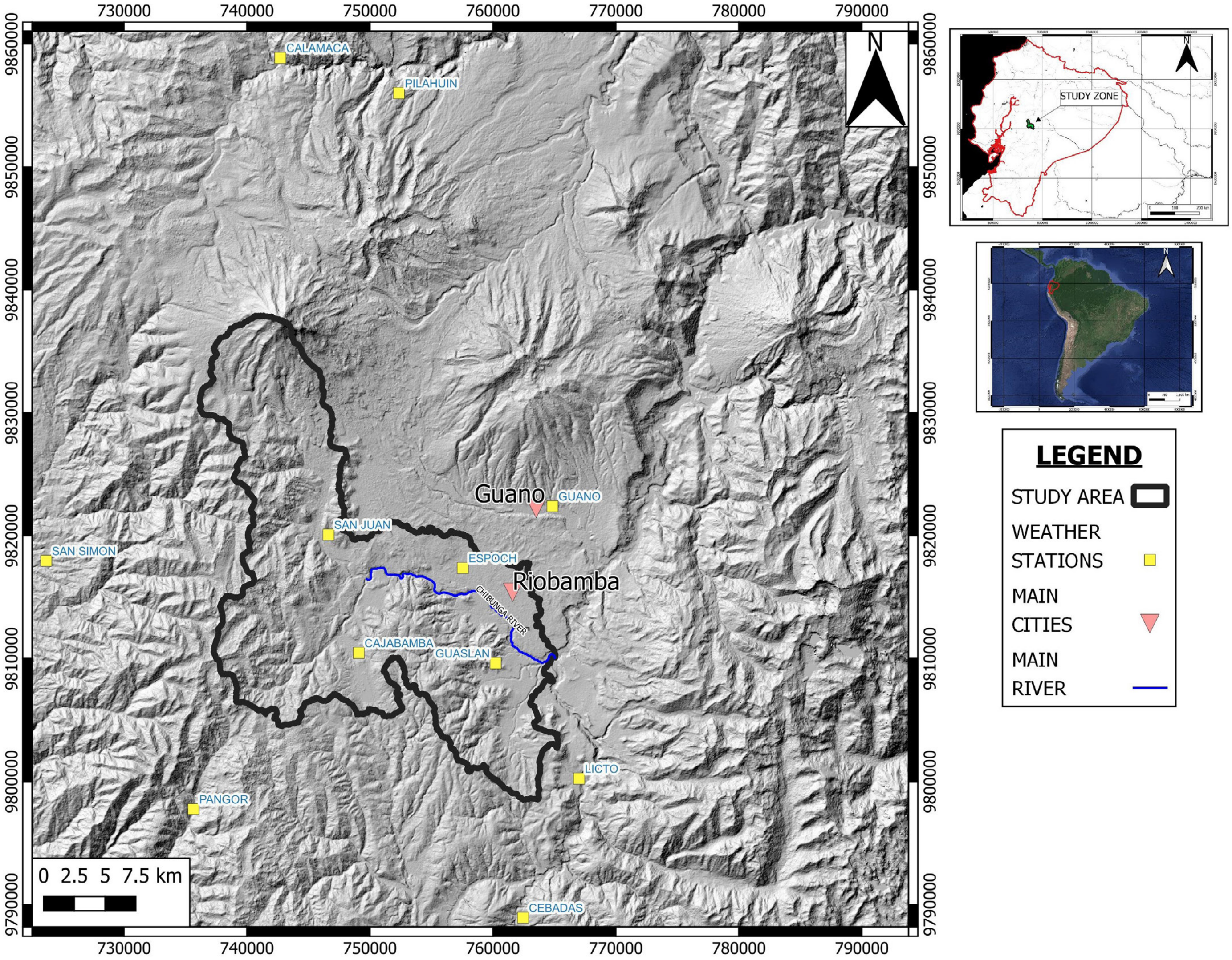

Fig. 1 - Chibunga River micro-basin map.

DETERMINATION OF MISSING RAINFALL DATA

The monthly mean data series had 261 blanks, for the estimation and filling of these blanks, the R statistical package called "Climatol" (Guijarro, 2018) was used to apply this methodology correctly, the data from the 11 stations over 30 years were organised, and the blanks were homogenised and standardised through an exploratory analysis, taking the data from the closest stations as a reference. Missing data were filled in given the rainfall series (Arias-Hidalgo et al., 2011). Finally, they were organised into 3 distinct periods. First period from 1990 to 1999, the second from 2000 to 2009 and the last from 2010 to 2020.

MANN-KENDALL STATISTICAL TESTS

Using Mann-Kendall statistical tests (Gómez-Gómez et al., 2003), the trend of the data series was determined, which operates based on mathematical formulae from the R programming language.

$$S = \sum_{i-1}^{n-1} \sum_{i-1}^{n-1} sgn(xj - xi)$$

$$sgn(xj - xi) = \begin{cases} 1\ if\ xj - xi > 0 \\ 0\ if\ xj - xi = 0 \\ -1\ if\ xj - xi < 0 \end{cases}$$

$$Var(s)Var(s) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} tk(tk - 1(2tk + 5)}{18}$$

$$Z = \frac{S-1}{\sqrt{Var(s)}}\ if\ S > 0, Z = 0\ if\ S = 0$$

$$Z = \frac{S-1}{\sqrt{Var(s)}}\ if\ S < 0$$

DETERMINATION OF AVERAGE TEMPERATURE AND PRECIPITATION OF THE BASIN

The kriging interpolation method was used as the basis for the study (Oñate-Valdivieso et al., 2020), correlating the standardized statistical data with the "Climatol", isotherm and isohyet maps of the study area.

