



MAPBIOMAS  
[AGUA]

# MapBiomass Water - VENEZUELA

General manual

## Theoretical basis document on algorithms (ATBD)

Collection 3, Versión 1

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*December 2025*



MAPBIOMAS  
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RED AMAZÓNICA DE INFORMACIÓN  
SOCIOAMBIENTAL GEORREFERENCIADA



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DE LA AMAZONIA



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## **1. Introduction**

### **1.1. Scope and content of the document**

MapBiomás Agua – Venezuela's main objective is to map the dynamics of surface water in Venezuelan territory (Figure 1), using a monthly and annual time series covering the period 2000–2024. In addition, the project includes identifying the type of water bodies according to their origin (natural or anthropogenic), their use, and mapping the water in solid form (snow and ice) present in the country.

The results generated are available in the water module of the MapBiomás Venezuela web platform. All information is publicly accessible, with the aim of facilitating its use by government institutions, academic organizations, educational centers, and other interested parties nationwide, promoting a greater understanding of these hydrological systems, their dynamics, uses, and management processes.

The objective of this Algorithm Theoretical Basis Document (ATBD) is to provide a detailed and transparent description of the methodological procedures applied to generate monthly and annual surface water data in Venezuela, as well as the approach used to determine the origin of water bodies. In the case of glacier mapping, the methodology will be presented in a separate ATBD, specifically developed for this use case, which is based on the guidelines and procedures described by Turpo et al. (2022).

**Figure 1.** Venezuelan territory.



## 1.2. General description

The MapBiomias Water initiative originated from a previous study conducted by Imazon and WWF-Brazil in the Brazilian Amazon biome, later expanded to the Upper Paraguay basin in the Chaco biome (Souza et al., 2019). This work demonstrated the potential to strengthen the MapBiomias Initiative's capacity to detect and monitor surface water dynamics across all of Brazil's biomes. Based on these results, the MapBiomias Water working group extended the approach and methodology to the entire Brazilian territory.

In 2022, MapBiomias and the Amazonian Network of Georeferenced Socio-Environmental Information (RAISG) established a partnership to adapt and apply the MapBiomias Water methodology to all Amazonian countries, with the goal of generating comparable information that allows for the analysis and understanding of water dynamics throughout the region. Collection 1 of this initiative was published in September 2023.

The methodology for mapping and monitoring surface water is based on the subpixel-level classification of satellite images from the Landsat 5, 7, 8, and 9 sensors. This approach allows for the evaluation of changes that have occurred over the last 25 years (2000–2024), associated with both natural hydromorphological dynamics and anthropogenic pressures, as well as the potential effects of accelerating climate change. Furthermore, all mapped water bodies were classified according to their origin (natural or anthropogenic) and their use. The processing was performed entirely within the Google Earth Engine (GEE) environment, and the results, including monthly dynamics and temporal trends, are available on the interactive platform of [MapBiomias Water Venezuela](#), geared towards use by various actors.

With this update and the publication of Collection 3, the MapBiomás Water – Venezuela initiative will promote training activities aimed at diverse users, including representatives from academia, the private sector, and government entities. In this way, the availability of robust and standardized information on the country's water resources is consolidated as an essential input for guiding strategic actions for the conservation, restoration, and sustainable management of water and freshwater ecosystems.

### 1.3. Regionalization

For the execution of the water surface area calculation processes, the Venezuelan territory underwent a regionalization process, driven by the high physiographic, climatic, and hydrological heterogeneity that characterizes the country. In this context, the water body classification methodology developed by MapBiomás Agua was adapted to specific regions in order to more accurately represent the spatial and temporal dynamics of surface water. In Collection 3 of MapBiomás Agua – Venezuela, this regionalization was carried out at the level of river basins, which integrate and reflect the environmental characteristics of the main Amazonian, deltaic, Andean, Llanos, and Caribbean systems (Figure 2).

Consistent with the initiative's regional approach, each Amazonian country defined its own regionalization criteria, taking into account the biophysical, hydrological, and socio-environmental characteristics of its territory. This approach allowed for a deeper understanding of the dynamics of surface water bodies and improved the robustness and comparability of the results at the regional and national levels.

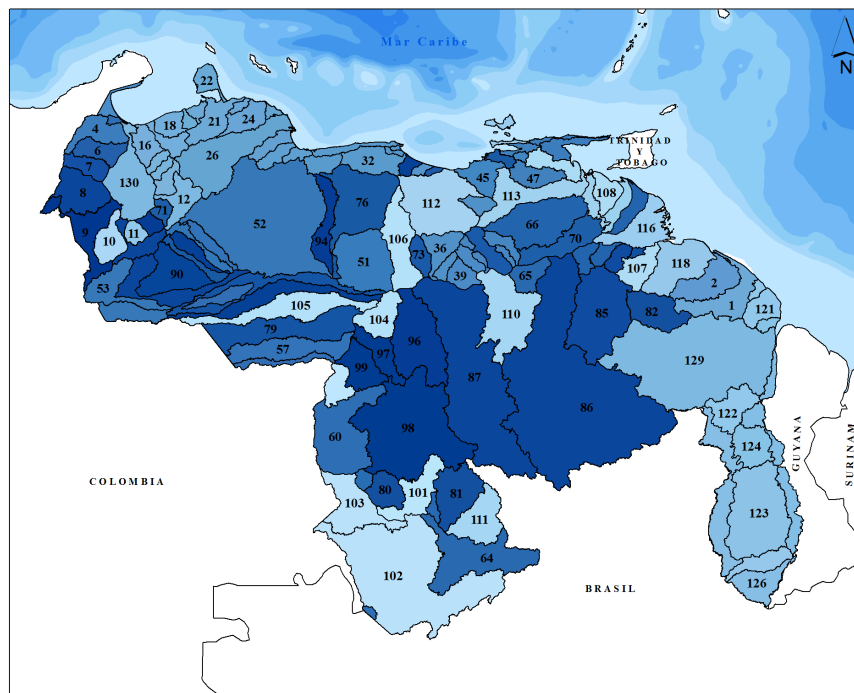


Figure 2. Regionalization of Venezuela

LEYENDA

100 Orinoco	128 Esequibo	37 Aragua	64 Mavaca	91 Pagüey
101 Cuncunuma	129 Cuyuní	38 Claro	65 Orocopiche	92 Guapo
102 Casiquiare - Río Negro	12 Motatán	39 Mapipe	66 Morichal Largo	93 Matiyure
103 Atabapo	130 Lago de Maracaibo	3 Carraipia - Paraguachón	67 Mariusa	94 Tiznado
104 Chaviripa	13 Motatán de los Negros	40 Cabrutica	68 Manaco	95 Tucaní
105 Arauca	14 Machango	41 El Perro	69 Upata	96 Cuchivero
106 Manapire	15 Chiquito	42 Aríbi	6 El Palmar	97 Suapure
107 Aganre	16 Pueblo Viejo	43 Limo	70 Uracoa	98 Ventuari
108 Capure	17 Maticora	44 Caris	71 Caús	99 Villacoa
109 San Juan	18 Capatárida	45 Neverí	72 Uchire	9 Catatumbo
10 Escalante	19 Lagarto	46 Carinucua	73 Aracay	
110 Aro	1 Barama	47 Guarapiche	74 Pao	
111 Ocamo	20 Arajó	48 Golfo de Cariaco	75 Manzanares	
112 Unare	21 Mitare	49 Norte de la Península de Paría	76 Guárico	
113 Amana	22 Península de Paraguaná	4 Guasare	77 Canaguá	
114 Manamo	23 Ricoa	50 Caño Guariquén	78 Apure	
115 Macareo	24 Hueque	51 Guariquito	79 Capanaparo	
116 Grande	25 Don Diego	52 Portuguesa	7 Apón	
117 Norte de la Península de Araya	26 Tocuyo	53 Uribante	80 Yagua	
118 Amacuro	27 Aroa	54 Sanare	81 Panamo	
119 Kuyuwini	28 Yaracuy	55 Santo Domingo	82 Corumo	
11 Mucujepé	29 Morón	56 Masparro	83 Aroy	
120 Maruca	2 Barima	57 Cinaruco	84 Candelaria	
121 Pomerun	30 Lago de Valencia	58 Meta	85 Yuruán	
122 Potaro	31 Litoral Central	59 Caño Guariquito	86 Caroní	
123 Rupununi	32 Tuy	5 El Limón	87 Caura	
124 Siparuní	33 Curiepe	60 Sipapo	88 Chama	
125 Superman	34 Cúpira	61 Guainía	89 Alto Apure	
126 Kassikaityu	35 Capaya	62 Mucuruco	8 Santa Ana	
127 Icabarú	36 Zuata	63 Iguapo	90 Suripa	

**Table 1.** Legend for Venezuela's classification regions

Note: For the territory corresponding to the state of Guayana Esequiba, the methodological regionalization followed a differentiated characterization. This is because it is a territory subject to international dispute, and its technical processing was carried out by the specialized team of MapBiomás Agua Venezuela, within the framework of the MapBiomás Agua initiative at the Amazonian scale.

