ISSN 2529-9824

Artículo de Investigación

Assessment of water availability using indicators: a case study in a transboundary basin

Evaluación de la disponibilidad de agua mediante indicadores: un estudio de caso en una cuenca transfronteriza

Fernando Oñate-Valdivieso[1]: Universidad Técnica Particular de Loja, Ecuador.
fronate@utpl.edu.ec
Cuenca Torres Ximena: Universidad Técnica Particular de Loja, Ecuador.
xccuenca@utpl.edu.ec

Date Received: 09/17/2024

Date of Acceptance: 12/20/2024

Date of Publication: 01/21/2025

How to cite this article:

Oñate-Valdivieso, F., & Cuenca Torres X. (2025). Assessment of water availability using indicators: a case study in a transboundary basin [Evaluación de la disponibilidad de agua mediante indicadores: un estudio de caso en una cuenca transfronteriza]. *European Public & Social Innovation Review*, 10, 1-17. https://doi.org/10.31637/epsir-2025-1498

Abstract:
Introduction: The continued growth of populations and economies has increased the demand for water. The situation is especially complicated in transboundary river basins where the availability of freshwater is increasingly limited, despite the implementation of policies, plans and legislation, aimed at the management and use of the vital liquid. For this reason, the purpose of this research is to evaluate the availability of water resources through the application of indicators. **Methodology**: Meteorological information was collected, which was processed by applying 3 indices to determine the availability and quality of water in the Catamayo – Chira Transfrontier Basin. **Results:** The sectoral demand for water was calculated for the Ecuadorian part, determining the Net Water Supply. aridity Water Use and water quality were determined. **Discussions:** 72% of the total area has a lower requirement for water resources to cover the needs of the vegetation. 63.11% of the basin has acceptable water quality, which indicates that it does not present major contamination that could affect human well-being. **Conclusions**: The basin presents acceptable conditions of water availability and quality, although an increase in sectoral demands could affect these conditions in the medium term.

[1] **Corresponding Author:** Fernando Oñate-Valdivieso. Universidad Técnica Particular de Loja (Ecuador).

Keywords: Transboundary basin; sectoral demand; aridity index; water supply index; water quality index; water availability; transboundary basin; Catamayo-Chira.

Resumen:
Introducción: El continuo crecimiento de las poblaciones y economías ha aumentado la demanda de agua. La situación es especialmente complicada en las cuencas fluviales transfronterizas donde la disponibilidad de agua dulce es cada vez más limitada, a pesar de implementar políticas, planes y legislación, dirigidos al manejo y aprovechamiento del vital líquido. Por tal motivo, el propósito de esta investigación es evaluar la disponibilidad del recurso hídrico mediante la aplicación de indicadores. **Metodología**: Se recopiló información meteorológica la que fue procesada aplicandose 3 índices para conocer la disponibilidad y la calidad del agua en la cuenca Transfronteriza Catamayo – Chira. **Resultados:** La demanda sectorial de agua fue calculada para la parte ecuatoriana determinándose el suministro de agua. Los índices de aridez, uso y calidad del agua fueron determinados. **Discusión**: El 72% del área total presenta un menor requerimiento de recursos hídricos para cubrir las necesidades de la vegetación. El 63,11% de la cuenca tiene una calidad de agua aceptable, lo que indica que no presenta mayor contaminación que pueda afectar el bienestar humano. **Conclusiones**: La cuenca presenta condiciones aceptables de disponibilidad y calidad del agua, auqneu un incremento de las demandas sectoriales podria afectar dichas condiciones en el mediano plazo.

Palabras clave: cuenca transfronteriza; demanda sectorial; índice de aridez; índice de suministro de agua; índice de calidad del agua; disponibilidad del agua; cuenca transfronteriza; Catamayo-Chira.

1. Introduction

Water is essential for human beings and influences economic and social growth, it is essential for agriculture and energy generation, so its availability covers or affects human activities.

The availability of water in transboundary basins is an issue of increasing importance and complexity in the current global context. These watersheds, which span the political borders of two or more countries, are essential to the livelihoods of millions of people and ecosystems. However, various interrelated factors affect its availability and sustainable management, generating significant challenges that require comprehensive and cooperative solutions (Oñate-Valdivieso et al., 2020).

Climate change is one of the most influential factors affecting water availability in transboundary basins. Alterations in precipitation patterns, increases in the frequency and severity of droughts and floods, and the accelerated melting of glaciers drastically modify the quantity and quality of available water (Beck y Bernauer, 2011). These unpredictable climate variations complicate water resource planning and management between nations, exacerbating existing tensions and putting regional water security at risk.

The constant increase in population and the expansion of urban areas intensifies the demand for water in transboundary basins. Domestic consumption, together with the infrastructure and service needs associated with urban growth, puts additional pressure on limited water resources (UNESCO, 2018). This situation is aggravated in regions where the water management and distribution capacity are insufficient to meet the growing needs of the population.

Agriculture, being one of the most water-demanding sectors, plays a crucial role in the availability of the resource in transboundary basins. Inefficient agricultural practices and excessive use of water for irrigation significantly decrease water reserves. Likewise, industrial expansion contributes to the depletion and contamination of water sources, especially when sustainable technologies and practices are not implemented (Muratoglu et al., 2022). Competition between agricultural and industrial sectors for access to water can generate conflicts and imbalances in the distribution of the resource.