POTENTIAL EVAPOTRANSPIRATION CALCULATION

Due to the limitations of the various meteorological stations in the area, some of the methods for calculating evapotranspiration that involve other climatological variables such as humidity, solar radiation, atmospheric pressure, and wind speed were discarded. The Thornthwaite evapotranspiration method was selected, using the mean temperature and correction factors, which depend on the latitude of the study area (Duque-Sarango et al., 2019).

Using Excel, Arc Gis and PETP V2.0.0 software, evapotranspiration results were calculated and checked, considering the following expressions for the calculation:

Monthly heat index:

$$i = \left(\frac{t}{5}\right)^{1.5}$$

Annual heat index

$$I = \sum i$$

Evapotranspiration uncorrected

$$ETP_{\text{un}\,corrected} = 16\left(\frac{10t}{I}\right)^{a}$$

$$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 0.01792 I + 0.49239$$

Corrected evapotranspiration

$$ETP = ETP_{\text{un}\,corrected}\,\frac{N}{12}\,\frac{d}{30}$$

Where:

t: Monthly average temperature

i: Monthly heat index

I: Annual heat index

a: Thermal constant

N: Daily number of sunshine hours

d: Number of days of the month

ETP: Potential evapotranspiration corrected.

WATER BALANCE CALCULATION

With the processed precipitation and evapotranspiration data, the useful precipitation was obtained.

Subtracting the variables, the field capacity is determined by the soil texture in the area, the water excesses, and deficits of each of the established months mark the rainy and dry seasons in the area, which are the product of the water resulting from the subtraction between precipitation, evapotranspiration and field capacity (Sokolov & Chapman, 1974).

One of the aspects considered for the water balance was the starting month of the hydrological year.

And it was considered the first month of the study range in which the amount of precipitation exceeded the amount of evapotranspiration.

The variations in storage were considered as field capacity, calculated between the month analysed with reference to the previous month. The accumulating water reserves, the useful precipitation was added to the reserves of previous months until the field capacity was reached. At this point the useful water took only positive values, and we will consider equal to 0 only when PE<P. If the useful water value is greater than the field capacity, the surplus water is considered as excess (Romero & Santos, 2018). If there is a deficit, the reserves start to decrease, and the value of useful precipitation will be negative.

Real evapotranspiration (RET) considers the months with water excesses and deficits; when there is no deficit, the value of potential evapotranspiration and real evapotranspiration are equal (Pinos et al., 2020). On the other hand, when there is a water deficit, the precipitation of the month to be analysed is considered by adding the difference between the reserve of the previous month and the reserve of the month studied (Alarcón-Africano & Díaz-Suescún, 2018).

DETERMINATION OF WATER SUPPLY

The water supply is the amount of flowing water determined by the excesses that are calculated in the water balance (Milly, 1994). The sum of the excess water is multiplied by the area of the basin and the net value of the water supply is obtained, (Dieter, 2018), however, reduction factors must be applied, considering the ecological flow that is specified in the Ecuadorian national environmental legislation and the water quality index (WQI) that the basin has (Vimos et al., 2016).

It is for this reason that the quality index determined by (Mayorga & Carbonel, 2018) was considered and the percentage reduction of WQI was obtained from the work carried out by (Corponariño, 2009) (See Tab. 2).

Table 2 - Reducing water supply according to quality. Source: Corponariño, 2009.

WQI		Reduction	Water scarcity	Severity of scarcity
			<1%	None
GOOD	100-80	0	1-10%	Low
MEDIUM	≤80	10%	10-20%	Moderate
UNSUITABLE	≤50	15%	20-50%	High
VERY UNSUITABLE	≤25	20%	>50%	Severe

DETERMINATION OF WATER DEMAND

The estimation of total water demand is based on population density and population consumption volumes (Dieter, 2018). (See Tab. 3) for which the records held by the National Institute of Statistics and Census (INEC, 2002) were used as a reference to determine the population of the study area.

Using the regulations of the National Water Secretariat "CO 10.07 - 601" (SENAGUA, 2015), the average water endowment for the area was obtained, with an approximate consumption flow of the basin for the different time periods studied. Finally, the scarcity index was also determined, knowing that it is the product of the quotient between demand and supply (Fries et al., 2020) expressed as a percentage using the references in Tab. 3.

Table 3 - Recommended supply. Source: Standards for the Study of Drinking Water Supply and Wastewater Disposal Systems for Populations of Over 1000 Inhabitants, 2015.

Population	Weather	Water supply (L.hab/day)
< 5000	Cold	120-150
	Mild	130-160
	Warm	170-200
5000 - 50000	Cold	180-200
	Mild	190-200
	Warm	200-230
> 50000	Cold	200
	Mild	220
	Warm	230

Table 4 - Mann-Kendall test for precipitation and temperature for each meteorological station considered.

PRECIPITATION		
STATION	**p-value**	**tau**
M030	0.617	0.0174
MI33	0.2512	0.039
M376	0.095	0.057
M393	0.8412	0.00693
M395	0.011	0.088
M407	0.0083	-0.091
M408	0.9063	-0.0041
M409	2.17E-07	-0.1802
M1036	0.5316	0.0217
M1069	0.2363	0.041
TEMPERATURE		
STATION	**p-value**	**tau**
M133	0.1729	0.0483
M393	0.067	-0.064
M408	0.039	0.072
M1036	0.531	0.021
M1069	0.474	0.025
M5186	0.061	0.065

RESULTS

The data obtained were analysed by statistical tests and do not show an increasing or decreasing trend, which favoured the use of the kriging interpolation model that requires stationary data.

