DETECTION AND CHARACTERIZATION OF COLOMBIAN WETLANDS: Integrating geospatial data with remote sensing derived data. USING ALOS PALSAR AND MODIS IMAGERY

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ABSTRACT:

Wetlands regulate the flow of water and play a key role in risk management of extreme flooding and drought. In Colombia, wetland conservation has been a priority for the government. However, there is an information gap neither an inventory nor a national baseline map exists. In this paper, we present a method that combines a wetlands thematic map with remote sensing derived data, and hydrometeorological stations data in order to characterize the Colombian wetlands. Following the adopted definition of wetlands, available spatial data on land forms, soils and vegetation was integrated in order to characterize spatially the occurrence of wetlands. This data was then complemented with remote sensing derived data from active and passive sensors. A flood frequency map derived from dense time series analysis of the ALOS PALSAR FBD /FBS data (2007-2010) at 50m resolution was used to analyse the recurrence of flooding. In this map, flooding under the canopy and open water classes could be mapped due to the capabilities of the L-band radar. In addition, MODIS NDVI profiles (2007-2012) were used to characterize temporally water mirrors and vegetation, founding different patterns at basin levels. Moreover, the Colombian main basins were analysed and typified based on hydroperiods, highlighting different hydrological regimes within each basin. The combination of thematic maps, SAR data, optical imagery and hydrological data provided information on the spatial and temporal dynamics of wetlands at regional scales. Our results provide the first validated baseline wetland map for Colombia, this way providing valuable information for ecosystem management.

1. INTRODUCTION

Wetlands are well known to provide a large number of ecosystem services. Among many functions, they are considered as key ecosystem for their capacity of regulating floods, filtering out pollutants and improve water quality as well as been a proper ecosystem for bird migration (Finlayson et al., 2005**).** Since 1971 their relevance was recognized in the Ramsar convention, which was the first global instrument seeking wetland ecosystem conservation (Matthews, 1993). In Colombia, wetlands are a government priority in conservation policies and risk management since 1997 when the Ramsar convention was signed (MADS), 2002). However, good spatial information is still missing for most of the Colombian territory, there is also lack of understanding on the water pulses and dynamics. Neither an inventory nor a national wetlands baseline exists.

After the flooding events in 2010-2011 caused by La Niña phenomenon, one of the Colombian government's strategies was to identify and delineate wetlands and *Paramos* (highlands water catchment ecosystems), considering their importance to conserve and regulate water flows. Wetlands in this study were understood as "an ecosystem that due to landforms and hydrological conditions accumulates water, temporally o permanently, and all these drives to a specific type of soils (hydromorphic) and organisms adapted to these conditions" (Vilardy *et al.* 2014). In this sense, Colombian wetlands are diverse and vary across the country; there might be permanent and temporal lakes, shrub swamps, swamp forests, seasonally flooded forests, meadows, rivers, mangroves, estuarine waters, coastal freshwater lagoons, saline lagoons, and many more. This diversity of wetlands types requires the integration of different data sources and techniques to showcase ecosystem spatial and temporal dynamics when a national product is developed.

In Colombia, the wetlands' surveys have focused on the Magadalena-Cauca basin, which holds more than 80% of population (Hydrology, Meteorology and Environmental Studies Institute (IDEAM) and Cormagdalena, 2001). SarVison and The Nature Conservancy (TNC) generated a flooding frequency map using Alos Palsar imagery for this basin, within the Kyoto and Carbon initiative (K&C) and the Japan Aerospace Exploration Agency (JAXA) collaboration (Quiñones 2013, Quiñones et al 2013). After La Niña phenomena 2010-2011, a flooding report was made by IDEAM and the National Geographic Institute Agustin Codazzi (IGAC) (2011) which centred in the Magdalena and Cauca regions reporting high damage. On the other hand, less populated and some of the largest basins in the country, such as the Amazons, Orionoco and Pacific, present a lack of information.

