MAPBIOMAS
COLOMBIA

Flooded Land Covers - Appendix

Algorithm Theoretical Basis Document - ATBD

Collection 4.0

Version 1.0



November de 2026

MapBiomas Colombia Project Coordination
Adriana Rojas Suárez

MapBiomas Colombia Project Technical Coordination
Karen Andrea Huertas

Cross-cutting Technical Leads for Floodable Areas
Janner Simbaqueba
Miguel Restrepo

Development
Luis Medina

Team of Specialists
Janner Simbaqueba
Miguel Restrepo

Document Structure and Writing
Miguel Restrepo
Janner Simbaqueba

Institution
Fundación Gaia Amazonas

Gaia
Amazonas

Calle 70a # 11- 30

Bogotá, Colombia.

(57-1) 772 35 42 / (57-1) 805 37 68

contacto@gaiaamazonas.org

https://www.gaiaamazonas.org

How to cite:
MapBiomas Colombia. (2026). Appendix – Floodable Land Cover. Collection 4.0 of the Annual Series of Land Cover and Land Use Maps of Colombia (1985–2025). Fundación Gaia Amazonas. https://plataforma.colombia.mapbiomas.org/

CONTENT

1. Introduction.....7
2. MapBiomas Colombia Methodology – Flooded Land Cover Cross-Cutting Theme.....11
    2.1. Methodological Workflow.....11
    2.2. Definition and Generation of Satellite Mosaics..... 12
    2.3. Topographic Correction.....13
    2.4 Comparison of Landsat Mosaic Processing..... 14
    2.5 Operational Classification Regions.....15
    2.6 Selección de variables de clasificación.....16
    2.7 Training Samples..... 18
3 Classification.....19
    3.1 Identified Classes..... 20
        3.1.1 Flooded Forest (ID 6).....20
        3.1.2 Wetlands - (ID 11).....25
        3.1.3 Flooded Andean Herbaceous and Shrubby Vegetation (ID 82)..... 29
4 Post-clasification..... 31
    4.1 Gap Fill..... 31
    4.2 Temporal filter..... 31
    4.3 Filtro espacial..... 32
    4.4 Frequency filter..... 32
    4.5 Spatial filter based on slope and HAND..... 33
5 References.....34

ÍNDEX TABLES

Table 1. Reference layers used in the project. Source: Adapted from MapBiomas Collection 3 (MapBiomas C3, 2025)..... 15

Table 2. Variables used for the classification of flooded land cover classes in Collection 4. *Kauth, R. J. and Thomas, G. S. (1976) developed coefficients to enhance the information contained in Landsat spectral bands, resulting in a set of equations known as the Tasseled Cap (TC) transformation. This transformation is represented by three components: Brightness, which is associated with variations in soil reflectance; Greenness, which is correlated with vegetation vigor; and Wetness, which is influenced by the middle-infrared bands and is related to vegetation and soil moisture (Kauth & Thomas, 1976).....17

Table 3. Reference sources for Flooded Forest (ID 6), Wetland (ID 11), and Flooded Andean Herbaceous and Shrubby Vegetation (ID 82). Source: Prepared by the authors.....18

Table 4. Temporal filter rules and results. Source: MapBiomas Collection 4, 2022. GR denotes a general rule, applied to all intermediate years (1986–2025); FR denotes a first-year rule, applied only to 1985; and LR denotes a last-year rule, applied to 2025. T0 is the year to which the filter is applied, T–n denotes the preceding years, and T+n the subsequent years. FF: Flooded Forest; WL: Wetlands; NO: Not observed.....32

LIST OF FIGURES

Figure 1. Flooded forests – Isana-Surubí Indigenous Territory (Photograph by: Felipe Rodriguez)..... 8
Figure 2. Formación natural no forestal inundable - Paz de Ariporo (Photograph by: Nestor Espejo)..... 8
Figura 3. Flooded Andean herbaceous and shrubby vegetation - National Natural Park Sumapaz (Photograph by: Yulieth Ávila)..... 9
Figure 4. Division by Natural Regions to Ensure Thematic Consistency in Land Cover Interpretation..... 10
Figure 5. Methodological Workflow for Flooded Land Cover Identification..... 12
Figure 6. Comparación de procesamiento de Mosaicos Landsat..... 14
Figure 7 Delineation of Classification Regions Based on Reference Maps. Source: Prepared by the authors. A total of 55 classification regions were delineated across the Colombian territory, of which 19 correspond to the Amazon biome, 13 to the Andean biome, 7 to the Caribbean biome, 7 to the Orinoquía biome, 6 to the Pacific biome, and 3 to the insular biome. 16
Figure 8.Training samples: (a) composition of the reference mask used for training sample generation, illustrated here with CIFOR reference data (yellow) and national reference data (red); (b) randomly selected training samples for Flooded Forest (ID 6); and (c) randomly selected training samples for Wetland (ID 11). Source: MapBiomas Colombia Collection 4 (2025)..... 19
Figure 9. Spectral Response of Flooded Forest in the Amazon Biome. Mapiripán, Meta, Colombia. Year: 2024. Scale: 2 km. Coordinates: -72.1335 W, 2.8923 N. (Legend Flooded Forest)..... 20
Figure 10. Spectral Response of the Flooded Forest Class in the Caribbean Biome. Magdalena River, border area between Bolívar and Santander. Year: 2022. Scale: 200 m. Coordinates: -73.82262 W, 7.76953 N (Legend Flooded Forest)..... 21
Figure 11. Spectral Response of Flooded Forests in the Orinoquía Biome. Tuparro River, Cumaribo, Vichada. Year: 2021. Scale: 1,000 m. Coordinates: -68.04943 W, 5.21289 N (Legend Flooded Forest)..... 22
Figure 12. Spectral Response of Flooded Forest in the Pacific Biome. Atrato River, Riosucio, Chocó. Year: 2024. Scale: 500 m. Coordinates -77.10302 W, 7.45646 N (Legend Flooded Forest)..... 23
Figure 13. Spectral response of Flooded Forest in the Andes biome. Otún Quimbaya Fauna and Flora Sanctuary (SFF), Riosucio, Risaralda. Year: 2023. Scale: 100 m. Coordinates: -75.564356 W, 4.732231 N (Legend Flooded Forest)..... 24
Figure 14. Spectral Response of Wetland in the Amazon Biome. Apaporis River, on the border between Vaupés and Amazonas departments. Year: 2021. Scale: 1 km. Coordinates: -70.91985 W, -0.16152 (Legend Wetlands)..... 25
Figure 15. Spectral Response of Wetland in the Andean Biome. Sopó, Cundinamarca. Year: 2021. Scale: 200 m. Coordinates: -73.98374 W, 4.95135 N. (Legend Wetlands).. 26
Figure 16.Spectral Response of Wetland in the Caribbean Biome. Zurra Swamp, Tenerife, Magdalena. Year: 2022. Scale: 500 m. Coordinates: -74.85062 W, 9.86896 N. (Legend Wetlands)..... 27
Figure 17. Spectral Response of Flooded Forest in the Orinoquía Biome. Tuparro River,

Cumaribo, Vichada. Year: 2021. Scale: 1,000 m. Coordinates: -68.04943 W, 5.21289 N. (Legend Wetlands)..... 28
Figure 18. Spectral Response of Flooded Forest in the Pacific Biome. Atrato River, Riosucio, Chocó. Year: 2018. Scale: 500 m. Coordinates: -77.10302 W, 7.45646 N (Legend Wetlands). 29
Figure 19 Spectral response of Flooded Andean Herbaceous and Shrubby Vegetation in the Andes biome. Location: Pasto, Nariño. Coordinates: -77.214138 W, 0.976932 N, Escale: 500 m, Year: 2024. (Legend Flooded Andean Herbaceous and Shrubby Vegetation).....30
Figure 20. Gap-fill filter. Source: MapBiomas Collection 4, 2026..... 31
Figure 21. Effect of the spatial filter. Source: MapBiomas Collection 4, 2026..... 32
Figure 22. Effect of the frequency filter. Source: MapBiomas Collection 3, 2025..... 33
Figure 23.Spatial filter based on slope and HAND. Source: MapBiomas Collection 3, 2025...34

1. Introduction

Colombia exhibits remarkable wetland diversity as a result of its topographic heterogeneity and intertropical location, which give rise to distinctive climatic regimes (Vilardy et al., 2004). These ecosystems provide a wide range of ecosystem services that are essential both for associated biota and for the human communities that depend on them (de Groot et al., 2006; Maltby et al., 2013). However, the interaction between natural dynamics and anthropogenic pressures results in high spatiotemporal variability within these systems, making their delineation and monitoring using remote sensing more challenging (MEA, 2005; Patiño & Estupiñan-Suarez, 2016).

This complexity, together with the ecological importance of these ecosystems, calls for the development of dedicated mapping methodologies capable of more accurately capturing their physical characteristics. In this context, the approach implemented in **MapBiomas Colombia Collection 4** addresses this challenge by classifying three key floodable land cover classes, providing a basis for further investigating and understanding their spatiotemporal dynamics: **Flooded Forests (ID 6), Natural Non-Forest Floodable Formations (ID 11), and Andean Floodable Grasslands or Shrublands (ID 82).**

The conceptual framework for mapping these land cover classes is based on the definition established by the Ramsar Convention (Iran, 1971). Article 1.1 of the Convention provides a broad definition:

"For the purpose of this Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.".

This definition is further expanded in Article 2, which states that wetlands **"may incorporate adjacent riparian and coastal zones, as well as islands or bodies of marine water deeper than six metres at low tide lying within the wetland"**. This general framework is adapted to specific regional contexts by incorporating the observations of Wittmann et al. (2011) for the Amazon Basin. These authors highlight that the characteristic unimodal flood pulse in this region generates water depths ranging from 6 to 16 metres, exceeding the Ramsar threshold and resulting in clearly differentiated annual aquatic and terrestrial phases (Wittmann et al., 2011).

Flooded forests are primarily distributed as continuous forest stands across alluvial valleys (see Figure 1). The largest areas are found in the Amazon and the biogeographic Chocó regions. In the Orinoquía region, they occur as gallery forests; in the Andes, riparian forests predominate; and in the Caribbean and Pacific regions, they include coastal mangrove formations and, specifically in the Caribbean region, structural components of the lower Magdalena River floodplain wetland complexes.



Figure 1. Flooded forests – Isana-Surubí Indigenous Territory (Photograph by: Felipe Rodriguez).

Wetlands formations are predominantly found in the savannas of the Orinoquía region (see Figure 2) and in the wetland complexes of the Magdalena-Cauca macro-basin, in the Caribbean region. In the Pacific region, these land cover types are mainly distributed along the banks of the Atrato River, whereas in the Andean region, they occur in flood-prone areas, most of which are associated with urban wetlands.



Figure 2. Formación natural no forestal inundable - Paz de Ariporo (Photograph by: Nestor Espejo)

Flooded Andean herbaceous and shrubby vegetation constitutes an important component of páramo complexes and high-Andean wetlands. For its identification and land cover classification, an altitudinal threshold of above 2,900 m above sea level was established (see Figure 3).



Figura 3. Flooded Andean herbaceous and shrubby vegetation - National Natural Park Sumapaz (Photograph by: Yulieth Ávila)

These land cover classes play a fundamental role in biodiversity conservation, water regulation, and nutrient cycling. They also provide multiple contributions to people and nature, particularly through their capacity to regulate water flows and help mitigate flood risk. Nevertheless, they are exposed to various pressures and threats that compromise their ecological integrity and functioning. In this context, accurate spatial data are essential for their identification, mapping, and systematic monitoring, providing a foundation for strengthening their conservation and sustainable management.

It is important to note that the classification process accounts for the specific characteristics of land cover types across the country's different ecoregions, with the aim of maintaining thematic and spatial consistency in their identification and interpretation. Accordingly, Colombia's five natural regions (Caribbean, Andean, Pacific, Orinoquía, and Amazon) are used as a geographical reference framework. Their spatial distribution is shown in Figure 4.

