Supply–Demand of Water Resource of a Basin With High Anthropic Pressure: Case Study Quenane-Quenanito Basin in Colombia

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ABSTRACT: Water scarcity has increased in the last century due to the effects of climate change and the over-exploitation of anthropic activities that deteriorate strategic ecosystems in watersheds. This study quantified the water consumption of anthropic activities according to the water footprint (WF) and the water supply available (WSA) using the GR2M hydrological simulation model in the Quenane-Quenanito basin in Colombia. The objective of this study was to analyze the dynamic supply–demand of water and identify potential conflicts associated with the use of water. The results of this study show that the WF of the basin was 17.01 million m^3/year, 79.97% of which was the green WF and 20.03% of which was the blue WF, and that the WSA of the basin was 272.1 million m^3/year. In addition, potential conflicts over the use of water were identified due to water scarcity in 11 sub-basins during the months of January to March. In conclusion, analyzing the demand and supply of water in basins and taking into account their spatiotemporal distribution allows us to measure the impacts of anthropic activities on water resources, which can prevent potential conflicts associated with the use of water between sectors or the involvement of ecological dynamics.

KEYWORDS: Water footprint, water deficit, water supply, anthropic activities

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Introduction

Water is fundamental to human activities in hydrographic basins.[1,2] However, in the last decade, the availability of water in some territories has been reduced[3,4] due to disorganized demographic increases and activities related to economic development, which lead to over-exploitation of surface water and groundwater resources.[5,6] For the scientific community, the landscape is a hindrance, keeping in mind that the water crisis will result in an intensification in water scarcity, pollution, and waste in the next 50 years.[7,8] In addition, water scarcity is caused by climate change, the loss of vegetal coverage, and inappropriate land use.[9,10] Excessive consumption of water is generated by the demands of an increasing population and its respective processes of industrialization.[11,12] This stage of scarcity is reflected in the decrease per capita of water, which is evidence for an increase of 18% in demand by 2050.[13,14] Colombia is a country with water wealth and is considered the nation with the sixth highest renewable water resources.[15] Nevertheless, the available quantity of water is affected by urban expansion and increases in agricultural production that generate higher pressure on surface water and groundwater resources.[16-18] For this reason, indicators related to water impact that enable the consumption and pollution of water resources are required[19,20] to achieve conservation in strategic ecosystems, without compromising heterogeneous water interests from sector in the hydrographic basins.[21,22]

In this context, the water footprint (WF) is an indicator that enables the water consumption from a process in a specific place and time to be quantified[23,24] to determine the impact on freshwater caused by the use of the water resource in anthropic activities from a territory.[25] The Water Footprint Network (WFN) approach is an important methodology because it analyzes the dynamics of water from a water resource management approach[26] and differentiates 3 uses of water: blue, green, and gray. The first corresponds to the water that is consumed from the extraction of surface or underground water sources; the second refers to the rainwater that is used and does not run off or infiltrate soil and is mainly for agricultural use. These 2 uses quantify the impact on water of its quantity,[27] and the third, the gray WF, refers to quality, that is, the volume of freshwater required to dilute a polluting load of a spill to the quality standards of the water rules according to environmental regulations.[28] Likewise, this methodology prioritizes the evaluation of fresh water regarding its sustainable use and equitable allocation, considering ecological flows and the variability over time from local and global contexts as a product, consumption pattern, or geographical approach.[29] In addition, the gray WF has played an important role in raising awareness about water problems in the last decade due to the analysis of the sustainability of the WF, which has enabled estimates of local impacts on natural, social, and economic dynamics.[30]