Pollution from industrial, agricultural, and urban waste deteriorates the quality of water in transboundary basins, reducing its availability for human consumption and natural ecosystems. The use of pesticides and chemical fertilizers in agriculture, industrial discharges without adequate treatment and the lack of efficient urban wastewater treatment systems contribute to the degradation of shared water bodies, affecting public health and biodiversity (Snowsill et al. 2024)

The absence of solid and effective international agreements for the joint management of transboundary basins is another determining factor in water availability. Differences in national policies, weak regulatory frameworks and the lack of cooperation and conflict resolution mechanisms make the equitable and sustainable management of the resource difficult. The implementation of comprehensive agreements and the creation of strong transnational institutions are essential to coordinate efforts and ensure fair distribution of water between the nations involved.

Territorial and political disputes between countries that share river basins can intensify challenges related to water availability. Competition for control and access to water resources can become a source of conflict, especially in regions where water is scarce. These geopolitical tensions hinder the cooperation necessary for sustainable basin management and may have broader implications for regional security and stability (UNESCO, 2019).

The existence and condition of water infrastructure, such as dams, canals and irrigation systems, significantly influence the availability and distribution of water. Obsolete or poorly maintained infrastructure can cause considerable water losses and limit efficient access (Oñate-Valdivieso et al., 2021). On the other hand, the adoption of modern technologies and efficient management practices, such as drip irrigation systems and advanced water treatment plants, can improve the conservation and quality of water available in transboundary basins.

Aquatic and terrestrial ecosystems dependent on watersheds play a crucial role in the regulation and maintenance of water quality and quantity. The degradation of these ecosystems due to unsustainable human activities reduces the natural capacity of the basins to store and purify water, affecting the availability of the resource (Cao et al., 2022). Conservation and restoration of key ecosystems, such as wetlands and riparian forests, are critical to sustaining the health and functionality of transboundary basins.

The continuous growth of populations and economies has increased water demand by 1% per year and is predicted to continue to increase for the following decades which could lead to a shortage in the resource, causing negative consequences (UNESCO, 2018). The situation is especially complicated in transboundary river basins where the availability of freshwater is increasingly limited, so government agencies and institutions at the local, national and international levels seek to implement policies, plans and legislation aimed at the management and use of the vital liquid (Mera-Parra et al., 2021)

This problem is not foreign to Ecuador, a country whose hydrography is divided into two watersheds that flow into the Pacific Ocean and the Atlantic Ocean through 79 river basins, eleven of which are transboundary basins, three of which are shared with Colombia and nine with Peru (Oñate-Valdivieso et al., 2021). The country, due to its location has a significant existing amount of water resource however it has had a progressive reduction, due to a natural inequality in the distribution of water, locating the largest water source in the slope that runs through the Amazon and flows into the Atlantic Ocean, only the remaining small part is distributed in the Pacific slope, where most of the population is concentrated, which generates greater demand for water for various uses producing an imbalance (SENAGUA, 2017).

One of the areas affected by this water source inequality is the south of the country, particularly the border of Ecuador and Peru. This has led to the implementation of binational projects in transboundary basins, which aim to provide a long-term solution to the water deficit and promote productive and social growth in both countries (Oñate-Valdivieso & Bosque, 2014).

One of these binational basins is the Catamayo – Chira, which has suffered deterioration as a consequence of poor agricultural practices, deforestation, overgrazing, and natural erosion that increases sedimentation in the basin (Oñate-Valdivieso & Bosque, 2014).

For this reason, the purpose of this research is to evaluate the availability of water resources by applying indicators that and to know their spatial variability, the demand will also be studied.

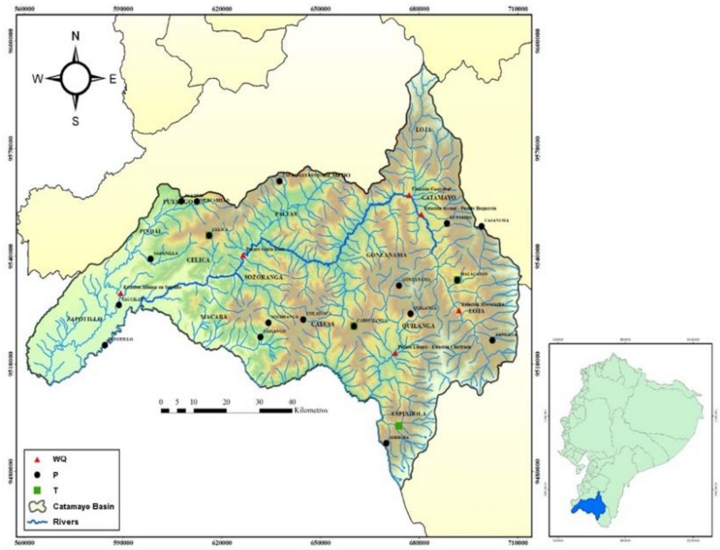
2. Materials and Methods

1.1. Study Area

The present study was carried out in the Ecuadorian portion of the Catamayo-Chira transboundary basin (Figure 1), which is located in the Ecuadorian province of Loja in the border area between Ecuador and Peru between 3° 30' and 5° 8' south latitude and 79° 10' and 81° 11' west longitude, it occupies an approximate area of 7199 km2 corresponding to 41,93% of the total surface of the Catamayo – Chira transboundary basin (Oñate-Valdivieso y Bosque, 2014).