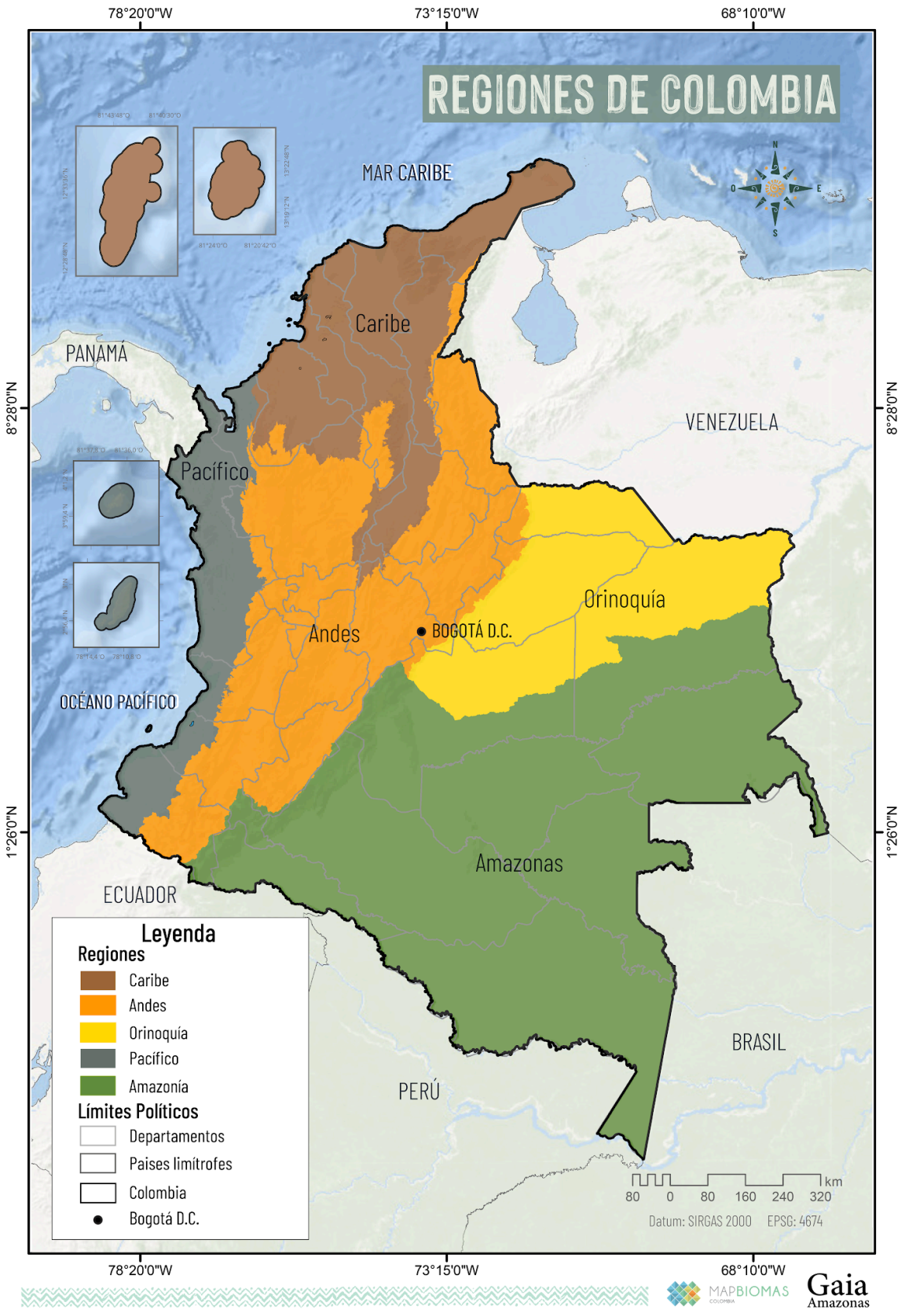


Figure 4. Division by Natural Regions to Ensure Thematic Consistency in Land Cover Interpretation.

2. MapBiomas Colombia Methodology – Flooded Land Cover Cross-Cutting Theme

2.1. Methodological Workflow

The mapping of flooded land cover classes was conducted over a 41-year time series spanning the period from 1985 to 2025, with the aim of detecting temporal and spatial variations driven by both natural dynamics and anthropogenic pressures affecting these land cover types. Key inputs to the interpretation and classification process included the experience gained from previous MapBiomas Colombia collections, together with expert guidance to better understand the dynamics and characteristics of these floodable land cover types. The overall classification process was structured into three main stages: (I) definition and generation of satellite mosaics, (II) classification, and (III) application of post-processing filters.

Each stage comprised several steps, including the compilation of reference data, definition of sampling areas, and preliminary classifications for testing and methodological refinement. The complete classification workflow is presented schematically in Figure 4.

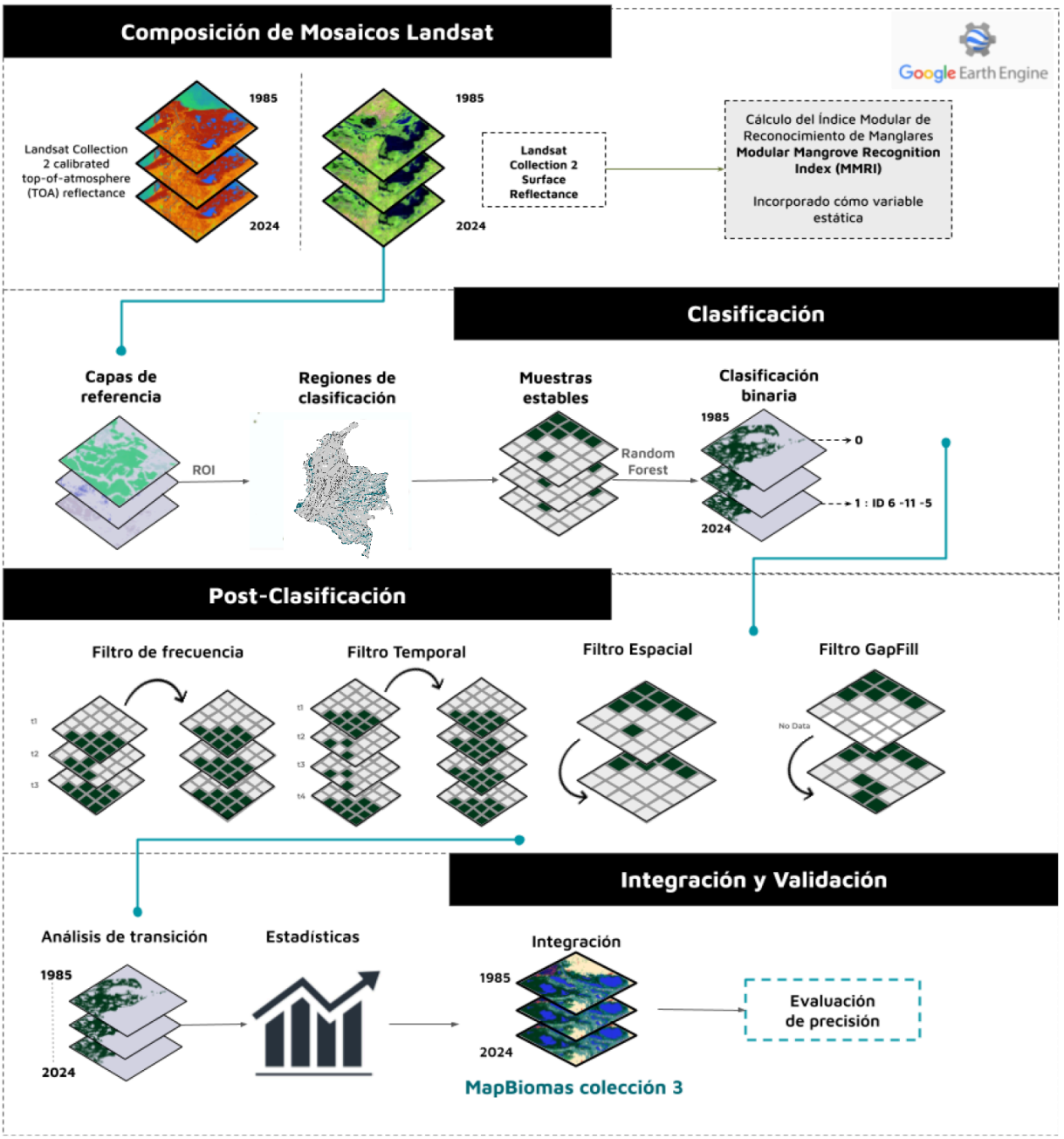


Figure 5. Methodological Workflow for Flooded Land Cover Identification.

2.2. Definition and Generation of Satellite Mosaics

The satellite mosaics used to identify flooded land cover classes were those generated for the MapBiomas Colombia Collection 4 land cover and land use maps. These mosaics were constructed using images from the Landsat constellation available in the Google Earth Engine® collections. In addition to the base spectral information, bands associated with the Tasseled Cap transformation (Crist & Cicone, 1984) were incorporated, covering its three components: Brightness, Greenness, and Wetness.

Each mosaic consisted of 141 bands, including the original satellite bands and derived spectral indices, calculated using the following aggregation methods[1]:

- Median (_median): Pixel-wise median of the images corresponding to the optimal mapping period defined for each year.
- Dry-season median (_dry): Pixel-wise median of images corresponding to the annual 25th percentile of NDVI.
- Wet-season median (_wet): Pixel-wise median of images corresponding to the annual 75th percentile of NDVI.
- Amplitude (_amp): Annual pixel-wise amplitude.
- Standard deviation (_stdDev): Annual pixel-wise standard deviation.
- Minimum (_min): Annual pixel-wise minimum.
- Maximum (_max): Annual pixel-wise maximum.

The selection of satellite scenes and the generation of the final mosaics were based on the following parameters, which were stored as metadata for each generated asset:

- ID: Unique identifier assigned to each region.
- Year: Year to which the mosaic corresponds (1985–2025).
- Map sheet: Map sheet identifier.
- Start and end dates: Date range used to select images from the collections available in Google Earth Engine.
- Sensor: Sensor identifier (L5: Landsat 5 TM; L7: Landsat 7 ETM+; L8: Landsat 8 OLI; L9: Landsat 9; LX: combination of Landsat 5 and Landsat 7 scenes; LY: combination of Landsat 8 and Landsat 9 scenes).
- Cloud cover: Maximum allowable cloud cover percentage. Scenes exceeding this threshold were excluded from mosaic generation.
- Blacklist: List of scenes identified as being of poor quality and therefore excluded from mosaic generation.

2.3. Topographic Correction

Several areas of Colombia are characterized by mountainous terrain, which frequently results in topographic shadows in Landsat imagery due to differences in slope orientation relative to the solar illumination vector and the illumination conditions of each scene, determined by the solar and sensor viewing geometry at the time of image acquisition. These limitations affect the spectral response of land cover types, causing some pixels belonging to the same land cover class to exhibit reduced reflectance values. Consequently, these variations may introduce classification errors.

One of the improvements implemented in MapBiomas Colombia Collection 3.0 was the application of topographic correction to the satellite mosaics, aimed at reducing the effects of terrain shadows and improving the spectral consistency across the mapping areas. This correction was applied to a total of 2,255 mosaics covering 57 Landsat path/row combinations across the different mosaic parameterization regions. It was not applied in the Orinoquía region

[1] These aggregation methods were applied to the Landsat images selected for each path/row and to all spectral indices derived from them.

or to the path/row scenes corresponding to the Alta Guajira area, where correction was deemed unnecessary due to the predominantly low terrain slopes.

An example of the changes introduced to the mosaics in Collection 3 is presented in Figure 5 for Tayrona National Natural Park, where a comparison between the mosaics can be observed.