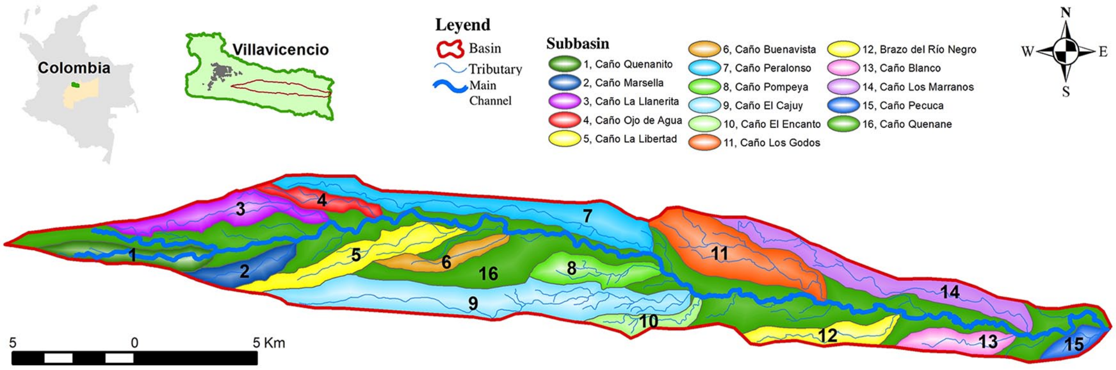

Figure 1. Geographical location of the study area, the map shows the 16 sub-basins analyzed.

To evaluate the sustainability of the WF at the basin level to establish a water balance, the volume of water consumed in anthropic activities (WF) should be compared with the water supply available (WSA) in the territory.[31,32] In this manner, to estimate the WSA, tools can be used to create models of hydrological simulations in basins to estimate the minimum and maximum flow rates, keeping in mind the ecological flow rates required by the strategic ecosystems for water production,[33,34] and later to estimate the pressure of socioeconomic activities on ecosystems with the appearance of water deficit scenarios in the function of supply and water demand from the territory through the application of indexes such as water scarcity.[20] These tools generate relevant information to make adequate decisions about water management and to foresee environmental conflicts.[35,36]

In this sense, this study has the following objectives: (1) to identify the spatiotemporal variations of water consumption in agricultural production and domestic and industrial activities in the Quenane-Quenanito basin through the indicator of the WF, (2) to estimate the water balance in the basin through a supply–demand analysis, and (3) to identify potential conflicts associated with the use of water. This study was performed in the Quenane-Quenanito basin, a basin with stationary mono-modal river behavior. Fundamental information was generated so that decision makers can generate management processes from the water resources at the hydrographical basin level.

Materials and Methods

Area of study

The Quenane-Quenanito basin is located in the borough of Villavicencio in east central Colombia. The length of its main channel is 52.6 km, and its area is 166 km^2, representing 12.4% of the borough, with temperatures that vary between 19.6°C and 33.5°C, an average precipitation of 2500 to 4000 mm/year, atmospheric humidity of 80%, and evapotranspiration of 1400 to 1250 mm/year. In addition, this basin experiences a high pressure of agricultural production with periods of strong runoff from December to March.[37] These peculiarities and the intermittent character of the current flow regime are characteristic of the Meta department. Therefore, the integrated analytic framework developed in this study could be replicated in other basins and therefore constitutes a useful guide to better evaluate the sustainability of agricultural production, domestic and industrial uses, and superficial water sources. In this study, the Quenane-Quenanito basin was divided into 16 sub-basins through the application of the digital model of elevation of curves to a level of 30 m SRTM (Shuttle Radar Topographic Mission), which is suitable to model the terrain of earth very accurately (Figure 1).[38]

Data collection

Secondary information about the inhabitants, hydroclimatic data, water concession, shedding permissions, and cultivated areas were taken from CORMACARENA, the entity that manages the natural resources in the region; the IDEAM, which is responsible for collecting meteorological information from scientists who work with the environment; and the DANE, which is the entity charged with planning, lifting, processing, analyzing, and sharing the official statistics of the country. In addition, the data were validated with the generation of primary information by means of observation tours in the study area and the application of interviews with the community, agricultural producers, and managers of the business management of the industries. Agricultural production was identified in 11 sub-basins with an area of 23.48 km^2 for oil palm, rubber, citrus, mango, soybean, dry rice, irrigated rice, corn, plantain, cassava, and other permanent shrub crops. For the domestic sector, 10 sub-basins had a population of 4663 inhabitants with a net water supply of 150 L/day. Finally, for industrial production, 13 companies related to the food, hydrocarbon, transportation, and gas industries were identified in 4 sub-basins.