Figure 1

Location and Stations of the Catamayo Hydrographic Basin



Source: Own elaboration.

It traverses both mountain ranges and the coastline, characterized by a tropical climate and a variety of ecosystems. The geography of the basin is rugged, with altitudes ranging from 0 to 3700 meters above sea level. Within this region, there are 11 distinct life zones, ranging from tropical deserts to mountain rainforests. The annual average precipitation varies between 10 mm in the lower areas to 1000 mm in the headwaters, with an overall range of 800 mm. The temperature oscillates around 24°C in the lowest areas, 20°C in the middle area, and 7°C in the highest areas (Oñate-Valdivieso et al., 2024). In general terms, the basin is covered by 20% natural forest, 21% dry forest, 30% grassland, 10% crops and 19% various uses. The basin is made up of three main tributaries: The Catamayo, Macará, and Alamor rivers, of which the largest water producers are the Catamayo river basin with an average flow of 30 m^3/s and the Macará River with 40 m^3/s.

Periodically, the study area is affected by the occurrence of ENSO (El Niño Southern Oscillation), a phenomenon that in its warm phase produces a warming of between 1 and 4 °C above the normal temperature of the ocean, causing excess evaporation and consequently heavy rains. The cold phase of the phenomenon, known as La Niña, produces accumulations of hot water in the western Pacific, so along the Peruvian coast there are decreases in normal ocean temperature, causing notable decreases in evaporation and precipitation with consequent periods of drought.

1.2. Data

Daily information on total precipitation and average temperature recorded in the network of the National Institute of Meteorology and Hydrology of Ecuador (INAMHI) was compiled for the period 1975 - 2015, which are shown in Table 1. Additionally, information on physical parameters was extracted. - water chemicals at the monitoring points included in Table 2.

Table 1.

Existing stations in the study área

Station	Variable	Longitude	Latitude	Elevation (m)
Malacatos	P, T	691.652	9.533.403	1.453
Cariamanga	P, T	660.171	9.520.506	1.950
Yangana	P	702.314	9.516.575	1.835
Célica	P, T	616.149	9.545.853	1.904
Gonzanamá	P	673.885	9.531.875	2.042
Zapotillo	P	584.481	9.515.181	223
Amaluza	P	673.864	9.492.681	1.672
Quilanga	P	677.415	9.524.004	1.956
Sozoranga	P	634.151	9.521.504	1.427
Alamor	P	607.680	9.555.383	1.250
Saucillo	P	588.685	9.526.416	328
Jimbura	P	670.031	9.487.897	2.100
Sabiango	P	631.771	9.517.484	700
Cajanuma	P	698.995	9.548.378	2.420
Colaisaca	P	644.789	9.522.377	2.410
El Tambo	P	688.478	9.549.169	1.601
Lauro Guerrero	P	637.574	9.560.932	1.945
Mercadillo	P	612.460	9.555.285	1.142
Sabanilla	P	598.318	9.539.272	710

Source: Own elaboration.

Table 2.

Sampling points for water quality

Station	Variable	Longitude	Latitude	Elevation (m)
Moyococha	WQ	692.085	9.524.898	1.487
Puente Boquerón	WQ	680.673	9.551.676	1.171
Guayabal	WQ	676.986	9.557.044	1.128
Lucero -Chiriyacu	WQ	6726.85	9.513.020	1.122
Alamor en Saucillo	WQ	589.271	9.529.727	251
Puente Santa Rosa	WQ	626.506	9.540.244	613

Source: Own elaboration.

1.3. Evapotranspiration

Evapotranspiration is a key process in the hydrological cycle that significantly affects the availability of water in a basin. It is the combination of two phenomena: evaporation, which is the loss of water from free surfaces, such as rivers, lakes, and the ground; and transpiration, which is the water that is lost through plants while they carry out photosynthesis. Together, these processes can represent one of the largest water outputs from a basin, directly impacting the amount of water that remains available for uses such as urban supply, agriculture, industry, and the maintenance of aquatic ecosystems.

One of the determining factors of evapotranspiration is climate. In hot and dry areas, evapotranspiration rates are usually higher due to the greater solar energy available to evaporate water and the lower relative humidity that allows plant transpiration to be more intense. This implies that in arid or semi-arid regions, a significant portion of precipitated water is lost back to the atmosphere, reducing surface runoff and aquifer recharge. On the other hand, in more humid regions, although evapotranspiration remains a relevant process, its impact on water availability may be lower compared to drier areas.

Vegetation cover also plays a crucial role in evapotranspiration dynamics. Forests, for example, have high transpiration rates due to the large amount of leaf surface area and the ability of roots to access deep water. However, the presence of vegetation also has a moderating effect, since plants, through transpiration, help maintain soil moisture and regulate the local microclimate. On the other hand, in areas devoid of vegetation, such as bare soil or urbanized landscapes, direct evaporation from the soil may be higher, but without the transpiration component offered by plants, which can also alter the water balance of the area basin.