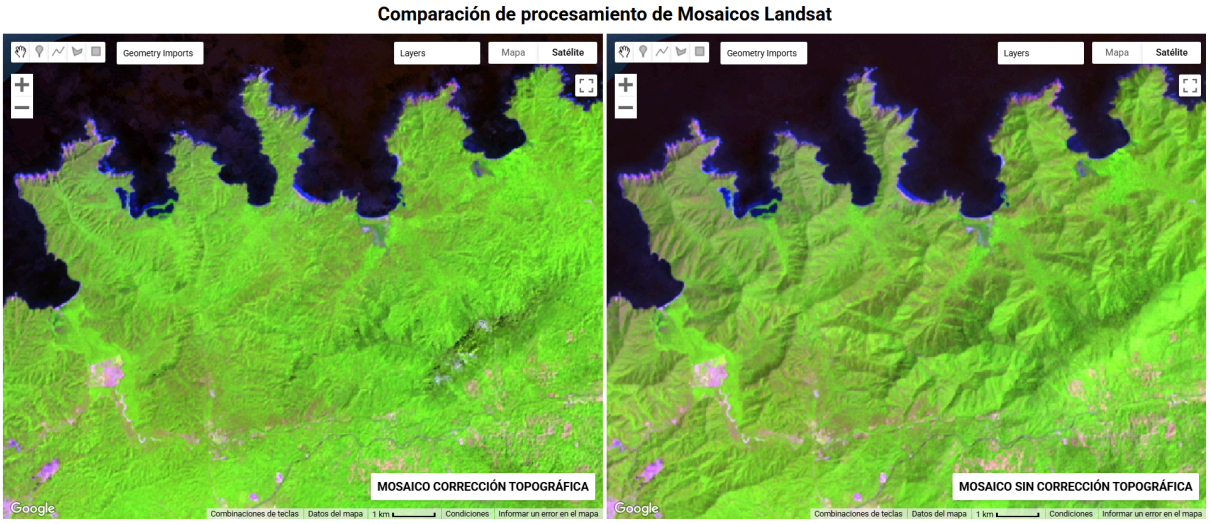


Figure 6. Comparación de procesamiento de Mosaicos Landsat

2.4 Comparison of Landsat Mosaic Processing

Based on the mosaics generated for each country, those corresponding to flood-prone areas were selected using vector layers from various sources to establish the boundaries of the floodable areas targeted for classification (Table 1, Figure 6). Only mosaics located within these areas were used for classification, while those falling outside the defined boundaries were excluded from the processing workflow. It is important to note that not all reference sources were used across all classification regions. Instead, for each region, reference datasets were selected based on their data quality and their suitability for representing the observed flooded land cover. This region-specific selection aimed to reduce noise introduced by poorly aligned reference layers and improve the thematic accuracy of the classification.

Reference	Source
Tropical and Subtropical Wetlands Distribution	Gumbricht, T.; Román-Cuesta, R.M.; Verchot, L.V.; Herold, M.; Wittmann, F; Householder, E.; Herold, N.; Murdiyarso, D., 2017, "Tropical and Subtropical Wetlands Distribution", https://doi.org/10.17528/CIFOR/DATA.00058, Center for International Forestry Research (CIFOR), V7 https://www2.cifor.org/global-wetlands/
LBA-ECO LC-07 JERS-1 SAR Wetlands Masks and Land Cover, Amazon Basin: 1995–1996	Hess LL, Melack JM, Novo EMLM, Barbosa CCF, Gastil M. LBA-ECO LC-07 JERS-1 S; 2015.
Multi-source Global Wetland Maps Combining Surface Water Imagery and Groundwater Constraints	Tootchi, Ardalan; Jost, Anne; Ducharne, Agnès (2018): Multi-source global wetland maps combining surface water imagery and groundwater constraints. Sorbonne Université, Paris, France, PANGAEA, https://doi.org/10.1594/PANGAEA.892657 https://doi.pangaea.de/10.1594/PANGAEA.892657?format=html#download
GFPLAIN250m, a Global High-Resolution Dataset of Earth's Floodplains	Nardi, F. et al. GFPLAIN250m, a global high-resolution dataset of Earth's floodplains. Sci. Data. 6:180309 doi: 10.1038/sdata.2018.309 (2019).
Terrestrial Ecoregions of the World	https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

Remote Sensing of the Distribution and Extent of Wetlands in the Amazon Basin	Melack JM, Hess LL; 2010. pp. 43–59
A Classification of Major Naturally-Occurring Amazonian Lowland Wetlands	Junk WJ, Piedade MTF, Schöngart J, Cohn-Haft M, Adeney JM, Wittmann F 2011;31: 623–640.
Global 30m Height Above the Nearest Drainage	Donchyts, Gennadii, Hessel Winsemius, Jaap Schellekens, Tyler Erickson, Hongkai Gao, Hubert Savenije, and Nick van de Giesen. "Global 30m Height Above the Nearest Drainage (HAND)", Geophysical Research Abstracts, Vol. 18, EGU2016-17445-3, 2016, EGU General Assembly (2016). https://gena.users.earthengine.app/view/global-hand
Mapa de humedales de Colombia, Memoria técnica cartografía de humedales del país a escala 1:100.000	Colombia en mapas - Flórez-Ayala, C., Estupiñán-Suárez, L. M., & Aponte, C. Memoria técnica cartografía de humedales del país a escala 1: 100.000.
Cobertura de la Tierra Metodología CORINE Land Cover Adaptada para Colombia Periodo 2018.	IDEAM, SINCHI, PNN http://geoservicios.ideam.gov.co/geonetwork/srv/spa/catalog.search;jsessionid=97B6F80606F3D7E735B92FA7456F174E#/metadata/285c4d0a-6924-42c6-b4d4-6aef2c1aceb5
Mapa de ecosistemas continentales, marinos y costeros de Colombia 2017. Versión 2.1	IDEAM, 2017 http://www.ideam.gov.co/web/siac/catalogo-de-mapas

Table 1. Reference layers used in the project. Source: Adapted from MapBiomas Collection 3 (MapBiomas C3, 2025).

2.5 Operational Classification Regions

Furthermore, based on the delineation of Colombia's natural regions, 55 operational classification regions were established as spatial subdivisions that enable the territory to be analyzed using more homogeneous analytical units. This approach facilitates the implementation of classification models, optimizes computational resource utilization, and supports the assessment of thematic and spatial consistency in the input data, as well as the consistency of the resulting classifications (see Figure 7).

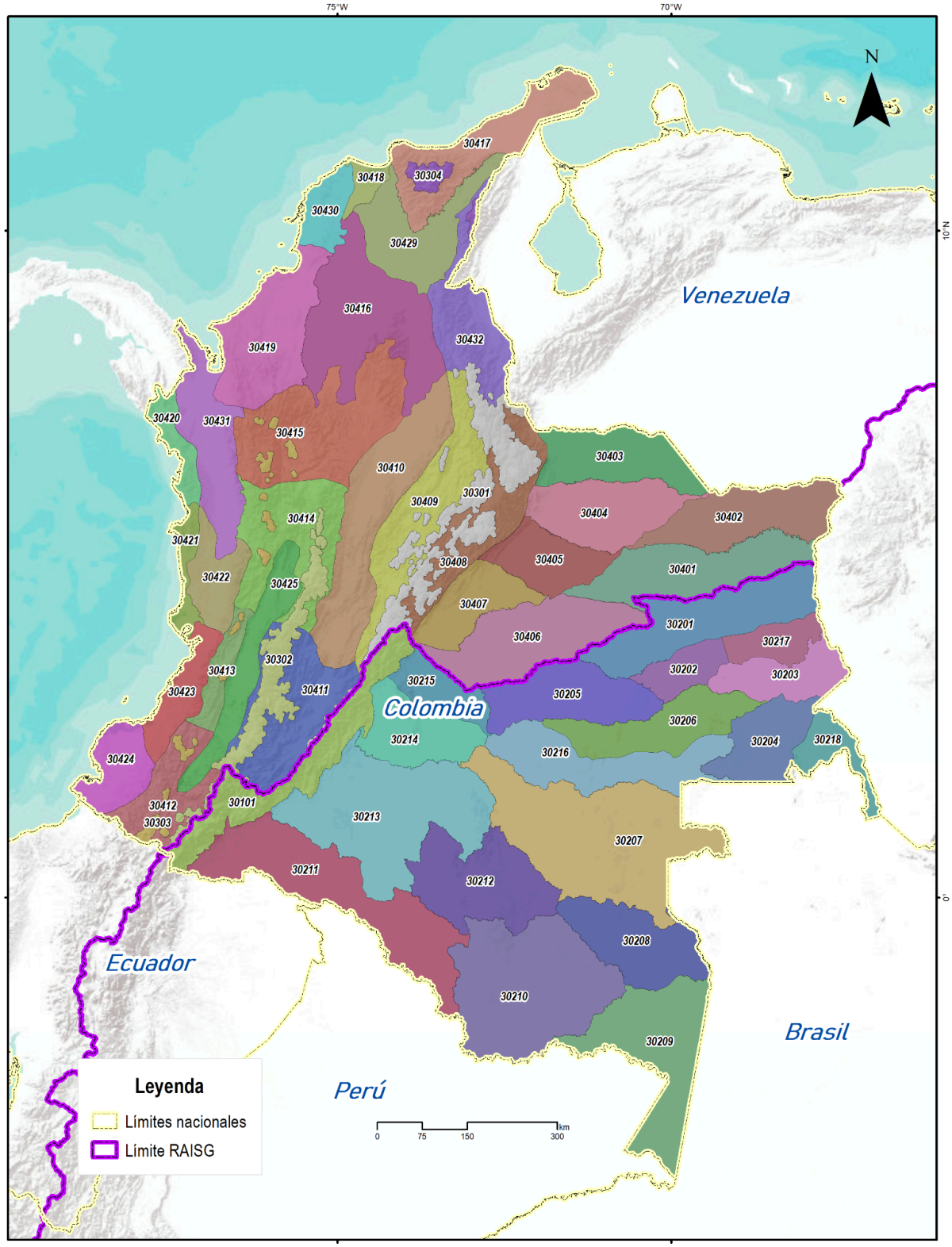


Figure 7 Delineation of Classification Regions Based on Reference Maps. Source: Prepared by the authors. A total of 55 classification regions were delineated across the Colombian territory, of which 19 correspond to the Amazon biome, 13 to the Andean biome, 7 to the Caribbean biome, 7 to the Orinoquía biome, 6 to the Pacific biome, and 3 to the insular biome.

2.6 Selección de variables de clasificación

Based on the regional mosaics generated, preliminary classification tests were conducted to identify and reduce the number of variables required for the final classification. Based on the results of these tests, the Tasseled Cap spectral indices (T-cap Brightness, T-cap Greenness, and T-cap Wetness) and topographic variables (elevation, slope, slppost, and HAND) derived from the SRTM Digital Elevation Model

(DEM) were also incorporated into the classification process. These additional variables are useful for detecting different phenological stages and vegetation types.

A total of 46 variables were used to implement the classification. A detailed description of each variable is provided in Table 2. Further information on their characteristics and functionality can also be found in the supplementary document **Appendix: Feature space**, which forms part of this ATBD.

Band / Variable	Description	Aggregation method[2]
Blue	Blue band reflectance	Median.
Green	Green band reflectance	Median, Min
Red	Red band reflectance	Median, Min
Nir	Near-infrared band reflectance	Median, Amp, StdDev
Swir1	Shortwave infrared 1 band reflectance	Median, Min
Swir2	Shortwave infrared 2 band reflectance	Median, Min
NDFI	Normalized Difference Fraction Index	Median, Amp, StdDev
NDFIB	Adaptation of the NDFI for the Andes	Median
GV	Fractional abundance of green vegetation	Median, StdDev
GVS	Shade-normalized green vegetation	Median, StdDev
NPV	Fractional abundance of non-photosynthetic vegetation	Median, StdDev
Shade	Fractional abundance of shade	Median
Soil	Fractional abundance of bare soil	Median, Amp, StdDev
Cloud	Fractional abundance of clouds	Median
EVI2	Two-band Enhanced Vegetation Index	Median, Amp, StdDev
NDVI	Normalized Difference Vegetation Index	Median, Amp, StdDev
MNDWI	Modified Normalized Difference Water Index	Median
SAVI	Soil-Adjusted Vegetation Index	Median, StdDev
SEFI	Savanna Ecosystem Fraction Index	Median,StdDev
MMRI	Modular Mangrove Recognition Index	Median
T-cap brightness*	Tasseled Cap component associated with soil brightness	
T-cap greenness	Tasseled Cap component associated with vegetation greenness	
T-cap wetness	Tasseled Cap component associated with surface and vegetation moisture	
slope	Terrain slope	
slppost	Stratified slope	
altitude	Elevation above sea level	
Hand	Height Above Nearest Drainage	

Table 2. Variables used for the classification of flooded land cover classes in Collection 4. *Kauth, R. J. and Thomas, G. S. (1976) developed coefficients to enhance the information contained in Landsat spectral bands, resulting in a set of equations known as the Tasseled Cap (TC) transformation. This transformation is represented by three components: Brightness, which is associated with variations in soil reflectance; Greenness, which is correlated with vegetation vigor; and Wetness, which is influenced by the middle-infrared bands and is related to vegetation and soil moisture (Kauth & Thomas, 1976).