Quantification of the water footprint (basin water footprint)

Quantification was performed according to the "The Water Footprint Assessment Manual."[39] In this study, the amounts of water associated with domestic use and industrial and agricultural production were quantified and taken as the blue WF and the Green WF in the Quenane-Quenanito basin following equations (1) and (2), respectively

$$WF_{Basin} = \sum WF_{Subbasin} \quad (1)$$

$$WF_{Subbasin} = \sum WF_{Domestic} + \sum WF_{Industrial} + \sum WF_{Agricultural} \quad (2)$$

Agricultural water footprint

This step used the coverage and use of the soil in the basin as determined by evaluation of satellite images from the Rapid Eye sensor, which has a space resolution of 5 m; the ENVI 5.0 software; and the Corine Land Cover methodology for Colombia to describe, characterize, classify, and compare the characteristics of land coverage with a scale of 1:25.000. The agricultural WF was estimated according to equations (3) and (4)

$$WF_{Agricultural} = \sum WF_{Blue} + \sum WF_{Green} \quad (3)$$

$$\begin{aligned} WF_{Agricultural} &= \sum CWR_{Crop} \times CA \\ &= \left(\sum CWR_{Green} + \sum CWR_{Blue}\right) CA \end{aligned} \quad (4)$$

where CWR_{Crop} is the request for blue and green water for cultivation (irrigation or precipitation) expressed in (m^3/he) and *CA* is the sown area in agricultural cultivation in every sub-basin (he). The *CWR* is calculated through equation (5).

$$CWR_{Crop} = \sum K_c \times ET_0 \quad (5)$$

where K_c is the coefficient of evapotranspiration from the referenced cultivation in Allen et al[40] and evapotranspiration (ET_0) is calculated using the Penman–Monteith model (equation (6))

$$ET_0 = \left(\frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \right) \quad (6)$$

where ET_0 = reference evapotranspiration (mm/dia); R_n = beta radiation on the surface of the crop (MJ/m^2/dia); R_a = extraterrestrial radiation (mm/dia); G = soil heat flow (MJ/m^2/dia); T = average air temperature at 2 m high (°C); u_2 = wind speed at 2 m high (m/s); e_s = saturation vapor pressure (kPa); e_a = real vapor pressure (kPa); $e_s - e_a$ = vapor pressure deficit (kPa); Δ = slope of the vapor pressure curve (kPa/°C); γ = Psychrometric constant (kPa/°C).

To differentiate the blue *CWR* and the green *CWR*, the blue *CWR* calculation was taken as the difference between the cultivation *CWR* and the effective precipitation (equation (5)). A negative value is equivalent to the cultivation not requiring blue water and the ability to meet the water requirements with green water (equations (7) and (8))

$$CWR_{Green} = \sum Min\left(CWR, P_{Effective}\right) \quad (7)$$

$$CWR_{Blue} = \sum CWR - CWR_{Green} \quad (8)$$

where the effective rainfall ($P_{effective}$) was calculated based on the total rainfall using the United States Department of Agriculture (USDA) SCS method of the Soil Conservation Service of the USDA. This method is incorporated into CROPWAT 8.0.[41] A series of 30-year rainfall data were taken from the Vanguardia weather station (73°37′13.8″ W-4º9′48.4″ N).