For the hydrometeorological parameters in the first period the temperature of the basin reached its highest point in the months of September and October, with 13.4 and 13.6 °C respectively, the lowest temperature was in the month of July with a value of 12.6 °C. (Fig. 4-A1).

Rainfall peaked in the months of March and April with 110.9 and 111.7 mm, being the wettest months within the period, the months of August and September recorded less rainfall with 31.6 and 41.8 mm respectively. (See Fig. 4-B1).

Evapotranspiration correlates with temperature, reaching its highest value in October with 58.7 mm and its lowest point in February with 49.4 mm (see Fig. 4-C1).

During the second period, the average temperature of the area did not vary significantly, however, its highest point was in the month of October with 14.2 °C, somewhat higher than in the previous period, as was the lowest point which was 13.1 °C, with an overall increase of 3.05% over the previous period. (See Fig. 4-A2).

In terms of rainfall the wettest months were March and April following the climatic pattern of the area, however, the amounts

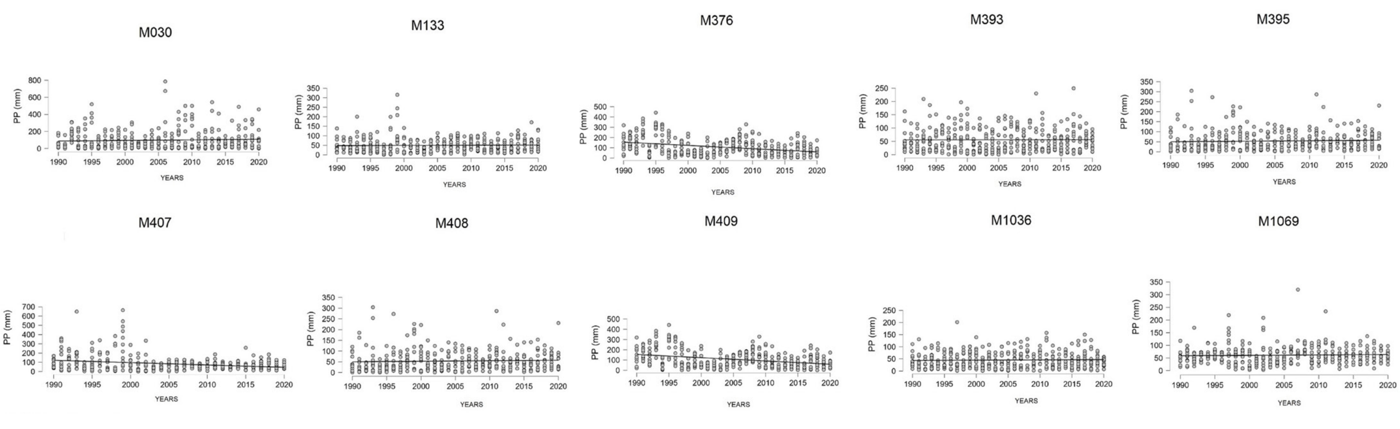

Fig. 2 - Precipitation trend test.