However, through a legislative act of April 3, 2024, the [Guayana Esequiba state](#) was formally incorporated into the legal system of the Bolivarian Republic of Venezuela. Consequently, this territory is considered an integral part of the national territory and must be included in the surface water dynamics detection and monitoring processes developed by MapBiomás Agua Venezuela.

#### 1.4. Science and key applications

The dataset on the dynamics of surface water bodies in Venezuela is a fundamental input for understanding aquatic systems and their interaction with other environmental components. This information is key to supporting informed decision-making and strengthening integrated water resource management, with a focus on sustainable development.

In particular, systematic surface water mapping provides technical evidence to support integrated territorial planning, monitoring of progress toward the Sustainable Development Goals, the design and implementation of sustainable water management initiatives, and the monitoring of water use concessions and small-scale hydraulic infrastructure. It also allows for the assessment of the state of freshwater ecosystems, the promotion of scientific research, and the analysis of spatiotemporal changes in water bodies in relation to anthropogenic impacts and the effects of climate change.

## **2. General information and background**

### **2.1. Context and key information**

The conditions of numerous freshwater ecosystems have deteriorated significantly due to human activities in recent decades. Accelerated changes in land use and land cover, the construction of hydraulic infrastructure—particularly hydroelectric dams—pollution, and the overexploitation of water resources for the production of goods and services have substantially altered the quality, availability, and connectivity of water on a global scale. Recent scientific evidence indicates that freshwater species are experiencing extinction rates approximately twice as high as those of terrestrial ecosystems. This is compounded by the increased frequency and intensity of droughts and floods associated with climate change, which intensifies the pressure on water reservoirs and aquatic ecosystems.

This scenario is especially concerning in a context of sustained population growth. The world's population currently exceeds 8 billion, which implies a growing demand for water for human consumption, food production, energy, and industry. In Venezuela, with an estimated population of nearly 29 million, water is a strategic resource for both social well-being and economic development, particularly due to its relationship with hydroelectric power generation, food security, and the conservation of key ecosystems. Without the implementation of integrated, evidence-based water management strategies, achieving the global Sustainable Development Goals will be impossible. In this context, the continuous and historical assessment of changes in water surface dynamics at national and continental scales represents one of the main challenges for informed decision-making regarding this essential resource (Oliveira and Souza, 2019).

These challenges are especially relevant in the Amazonian countries, a region with the highest per capita freshwater availability on the planet, albeit with highly heterogeneous spatial distribution and quality. This situation demands differentiated actions and decisions that consider regional particularities, as well as the interconnected and cumulative effects of water use on ecosystems and societies. Addressing this complexity is only possible through access to consistent, detailed, and comparable data on surface water dynamics.

In this context, the surface water mapping methodology adopted by the MapBiomás Agua initiative has demonstrated its ability to identify, quantify and analyze the spatio-temporal dynamics of freshwater surface in Amazonian countries, with special emphasis on wetlands and other strategic aquatic ecosystems (Souza et al., 2019).

## **2.2. Historical perspective: existing maps and cartographic initiatives**

The use of satellite data has substantially transformed the ability to map, quantify, and analyze the spatial distribution and temporal dynamics of continental surface waters at regional, national, and global scales. In particular, the free and continuous availability of the historical Landsat image series, combined with the development of cloud computing infrastructures, enabled for the first time the generation of multi-decade global datasets on surface water dynamics.

In this context, the Global Surface Water (GSW) dataset, developed by the European Commission's Joint Research Centre (Donchyts et al., 2016; Pekel et al., 2016), stands out. It provides information on the extent, recurrence, and changes of surface waters globally, based on the analysis of more than 30 years of pixel-processed Landsat imagery. This product has been widely used in scientific studies and applications related to water management, hydrological risk assessment, and large-scale environmental change analysis.

However, the direct use of GSW for national or subnational analyses has significant limitations, particularly in regions characterized by extensive floodplains, complex wetlands, and small water bodies or those with high intra-annual variability. These limitations are mainly associated with the pixel-level classification approach, which can underestimate the presence of water in environments with spectral mixing, emergent vegetation, or pronounced seasonal hydrological dynamics.

To overcome some of these limitations, the MapBiomás Agua initiative adopts the same general paradigm of integrating Landsat imagery and cloud computing, but incorporates methodological innovations aimed at improving the detection, quantification, and characterization of surface water. Among these innovations, the application of a subpixel-level surface water classifier (Surface Water Subpixel Classifier, SWSC) stands out. Initially developed for the Brazilian Amazon biome, it was later expanded to other regional contexts (Souza et al., 2019).

This approach allows for a more accurate representation of the water fraction within each pixel, significantly improving the detection of small bodies of water, floodplains, wetlands, and areas with aquatic vegetation. The following sections of this ATBD describe in detail the conceptual foundations, data inputs, and methodological procedures associated with the implementation of this classifier in the context of MapBiomás Agua – Venezuela.

## **3. Methodology**

Integrating the historical Landsat imagery series with the cloud processing capabilities of the Google Earth Engine platform enabled the MapBiomás Agua initiative to generate a systematic and consistent dataset on surface water dynamics for all Amazonian countries. This approach facilitated the efficient processing of large volumes of satellite data and the continuous temporal analysis of water surface at multiple scales.

Figure 3 summarizes the main methodological steps of the process, which include the application of a surface water subpixel classifier (SWSC), the use of decision trees for class

discrimination, and a series of post-classification procedures aimed at refining the results. The final product is the generation of surface water datasets with monthly and annual temporal resolution, suitable for analyzing trends, transitions, and spatial patterns of continental water dynamics.