Potential evapotranspiration was determined using the Thornthwaite equation (Trajkovic et al., 2019).

$$ETP = 1.6K_a\left(\frac{10T_j}{I}\right)^a$$

Where: ETP is the monthly potential evapotranspiration of month j, in cm, Tj is the average temperature in month j, in °C Ka is a constant that depends on latitude and the month of the year; a and I are constants that are evaluated by applying:

$$I = \sum_{j=1}^{12} i_j$$

Where:

$$i_j = \left(\frac{T_j}{5}\right)^{1.514}$$

$$a = 675x10^{-9}I^3 - 771x10^{-7}I^2 + 179x10^{-4}I + 0.492$$

Actual Evapotranspiration is determined from Potential Evapotranspiration, using the Budyko equation (Sposito, 2017), which relates these two variables.

$$ETR = \sqrt{ETP \times P \times \tan h\left(\frac{P}{ETP}\right) \times \left[1 - \cos h\left(\frac{ETP}{P}\right) + \sin h\left(\frac{ETP}{P}\right)\right]} \qquad (1)$$

Where: ETR: Real evapotranspiration in mm/year, P: Multi-year mean annual precipitation in mm/year

1.4. Water Supply of the Basin

The water supply of a basin is a critical component of its hydrological balance, encompassing all sources of water that contribute to the overall availability of the resource within the watershed. This supply is primarily derived from precipitation, which includes rainfall and snowfall, and is supplemented by surface water inflows from upstream regions, groundwater recharge, and in some cases, glacial melt. The water supply is regulated by various factors such as the basin's topography, land use, and climatic conditions, which influence how much of the incoming water is retained, stored, and ultimately made available for use. Additionally, the presence of reservoirs and artificial lakes can play a significant role in controlling the distribution and availability of water throughout the year, helping to mitigate the effects of seasonal variations. The balance between water supply and demand in the basin is crucial for sustaining ecosystems, supporting agriculture, industrial activities, and meeting the needs of local communities, making it an essential focus of integrated water resource management efforts.

In this study it is considered that the surface water supply is the water that runs through rivers after having gone through the processes of evapotranspiration and infiltration, essential to satisfy both social and economic demand. It is evaluated with the equation:

$$Net\ Water\ Supply = Total\ Warer\ Supply - Q\ ecoogical \qquad (7)$$

Where,

$$Q\ ecological = 0{,}25 \times Total\ Warer\ Supply \qquad (8)$$

1.5. Sectoral Water Demand of the Basin

Sectoral water demand refers to the amount of water required by different sectors of society, such as agriculture, industry, domestic use, and the environment, to meet their specific needs. Each sector has its own demands based on its activities and processes; For example, agriculture is typically the largest consumer of water due to irrigation, while industry uses water for production, cooling, and other processes. Sectoral water demand is a key concept in water resources management, as it helps plan and distribute water in a way that meets the needs of all sectors, minimizing conflicts and ensuring sustainable use of the resource.

Water demand is the sum of all the sectors that require the resource of the hydrographic basin, so it is calculated by applying:

$$DHT = DUP + DUA + DUI + DUM + DUPI + DUR \qquad (9)$$

Where, DHT is the Total Water Demand, DUP is the demand for water for population use, DUA is the demand for water for agricultural use, DUI is the demand for water for industrial use, DUM is the demand for water for mining use, DUPI is the demand for water for fish farming use, DUR in the Demand for water for recreational use.

The information for determining the sectoral water demand of the Catamayo Basin was carried out based on the Water Characterization and Adequacy between Supply and Demand of the Catamayo – Chira Binational Basin (ATA, UNP, UNL, 2005).

1.6. Aridity Index (AI)

The aridity index of a basin is a parameter that measures the relationship between total annual precipitation and annual potential evapotranspiration, indicating the water balance of the region and whether it is more prone to humid or dry conditions. A low index suggests an arid or semi-arid basin with low water availability, while a high index indicates a water surplus in humid regions. This index is essential for water resources management, climate classification, assessment of environmental risks such as drought and desertification, and agricultural and land use planning. In addition, it is a key tool in sustainability studies, helping to design policies that promote equitable and efficient use of water, adapting to the climatic limitations of the region.

Basically, this index is a numerical indicator of the climate based on the interaction between precipitation, temperature and evapotranspiration that qualitatively determines areas with a deficit or surplus of water resources, thus allowing the monitoring of certain changes that occur in terms of the availability of water in the area (IDEAM, 2018). The calculation of the Aridity Index was carried out using the following equation:

$$IA = \frac{(ETP - ETR)}{ETP} \qquad (10)$$

Where: IA: Aridity Index (dimensionless), ETP: Potential Evapotranspiration (mm/year), ETR: Actual Evapotranspiration (mm/year)

Table 3.

Interpretation of Aridity Index

Category	Range
Highly water deficient	> 0,60
Water deficit	0,50 - 0,59
Moderate and water deficient	0,40 - 0,49
Moderate	0,30 - 0,39
Moderate and excess water	0,20 – 0,29
Surplus water	0,15 – 0,19
High water surpluses	< 0,15

Source: IDEAM (2018).