Water footprint of domestic consumption (domestic water footprint)

To determine the number of inhabitants, updated cadastral information of the city and the sub-basin layer were used to identify the number of properties in each of the units of the study, and based on this information, the number of inhabitants per sub-basin was established in the DANE,[42] in which it is established that for the populated and rural dispersed centers, the average number of people per household is 3.52. Taking into account that the population of this area does not have an aqueduct service and thus there are no systems for measuring the volume of water consumed per inhabitant or per dwelling, a net provision of water per inhabitant per day of 150 L of water is assumed. According to the provisions of the RAS del MV, Ciudad y Territorio,[43] and considering that the area of the studio does not have a borough aqueduct, there is not a system for measuring the water volume consumed per house. Thus, according to Arango et al,[44] the calculated WF for humans is 10% of the water volume that enters the house (equations (9) and (10))

$$WF_{Domestic} = \sum WF_{Blue} \quad (9)$$

$$WF_{Domestic} = \sum Peo \times NWS \times 10\% \quad (10)$$

where *Peo* is the number of people living in every sub-basin and *NWS* is the net water endowment (person/L/d).

Industrial water footprint

To calculate the industrial WF, the data corresponding to the volume of water concession and the discharge of the company were requested from CORMACARENA, the competent environmental authority. In addition, through interviews with managers, information was collected regarding the number of workers and the water efficiency required to operate equipment. The industrial WF is the difference of the water volume that enters an industrial process and leaves it in shedding form (equations (11) and (12)), and a certain water volume is assumed to evaporate in the process or be incorporated in the product

$$WF_{Industrial} = \sum WF_{Blue} \quad (11)$$

Table 1. Scarcity index based on the supply–demand relationship.[45]

CATEGORY	RANK	DESCRIPTION
Critical	$>50\%$	High demand
Very high	21%–50%	Appreciable demand
High	11%–20%	Low demand
Moderate	1%–10%	Very low demand
Low	$<1\%$	Non-significant demand

$$WF_{Blue} = \sum Vol_{Affluent} - Vol_{Effluent} \tag{12}$$

where $Vol_{Affluent}$ is the total volume of water used by the company and $Vol_{Effluent}$ is the total volume of residual water generated by the company. To complement missing data for the calculation, a revision of environmental guides is performed in every process in the industries, and the primary information is compiled to generate theoretical calculations of the WF in the allowed industries, keeping in mind equation (13)

$$WF_{Blue} = \sum P_R \times C_R + \sum (W \times NWS \times F)10\% \tag{13}$$

where P_R is the quantity of processed raw material; C_R is the water consumption performance of the equipment; NWS is the required water endowment according to the WRS2000,[43] and its complexity level is 4.5 m^3/person/month; F is the labor frequency; and W is the number of workers.

Water supply available

A semidistributed hydrological model called GR2M proposed by Makhlouf and Michel[45] was used to generate a continuous simulation from the historical series of flow rates to a monthly temporary scale in the different sub-basins of the study area, which guaranteed the simulation of the hydrological answer from the basin and its temporary variability; likewise, the pattern enabled the evaluation of changes in the availability of water resources for scenarios in which climatic variability influences the modifications of the rain patterns. The data input to the model correspond to the average monthly series of precipitation and the potential evapotranspiration (calculated through the temperature and solar brightness) per sub-basin of the fluviometric and climatological stations close to the study area. Each variable was preprocessed, which consisted of normality tests and completing missing data to obtain a continuous series for a period of 39 years. Because the study basin does not have capacity stations to provide continuous flow information, calibration and validation of the model were performed based on historical flow information at 2 of the nearby hydrological stations. To validate the parameters of the model, simulated flows at different points of the Quenane-Quenanito pipes were compared with flow data obtained from gaps made in both water sources over several years and at different times of the year to account for conditions of high rainfall and the dry period. This comparison allowed an adjustment to be made in one of the parameters of the model of the range of the simulated values to the range of flow variation observed in the gates. A calibration process was performed with parameter X1 from the model GR2M (the static storage capacity in the ground), which was the most useful parameter because it is complemented with the curve number (CN) parameter. One of the most commonly applied methods to describe this relationship between the direct runoff and storm rainfall depth is the Soil Conservation Service–Curve Number (SCS-CN), developed by the USDA.[46]

Potential conflicts because of water use

Using the water scarcity index (WSI) proposed by the IDEAM,[47] UNESCO, and CAR,[48] a percentage relation between the demand (WF) and water supply (WSA) was determined at the monthly scale in the sub-basins (equation (14))

$$WSI = \sum \left(\frac{WF_{Blue}}{WSA_{Blue}} \right) 100 \tag{14}$$

where WSI is the water scarcity index (%), blue WF is the blue water footprint (m^3/month) and the WSA (m^3/months) is used to categorize the results. This method adopts the proposed parameters in resolution 865 from 2004 by the Ministry of Environment, Living and Territorial Development (Table 1).