[2] The aggregation methods mentioned above are described in Section 2.2, Definition and Generation of Satellite Mosaics, under the subsection on aggregation methods.

2.7 Training Samples

The training samples used for classification were generated based on the reference maps of flooded land cover classes. Table 3 presents a count of the reference samples used for each study class across the different classification regions.

Reference dataset	Flooded Forest regions	Wetlands and Flooded Andean Herbaceous and Shrubby Vegetation regions
CIFOR (2017) – Global Wetlands Map (SWAMP)	3	1
Global Wetlands Map	3	0
Global 30m Height Above the Nearest Drainage (Hand Model)	16	22
Mapa de humedales de Colombia	41	36
Cumulative samples from Collection 3	46	33
Stable samples from Collection 3	35	15
Non-flooded formations	9	3

Table 3. Reference sources for Flooded Forest (ID 6), Wetland (ID 11), and Flooded Andean Herbaceous and Shrubby Vegetation (ID 82). Source: Prepared by the authors.

A detailed analysis of the reference datasets revealed that several regions lacked mapped flooded land cover. For Flooded Forest (ID 6), the absence of mapped coverage was identified in 29.6% of the regions. In the case of Wetland (ID 11) and Flooded Andean Herbaceous and Shrubby Vegetation (ID 82), the corresponding absence was 12.7% of the regions analyzed. A key aspect of the classification process was the contribution of national reference maps published by the Humboldt Institute, including the map of the spatial distribution of continental wetland systems in Colombia (Flórez et al., 2016) and the map of wetland classification in Colombia (Ricaurte et al., 2019). These datasets made a significant contribution to the training of the classification algorithm, improving thematic accuracy in the identification of flooded land cover classes.

For each region where these classes were present, samples were randomly selected based on the national reference layer and stable samples from MapBiomas Colombia Collection 3. This process was further supplemented with cumulative samples from the same collections. The resulting mapping showed a considerable improvement over the previous collection, largely due to the higher quality of the training samples (Figure 8).

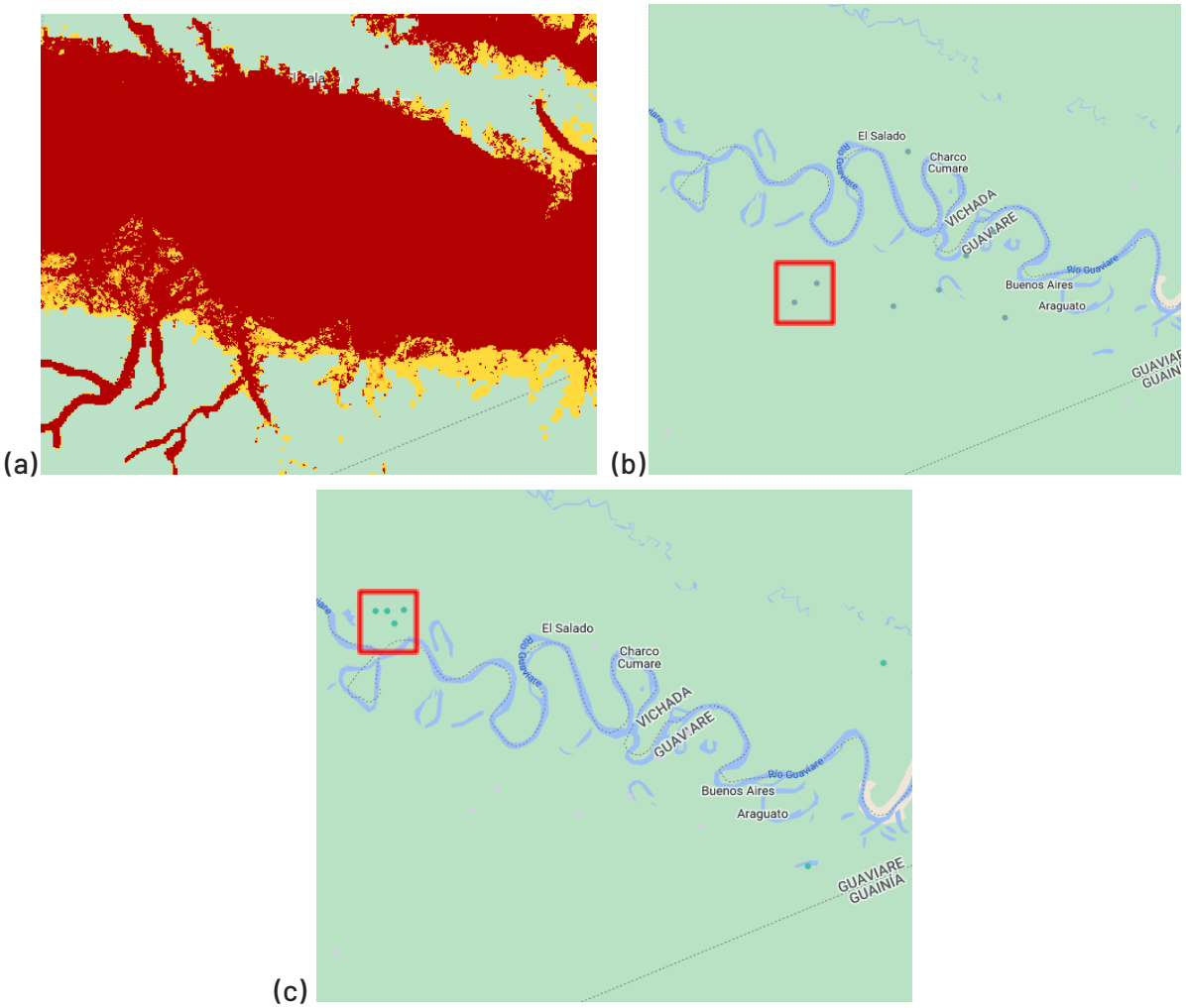


Figure 8.Training samples: (a) composition of the reference mask used for training sample generation, illustrated here with CIFOR reference data (yellow) and national reference data (red); (b) randomly selected training samples for Flooded Forest (ID 6); and (c) randomly selected training samples for Wetland (ID 11). Source: MapBiomas Colombia Collection 4 (2025).

3 Classification

The selected mosaics (see the previous section of this document) were used to perform a supervised classification based on the Random Forest algorithm (Breiman, 2001). All processing was carried out within the Google Earth Engine platform, and the resulting classifications were stored as image collections within the same platform. The mapping process focused on identifying the three main flooded land cover classes present in the study areas: Flooded Forest (ID 6), Wetland (ID 11), and Flooded Andean Herbaceous and Shrubby Vegetation (ID 82).

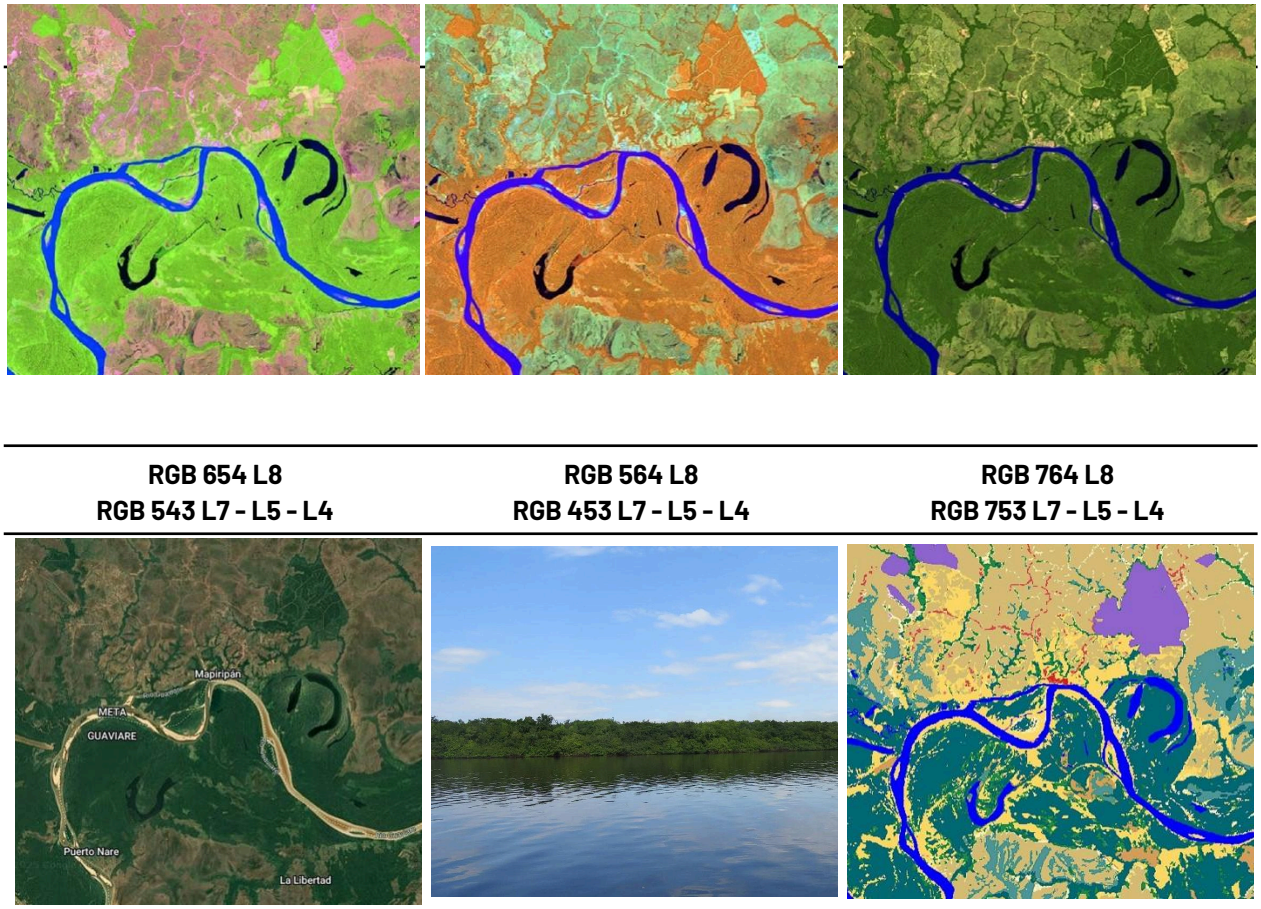
The classification process was performed independently for each target land cover class, considering only two possible classes in each case: the class of interest (Flooded Forest or Wetland) and the Not observed class, which comprised all land cover types other than the target class.