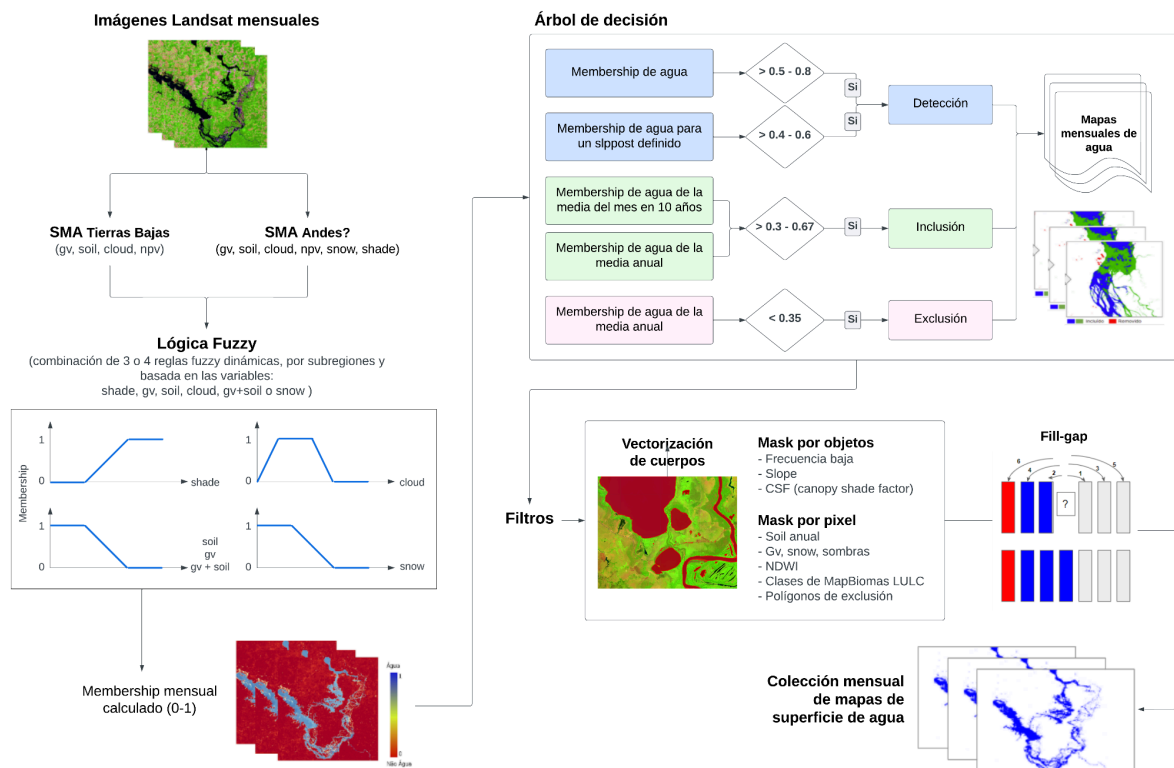


Figure 3. Methodological process for producing water surface data, 1996 - 2023.

### 3.1. Landsat images

The MapBiomass Agua initiative used images from the Landsat archive available on the Google Earth Engine (GEE) platform, incorporating data from the Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) sensors, corresponding to the Landsat 5, Landsat 7, Landsat 8 satellites. These images have a spatial resolution of 30 meters, suitable for the systematic analysis of surface water dynamics at a national scale.

Landsat Collection 2, Level 1, was used, composed of orthorectified and radiometrically calibrated images, which guarantees spatial and temporal consistency throughout the entire historical series. For processing, all Landsat scenes covering Venezuelan territory during the analysis period were considered, applying metadata-based filtering to exclude scenes with high cloud cover (greater than 70%) in order to optimize the quality of the information used in the classification.

The use of this multi-temporal historical series allowed for a robust characterization of the monthly and annual dynamics of the water surface in Venezuela, constituting the fundamental database for the application of the surface water classifier at the subpixel level and the subsequent post-classification processes developed by the MapBiomass Water initiative in Venezuela.

## **3.2. Algorithm for the Detection of Water Surfaces**

### **3.2.1. Spectral mixture analysis**

Spectral Mixture Analysis (SMA) allows for the estimation of the fractional composition of pure pixels (endmembers) of green vegetation (GV), non-photosynthetic vegetation (NPV), soil, clouds, shade, and snow. The subpixel-level information obtained through SMA is particularly useful for characterizing water bodies mixed with other components, such as soil and vegetation, thus overcoming the limitations of classifiers based on whole pixels. This capability is fundamental for mapping wetlands, floodplains, narrow rivers, and small water bodies.

The SMA application uses a generic endmembers library for Landsat images, which allows calculating the percentage of each component using the spectral demixing algorithm implemented in Google Earth Engine. Two application cases are presented:

- i) Amazon and lowland regions: The SMA is applied to each pixel using four endmembers: GV, Soil, NPV, and Cloud. The Shade fraction is calculated as photometric shade (zero reflectance in all bands) by subtracting the sum of GV, Soil, Cloud, and NPV from 1.
- ii) Andean regions, transition with Amazon and Pacific: in these regions the fractions are calculated directly using six endmembers in the SMA: GV, Soil, NPV, Cloud, Snow and Shade.

This approach ensures an accurate estimation of the subpixel composition in different regions of the territory, allowing the reliable detection of surface water mixed with other components, crucial for the characterization of complex ecosystems such as wetlands and floodplains.

### **3.2.2. Water surface subpixel classifier (SWSC)**

The Surface Water Subpixel Classifier (SWSC) is based on three hierarchical binary (true/false) decision rules, which use fractional information from Shade, GV, Soil and Cloud obtained through the SMA.

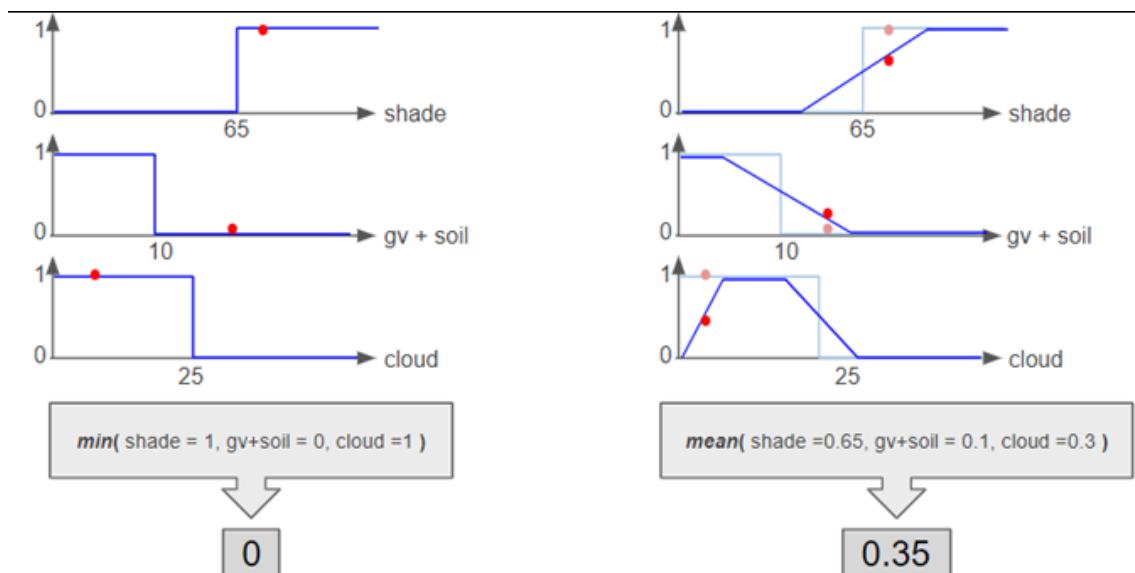
- Radiation absorption by water: Because water absorbs much of the electromagnetic radiation in the visible, near-infrared, and shortwave infrared bands of Landsat, pixels with a Shade fraction > 65% are initially classified as surface water.
- Mixture with vegetation and soil: Combined fractions of GV and Soil less than 10% allow the identification of surface water mixed with vegetation and soil, typical in the edges of water bodies, narrow rivers, wetlands and floodplains.
- Residual Cloud Fraction: A residual cloud fraction (<25%) is incorporated to detect surface water with high sediment load. This fraction accounts for the spectral

ambiguity of the cloudy soil endmember caused by the soil's spectral response in cloud-free pixels.

**Regional adaptation of the SWSC:** The fractional information used in the SWSC comes from the SMA, which is adjusted according to the region:

- In Amazonia and lowlands, the SMA uses four endmembers (GV, Soil, NPV, Cloud) with the Shade fraction calculated as photometric shade.
- In the Andes, transitioning with the Amazon and Pacific, the SMA uses six endmembers (GV, Soil, NPV, Cloud, Snow and Shade) to accurately capture subpixel composition in regions with snow and topographic complexity.

Empirical evaluations showed that the initial binary thresholds still excluded some surface water. To resolve this, transition rules (Figure 4) were defined using linear functions, transforming the binary logic into three independent fuzzy logics. Each pixel is assigned a membership level indicating the certainty of its classification as water, with values between 0 and 1. Subsequently, the average of the membership levels is calculated to generate a continuous surface water map, from which the monthly water surface layers are derived.