To identify critical WSI values, the presence of scenarios ranging from temporary to permanent water scarcity in the sub-basins is assumed, and potential conflicts associated with the use of water between the sectors related to the WF are considered.

Space–time representation

All the WF, WSA, and WSI results were simulated in space and time through mapping, which was performed with ArcGIS 10.1.

Results and Discussion

Table 2 shows the corresponding values of the quantified WF at the sub-basin level in every month of the year. The total yearly WF of the Quenane-Quenanito basin was 17.01 million m^3, which represents 0.006% of the national WF.[49]

Regarding the production dynamics, agricultural accounted for 98.87%, followed by industrial production at 0.98% and domestic use at 0.15%, which is similar to the worldwide productive consumption dynamics.[29] From the total value of the WF, 20.03% corresponds to the blue WF and 78.96% corresponds to the green WF (Figure 2), indicating the water potential from atmospheric water due to the high rainfall in the region.[37]

Table 2. Green and blue WF of the sub-basins of the Quenane-Quenanito basin in Villavicencio, Colombia (m^3/month).

SUB-BASIN	WF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Caño Quenanito	Green	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Blue	42.8	38.6	42.8	41.4	42.8	41.4	42.8	42.8	41.4	42.8	41.4	42.8	503.7
Caño Marsella	Green	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Blue	391.6	353.7	391.6	379.0	391.6	379.0	391.6	391.6	379.0	391.6	379.0	391.6	4610.7
Caño La Llanerita	Green	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Blue	57.7	52.1	57.7	55.8	57.7	55.8	57.7	57.7	55.8	57.7	55.8	57.7	678.9
Caño Ojo de Agua	Green	4024.0	9932.9	18 150.2	40 345.6	53 878.9	34 267.3	21 242.3	24 080.3	10 102.3	30 370.4	13 173.2	5527.7	265 095.0
	Blue	124.4	112.4	124.4	120.4	124.4	120.4	124.4	124.4	120.4	124.4	120.4	124.4	1464.7
Caño La Libertad	Green	5208.2	12 856.0	14 934.4	52 219.1	69 735.1	44 352.0	27 493.8	32 451.5	13 894.4	41 770.7	17 293.0	7154.4	339 362.7
	Blue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caño Buenavista	Green	350.4	865.0	1580.7	3513.6	4692.2	2984.2	1849.9	2097.1	879.8	2644.9	1147.2	481.4	23 086.4
	Blue	48.4	43.7	48.4	46.8	48.4	46.8	48.4	48.4	46.8	48.4	46.8	48.4	569.4
Caño Peralonso	Green	11 600.6	28 635.3	52 325.0	116 311.7	155 326.5	98 788.6	61 239.2	69 420.7	29 123.7	87 554.3	37 976.8	15 935.6	764 238.0
	Blue	15 814.0	13 068.0	14 727.0	13 139.4	14 118.0	12 445.4	12 960.0	13 977.0	12 954.4	12 751.0	13 844.4	13 537.0	163 335.7
Caño Pompeya	Green	15 189.6	37 494.3	68 513.0	152 295.6	203 380.6	129 351.3	80 185.0	90 897.7	38 133.9	114 641.4	49 725.9	20 865.7	1 000 674.1
	Blue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caño El Cajuy	Green	16 470.5	40 656.1	74 290.6	167 134.1	225 385.2	143 346.4	88 860.6	100 066.3	41 835.0	125 768.1	54 063.2	22 625.3	1 100 501.3
	Blue	18 344.5	13 880.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13 272.1	45 496.6
Caño El Encanto	Green	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(Continued)

Table 2. (Continued)