3.1 Identified Classes

3.1.1 Flooded Forest (ID 6)

For this study, Flooded Forest was broadly defined as any continuous area of natural, predominantly tree-covered vegetation larger than half a hectare (approximately more than 6 Landsat pixels, or 0.5 ha), subject to seasonal or permanent flooding. This definition draws on national and regional scientific references (Carrera et al., 2009; IDEAM et al., 2017; Wittmann et al., 2011).
However, not all flooded forests in Colombia share the same characteristics. Therefore, biome-specific definitions were established:

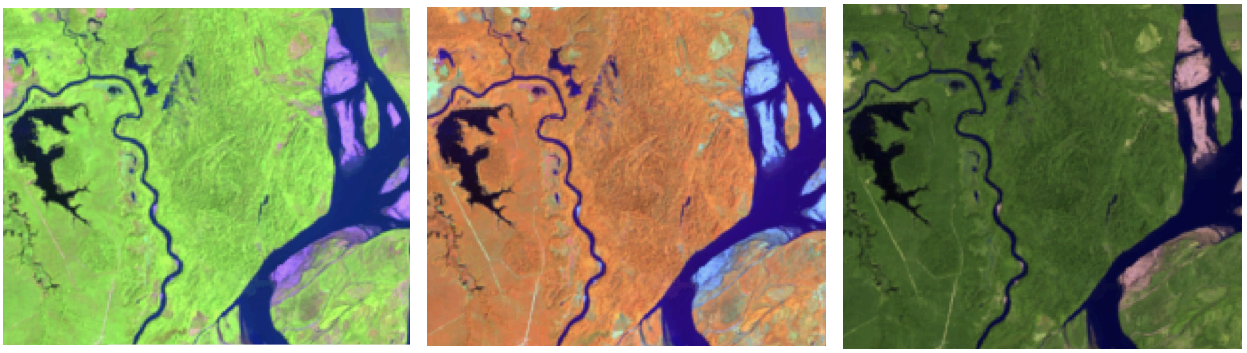
Amazon: Forest cover with a canopy height exceeding 5 m, occurring near or adjacent to water bodies and characterized by plant species adapted to seasonal (4–8 months per year) or permanent flooding conditions. These areas generally maintain moist soil conditions throughout most of the year and are typically found in the floodplains of river valleys and alluvial plains (Figure 9).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	Paisaje	MapBiomas

Figure 9. Spectral Response of Flooded Forest in the Amazon Biome. Mapiripán, Meta, Colombia. Year: 2024. Scale: 2 km. Coordinates: -72.1335 W, 2.8923 N. (Legend Flooded Forest)

Caribbean: Forest cover along riverbanks includes vegetation distributed across different vertical strata, with woody and tree-forming vegetation reaching heights of 3 m or more. These formations occur along riverbanks subject to seasonal or permanent flooding. Due to the relatively flat topography of these areas, they are also commonly referred to as gallery forests, although not all gallery forests fall within this land cover class (Figure 10).



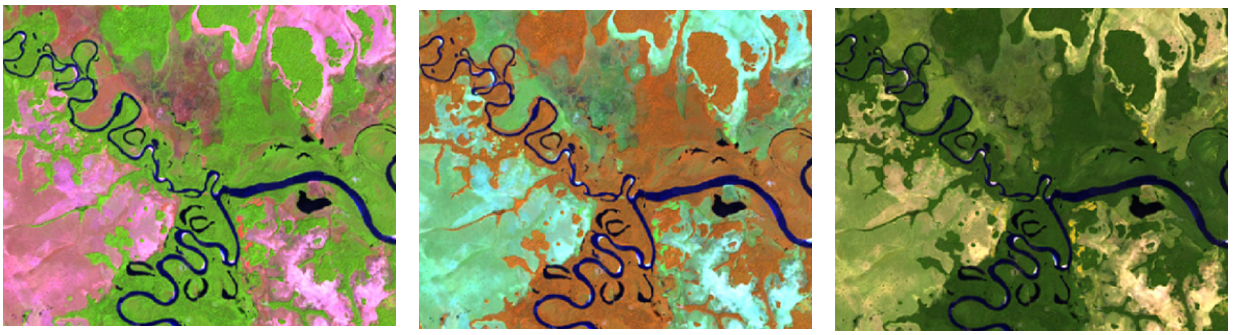
RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4



Google Earth	Paisaje	MapBiomas

Figure 10. Spectral Response of the Flooded Forest Class in the Caribbean Biome. Magdalena River, border area between Bolívar and Santander. Year: 2022. Scale: 200 m. Coordinates: -73.82262 W, 7.76953 N (Legend Flooded Forest)

Orinoquía: Forest cover along riverbanks comprises several vegetation strata, with a predominance of woody and tree-forming plants reaching heights greater than 3 m. These formations occur along rivers subject to seasonal or permanent flooding. Due to their location in relatively flat terrain, they are commonly referred to as gallery forests; however, not all gallery forests are necessarily subject to flooding (Figure 11).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4



Google Earth	Paisaje	MapBiomas

Figure 11. Spectral Response of Flooded Forests in the Orinoquía Biome. Tuparro River, Cumaribo, Vichada. Year: 2021. Scale: 1,000 m. Coordinates: -68.04943 W, 5.21289 N (Legend ■ Flooded Forest)

Pacific: Forest cover along riverbanks comprises vegetation distributed across different vertical strata, with woody and tree-forming vegetation reaching heights of 3 m or more. These formations occur along riverbanks subject to seasonal or permanent flooding. Due to the relatively flat topography of these areas, they are also commonly referred to as gallery forests; however, not all gallery forests are necessarily subject to flooding.

In the Colombian Pacific region, specialized flooded forest formations such as sajales and guandales are also found. These plant communities are characterized by even-aged stands of tree species adapted to persist under highly waterlogged soil conditions (Figure 12).

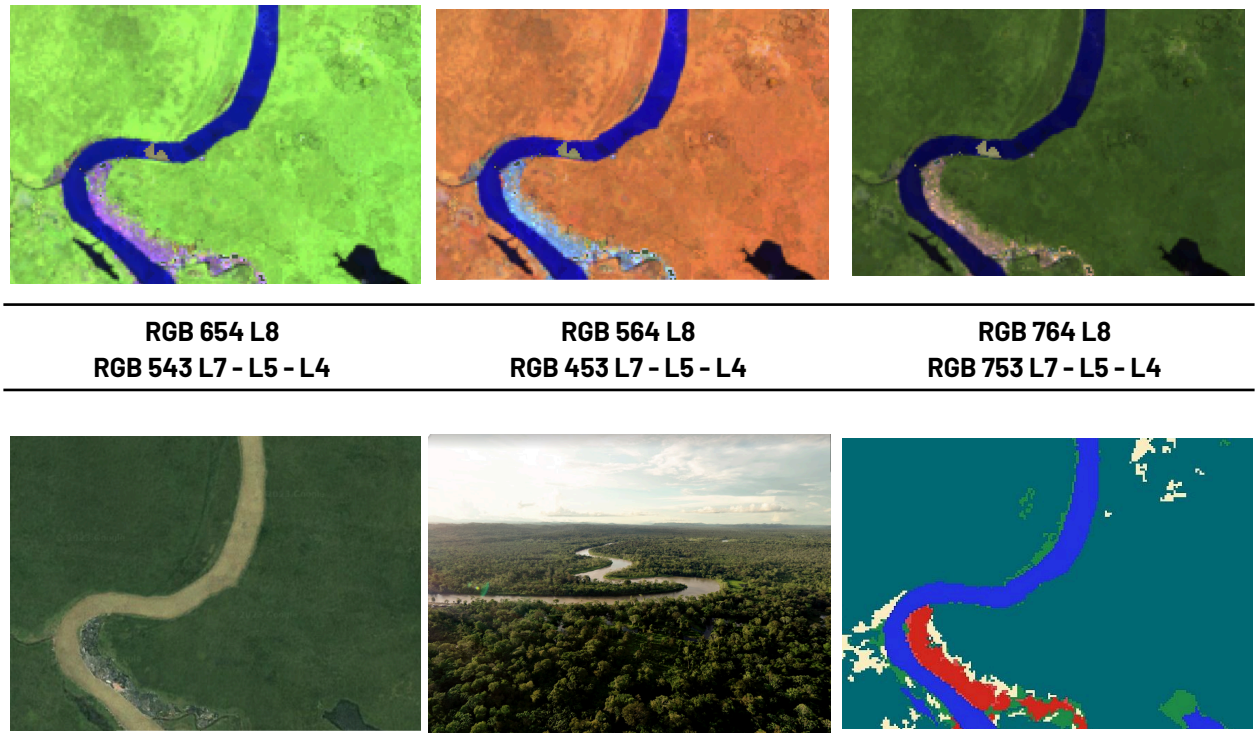
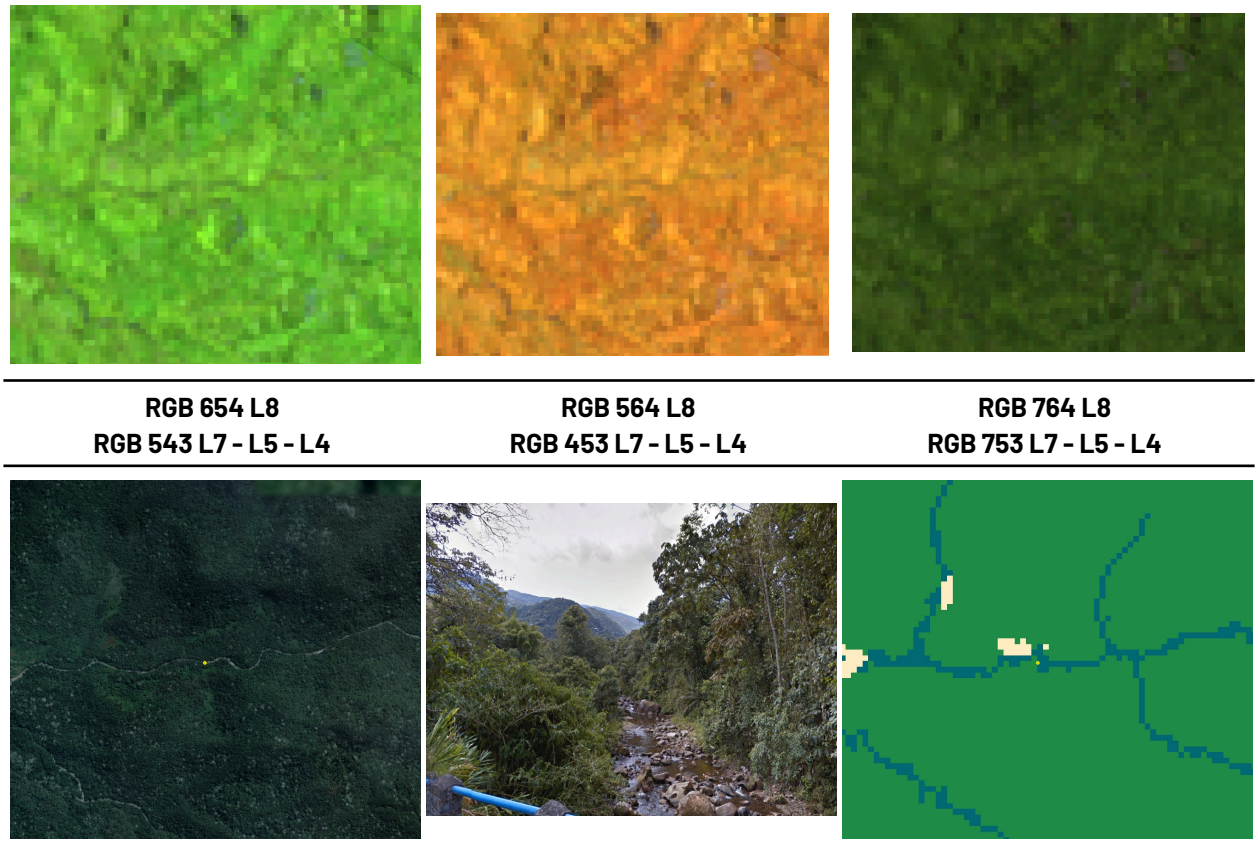


Figure 12. Spectral Response of Flooded Forest in the Pacific Biome. Atrato River, Riosucio, Chocó. Year: 2024. Scale: 500 m. Coordinates -77.10302 W, 7.45646 N (Legend Flooded Forest)

Andes: Land cover dominated by tree vegetation that develops along the margins of permanent or intermittent water bodies and watercourses, as well as along natural drainage systems. Its spatial distribution is controlled by the configuration and width of the channels; consequently, it typically occurs as narrow, elongated strips. In the Andean region, these forest formations are known as riparian forests and perform key ecological functions: they protect riverbanks, regulate hydrological flows, enhance ecological connectivity, and support biodiversity conservation (IDEAM et al., 2017).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Paisaje**	**MapBiomas**

Figure 13. Spectral response of Flooded Forest in the Andes biome. Otún Quimbaya Fauna and Flora Sanctuary (SFF), Riosucio, Risaralda. Year: 2023. Scale: 100 m. Coordinates: -75.564356 W, 4.732231 N (Legend Flooded Forest)

3.1.2 Wetlands - (ID 11)

The Wetland class mapped in this project encompasses all areas of natural herbaceous or shrubby vegetation subject to periodic or permanent flooding. This definition draws on reference sources including Instituto SINCHI (2009), Wittmann et al. (2002), and MINAM (2019). As with Flooded Forest, biome-specific definitions were established, as described below:

Amazon: Natural vegetation cover dominated by herbaceous vegetation (more than 70%) or shrubby vegetation (between 30% and 50%), occurring on hydromorphic soils that remain permanently saturated and may become covered by a layer of water during the rainy season, which lasts between 4 and 8 months per year. This vegetation may include scattered trees occurring in patches or as small forest islands locally known as matas de monte, as well as palm-dominated communities known as morichales. Together, these woody and palm components account for no more than 10% of the total cover. This vegetation type occurs mainly across valley floodplains and alluvial plains (Figure 14).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4



Google Earth	Paisaje	MapBiomas

Figure 14. Spectral Response of Wetland in the Amazon Biome. Apaporis River, on the border between Vaupés and Amazonas departments. Year: 2021. Scale: 1 km. Coordinates: -70.91985 W, -0.16152 (Legend Wetlands)

Andes: This land cover class occurs in low-lying, marshy areas characterized by spongy soils composed primarily of mosses and decomposed plant material, commonly known as peatlands, located below 2,900 m above sea level (Figure 15). It also includes herbaceous vegetation growing in marshy areas near water bodies, as well as natural plant species that partially or completely cover the water surface, as observed in Andean lakes and lagoons undergoing eutrophication (IDEAM et al., 2017).