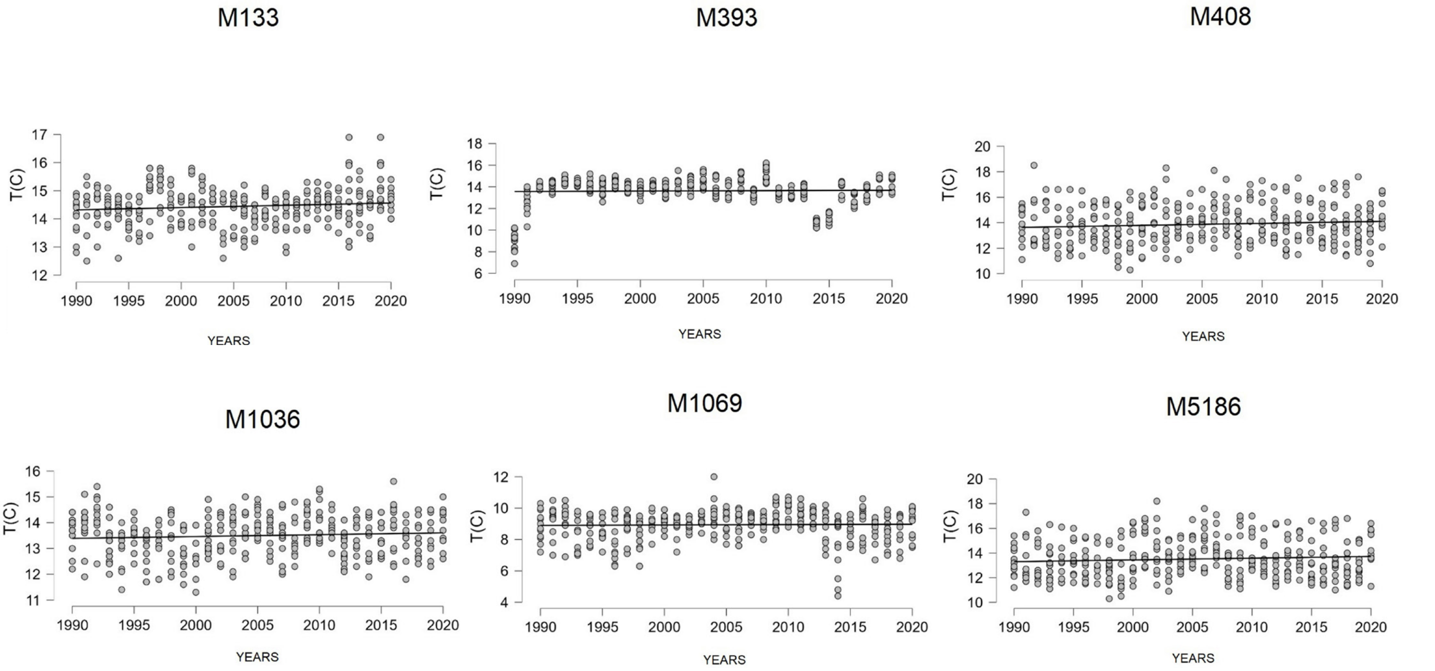

Fig. 3 - Temperature trend test.

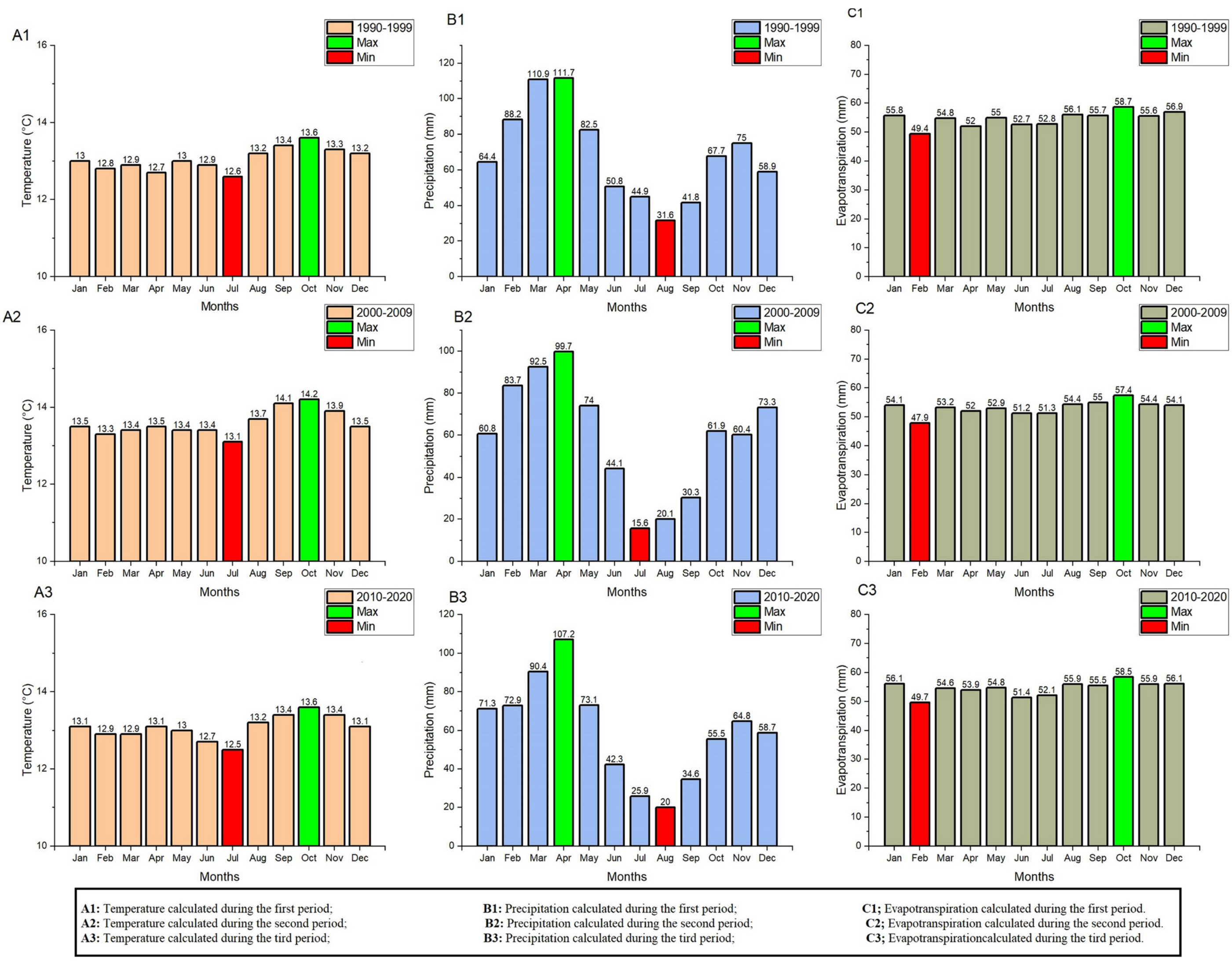

Fig. 4 - Hydrometeorological parameters of 30 years of study.

have decreased compared to the last period with 92.5 mm and 99.7 mm respectively. The months with the lowest rainfall continue to be July and August with a significant decrease in rainfall of 15.6 mm and 20.1 mm respectively. (See Fig. 4-B2).

Evapotranspiration follows the same climatic pattern as in the previous period, reaching its peak in October with 57.4 mm and its lowest point in February with 47.9 mm, a value that indicates a decrease in atmospheric humidity around 2.51% (See Fig. 4-C2).