SUB-BASIN	WF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
	Blue	399.4	360.8	399.4	386.6	399.4	386.6	399.4	399.4	386.6	399.4	386.6	399.4	4703.0
Caño Los Godos	Green	0.0	0.0	0.0	251 533.3	611 759.8	389 083.0	241 193.0	94 238.2	1001.1	3009.7	1305.5	474.3	1 593 597.9
	Blue	13.0	11.8	13.0	383 033.6	389 295.3	331 614.4	371 577.3	15 749.2	12.6	13.0	12.6	13.0	1 491 358.8
Brazo del Río Negro	Green	8905.9	21 983.5	40 170.3	171 253.0	318 581.0	202 619.6	125 604.1	92 279.8	34 614.7	104 061.9	43 599.6	12 795.4	1 176 468.9
	Blue	0.0	0.0	0.0	134 854.0	137 058.4	116 750.3	129 774.3	9255.3	0.0	0.0	0.0	0.0	527 692.4
Caño Blanco	Green	797.5	1968.7	3597.3	7996.4	10 678.7	6791.7	4210.2	17 130.0	19 810.2	59 555.2	25 832.2	9532.9	167 900.9
	Blue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caño Los Marranos	Green	22 440.0	55 391.3	101 216.2	285 462.2	447 534.4	284 634.7	176 445.4	156 774.6	56 336.2	169 362.9	73 461.4	30 825.5	1 859 884.6
	Blue	18 383.5	13 915.3	39.1	20 521.9	20 858.0	17 771.9	19 749.2	1901.5	37.8	39.1	37.8	13 311.2	126 566.3
Caño Pecuca	Green	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Blue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caño Quenane	Green	55 066.8	135 928.0	248 380.2	809 704.1	1 363 798.7	867 384.6	537 692.7	432 020.5	147 893.9	444 611.7	192 612.7	79 401.8	5 314 495.6
	Blue	7888.2	6164.4	1336.6	262 037.1	266 342.6	227 033.1	252 240.2	7669.1	1293.5	1336.6	1293.5	6076.7	1 040 711.6
Total		201 561.1	393 712.0	640 337.9	2 872 384.5	4 293 487.5	2 910 248.4	2 153 381.5	1 161 072.9	408 953.3	1 198 555.1	526 408.8	252 894.1	17 012 997.1

Abbreviation: WF, water footprint.

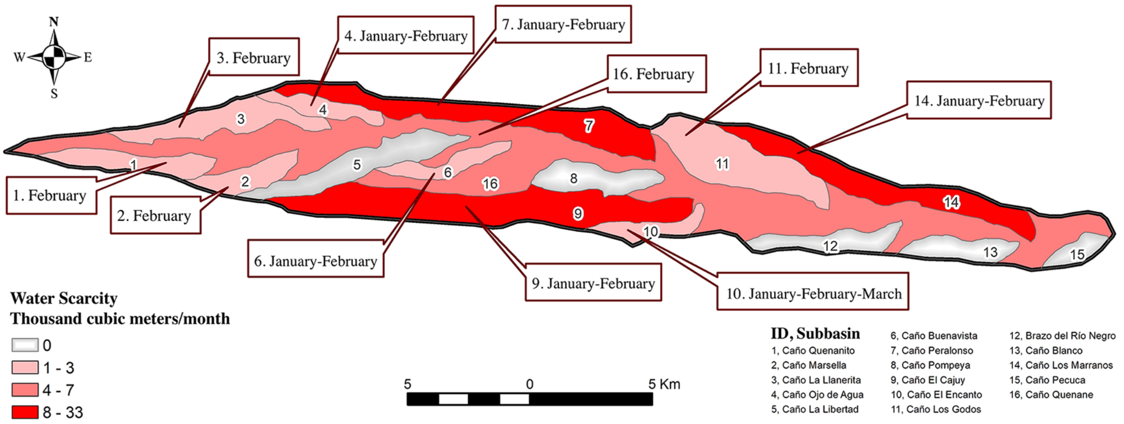

Figure 2. Blue and green water footprint of the 16 sub-basins of the Quenane-Quenanito basin in Villavicencio, Colombia.