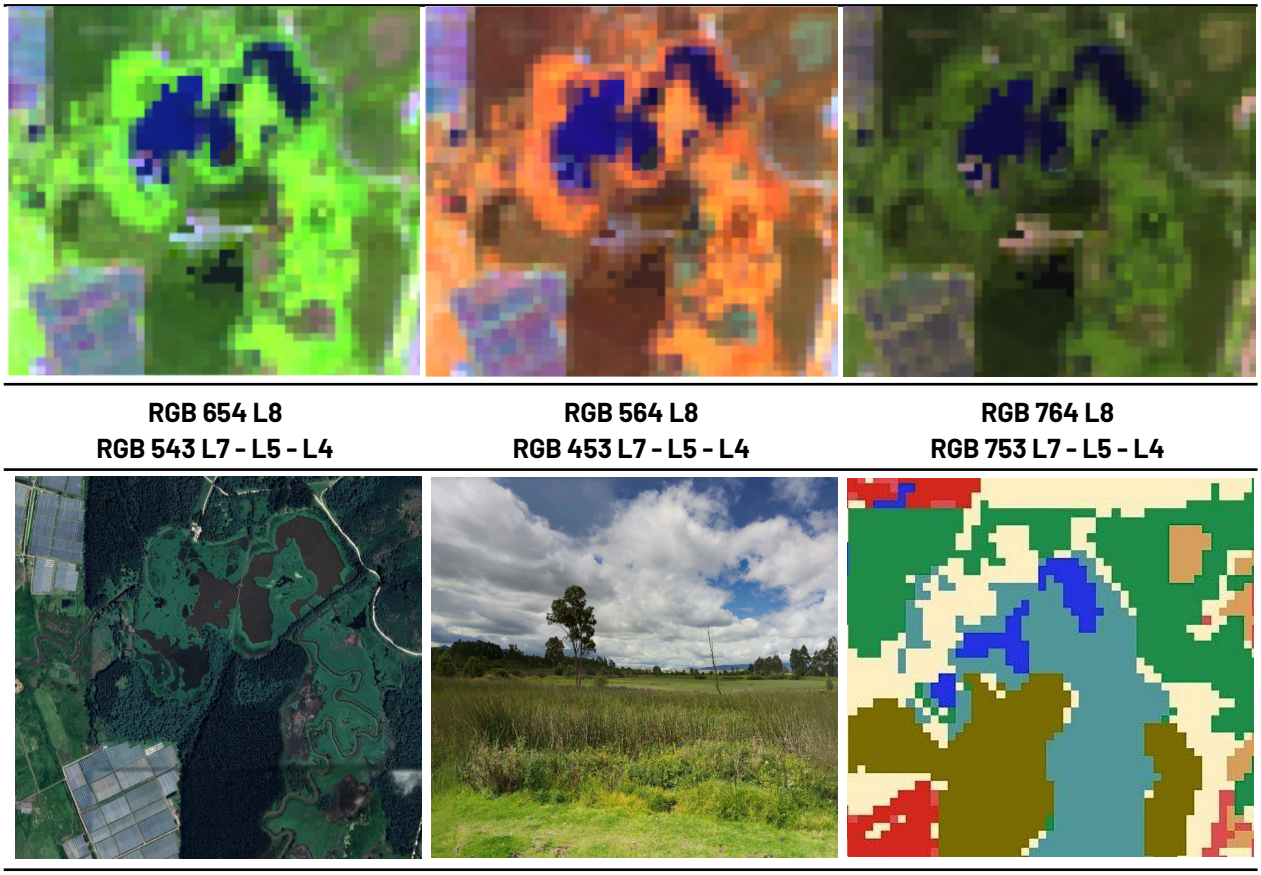
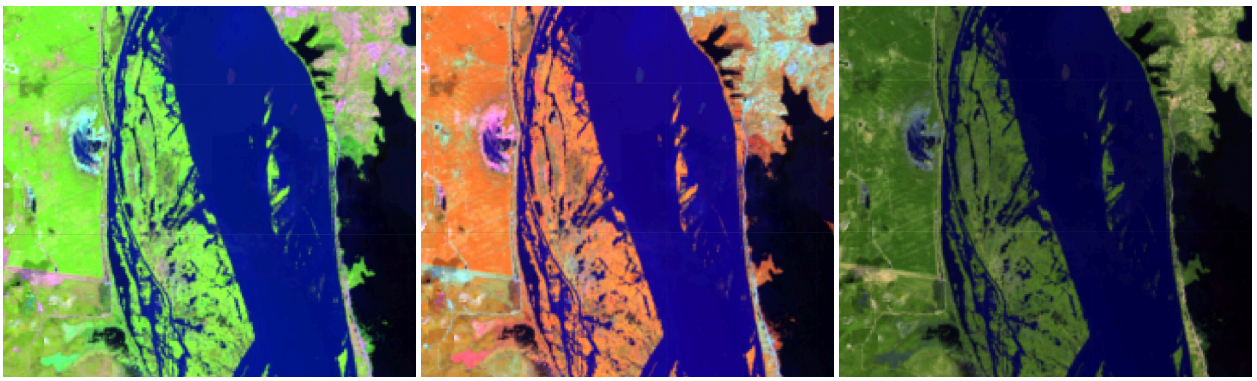


Figure 15. Spectral Response of Wetland in the Andean Biome. Sopó, Cundinamarca. Year: 2021. Scale: 200 m. Coordinates: -73.98374 W, 4.95135 N. (Legend Wetlands)

Caribbean: This land cover class consists primarily of herbaceous vegetation and, to a lesser extent, shrubby vegetation, occurring in areas associated with river deltas, estuaries, swamps, coastal lagoons, and marine floodplains, as well as in abandoned river channels and oxbow lakes (Figure 16). These formations may also occur in low-lying coastal areas, where vegetation has adapted to brackish water environments under tidal influence (IDEAM et al., 2017).



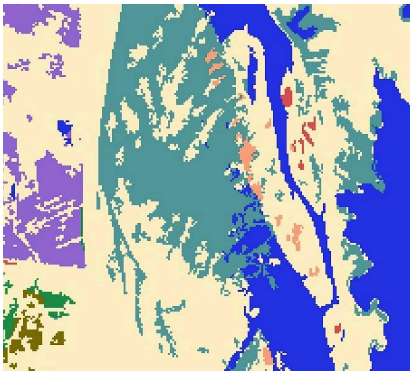
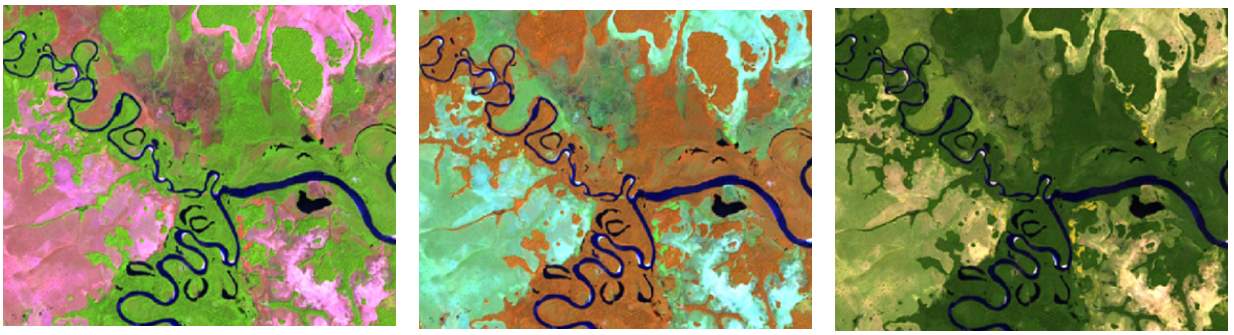
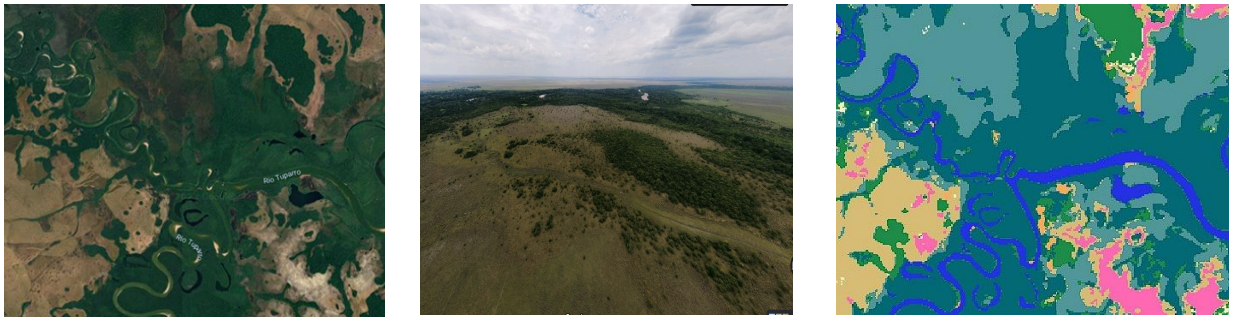
RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
		
Google Earth	**Paisaje**	**MapBiomas**

Figure 16. Spectral Response of Wetland in the Caribbean Biome. Zurra Swamp, Tenerife, Magdalena. Year: 2022. Scale: 500 m. Coordinates: -74.85062 W, 9.86896 N. (Legend Wetlands)

Orinoquía: Herbaceous vegetation, predominantly composed of grasses, subject to permanent or seasonal flooding (at least once a year) in response to natural flood pulses. These formations are generally located in low-lying areas, which may include river channel migration zones, floodplains, former river meander belts, and natural depressions where the water table reaches the surface either permanently or seasonally (Figure 17). They may also contain scattered tree and/or shrub elements (IDEAM, 2010; Fundación Gaia Amazonas, 2022).