The calculation of the Potential Evapotranspiration (ETP) was carried out using the Thornthwaite equation and to determine the Real Evapotranspiration (ETR), the Budyko equation was applied, categorizing the results based on Table 3.

1.7. Water Use Index (IUA)

The water use index is an indicator that quantifies the proportion of water extracted or used in relation to the total water availability in a basin or region. This index is essential to evaluate the pressure that human activities, such as agriculture, industry and domestic consumption, exert on water resources. A high value of the water use index indicates a high level of extraction compared to the amount of water available, which may signal a risk of overexploitation and water stress, compromising the long-term sustainability of the region's water resources. This index is essential in the planning and integrated management of water resources, helping to identify areas where more efficient management or the implementation of conservation policies is required to avoid the degradation of aquatic ecosystems and guarantee an adequate supply for future generations.

Due to the different and current limitations of water availability and the growing water demand, an important factor to consider is the sustainable management of water resources, therefore, the water use index (IDEAM, 2018) provides information on whether the use of water resources is sustainable or if it is developing water scarcity, it is determined with the following equation.

$$IUA_j = \frac{DH}{OHTD} * 100 \tag{11}$$

Where: IUA in the Water Use Index in the spatial reference unit j for average hydrological condition or dry year (%), DH in the Water demand of socioeconomic activities and ecosystems in the spatial reference unit j (hm^3/year), OHTD is the total surface water supply available in the spatial reference unit j for average or dry year hydrological condition (hm^3/year)

The index results can be categorized according to the ranges shown in Table 5

Table 4.

Range of Water Use Index Values

Range	Category	Water retention and regulation index
> 100	Critical	The pressure exceeds the conditions of the available surface supply.
50,01 - 100	Very high	Demand pressure is very high compared to the available surface supply.
20,01 - 50	High	Demand pressure is high compared to the available surface supply.
10,01 - 20	Moderate	Demand pressure is moderate compared to the available surface supply.
1,0 - 10	Low	Demand pressure is low compared to the available

		surface supply.
≤ 1	Very low	Demand pressure is not significant with respect to the available surface supply.

Source: IDEAM (2018).

1.8. Water Quality Index (WQI)

A water quality index is a tool used to evaluate and summarize the state of water quality in a water body, such as a river, lake, or aquifer, in a simplified and understandable way. This index combines several physical, chemical, and biological parameters, such as the level of dissolved oxygen, pH, turbidity, presence of contaminants and microorganisms, on a single numerical or categorical scale. The objective is to provide an overview of the health of the water, indicating whether it is suitable for human consumption, recreation, irrigation, or aquatic habitat, and to assist in decision-making for its management and conservation.

The water quality index is an easily interpreted expression that includes several physical, chemical, and bacteriological parameters of the quality of a body of water (Galal et al., 2019; Oñate-Valdivieso et al., 2021). It determines physicochemical conditions of the quality of a water stream and also shows to a certain extent problem related to pollution at a point for a specific time, thus defining possibilities or limitations of the use of water resources for certain activities (IDEAM, 2018).

This indicator is calculated using the following expression:

$$ICA_{njt} = \left(\sum_{i=1}^{n} W_i * I_{ikjt} \right) \quad (12)$$

Where: ICA_njt: Water quality index of a given surface stream at water quality monitoring station j at time t, evaluated based on n variables, W_i: Relative weight assigned to quality variable i, I_ikjt : calculated value of variable i, n : number of quality variables involved in the calculation of the indicator.

The weighting of each of the variables involved in the index was carried out as shown in Table 5, which was characterized according to Table 6.

Table 5.

Weighted weight of each of the variables

Variable	Weighting factor (W)
Dissolved oxygen OD	0,25
Total solids	0,25
Electrical conductivity	0,25
pH	0,25

Source: IDEAM (2018).

Table 6

Qualification of ICA Ranges

Categories	Water Quality Rankig	Warning signal
0,00 – 0,25	Very bad	Red
0,26 – 0,50	Bad	Orange
0,51 – 0,70	Regular	Yellow
0,71 – 0,90	Acceptable	Green
0,91 – 1,00	Good	Blue

Source: IDEAM (2018).

3. Results and discussion

3.1. Evapotranspiration

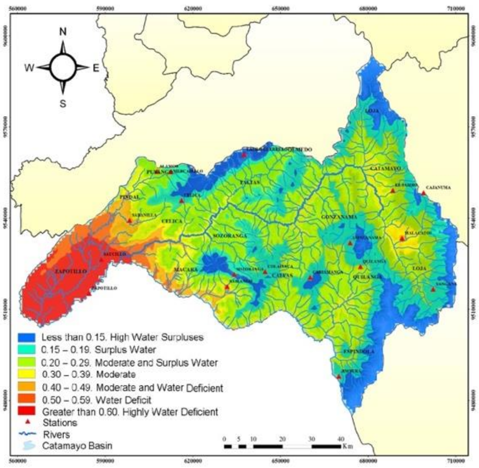
The variation of evapotranspiration in the Ecuadorian part of the Catamayo Chira transboundary basin is presented in Figure 2. In this it can be seen that the highest values occur in the southwest of the study area, specifically in the Zapotillo canton where the ETP reaches values of 2500 mm annually, although sectors of Macará and Pindal present high values that oscillate around 2000 mm annually. The rest of the study area presents potential evapotranspiration ranges between 500 and 1000 mm per year. The geographical position of the basin, close to the equator, the large number of hours of sunshine to which the study area is subjected, as well as its relatively high temperature, produces a high potential evapotranspiration.