**Figure 4.** Binary rules of the surface water subpixel classifier. The diagram on the left shows an example of undetected surface water for a pixel with fraction values indicated by the red dots (the gv + soil value is above the threshold > 10 to be classified as water). The example on the right applies linear fuzzy logic to the variable, and the average value allows the pixel (red dot) to be correctly classified as surface water.

### 3.2.3. Adjustments based on the use of masks

- **Slope:** To generate monthly surface water maps of Venezuela, monthly membership maps were initially produced by calculating the median pixel memberships from all available Landsat scenes for each month between 2000 and 2024. Subsequently, pixels were classified as water based on defined membership thresholds (0.5–0.8), which vary according to the classification region. In some areas, a mask based on low stratified slope values (SLPPOST) was additionally applied, adjusting the threshold to

0.4–0.6, to broaden the detection of narrow rivers and water bodies with significant soil and vegetation mixing. This procedure allowed for the construction of monthly surface water time series for the entire period 2000–2024.

- CSF (Canopy Shade Factor / Factor de Sombra de Dosel): This index estimates vegetation cover and density based on the amount of sunlight intercepted by tree canopies and other plants. In Venezuela, it was used as an additional filter to eliminate false positives, preventing densely vegetated areas from being incorrectly classified as surface water.
- NDWI (Normalized Difference Water Index / Índice de Diferencia Normalizada de Agua): This spectral index is widely used in water body mapping, taking advantage of the differences in reflectance between the green and near-infrared (NIR) bands to highlight the presence of water. For Venezuela (and the other Amazonian countries), surface reflectance from Landsat images was used as input for calculating the NDWI.
- Coverage masks: Based on the land cover and land use product of MapBiomás Venezuela (Collection 2), thematic classes (e.g., urban or agricultural areas) were defined that served as input to generate masks, spatially reducing the incidence of false positives and improving the accuracy of the detection of bodies of water.

### 3.2.4. Obtaining monthly water data

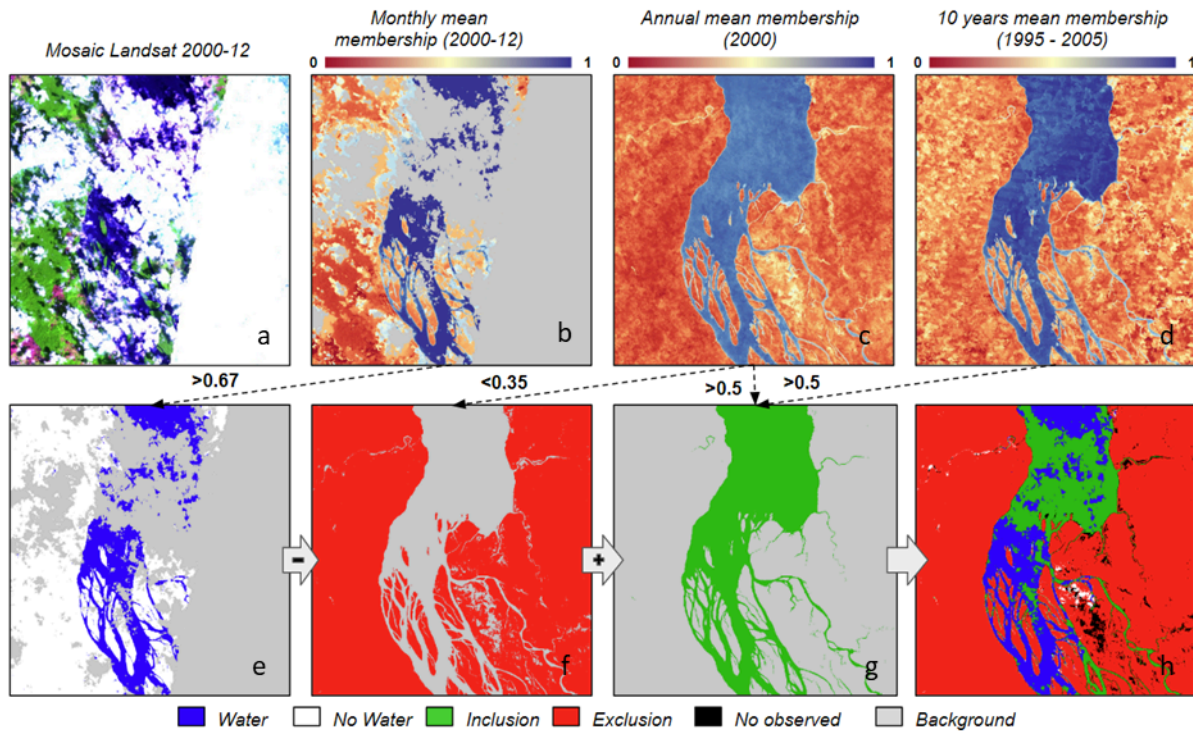
The generation of the monthly surface water maps included specific procedures to restore false negatives and eliminate false positives, based on temporal metrics (Figure 5).

First, the annual median water membership was calculated for each pixel (intra-annual median), as well as the corresponding ten-day median for each month. These values were used to implement gap filling, which allows pixels temporarily covered by clouds or lacking Landsat images during a given month to be reclassified as water. The reclassification was applied using a combination of two rules:

- The median probability within the year  $> 0.3–0.67$ .
- The ten-year median for the corresponding month  $> 0.3–0.67$ .

The range of thresholds is adjusted according to the classification region to reflect the geographical heterogeneity and hydromorphological characteristics of each area.

Additionally, a false positive removal filter was applied to correct the classification of surface water affected by cloud shadows or other dark objects present in the Landsat images. In this step, pixels with a median monthly membership  $< 0.35$  were reclassified as non-water, ensuring greater accuracy in the identification of surface water bodies.



**Figure 5.** a: Monthly Landsat mosaic; b: Monthly median SWSC membership; c: Annual monthly median SWSC membership; d: Decadal monthly median SWSC membership; e: Monthly surface water classification; f: Total surface water per decade; g: Area likely to be surface water based on the thresholds in c and d. h: Final surface water map for the month, with corresponding inclusion and removal.

### 3.2.5 Obtaining annual water data

Annual surface water maps include the classification of water bodies as permanent and seasonal, based on how frequently a pixel is classified as water throughout the year.

- Permanent water: pixels frequently  $\geq 6$  months a year.
- Seasonal water: pixels with a frequency between 1 and 5 months per year.

The threshold for identifying permanent water considers the existence of dry and wet seasons in most regions of the country, ensuring that all water bodies that maintain flow or storage during the dry season, but exhibit some natural variability, are correctly classified as permanent. This distinction allows for an accurate reflection of the annual hydrological dynamics of rivers, lakes, wetlands, and other aquatic ecosystems in Venezuela.

### 3.2.6. Categorization of bodies of water

The mapping of the water surface in Venezuela was structured in a two-level classification scheme, which considers both the origin and the use of water bodies:

According to its origin:

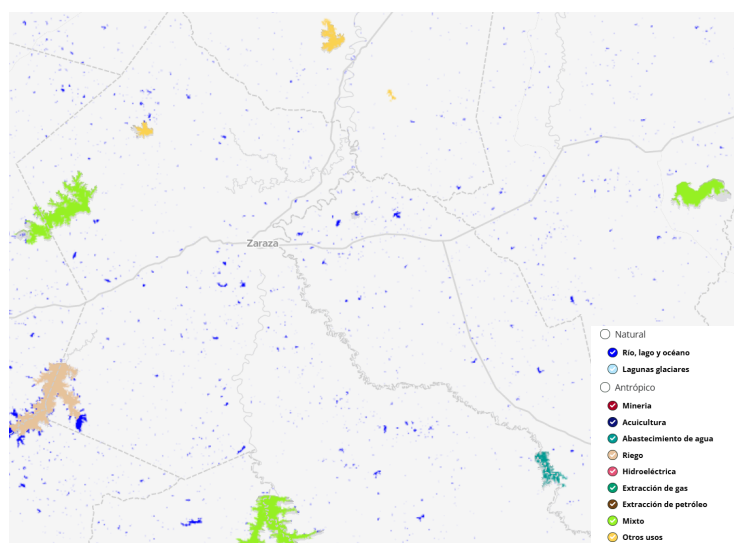
1. Natural: bodies of water that formed naturally.
2. Anthropogenic: bodies of water created or modified by human activities.