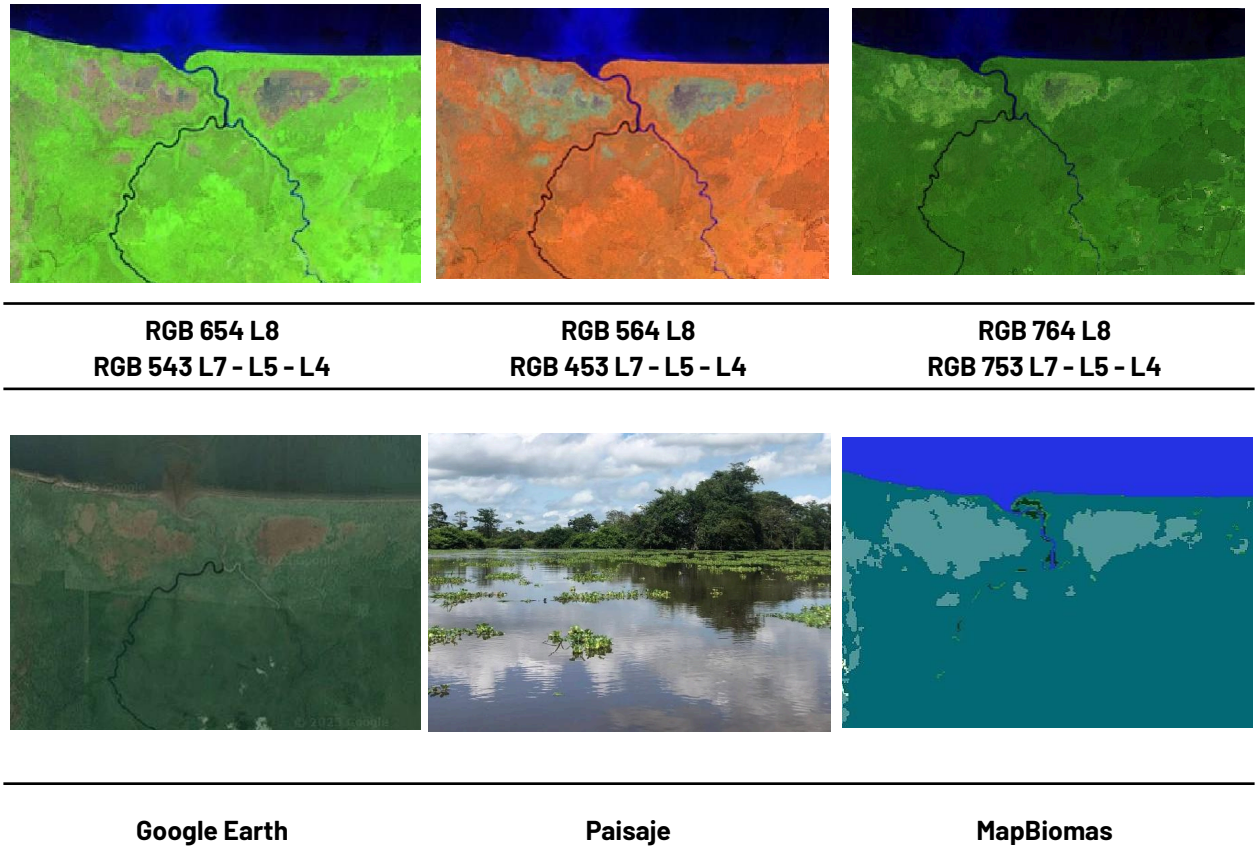
RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4



Google Earth	Paisaje	MapBiomas

Figure 17. Spectral Response of Flooded Forest in the Orinoquía Biome. Tuparro River, Cumaribo, Vichada. Year: 2021. Scale: 1,000 m. Coordinates: -68.04943 W, 5.21289 N. (Legend Wetlands)

Pacífic: Areas dominated by natural herbaceous vegetation, which may contain scattered tree elements to a lesser extent, as well as dispersed palm-dominated communities locally known as morichales, which together account for no more than 10% of the total cover (Figure 18). These areas are generally found across valley floodplains and alluvial plains (IDEAM, 2010).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	Paisaje	MapBiomas

Figure 18. Spectral Response of Flooded Forest in the Pacific Biome. Atrato River, Riosucio, Chocó. Year: 2018. Scale: 500 m.
Coordinates: -77.10302 W, 7.45646 N (Legend Wetlands)

3.1.3 Flooded Andean Herbaceous and Shrubby Vegetation (ID 82)

Natural vegetation cover restricted to the Andes and associated with lacustrine, palustrine, and fluvial freshwater systems, dominated mainly by herbaceous species and, to a lesser extent, by shrubs. It develops on alluvial plains, in riparian zones, and in marshy environments above 2,900 m.a.s.l. The vegetation is adapted to high humidity, frequent cloud cover, heavy rainfall, intense direct solar radiation, and low temperatures, and grows on soft soils largely composed of mosses and decomposing organic matter that give rise to peatlands. This class also includes species that partially or completely cover the water surface of Andean lakes and ponds undergoing eutrophication.

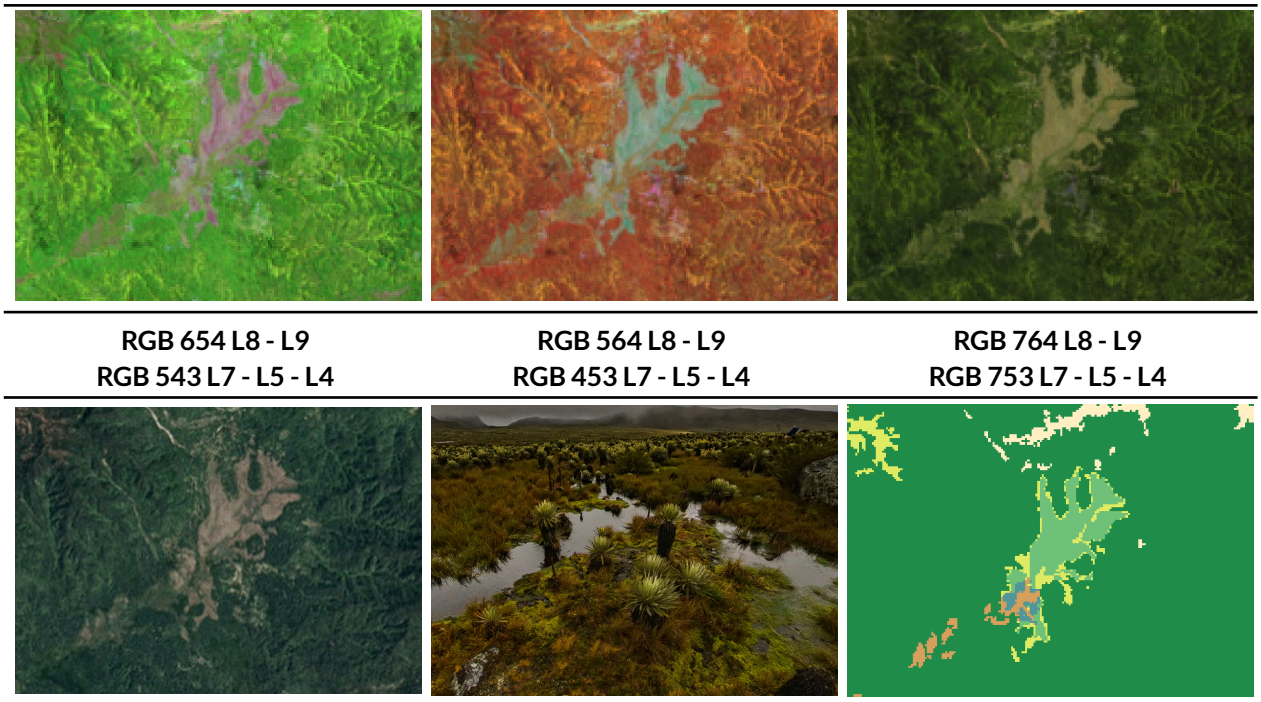


Figure 19 Spectral response of Flooded Andean Herbaceous and Shrubby Vegetation in the Andes biome. Location: Pasto, Nariño. Coordinates: -77.214138 W, 0.976932 N, Escale: 500 m, Year: 2024. **(Legend Flooded Andean Herbaceous and Shrubby Vegetation)**

4 Post-clasification

Owing to the pixel-based nature of the classification method and the use of a long time series, a chain of post-classification filters was applied. The post-classification process comprises gap-filling, temporal, spatial, and frequency filters.

4.1 Gap Fill

The filter sequence begins with gap filling. In long time series covering regions severely affected by cloud cover, gaps (no-data values) commonly occur in the median composites. This filter replaces such gaps with the temporally nearest valid classification (Figure 18). In this procedure, if no valid value is available from the previous year, the gap is filled with the value from the following year. Consequently, gaps should remain only where a pixel is classified as "no data" throughout the entire time series.

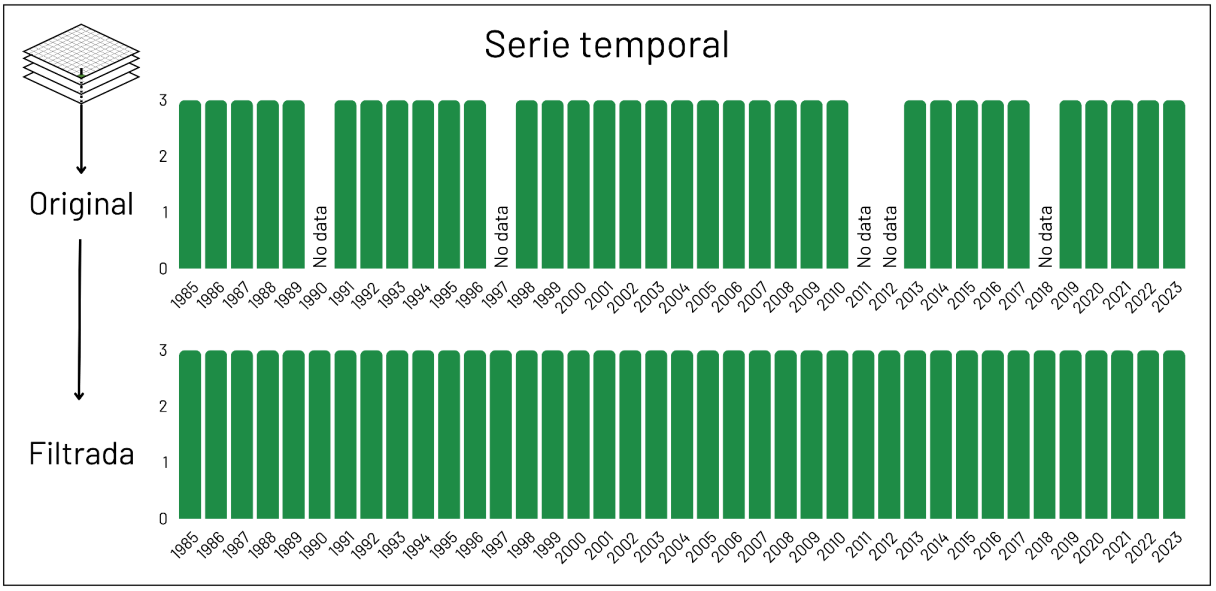


Figure 20. Gap-fill filter. Source: MapBiomas Collection 4, 2026.

4.2 Temporal filter

After gap filling, a temporal filter was applied to remove noise, also known as the "salt-and-pepper" effect. This filter replaces pixels with inconsistent land cover classifications caused by gradual year-to-year changes or by missing or distorted information in a mosaic. The temporal filter comprises three types of filters (middle-year, first-year, and last-year filters), applied over a 3-, 4-, or 5-year unidirectional moving window to identify temporally inconsistent transitions. The filter is based on general rules (GR), applied to all intermediate years of the series (1986–2024); first-year rules (FR), applied to 1985; and last-year rules (LR), applied to 2025. For each year of interest, the filter evaluates the central pixel and reclassifies it according to the rules in Table 4.

	Input sequence	Output sequence

	T-2	T-1	T0	T+1	T+2	T-2	T-1	T0	T+1	T+2
GR		FF/WL	No	FF/WL			FF/WL	FF/WL	FF/WL	
	FF/WL	No	No	FF/WL	FF/WL	FF/WL	FF/WL	FF/WL	FF/WL	FF/WL
FR			No	FF/WL	FF/WL			FF/WL	FF/WL	FF/WL
LR	FF/WL	FF/WL	No			FF/WL	FF/WL	FF/WL		

Table 4. Temporal filter rules and results. Source: MapBiomas Collection 4, 2022. GR denotes a general rule, applied to all intermediate years (1986–2025); FR denotes a first-year rule, applied only to 1985; and LR denotes a last-year rule, applied to 2025. T0 is the year to which the filter is applied, T−n denotes the preceding years, and T+n the subsequent years. FF: Flooded Forest; WL: Wetlands; NO: Not observed.

4.3 Filtro espacial

The spatial filter is based on the Connected Pixel Count function, which identifies groups of connected pixels (neighborhoods) sharing the same class value, thereby removing the "salt-and-pepper" effect. This makes it possible to correct residual classification errors and improve the accuracy of fine-scale detail in the map. Only pixels that do not meet a predefined minimum number of connections are considered isolated and are reclassified (Figure 19). For both classes, the minimum connection threshold was set at 5 pixels (approximately 0.5 ha).