3.2. Aridity index

The aridity index in the period 1975 - 2015 in the Catamayo River hydrographic basin is presented in Figure 3 and the area percentages according to each category are summarized in Table 7. As can be seen, 5193.41 km2 surface area equivalent to 72% of the total area, have indexes classified as areas with moderate water resources to areas with water surpluses, this indicates a lower requirement for water resources to cover the needs of the vegetation.

Figure 2.

Evapotranspiration in the Ecuadorian part of the Catamayo Chira transboundary basin



Source: Own elaboration.

In the case of Macará and Pindal, areas with tropical climates, it presents indices in a range of 0,40 to 0,49, being territories in moderate conditions to lacking resources, in terms of surface it represents 4,29% of the total area of the basin, the vegetation and fauna can develop without any problem.

Otherwise, it can be observed specifically in the area of Zapotillo, located in the border area with Peru and which has a hot semi-arid climate, presenting aridity index values greater than 0,60, making up 7,83% of the total area of the basin which is considered highly deficient in water, a fact that must be considered for territorial planning purposes.

Improving a basin's aridity index, involves implementing strategies to increase water availability and reduce atmospheric demand. Key actions include reforestation to improve soil water retention and reduce excessive evaporation, conservation and restoration of wetlands that act as natural sponges and optimizing water use through efficient irrigation practices. Furthermore, encouraging the capture and storage of rainwater, as well as improving water resource management to ensure balanced and sustainable use, can help mitigate the effects of aridity. These measures contribute to balancing the water cycle and reducing the water deficit in the basin.

Table 7

Surface and Equivalent Percentage in the Aridity Index

Aridity Index Range	Area (Km^2)	Percentage %
< 0,15 High water surpluses	966,83	13,43
0,15 – 0,19 Surplus water	1.646,94	22,88
0,20 – 0,29 Moderate and excess water	2.579,64	35,84
0,30 – 0,39 Moderate	902,32	12,53
0,40 – 0,49 Moderate and water deficient	308,59	4,29
0,50 – 0,59 Water deficit	230,95	3,21
> 0,60 Highly water deficient	563,36	7,83

Source: Own elaboration.

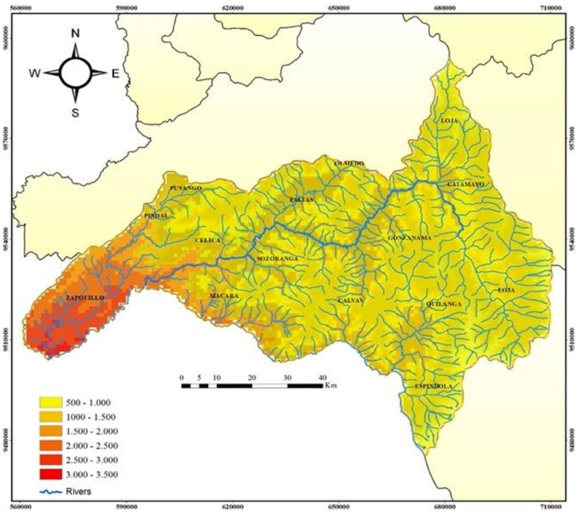
3.3. Water Use Index (ICA)

The values of sectoral water demand are presented in Table 8. In this agricultural use is the one that demands the greatest amount of water, being equivalent to 97,6% of the total demand. In the study area there are large areas dedicated to agriculture, especially in Macará, Zapotillo and Pindal. Irrigation systems are still low-tech, which significantly increases demand. Far below is population demand, which reaches only 1,7% of total demand, followed by mining demand, which reaches 0,4%, and industrial demand, which reaches only 0,2%. Clearly the vocation of the study area is agricultural, although improvements in irrigation systems are necessary to optimize water use.

The results of the water use index for the entire Catamayo River Basin in the study period 1975 - 2015 are presented in Table 9. As can be seen, they indicate that the pressure of water demand corresponds to 34,04% of the net water supply, which is categorized as high. Although the basin can supply sectoral demand, the increase in population and requirements for productive activities could increase pressure on available resources, which are additionally affected by climate change, so it is It is necessary to establish strategies that allow sustainable management of the basin's water resources and establish adaptation measures to minimize the risk of water deficit in the future.

Figure 3.

Aridity Index Map



Source: Own elaboration.

Table 8.

Sectoral water demand

Use-Activity	Millon of m³ (hm³)	Porcentage
Population	13,13	1,7
Agriculture	739,73	97,6
Industrial	1,66	0,2
Miner	3,15	0,4
Fish farming	0,51	0,1
Recreational	0,01	0,0
Total Water Demand	758,19	100

Source: Own elaboration.