According to its use:

1. Natural:
  - a. Rivers, lakes and oceans.
  - b. Glacial lakes.
2. Anthropogenic:
  - a. Bodies of water associated with mining activities.
  - b. Bodies of water linked to oil exploitation.
  - c. Bodies of water linked to gas extraction.
  - d. Aquaculture.
  - e. Reservoirs for drinking water supply.
  - f. Reservoirs for agricultural irrigation.
  - g. Mixed-use reservoirs.
  - h. Hydroelectric plants.
  - i. Other uses.

Additionally, a false positive category was incorporated as a byproduct of the classification process, intended to eliminate residual cases of erroneous detections that could persist in the monthly and annual water surface layers.

This multi-level approach allows not only the identification of the presence of surface water, but also its characterization according to its origin and function, facilitating hydrological analysis, water resource management and territorial planning.



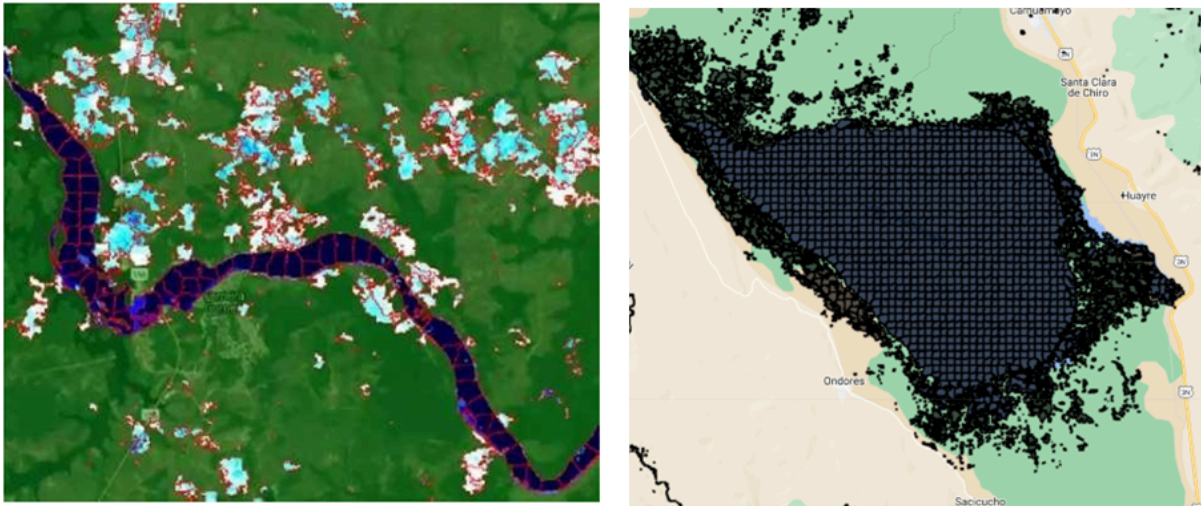
**Figure N° 6.** Example of categories of water bodies according to their origin and use, Orinoquia biome

### 3.2.6.1. Object delimitation

The vector delimitation of the water bodies was carried out through a process called annual vectorization, which consists of converting the monthly frequency raster maps of water surface into regular polygons (vector data) corresponding to each year, respecting the spatial delimitation of the identified water bodies.

For this procedure, a segmentation tool was used, in which a given body of water could generate one or more polygons, depending on its shape and spatial dynamics. In particular, the SNIC (Simple Non-Iterative Clustering) function available in Google Earth Engine was used, which allows the generation of small, regular segments consistent with the morphology of the bodies of water.

Figure 7 presents examples of annual segmentation based on monthly frequency data, illustrating how vectorization transforms raster maps into vector polygons ready for hydrological analysis, land planning, and water resource management.



**Figure N° 7.** Examples of the segmentation process that converts raster data (monthly frequency within each year) into a mesh of regular vectors

### **3.2.6.2. Assigning object properties (SNIC - properties)**

After generating the vector objects for each year, each object was assigned a set of attributes with properties relevant for its subsequent use in the classification and analysis of water bodies. These properties include information related to the object's morphology, geomorphology, and qualitative data from other studies on water body classification and land cover and land use mapping.

The variables assigned to each object include:

1. Morphometrics: area, perimeter, area/perimeter ratio, compactness, roundness, degree of elongation, Laenge-Breite ratio, convexity, maximum extension.
2. Spatial: number of neighbors, number of neighbors within a 50-meter buffer.
3. Classification of origin and use: ANA classification (anthropogenic), ANA classification (hydroelectric).
4. Land cover and land use: MapBiomass classes (urban, mining, forest, non-forest class, pasture).
5. Other variables: maximum value of the SRTM model and mean of the total water frequency.

The integration of these properties allows for a detailed characterization of each body of water, facilitating morphometric, spatial, and functional analyses, as well as the implementation of more precise and consistent classification processes throughout the time series.

### 3.2.6.3. Object classification based on training samples

The classification of water bodies was carried out using the Random Forest algorithm, an ensemble classifier based on decision trees that allows handling large volumes of data and correlated variables, guaranteeing high accuracy and robustness in prediction.

Training samples were collected representatively across the country's various biomes, encompassing five of the 11 classes defined for classification. To ensure spatial and temporal coverage, samples were selected using a set of predefined grids in each biome, including different years within the analyzed time series (2000–2024). This approach allowed for capturing the spectral and morphological variability of water bodies, optimizing classifier performance and ensuring the consistency of results across the different ecosystems and time periods analyzed.

For use, all available sample collections were grouped into a single asset, ensuring that all reference points are centralized and ready for analysis along with their properties, facilitating classifier training and results validation.

Finally, the prepared samples are used directly in training the Random Forest algorithm, ensuring that the classification correctly captures the differences between natural and anthropogenic water and reducing false positive and negative errors.

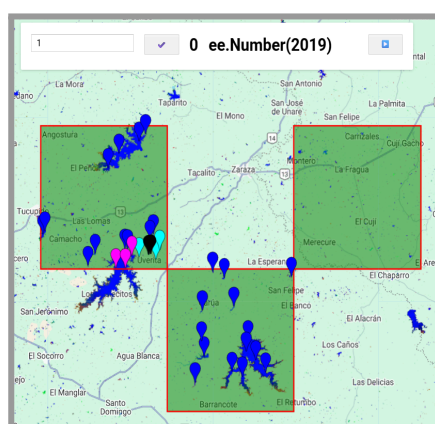


Figure N° 8. Sampling

### 3.2.6.4. Temporary filter

Following the classification of the water bodies, the results underwent a post-classification process using a temporal filter. The logic behind this filter was to eliminate improbable transitions between classes within the same segment over the time series, ensuring the spatial and temporal consistency of the data.

Additionally, all polygons classified as false positives in each year were converted to raster format and used to clean the annual and monthly water surface datasets. This procedure eliminated residual false positives, improving the accuracy and consistency of the final MapBiomass Agua Venezuela products.

### 3.2.6.5. Post-classification filter

During the post-classification of water bodies, sequential filters were implemented to improve the consistency and accuracy of the annual classification. These filters primarily aim to eliminate false positives, correct unlikely transitions, and adjust the classification based on the actual dynamics of the water bodies.