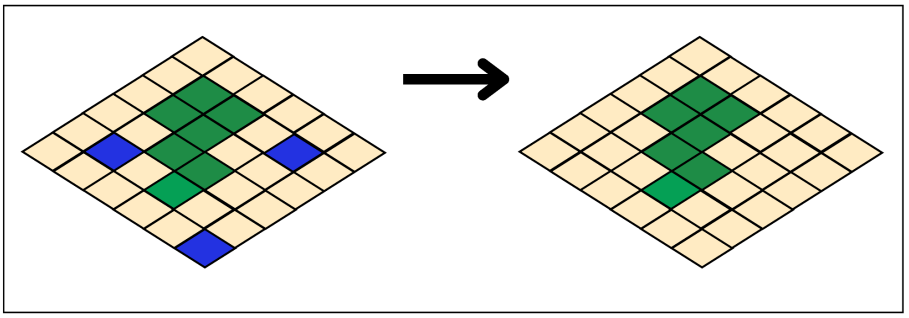


Figure 21. Effect of the spatial filter. Source: MapBiomas Collection 4, 2026.

4.4 Frequency filter

Another filter applied in the sequence was the frequency filter. As shown in Figure 19, this filter considers the occurrence of each class throughout the time series to refine the classification results.

On the one hand, this filter helped to fill in classifications in cloud-affected areas where the temporal filter had failed to recover the information. For the Wetlands class, which is characterized by high moisture variability over time (with expansion and contraction of the flooded area), an 80% threshold was applied. This means that gaps were filled only if the class showed a temporal persistence of at least 29 years. For Flooded Forest, a more lenient threshold (60%) was applied because this cover type is more stable over time and is well detected in most regions.

On the other hand, the frequency filter was also adjusted to identify and remove temporal noise and misclassifications. Unlike the thresholds applied in the previous step, pixels of Wetlands and Flooded Andean Herbaceous and Shrubby Vegetation with a frequency of less than 20% across the time series were excluded from the classification, whereas Flooded Forest pixels with a frequency below 40% were removed.

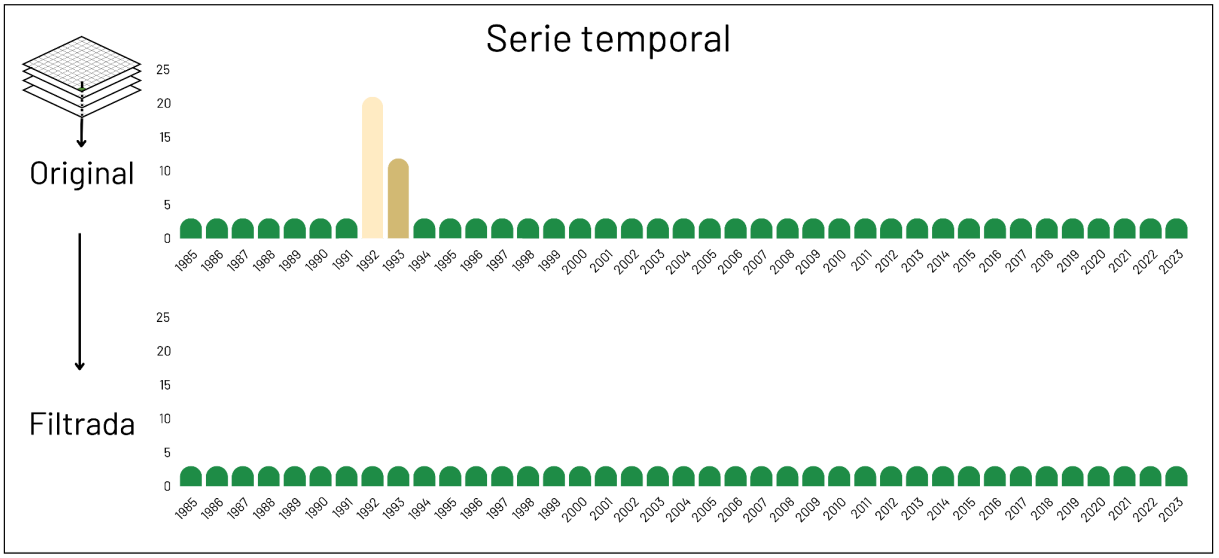


Figure 22. Effect of the frequency filter. Source: MapBiomas Collection 3, 2025.

4.5 Spatial filter based on slope and HAND

This spatial filter was applied to improve the thematic and spatial consistency of the Wetlands class across the entire 1985–2025 time series. To this end, areas classified as Wetlands located on slopes steeper than 10° or at high relative elevations were removed, using the SRTM digital elevation model and the HAND (Height Above Nearest Drainage) model as references. In a second application, forests in the Andes, Caribbean, and Pacific regions were reclassified as Flooded Forest where HAND was ≤ 3 m, that is, where pixels lie no more than 3 m above the water level of the nearest stream or river.

HAND is a DEM-derived variable that represents the height of each pixel relative to the nearest drainage channel (river, stream, or canal), rather than its absolute elevation (Rennó et al., 2008). In Figure 20, the vertical axis has been adjusted so that the channel lies at 0 m, allowing HAND values to be represented directly. Based on hydrological criteria, low HAND values (0–5 m) are associated with areas prone to waterlogging because of their proximity to the drainage network, whereas high values (e.g., >10 m) indicate elevated areas with a low likelihood of water saturation. The blue hatched areas indicate zones that simultaneously meet two conditions: a slope ≤ 10° (predefined segments along the x-axis) and HAND ≤ 5 m. This combination represents optimal topographic conditions for the occurrence of flood-prone areas. Accordingly, pixels that do not meet the HAND and slope thresholds are reclassified from class 11 (Wetlands) or class 82 (Flooded Andean Herbaceous and Shrubby Vegetation) to class 27 (Not observed).

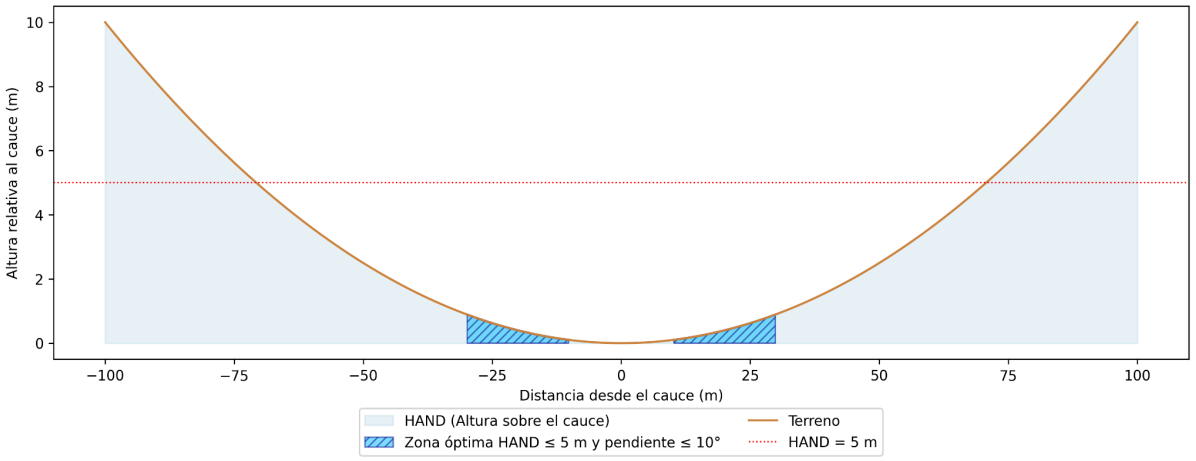


Figure 23. Spatial filter based on slope and HAND. Source: MapBiomas Collection 3, 2025.

5 References

Breiman, L. (2001). Random Forests. *Machine Learning*, *45*(1), 5–32. https://doi.org/10.1023/A:1010933404324

Carrera, E. R., García, U. G. M., Huertas, C. M., Rodríguez, J. M., & Castellanos, H. O. (2009). *Fichas técnicas de los patrones de las coberturas de la tierra de la Amazonia colombiana*. Instituto Amazónico de Investigaciones Científicas" SINCHI".

Crist, E. P., & Cicone, R. C. (1984). Application of the tasseled cap concept to simulated thematic mapper data. *Photogrammetric engineering and Remote sensing*, *50*(3), 343–352.

de Groot, R., Stuip, M., Finlayson, M., & Davidson, N. (2006). *Valuing wetlands: Guidance for valuing the benefits derived from wetland ecosystem services* (Número H039735). International Water Management Institute. https://EconPapers.repec.org/RePEc:iwt:rerpts:h039735

Flórez, C., Estupiñán-Suárez, L. M., Rojas, S., Aponte, C., Quiñones, M., Acevedo, Ó., Vilardy, S., & Villa, Ú. J. (2016). Identificación espacial de los sistemas de humedales continentales de Colombia. *Biota Colombiana*, *17*, 44–62.

IDEAM, M., IAvH, I., IIAP, S., & PNN, I. (2017). Mapa de Ecosistemas Continentales, Costeros y Marinos de Colombia a escala 1: 100.000. *Bogotá, DC, Colombia*.

Kauth, R. J., & Thomas, G. (1976). *The tasselled cap—A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat*. 159.

Maltby, E., Acreman, M., Blackwell, M. S. A., Everard, M., & Morris, J. (2013). The challenges and implications of linking wetland science to policy in agricultural landscapes – experience from the UK National Ecosystem Assessment. *Bringing Together Science and Policy to Protect and Enhance Wetland Ecosystem Services in Agricultur*, *56*, 121–133. https://doi.org/10.1016/j.ecoleng.2012.12.086

MEA. (2005). *Ecosystems and Human Well-Being: Wetlands and Water.* [World Resour.].

Patiño, J. E., & Estupiñan-Suarez, L. M. (2016). Hotspots of Wetland Area Loss in Colombia. *Wetlands*, *36*(5), 935–943. https://doi.org/10.1007/s13157-016-0806-z

Rennó, C. D., Nobre, A. D., Cuartas, L. A., Soares, J. V., Hodnett, M. G., Tomasella, J., & Waterloo, M. J. (2008). HAND, a new terrain descriptor using SRTM-DEM: Mapping terra-firme rainforest environments in Amazonia. *Remote Sensing of Environment*, *112*(9), 3469–3481. https://doi.org/10.1016/j.rse.2008.03.018

Ricaurte, L. F., Patiño, J. E., Zambrano, D. F. R., Arias-G, J. C., Acevedo, O., Aponte, C., Medina, R., González, M., Rojas, S., Flórez, C., Estupinan-Suarez, L. M., Jaramillo, Ú., Santos, A. C., Lasso, C. A., Nivia, A. A. D., Calle, S. R., Vélez, J. I., Acosta, J. H. C., Duque, S. R., … Junk, W. J. (2019). A Classification System for Colombian Wetlands: An Essential Step Forward in Open Environmental Policy-Making. *Wetlands*, *39*(5), 971–990. https://doi.org/10.1007/s13157-019-01149-8

Vilardy, S., Jaramillo, Ú., Flóres-Ayala, C., Cortés-Duque, J., Estupiñan-Suarez, L., Rodriguez, J., Aponte, C., Peláez, S., Santos, A. C., Samacá, W., & Acevedo, O. (2004). *Principios y criterios para la delimitación de humedales continentales: Una herramienta para fortalecer la resiliencia y la adaptación al cambio climático en Colombia.* (Instituto de Investigación de Recursos Biológicos Alexander von Humboldt). http://hdl.handle.net/20.500.11761/31444

Wittmann, F., Schöngart, J., & Junk, W. J. (2011). Phytogeography, Species Diversity, Community Structure and Dynamics of Central Amazonian Floodplain Forests. En W. J. Junk, M. T. F. Piedade, F. Wittmann, J. Schöngart, & P. Parolin (Eds.), *Amazonian Floodplain Forests:*

Ecophysiology, Biodiversity and Sustainable Management (pp. 61–102). Springer Netherlands. https://doi.org/10.1007/978-90-481-8725-6_4