Improving the water use rate in a watershed requires integrated strategies such as the adoption of efficient irrigation technologies, the promotion of wastewater recycling and reuse, and the implementation of integrated water resources management. In addition, it is crucial to promote public education and awareness about water conservation, establish policies and regulations that promote responsible use, modernize water infrastructure to reduce losses, and protect and restore natural ecosystems that support the regulation of the hydrological cycle. These actions, coordinated and adapted to the specific conditions of the basin, can reduce pressure on water resources and ensure their sustainability.

Table 9.

Water Use Index

Component	Value	Unit
Net Water Supply	2227.50	hm³
Sectoral Water Demand	758.19	hm³
Water Use Index (IUA)	34.04	%

Source: Own elaboration.

3.4. Water Quality Index (ICA)

The results are presented in ranges from 0 to 1 as can be seen in Table 10. In general, the Catamayo Hydrographic Basin has a quality body of water in regular conditions, since indices of 0,65 to 0,89 were obtained in its determination. The 36,86% of the total surface of the basin has a water resource quality categorized as regular while 63,11% of the basin has an acceptable water quality, which indicates that it does not present major contamination that may affect human well-being.

According to the monitoring points, the areas of Loja, Calvas, Gonzanamá among others have better water quality, the opposite is found in the cantons of Zapotillo and Macará where it has a regular water quality.

Table 10.

Water Quality Index Results

Station	IpH	ICE	IOD	IST	ICA	Qualification
Moyococha	0,25	0,22	0,25	0,17	0,89	Acceptable
Puente Boquerón	0,25	0,16	0,23	0,14	0,78	Acceptable
Guayabal	0,20	0,12	0,23	0,11	0,65	Regular
Lucero - Chiriyacu	0,22	0,18	0,23	0,10	0,73	Acceptable
Alamor en Saucillo	0,25	0,12	0,24	0,06	0,66	Regular
Puente Santa Rosa	0,25	0,11	0,24	0,08	0,67	Regular

Source: Own elaboration.

To improve the water quality index, it is essential to adopt several integrated strategies. First, advanced treatment systems must be implemented to remove industrial and urban pollutants before the water reaches natural water bodies. The protection and restoration of riparian zones and wetlands contributes to natural filtration and pollution reduction. It is also crucial to promote sustainable agricultural practices, such as the use of fertilizers and pesticides in a controlled manner, to minimize nutrient and chemical runoff. Additionally, wastewater management should be improved by installing and maintaining appropriate treatment systems, and public education about the importance of water conservation and contaminant reduction should be encouraged. These combined actions help maintain and improve water quality, ensuring its safety and sustainability.

4. Conclusions

A description of the state of water resources in the Ecuadorian portion of the Catamayo Chira river basin was carried out. The areas with greater aridity, with better water quality and those economic sectors that exert greater pressure on available water resources can be identified.

The Catamayo hydrographic basin presents a Net Water Supply, three times greater than the Total Sectoral Water Demand, which guarantees availability of the water resource for socioeconomic growth.

The indices of aridity, quality and use of water determined in this research are useful in the evaluation of the availability of bodies of water, in quantity and quality, given the results of their determination, the Catamayo River Hydrographic Basin has a quantity of resource water that covers each of the users' needs, with agriculture being the largest with 97,6% of the total water demand, followed by human consumption that corresponds to 1,7%, with acceptable water quality for the growth of flora and fauna.

The critical area within the Ecuadorian portion of the Catamayo-Chira Basin is the southwestern portion, specifically the Zapotillo canton, a border area with high temperatures, has deficient water resources and poor quality, not suitable to supply the needs or the population or agriculture, therefore, projects are required where the right to quality water is guaranteed.

The indices applied are very versatile and easy to apply anywhere, so they could contribute to studying hydrographic basins in different countries.

The Catamayo – Chira basin is subject to conditions that can affect the availability of water in the long and medium term, so in future research aspects such as the advance of desertification, the change in vegetation cover, the incidence of droughts, among others could be studied.

5. References

ATA-UNP-UNL. (2005). *Caracterización Hídrica y Adecuación entre la Oferta y Demanda - Caracterización Territorial y Documentación Básica*. Proyecto Binacional Catamayo - Chira.

Beck, L., & Bernauer, T. (2011) How will combined changes in water demand and climate affect water availability in the Zambezi river basin?, *Global Environmental Change*, 21(3). 1061-1072. https://doi.org/10.1016/j.gloenvcha.2011.04.001.

Cao, Z., Wang, S., Luo, P., Xie, D., & Zhu, W. (2022) Watershed Ecohydrological Processes in a Changing Environment: Opportunities and Challenges. Water, (14), 1502. https://doi.org/10.3390/w14091502

Galal Uddin Md., Nash, S., & Olbert, A. I. (2021) A review of water quality index models and their use for assessing surface water quality, *Ecological Indicators 122*, 107218. https://doi.org/10.1016/j.ecolind.2020.107218

IDEAM. (2018). *Estudio Nacional del Agua*. Instituto de Hidrología, Metereología y Estudios Ambientales.