1. False positive frequency filter:
  - a. The frequency of false positives was calculated over the time series (2000 - 2024).
  - b. Pixels with false positive frequency above the threshold ( $\geq 40\%$ ) were reclassified, ensuring that persistent detections of erroneous classes were corrected.
2. Filters based on time sequences:
  - a. The sequences of appearance of natural and anthropogenic water were evaluated in the different years, using the first years of detection as a reference.
  - b. This information allowed for the reclassification of inconsistent pixels, preventing incorrect assignments of natural water as anthropogenic water and vice versa..
3. Consistency filter with integrated annual maps:
  - a. The classification results were compared with annual water frequency maps (pixels classified as water  $\geq 6$  months per year).
  - b. Pixels that did not match this frequency were adjusted, eliminating inconsistent or temporary water detections that could correspond to false positives.
4. Water presence percentage filter:
  - a. The proportion of water detections per pixel was calculated over the time series.
  - b. Those pixels with a presence above a defined threshold ( $\geq 75\%$ ) were consolidated as natural water, while pixels with less consistency were reclassified to avoid residual errors.

These filters integrate frequency information, time sequences, and annual maps, ensuring that the final classification of water bodies is consistent, accurate, and representative of the actual hydrological dynamics, allowing its reliable use in hydrological analysis, water resource management, and land-use planning.

### 3.2.6.6. Masking of anthropic classes

In this phase, specific masks were applied to identify and classify bodies of water of anthropogenic origin, differentiating their typology according to use: reservoirs of drinking water, irrigation and mixed, bodies associated with oil and gas extraction, aquaculture, hydroelectric and other uses.

To achieve this, auxiliary vector and raster layers representing the location of each typology were used. These layers were reprojected, buffered, and converted to raster, generating binary masks that were integrated with the segmented objects and the MapBiomias Water base classification.

Masking allowed for the correct assignment of pixels to their corresponding anthropogenic category and prevented the incorrect reclassification of natural water bodies. In this way, the final classification combines information on origin and use, ensuring spatial and temporal consistency across the 2000-2024 data series.

### 3.2.6.7. Types of bodies of water

The classification of water bodies in MapBiomias Agua is structured in two hierarchical levels: by origin (natural vs. anthropogenic) and by use, allowing for a functional and ecological characterization of the water bodies identified in Venezuelan territory. This classification is based on definitions gathered from scientific literature and water resource management guidelines that consider hydrological, geomorphological, and functional criteria of water bodies.

#### Level 1: Origin of bodies of water

1. **Natural:** These are bodies of water that exist in the landscape without direct human intervention, resulting from hydrological and geomorphological processes inherent to the Earth system. These water bodies are generated by the accumulation, flow, or storage of surface water and perform essential ecological functions in hydrological and biogeochemical cycles.
2. **Anthropogenic:** These are bodies of water created, modified, or maintained by human activities, such as the construction of hydraulic structures, the alteration of riverbeds, the exploitation of resources, or the design of production units. These bodies of water may not exist naturally in the absence of human intervention, or they may exhibit significant alterations to their original hydromorphology.

#### Level 2: Classification according to use

1. **Natural bodies of water:** These classes correspond to bodies of water whose existence and essential dynamics respond to natural processes of the physical and biological environment.

- 1.1. Rivers, lakes, and oceans: Surface bodies of water with continuous or periodic flow along a defined channel, transporting water from higher elevations to lower elevations or to other receiving bodies of water (lakes, lagoons, or oceans). They represent lotic systems characteristic of continental hydrographic networks.
- 1.2. Glacial lakes: These are surface water bodies formed as a result of glacial activity, typically in depressions created by glacial erosion or in moraine areas. These lakes are characterized by their recent geological origin, cold waters, and low nutrient load, and are usually found in mountainous regions or at high latitudes. They play a crucial ecological and hydrological role, serving as freshwater reservoirs and regulating flows in tributary rivers. (Glasser et al., 2016)
2. Anthropogenic water bodies: The following classes are used to categorize water bodies whose presence, form, or function are directly associated with human activities:
  - 2.1. Reservoirs for drinking water supply: Bodies of water artificially stored by structures (dams, dikes) intended for the collection, regulation, and supply of water for human consumption. The creation of reservoirs is part of water resource management to guarantee availability during dry periods or periods of high demand.
  - 2.2. Reservoirs for agricultural irrigation: Reservoirs constructed primarily to store water for use in irrigation systems, supporting agricultural activities. Their operation is aligned with seasonal moisture requirements.
  - 2.3. Mixed-use reservoirs: Water storage structures that combine multiple purposes, such as human supply, irrigation, flood control, recreation, or energy generation.
  - 2.4. Hydroelectric plants: Bodies of water that are dammed and managed for the purpose of generating electricity, where the regulation of the flow and level of water is geared towards the production of energy.
  - 2.5. Aquaculture: Bodies of water designed and maintained for the rearing and production of aquatic organisms, such as fish and shrimp, in controlled production systems. This use modifies the original aquatic system and creates a body of water managed for production purposes.
  - 2.6. Water bodies associated with mining activities: these are those whose formation or alteration is linked to the extraction of minerals, deposits or materials, where the extractive processes affect the hydromorphology and water quality.
  - 2.7. Water bodies linked to oil exploitation: these are surface water bodies that result from or are affected by hydrocarbon extraction activities, including wells and associated operating areas, with potential hydrological and chemical impact.
  - 2.8. Water bodies linked to gas extraction: With characteristics similar to bodies intended for oil exploitation, these water bodies are associated with gas extraction activities, whose operational mechanisms can modify the local aquatic environment.
  - 2.9. Other anthropogenic uses: Includes bodies of water created or maintained for various activities that do not fit into the above categories, such as storage for industrial, recreational, or other specific socioeconomic purposes.