Agricultural sector

The agricultural WF is estimated to be 16.8 million m^3/year, corresponding to 0.03% of the national WF of this sector,[49] keeping in mind that the 2348 he of the study area use for agricultural cultivation represents 19.8% of the area cultivated in the borough,[50] which shows the importance of agriculture in the borough for the country; the main crops are rice (44.8%), citrus (28%), oil palm (16.8%), and corn (5.7%). The blue WF represents 19.12% of the total (3.21 million m^3/year), and the green WF represents 80.88% of the total (13.60 million m^3/year). The sub-basin with the largest WF was Quenane, with 33.65%, and the sub-basin with the lowest WF was Caño Godos, with 14.13%. The behavior of the monthly WF is determined by the harvest periods from agricultural cultivation.[51]

Industrial sector

The industrial WF was 166 689 m^3/year, which is equivalent to 0.002% of the national WF of this sector[49]; corresponding to 13 industries that occupy 0.7% of the study area. The sector of hydrocarbons, the subsector with the largest incidence in the gross domestic product (GDP) of the country,[52] is the main contributor, with 95.2% of the WF in the production processes and industrial transformation. It is important to show that the WF this sector generated is mainly because of the transfer of water to another basin because the industry has a catchment but does not provide a shedding spot. However, this situation can have negative impacts on the environmental and socioeconomics systems of the territories if there is not an adequate distribution of extraction and no return of water at its source.[53] The sub-basin with the largest WF is the Caño Peralonso sub-basin, with 95.2%.

Domestic sector

The basin has 4663 habitants, which is equivalent to 0.98% of the borough population distributed in 10 sub-basins, for which it is estimated that the domestic WF is 25 528 m^3/year, corresponding to 0.007% of the national WF, with a per capita value of 5.5 m^3/habitant. These results represent a consumption that is 1.6 times lower than that of the country.[47] This low consumption per capita in the study area is due to the (rural) population and the water supply system (community aqueduct). Arpke and Hutzler[54] suggest that the population of the urban area has a greater need to cook, wash, and heat water. On the contrary, the sub-basin from the Quenane spout exerts the most pressure on the water resources in the basin because it contains 41% of the population of the study area.

Water balance (supply–demand analysis)

The WSA of the basin is estimated to be 272.1 million m^3/year, which is equivalent to a high water supply of 1.64 m^3/m^2, with a WF of 0.10 m^3/m^2. However, the spatiotemporal distribution of the WSA is unequal in the study area, a dynamic in the country,[55] and is mainly responsible for the appearance of water scarcity scenarios,[56,57] keeping in mind that the 35% WSA represents the sub-basin Caño Quenane, followed of the sub-basin El Cajuy, with 11.8%. On the contrary, the months from May to October account for 79% of the total supply.

Figure 3 shows that 11 of the sub-basins have three months some form of temporary water deficit during January, February, and March, the months with the largest runoff amounts during the year in the region[58]; the first corresponds to a natural water scarcity (drought) because the WSA of the basin is not large enough to meet the ecological needs of the territory, and there is an inherent behavior in the territory of meandering rainy drainage, which is characteristic of a savanna basin or plain.[59] The second stage corresponds to the anthropic-ecological water scarcity, which suggests that the WSA does not meet the ecological needs; nevertheless, there is water demand due to the socioeconomics activities in the territory.[60] The last stage is anthropic water scarcity, which refers to a higher WF demand of the WSA and is due to the intensification of socioeconomics activities in a territory without water planning.[61,62]

Potential conflicts associated with the use of water

To determine the participation of the studied sectors in placing pressure on the water resources in a territory, the impacts on the ecological and socioeconomics dynamics of the basins must