As for the third period, the temperature of the area had a maximum of 13.6 °C in October and a minimum of 12.5 °C in July, with an overall reduction of 3.05% compared to the second period and presenting a similar pattern to the first period (See Fig. 4-A3).

The wettest month for precipitation was April with 107.2 mm and the driest months were July and August with 25.9 and 20 mm respectively, rainfall patterns have not changed and have increased compared to the previous period (See Fig. 4-B3).

Evapotranspiration follows the same pattern as in the previous 2 periods, peaking in October with 58.5 mm and reaching its lowest point in February with 49.7 mm (see Fig. 4-C3).

WATER BALANCE RESULTS

For the calculation of the water balance for the three periods, the beginning of the hydrological year in January was considered and the corresponding calculation expressions for inflows, outflows and water storage were applied. Thus, for the first period we obtained the value of inflows equal to 828.40 mm, outflows of 655.50 mm and water storage of 153.90 mm. There was a water surplus in the months of February to May and in November and December, with 184.10 mm and a dry period in August and September with a water deficit of 29.70 mm (Tab. 5).

For the second period the inflows were equal to 716.40 mm, decreasing by 13.52% compared to the previous period, outflows equal to 637.90 mm decreasing by 2.68% compared to the first balance, and water reserves equal to 125.40 mm decreasing by 13.6% compared to the first period. (Tab. 5).

Total inflows in the third period amounted to 716.70 mm, decreasing by 13.48 % compared to the first period and increasing by 0.04 % compared to the second period. Outflows totalled 654.50 mm decreasing by 0.15% compared to the first period and increasing by 2.54% compared to the second period. The water reserves registered a total of 117.60 mm presenting a reduction of 20.66% compared to the first period and 4.25% compared to the second, the excesses totalled 127.3 mm decreasing by 45.63% compared to the first period and 10.41% compared to the second. There was a 51.76% increase in the water deficit compared to the first period and a 10.85% reduction compared to the second period. (Tab. 5).

Table 5 - Calculate water balance for each period.

Water elements	Water Balance (1990-1999)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	64.40	88.20	110.90	111.70	82.50	50.80	44.90	31.60	41.80	67.70	75.00	58.90	828.40
PE	55.80	49.40	54.80	52.00	55.00	52.70	52.80	56.10	55.70	58.70	55.60	56.90	655.50
P-PE	8.60	38.80	56.10	59.70	27.50	-1.90	-7.90	-24.50	-13.90	9.00	19.40	2.00	
ST	8.60	18.5	18.5	18.5	18.5	16.6	8.7	0	0	9.00	18.50	18.50	153.90
Δ ST	8.60	9.9	0	0	0	-1.90	-7.90	-8.7	0	9.00	9.50	2.00	
S	0	28.90	56.10	59.70	27.50	0	0	0	0	0	9.90	2.00	184.10
D	0	0	0	0	0	0	0	-15.80	-13.90	0	0	0	-29.70
AE	55.80	49.40	54.80	52.00	55.00	52.70	52.80	40.30	41.80	58.70	55.60	56.90	625.80
Water elemens	Water balance (2000-2009)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	60.80	83.70	92.50	99.70	74.00	44.10	15.60	20.10	30.30	61.90	60.40	73.30	716.40
PE	54.10	47.90	53.20	52.00	52.90	51.20	51.30	54.40	55.00	57.40	54.40	54.10	637.90
P-PE	6.70	35.80	39.30	47.70	21.10	-7.10	-35.70	-34.30	-24.70	4.50	6.00	19.20	
ST	6.50	18.50	18.50	18.50	18.50	11.40	0	0	0	4.50	10.50	18.50	125.40
Δ ST	6.50	12.00	0	0	0	-7.10	-11.40	0	0	4.50	6.00	8.00	
S	0	23.80	39.30	47.70	21.10	0	0	0	0	0	0.00	11.20	143.30
D	0	0	0	0	0		-24.30	-34.30	-24.70	0	0	0	-83.30
AE	54.10	47.90	53.20	52.00	52.90	51.20	27.00	20.10	30.30	57.40	54.40	54.10	554.60
Water elements	Water balance (2010-2020)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	71.30	72.90	90.40	107.20	73.10	42.30	25.90	20.00	34.60	55.50	64.80	58.70	716.70
PE	56.10	49.70	54.60	53.90	54.80	51.40	52.10	55.90	55.50	58.50	55.90	56.10	654.50
P-PE	15.20	23.20	35.80	53.30	18.30	-9.10	-26.20	-35.90	-20.90	-3.00	8.90	2.60	
ST	15.20	18.5	18.5	18.5	18.5	9.40	0	0	0	0	8.90	11.50	119.00
Δ ST	15.20	3.30	0	0	0	-9.10	-9.40	0	0	0	8.90	2.60	
S	0	19.90	35.80	53.30	18.30	0	0	0	0	0	0	0	127.30
D	0	0	0	0	0	0	-16.80	-35.90	-20.90	-3.00	0	0	-76.60
AE	56.10	49.70	54.60	53.90	54.80	51.40	35.30	20.00	34.60	55.50	55.90	56.10	577.90