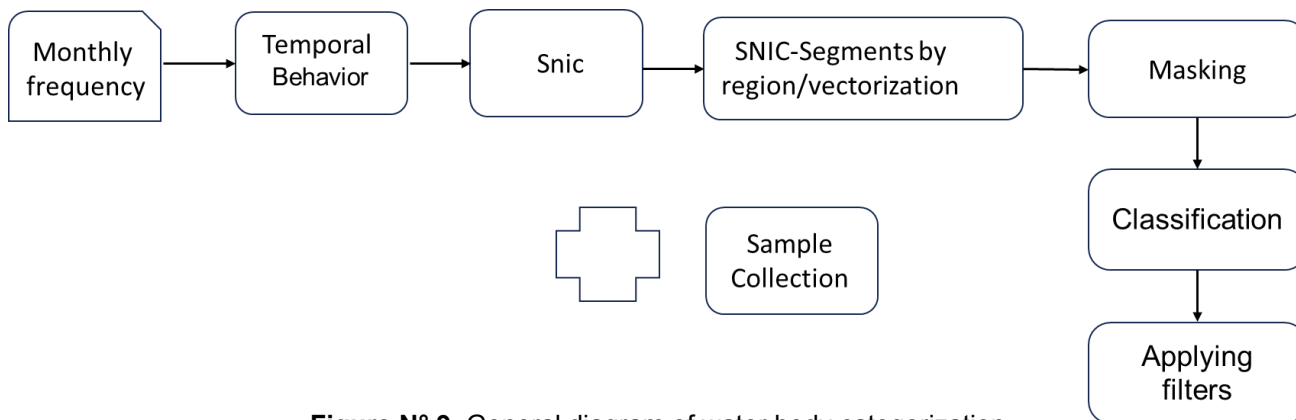


Figure N° 9. General diagram of water body categorization

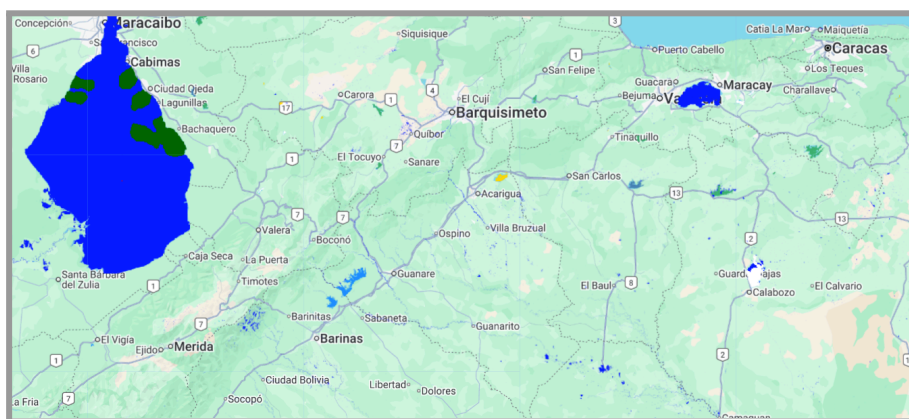


Figure N° 10. Preliminary result of the classification of water bodies

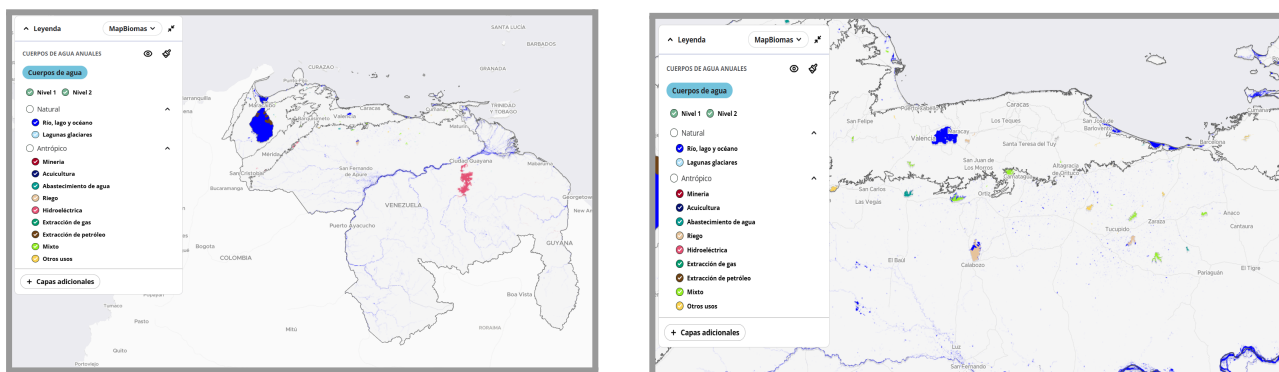


Figure N° 11. Show the results obtained for Venezuela.

Codes for the classes of water bodies and color palette used in Collection 3 of MapBiomias Water Venezuela				
Level 1				
2. The classification of bodies of water according to their origin	2. La clasificación de los cuerpos hídricos según su origen			
2.1. Natural	2.1 Natural	1	#0000ff	
2.2 Anthropics	2.2 Antrópico	2	#00D7EE	
Nivel 2				
The classification of bodies of water according to their use	La clasificación de los cuerpos de agua según su uso			
1. Rivers, lakes and oceans	1. Ríos, lagos y océanos	1	#0000ff	
Glacial lagoons	1.1. Lagunas Glaciares	4	#b3e5fc	
2. Anthropics	2. Antrópicos			
2.1. Mining	2.1. Minería	2	#AC0024	
2.2. Aquaculture	2.2. Acuicultura	3	#091077	
2.3. Water supply	2.3. Abastecimiento de agua	5	#009b94	
2.4. Irrigation	2.4. Riego	6	#e8c39e	
2.5. Mixed	2.5. Mixto	7	#97f425	
2.6. Hydroelectric	2.6. Hidroeléctrica	8	#E65277	
2.7. Other uses	2.7. Otros usos	9	#fed353	
2.8. Gas extraction	2.8. Extracción de gas	10	#009d71	
2.9. Oil extraction	2.9. Extracción de petróleo	11	#704214	

**Table 2.** Legend Level 1 and 2 of the water bodies of the MapBiomias Water collection.

#### 4. Collection of maps and analyses

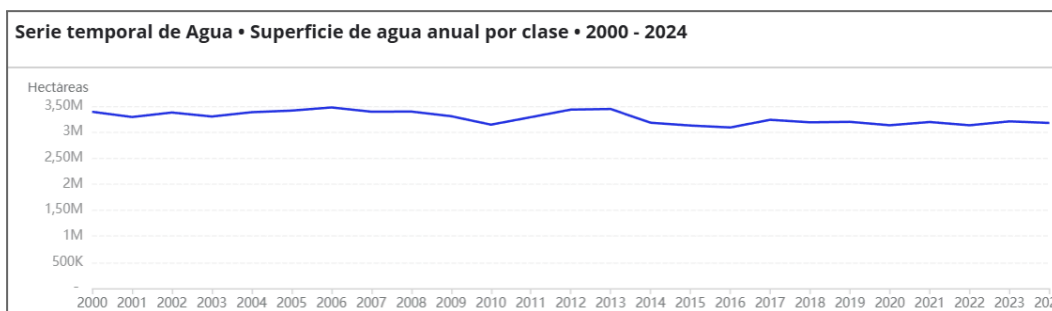
Collection 3 of the water surface mapping, both liquid and solid, is available on the MapBiomias Agua Venezuela public web platform: <https://plataforma.venezuela.mapbiomas.org/agua>.

Esta plataforma integra cuatro coberturas principales de información: (i) water surface, (ii) annual water bodies classified according to their origin and type of use, (iii) Glacier, and (iv) monthly water surface, (V) water frequency

##### 4.1. Annual surface water area

The surface water layer corresponds to the annual coverage mapped for the entire Venezuelan territory, including all 26 federal entities. The data covers the period 2000–2024 and shows the presence of water.

The information is also structured by different administrative and ecological boundaries, such as country, biomes, state, municipality, watersheds, administrative regions, physiographic regions, and indigenous territories. This allows the user to select the territorial grouping of interest and define specific time ranges, dynamically updating maps, charts, and statistics according to their analysis preferences.



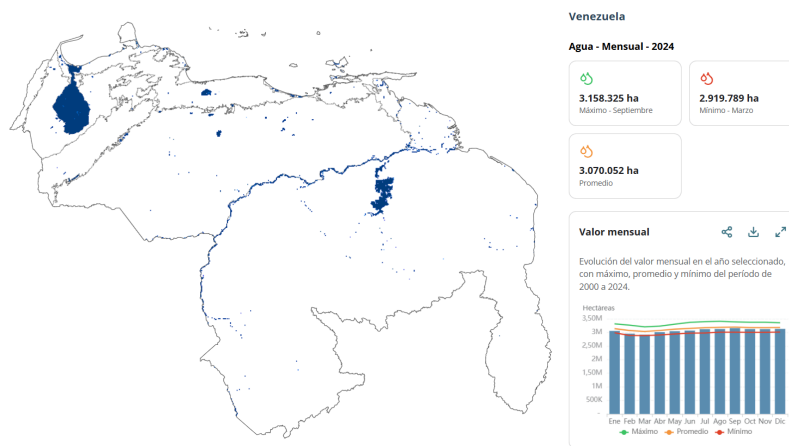
**Figure 12.** Example of visualization of the water surface layer data (map and graph) on the MapBiomias Agua Venezuela platform.

#### 4.2. Monthly surface water area

The monthly surface water layer provides detailed information on the temporal dynamics of water bodies in Venezuela, covering the period 2000–2024. This layer provides the water surface area for each month of the year, allowing precise identification of the months with maximum and minimum water extent within the selected year.

In addition to spatial visualization, the platform incorporates monthly graphs showing the variation in water surface area throughout the year, as well as monthly trends calculated for the entire analysis period. This functionality allows for the evaluation of seasonal patterns and the detection of significant changes in surface water availability over time.

Similar to the annual layer, the monthly data can be visualized and analyzed according to different territorial groupings: country, biome, state, municipality, watersheds, administrative regions, physiographic regions, and indigenous territories. This facilitates a comparative and detailed analysis of water dynamics at different spatial and temporal scales, adapting to the specific needs of the user.



**Figure N° 13.** Visualization of monthly water surface layer data on the MapBiomos Agua Venezuela platform.

### 4.3. Annual water frequency

The water frequency layer provides annual information on the persistence of water surfaces in Venezuelan territory, considering the period 2000–2024. This layer represents the frequency with which a pixel is detected as water throughout the year, showing values ranging from 1 time to 25 times or more, depending on the constancy and permanence of the water bodies.