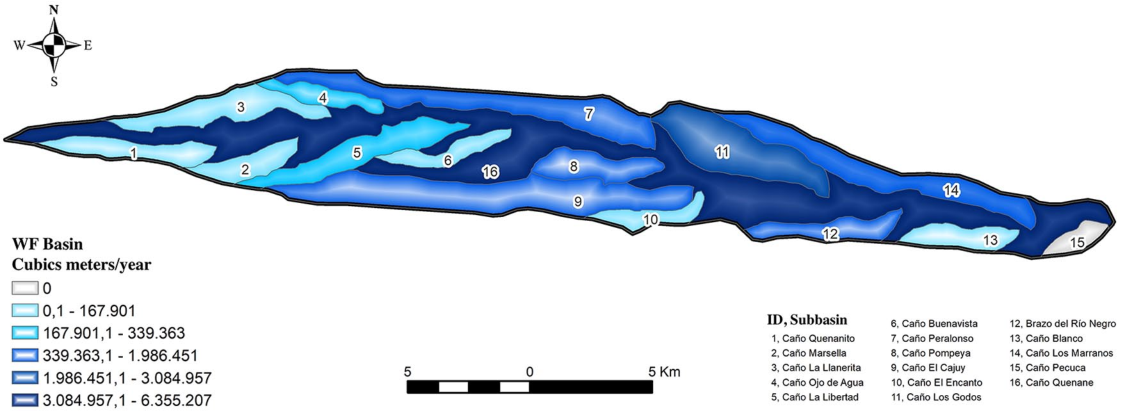

Figure 3. Identification of the months of the year with scarcity according to the water scarcity index.

be identified in terms as functions of its water interest and the WSA.[20] In this sense, the results show that 5 of the sub-basins with a water scarcity of 100% are due to the WF of the agricultural sector, and water is a necessary resource for irrigation during all stages of the physiological development of cultivation to guarantee optimum performance.[62] However, the results suggest that in these sub-basins, water competition and conflict between agricultural production and the natural systems exist. On the contrary, 3 sub-basins with water scarcity have a 100% WF for domestic use, an essential resource for everyday human activities.[63–65] Nevertheless, it can be inferred that there is competition with the natural system for the use of water, generating irreversible effects on the ecosystems. Finally, the results show that in 3 sub-basins with water scarcity, there is competition for the use of water between the studied sectors due to the limited availability of water and a heterogeneous water interest between these sectors. According to Mekonnen and Hoekstra,[66] this situation will intensify until the middle of the century. In this context, it is imperative to study the sustainability of the actual socioeconomic activities and the available water supply in the territory not only the productive yields or utility generated.[22]

Conclusions

The high atmospheric water supply of the Quenane-Quenanito basin is abundant, and rice crop production is the activity with the largest specifically green WF because the cultivation system is established in the rainy season, taking advantage of the efficient natural water supply. The green WF has a relatively lower opportunity cost than the blue WF. Thus, the green WF of rice production does not have significant negative environmental or economic impacts. Likewise, as a mechanism for water resource management, it is necessary to manage the effective use of rain so that this resource can reach other areas of the river basin with less supply. For the basin, 72% of the total available water supply is concentrated in the months of May to October (rainy season). In addition, it was determined that 55% of this natural water supply is concentrated in 2 of the 16 sub-basins, that is, the resource is not available homogeneously throughout the territory.

Eleven sub-basins presented water scarcity scenarios during the months of December to March (dry season), mainly related to anthropic activities, which implies the appearance of conflicts for water use between the domestic, industrial, and agricultural sectors, and in some cases, the requirements of the ecosystems are not met. In this sense, institutional mediation is necessary to ensure priority use of the resource, especially during the dry season.

Finally, this study allowed us to understand that water availability is not guaranteed by its abundance in the territory but by its spatiotemporal distribution. With the evaluation of the WF, it was possible to measure the pressure of anthropic activities on the water resources of the basin and show that it is an effective planning tool for water resources, with the identification of the heterogeneous interests that compose it and the potential water conflicts between the productive and social sectors. These findings are fundamental when establishing processes for the sustainable management of water resources.

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Author Contributions

All authors contributed to the analyzing and implementation of the research and to the writing of the manuscript.

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