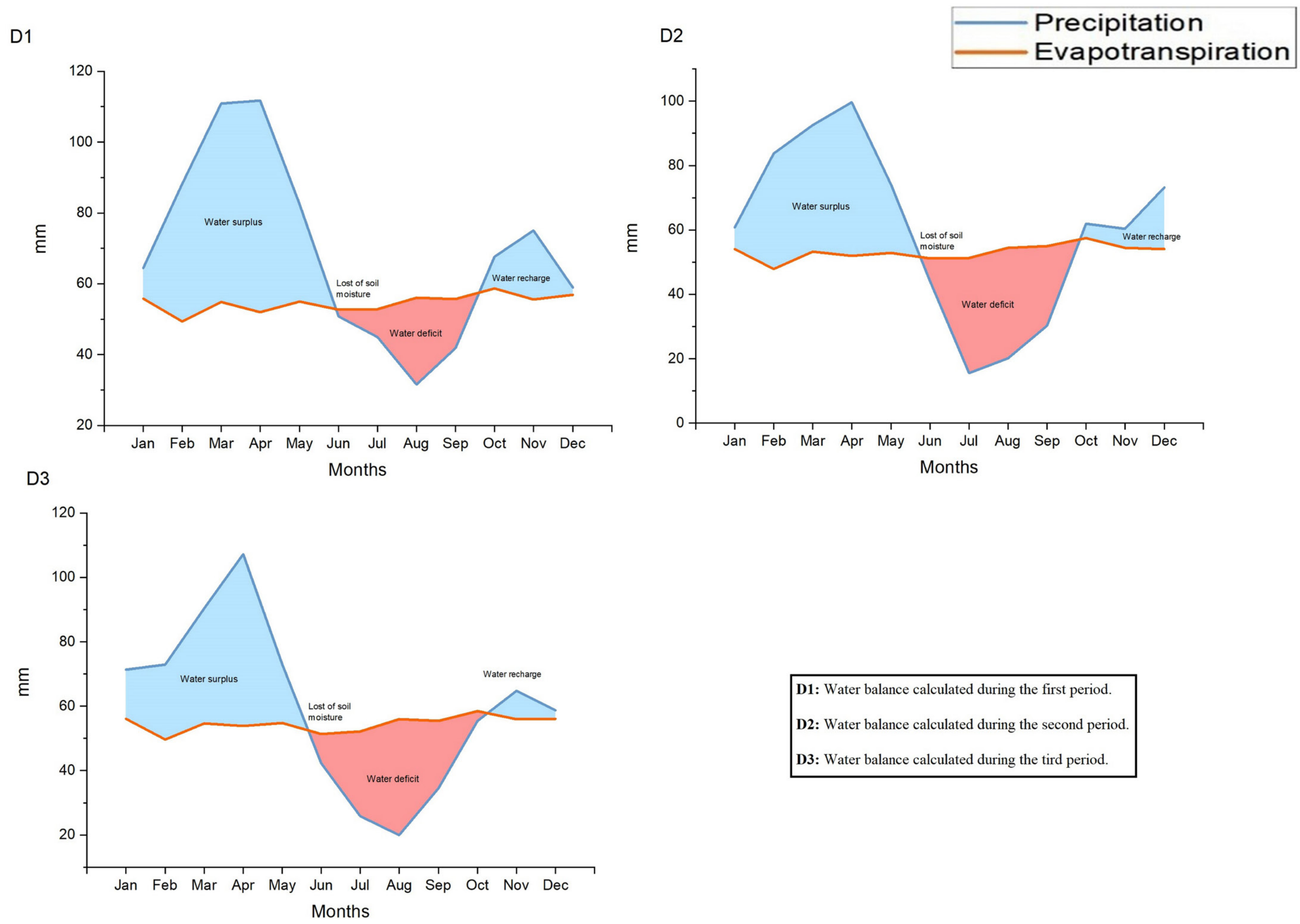

Fig. 5 - Graphical water balance for each period studied.

RESULTS OF THE SCARCITY INDEX FOR THE MICRO-BASIN

During the first period the sum of the excesses was 184.10 mm with a total water supply of 77.04 Mm^3 (Mega-Cubic Meters), subtracting the ecological flow of 7.70 Mm^3 and 9.49 Mm^3 for water quality, a net water supply of 57.78 Mm^3 was obtained. In contrast, the second period had an excess of 143.30 mm, giving a total water supply of 59.97 Mm^3, with an ecological flow of 5.99 Mm^3 and water quality of 5.12 Mm^3. Obtaining a net water supply of 44.98 Mm^3, with a reduction of 24.17% compared to the previous period.

In the third period the sum of the excesses was 127.30 mm, resulting in a total water supply of 53.27 Mm^3, reducing by 5.32 Mm^3 due to ecological flow and 7.99 Mm^3 due to water quality. A net water supply of 39.95 Mm^3 was obtained, a reduction of 31.34% compared to the first period and 9.45% compared to the second period (See Fig. 6 -E1).

In the first period, with the information from INEC (2002) a population of 60658 inhabitants was calculated in the area, with a base supply of 230 (Litres * inhabit/day) an approximate demand of 5.09 Mm^3 was obtained. Calculating a scarcity index of 8.86%, this means that the pressure of demand on supply is very low, classifying it as Low.

For the second period the approximate population was 69537 inhabitants, calculating with the endowment an approximate water demand of 5.84 Mm^3 was obtained, increasing by 14.73% compared to the previous period.

The scarcity index of the micro-basin is 12.98%, classified as moderate, which means that for this period the water demand is low.

Table 6 - Chibunga micro-basin water balance.