The data are presented in a geospatial manner and can be grouped according to different territorial boundaries, including country, biomes, state, municipality, watersheds, administrative regions, physiographic regions and indigenous territories, allowing analysis at different spatial scales and facilitating comparison between regions and types of water bodies.

Additionally, the platform's right-hand panel provides a frequency graph by class, showing the pixel distribution according to the number of times water is detected. This graph includes numerical values for each frequency class, allowing the user to quantify and analyze the persistence of water bodies in each selected territorial unit or category.

This information is fundamental for studies of water dynamics, water resource management, conservation of aquatic ecosystems and territorial planning, as it allows the identification of areas of permanent, seasonal or transient water.

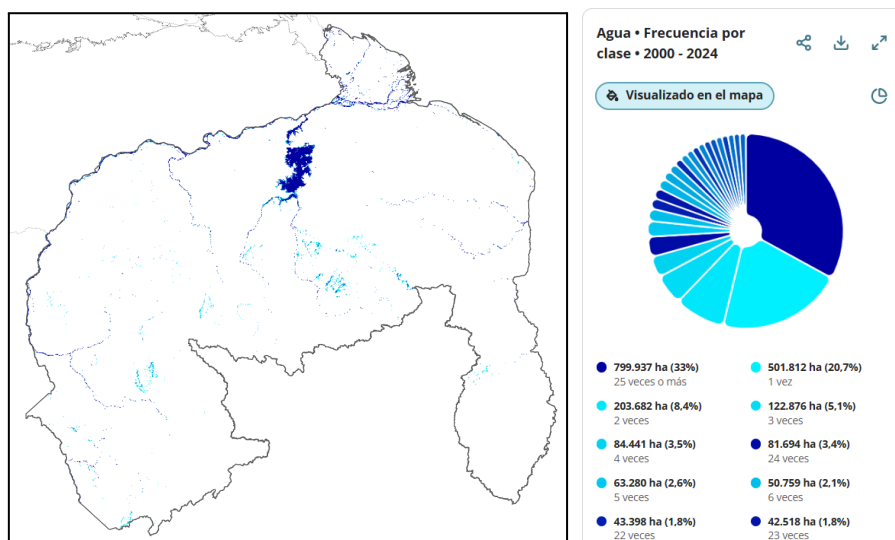


Figure N° 14. Visualization of water frequency layer data on the MapBiomás Agua Venezuela platform.

#### 4.4. Annual bodies of water

The annual water bodies layer presents the detailed classification of water bodies in Venezuela, showing the different categories according to their origin and use, including natural water bodies (rivers, lakes, oceans and lagoons of glacial origin) and anthropogenic ones (reservoirs for drinking water supply, irrigation, mixed use, hydroelectric, aquaculture, oil and gas extraction, mining and other uses).

Data is available for each year in the 2000–2024 series, allowing for the evaluation of the temporal dynamics of each type of water body. Visualization can be performed using different territorial groupings, as in the previous cases, thus offering flexible analysis at different spatial scales.

The right-hand side panel of the platform provides graphics that allow you to explore both the surface area occupied by each type of water body and the associated temporal trend, facilitating the identification of patterns of expansion, contraction or stability of the different water bodies over the years.

This layer is essential for water resource management, land-use planning, monitoring of human impacts and conservation of aquatic ecosystems, by providing accurate and categorized information on the annual distribution and behavior of water bodies in Venezuela.

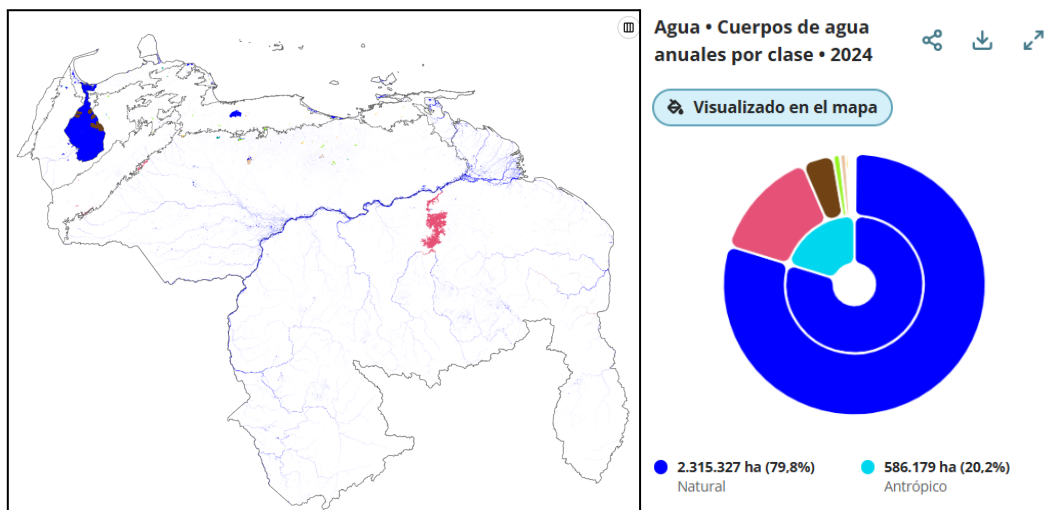


Figure N° 15. Visualization of water body type data on the MapBiomás Agua Venezuela platform.

## 5. Practical considerations

The third version of this product represents a significant step forward in continuous improvement, incorporating observations and suggestions derived from the use and analysis of the first version. This product is conceived as a dynamic tool, designed not only to provide reliable and relevant data, but also to evolve in response to user needs and available technological innovations.

All generated data is publicly available, promoting transparency and open access. This approach allows users to review the content, assess its accuracy, and identify potential adjustments, facilitating an iterative feedback process that strengthens the product's updates and relevance. Contributions from the scientific community and other users are essential to ensuring that future versions continue to improve and adapt to practical and analytical requirements.

Users are advised to consider that the application of quantitative data should be accompanied by a rigorous review of the levels of precision and associated uncertainty metrics (this collection includes details on data precision in the Andes and tepuis in the information note). This ensures a robust interpretation and a proper assessment of its applicability in different contexts. The data should be compared with other sources or complementary studies to validate the results and identify potential limitations.

This adaptive approach reinforces the developers' commitment to the quality and usefulness of the product, promoting collaboration between the scientific community and users, and maximizing the positive impact of this dataset on research, water resource management, and evidence-based decision-making.

## 6. Final conclusions and perspectives

The MapBiomass Water Collection 3 is a fundamental product for mapping water surface areas in Amazonian countries, consolidating the progress achieved in Collection 2. This product represents a significant contribution to understanding the spatial and temporal dynamics of freshwater ecosystems, providing detailed information on patterns of change, cycles of increase or decrease, and allowing for the estimation of gains or losses of water surface area over time.

The results obtained allow us to associate the observed changes with human activities, such as agricultural use, reservoir creation, mining or energy exploitation, and other anthropogenic pressures, generating valuable knowledge about the interactions between natural systems and human interventions. In this way, mapping not only offers a quantitative description of water surface areas, but also becomes a tool for analyzing processes and trends critical to the sustainable management of water resources.

The development of this product strengthens the objectives of the MapBiomass Agua and RAISG initiatives, highlighting the value of collaborative work among institutions, researchers, and local communities. The public availability of the data promotes transparency, facilitates open access, and allows its use by decision-makers, environmental managers, researchers, and communities, who can employ the information for planning actions related to the conservation, restoration, and sustainable use of water resources.

It is emphasized that, for proper interpretation of the data, users should consider the levels of precision and associated uncertainty metrics, comparing the information with other sources or complementary studies when necessary. This approach ensures responsible use and a robust assessment of the data's applicability in different environmental and management contexts.

In general terms, Collection 3 of MapBiomass Water represents a significant technological and scientific advance, consolidating a dynamic and updated product that contributes to the comprehensive understanding of water bodies in the Amazon region, promoting continuous improvement, scientific collaboration and the generation of knowledge that supports the sustainable management and conservation of aquatic ecosystems.

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