Mera-Parra, C., Oñate-Valdivieso, F., Massa-Sánchez, P., & Ochoa-Cueva, P. (2021) Establishment of the baseline for the IWRM in the ecuadorian andean basins: Land use change, water recharge, meteorological forecast and hydrological modeling. *Land 10*(5), 513. https://doi.org/10.3390/land10050513

Muratoglu, A., Iraz, E., & Ercin, E. (2022) Water resources management of large hydrological basins in semi-arid regions: Spatial and temporal variability of water footprint of the Upper Euphrates River basin, *Science of The Total Environment*, 846, 157396. https://doi.org/10.1016/j.scitotenv.2022.157396.

Oñate-Valdivieso, F., & Bosque Sendra, J. (2014) Semidistributed hydrological model with scarce information: Application to a large South American binational basin. *Journal of Hydrologic Engineering, 19*(5), 1006-1014. https://doi.org/10.1061/(ASCE)HE.1943-

5584.0000853

Oñate-Valdivieso, F., Uchuari, V., & Oñate-Paladines A. (2020) Large-scale climate variability patterns and drought: a case of study in South–America *Water Resources Management 34*, 2061-2079. DOI: 10.1007/s11269-020-02549-w

Oñate-Valdivieso, F., Massa-Sánchez, P., León, P., Oñate-Paladines, A., & Cisneros, M. (2021) Application of Ostrom's institutional analysis and development framework in river water conservation in southern Ecuador. Case study—The Zamora river. *Water, 13*(24), 3536. https://doi.org/10.3390/w13243536

Oñate-Valdivieso F, Oñate-Paladines A., & Díaz R (2024), Soil degradation in andean watersheds: a case study using remote sensing. *Front. Earth Sci. 12*:1325189. https://doi.org/10.3389/feart.2024.1325189

SENAGUA. (2017). *Boletín de la Estadística Sectorial del Agua*. Secretaría del Agua.

Snowsill, A., Hamilton, R., Schneider, L., Mahanty, S., & Doron, A. (2024) Re-viewing pollution: A tale of two basins, Environmental Science & Policy, (156), 103751, https://doi.org/10.1016/j.envsci.2024.103751

Sposito, G. (2017) Understanding the Budyko Equation. Water 9, 236. DOI: https://doi.org/10.3390/w9040236.

Trajkovic, S., Gocic, M., Pongracz, R., & Bartholy, J. (2019) Adjustment of Thornthwaite equation for estimating evapotranspiration in Vojvodina. *Theor Appl Climatol 138*, 1231–1240. https://doi.org/10.1007/s00704-019-02873-1

UNESCO. (2018). *Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2018: Soluciones basadas en la naturaleza para la gestión del agua*. Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura.

UNESCO. (2019). *Informe Mundial de la Naciones Unidas sobre el Desarrollo de Recursos Hidricos 2019: No dejar a nadie atrás*. Organización de la Naciones Unidas para la Educacion, Cienca y Cultura.

CONTRIBUCIONES DE AUTORES/AS, FINANCIACIÓN Y AGRADECIMIENTOS

Contribuciones de los/as autores/as:

Conceptualización: Oñate-Valdivieso, Fernando; **Software:** Cuenca Torres Ximena; **Validación:** Oñate-Valdivieso, Fernando, Cuenca Torres, Ximena; **Análisis formal:** Oñate-Valdivieso, Fernando; **Curación de datos:** Oñate-Valdivieso, Fernando**; Redacción-Preparación del borrador original:** Oñate-Valdivieso, Fernando, Cuenca Torres, Ximena**; Redacción-Re- visión y Edición:** Oñate-Valdivieso, Fernando; **Visualización:** Oñate-Valdivieso, Fernando, Cuenca Torres, Ximena; **Supervisión:** Oñate-Valdivieso Fernando; **Administración de proyectos:** Oñate-Valdivieso, Fernando; **Todos los/as autores/as han leído y aceptado la versión publicada del manuscrito:** Oñate-Valdivieso, Fernando, Cuenca Torres, Ximena.

Financiación: Esta investigación no ha recibido financiamiento externo.

Conflicto de intereses: Los autores declaran no tener conflicto de intereses.

AUTOR/ES:

Fernando Oñate-Valdivieso
Department of Civil Engineering. Universidad Técnica Particular de Loja

Doctor in Hydrology from the University of Alcalá (spain). Civil Engineer from the Universidad Técnica Particular de Loja (UTPL) (Ecuador). University professor since 1999 at UTPL. Principal professor of the subjects of hydrology, geographic information systems in undergraduate and postgraduate. He has been principal investigator and director of projects funded by national and international government and research entities. He has extensive experience in hydrological modeling applied to the water resources management, infrastructure design and risk prevention. He has been Director of the department of Geology, Mines and Civil Engineering and Director of the Water Resources Master Program at UTPL. He is the author of scientific publications in scientific journals and book chapters.
fronate@utpl.edu.ec

Orcid ID: https://orcid.org/0000-0002-2400-0510
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId= 36617848100

Ximena Cuenca Torres
Department of Civil Engineering. Universidad Técnica Particular de Loja

Civil Engineer from the Universidad Técnica Particular de Loja with experience in hydrology and management of hydrographic basins. He has participated in research and consulting projects on topics related to water resources management.
xccuenca@utpl.edu.ec