WATER BALANCE/PERIOD			
PARAMETERS	1990-1999	2000-2009	2010-2020
Inputs (mm)	828.4	716.4	716.7
Outputs (mm)	655.5	637.9	654.5
Basin surface (Km²)	522		
Total water supply (Mm³)	77.04	59.97	53.27
Ecological flow reduction (Mm³)	7.7	6	5.33
Water quality reduction (Mm³)	9.49	5.12	7.99
Net water supply (Mm³)	57.78	44.98	39.95
Population (inhabitants)	60658	69537	79909
Water demand (Mm³)	5.09	5.84	6.71
Water scarcity index (%)	8.81	12.98	16.79

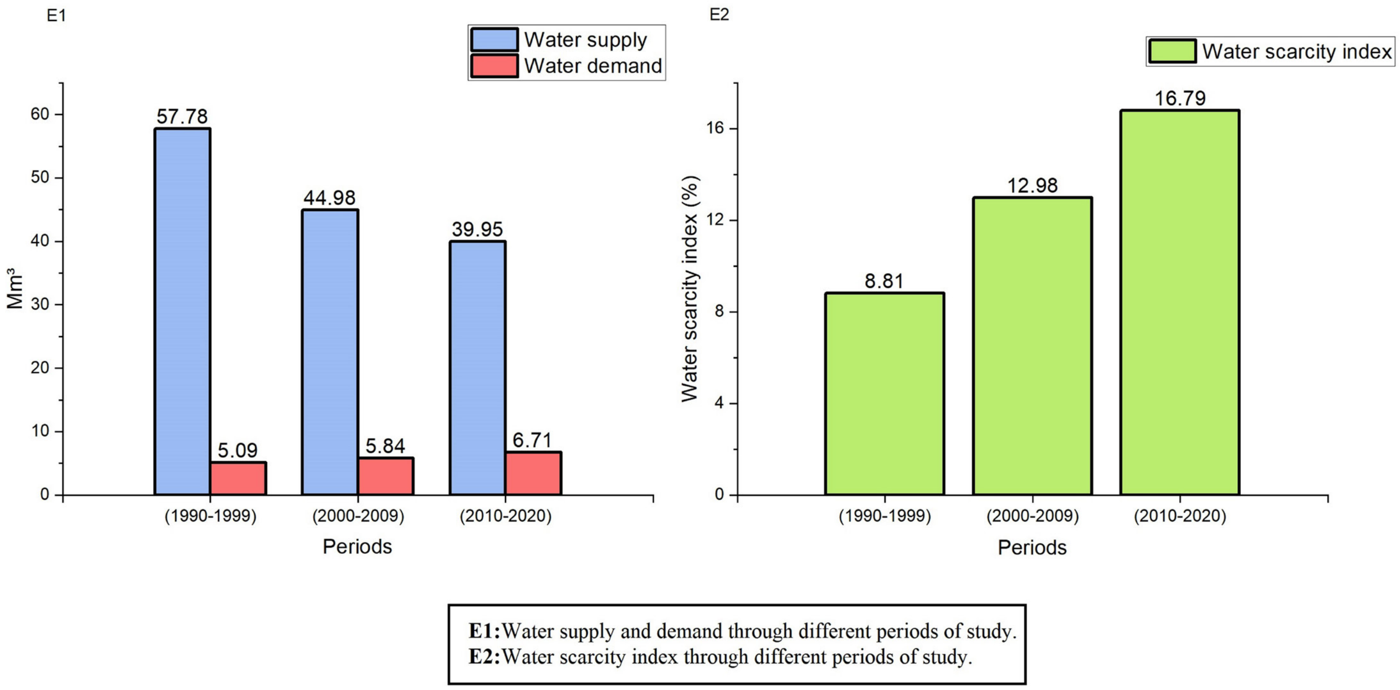

Fig. 6 - Graphical representation of the water availability obtained.

The 79909 inhabitants calculated in the third period determined a water demand of 6.71 Mm^3 increasing by 31.83% compared to the first period and 14.9% compared to the second period.

When calculating the scarcity index, a value of 16.79% was obtained, almost doubling with respect to the first period, being tendentially higher than the second, being classified as a moderate index, which means that water demand exerts a low pressure with respect to supply (See Fig. 6-E2).

DISCUSSION

The micro-basin of the Chibunga River has a well-defined climatology, which although it has not undergone significant changes in seasonality over the years, the months with the highest rainfall are April and March, the amount of rainfall has changed over time, which can be seen in the inflows and outflows of water, where the main water surpluses occur from February to May. The water balance conducted by (Duque-Sarango & Hernández, 2020) in the "Guarango" river in the Ecuadorian highlands has similar conditions to the one carried out in this study. It is evident that in the month of March there is more precipitation than in the other months, likewise April and May are among the months with the highest precipitation, followed by March. The same study indicates that the months of January, March, April, and May show important values of water surplus.

Climatology is of vital importance in the determination of the water balance since, according to the spatial distribution of the study areas, diametrically different results can be obtained, as was done by (Neira et al., 2009) when analysing rainfall in the basins of the Chone and Portoviejo rivers, which are located at 17 m above sea level with an average temperature ranging from 22 to 28°C and whose maximum rainfall reaches a total value of 500 mm. In contrast to the data obtained in this study, which is located at 3600 m above sea level, with a temperature of 10 to 14°C and whose maximum precipitation reaches a total value ranging from 700 to 800 mm.

Using national meteorological data and the application of statistical modelling and information normalization, parameters that infer climate behaviour in the Chibunga River micro-basin could be obtained. (Gebrechorkos et al., 2019) applies a statistical downscaling model to generate a high-resolution climate projection, equivalent to future station data, with the aim of driving impact assessment models in selected agricultural catchments in Ethiopia. The observed large-scale climate variables (parameters) are obtained from the Ethiopian national meteorological agency and international databases.

The Thornthwaite method was applied for the estimation of potential evapotranspiration due to limited hydrometeorological information from the stations obtaining evapotranspiration results using a minimum of available data on both climate and terrain in the study area (Costa & Foley, 1997; Bruno et al., 2007) takes into account climatological water balances based on the estimation of evapotranspiration using the Thornthwaite and Penman-Monteith methods. Their study concluded that the climatological methods underestimated actual evapotranspiration and soil water storage changes, with Penman-Monteith performing better and Thornthwaite's method more efficient in terms of data collection.

The temporal distribution of the input data is also of vital importance for an effective water balance as shown by (Tapia-Silva, 2014) where the generalities of obtaining hydrometeorological data were established, specifically precipitation, since it is normally the only source of moisture in the soil, this information must always be from large periods of time, the data must be normalized and the way to calculate the precipitation of specific areas with the greatest possible accuracy is by means of the kriging or spline method. For this study we worked with information covering 30 years of records, and the average precipitation was also determined using the normalized geostatistical kriging method.

Molden & Sakthivadivel (1999) demonstrate a methodology for accounting for the uses and productivity of water resources in which they classify the outputs of the water balance into various categories providing information on the scarcity of water due to its various uses and the water supply available for downstream uses. The methodology is applicable at different levels of analysis ranging from micro to macro level.

In the report (MAGAP & INAMHI, 2012), the results of the water deficit of the canton of Chambo were cited by means of the water balance of 2 climatological stations. For the calculation of the necessary parameters, monthly data from a series of 25 years were used, the results for the entire canton with water deficit values ranging from 10 to 100 mm throughout the territory. On the other hand, in this study, using a base of 10 stations with data from a 30-year period, a deficit ranging from 30 to 80 mm over the established period was obtained.

(Crespo et al., 2010) analyse the anthropic activities that take place in the basins that have the paramo ecosystem, these are related to agricultural and livestock production, they determined the variations in water supply and demand. This study used hydrological modelling tools demonstrating that there are changes in land use increasing its water vulnerability. A similar problem was observed in the Chibunga River micro-basin. Agricultural activities and the presence of pollutants and surfactants in the river have reduced the quality and availability of the resource (Mayorga & Carbonel, 2018).

In general terms, we see that the water demand presented in the micro-basin is low in relation to the supply that can be found in the area, as confirmed by the study of (Cevallos Gaibor, 2020) which for 2016 obtained a blue water footprint of the city of Riobamba equal to 3,599,905 m^3, which is quite low for the supply that is found according to Emapar. Procel 2018 studied the lower zone of the Chambo sub-basin and suggests low water deficits, in relation to the supply, reinforcing the results of the variables obtained in this study. (Espinosa & Rivera, 2016) studied the influence of land use change on the volume of water, determining that the amount of high runoff compared to the average annual volume of water to meet the demands, produces a deficit in the water supply of the city of Riobamba.

(Ilbay-Yupa et al., 2021) Using the monthly normalized precipitation index (SPI), the impact of climate change was assessed for wet events and droughts from a meteorological perspective by projecting changes in the flow of the Daule River. On average, an increase in temperature (~2 °C) and precipitation (~6%) is expected. A 7 % increase in precipitation would result in a 10 % increase in flow during flood periods, while an 8 % decrease in precipitation could result in a flow reduction of approximately 60 % during dry periods. This helps to corroborate the results of this study as on average temperature has undergone a 3% increase, precipitation a decrease of approximately 13.5% over a 30-year period.

The water balance obtained serves to know the current situation of the micro-basin through historical data and records, estimating the different periods of drought and rainfall. On the other hand (Zambrano Navarrete et al., 2021) using the water balance estimated with intensity duration frequency curves (IDF) can predict hydrological events in a study area by means of a storm design and various terrain parameters. In addition, flood zones in each area can be modelled.

The results obtained in general constitute a valuable tool for specialists of governmental and non-governmental institutions in charge of the control, planning and development of water resources in any region (Campos Cedeno et al., 2019).

CONCLUSIONS

The state of the soil, with a high erosion potential, and the high slopes mean that the infiltration capacity is limited. The rainfall, temperature and evapotranspiration patterns do not show any significant changes in their temporal distribution, with the wettest months from March to May and the driest months from July to September, but the amounts vary, with water surplus decreasing by 22.18% from the first to the second period and by 11.17% from the second to the third. Similarly, the deficit increased by 64.35% from the first to the second period and decreased by 8.04% from the second to the third. The water supply and demand of the basin during the different periods identified, showed variations in quantity, but not in lack of local supply, showing the flow available for the area in question. The population has increased by about 15% in each period, this aspect influences the water demand, with 4.43 Mm^3 in the first period, increasing by 14.67% in the second with 5.08 Mm^3 and 14.76% in the third with 5.83 Mm^3. The scarcity index was not significant in the first period with 8.81%, it increased in the second period with 12.98%, being classified as moderate, and in the third period the scarcity index increased a little more with 16.79%, maintaining its classification. This means that the pressure of water demand on supply has gone from being insignificant to being classified as low over a period of 30 years.

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