Worldwide wetlands' surveys have had different remote sensing approaches and have been used for multiple purposes among countries. For example, Albania leaded its wetlands inventory through unsupervised classification algorithms of LandSat imagery. They calculated the Normalized Difference Vegetation Index (NDVI) and the wettest Tasseled Cap band, and used both as an input in a classification algorithm (Apostolakis 2008). Tasseled cap was described by Cris and Cicone in 1984, it is one of the first imagery transformation that highlights water and is still used. After, some other indexes have been developed for water mirror delineation using mainly LandSat images.

Some examples are de Normalized Water Difference Extraction Index NDWI (McFeeters 1996), the Modified Normalized Water Difference Extraction Index MNDWI (Xu 2006) and the Automated Water Extraction Index (Feyisa et al. 2014). All seek to improve separability between water, build-ups and shadows.

Moreover, NDVI has been demonstrated to be an indirect measure with good performance in surveys related to wetlands, taking into account that it includes information of water reflectance but also from vegetation. A methodology to detect wetlands using NDVI MODIS images was proposed by Landmann et al. (2006), it is based on the comparison of images from the dry and rainy season.

Detection of wetlands must be supplemented with hydrological data because the hydro-period brings with it an understanding of the ecological function of wetlands (van Dongen, et al 2012). Information on the ecosystem types and dynamics is required to establish conservation and management strategies.

This study aims to integrate a thematic wetlands map based on spatial geo-information (landforms, soils and Vegetation data) with information captured by active and passive sensors (Alos Palsar I MODIS respectively) and hydrological stations. Our outcomes include spatial and temporal information that can guide national and local stakeholders, ONGs and environmental agencies of the government towards a better planning of the territory.

2. METHODS

2.1 Study Area

This study was carried out on the continental territory of Colombia. It is located in the equatorial zone between -66.76° and -79.09° of longitude and -4.31° and 12.5° of latitude. Colombia is a country of high landscape diversity with mountainous and lowland ecosystems. Altitude ranges from 0 to 5.800 m.a.s.l. with the Andes as the main mountain chain, with diverse ecosystems with very dry or very high precipitation regimes. The annual mean rainfall varies from 500 to 10.000 mm and the mean temperature at 0 m.a.s.l. is 28°C and 6°C at 4.000 m.a.s.l. (IDEAM 2005). The mountain system in Colombia and their interaction with atmospheric circulation determine the regional hydrological behavior. Consequently, an altitudinal distribution pattern indicates a clear increase in precipitation and runoff with increased levels of relief. Runoff production is directly related to precipitation and evaporation, which are conditioned by elements of the landscape and the location of Colombia on the globe. Other factors such as vegetation cover, soils, land use, geology and others affect runoff through their influence on precipitation and evaporation processes (IDEAM 2010a).

Toward a better understanding of Colombian wetlands, the results were analysed at regional scales. The country was divided into eight zones that correspond to the main river basins of Colombia and were proposed by IDEAM (2010a). They are: Amazon, Caribbean, Catatumbo, Cauca, High Magdalena, Middle Magdalena, Orinoco and Pacific (Figure 1).

2.2 Wetlands thematic map

The wetland's thematic map has incorporated data from geophysical variables. Firstly, a conceptual approach was designed with a literature review and expert's workshops identifying the criteria that allow the spatial identification of wetlands (Cortes-Duque and Rodríguez-Ortiz, 2014). The selected criteria were landforms, hydromorphic soils, wet vegetation and the river networks including water bodies. Each criteria has its own spatial layer (IDEAM 2010, IGAC 2014a, IGAC 2014b) which was assessed by thematic experts. Each expert calculated an association level of the variables related to wetlands ecosystems. Later, a cartographic edition process was performed manually to integrate scales at 1:100.000. Final integration was based on weighted overlay analysis performed in ArcGIS 10.1. following the criteria and weight defined by each thematic expert. The accuracy of the wetland map is subject of an ongoing study.

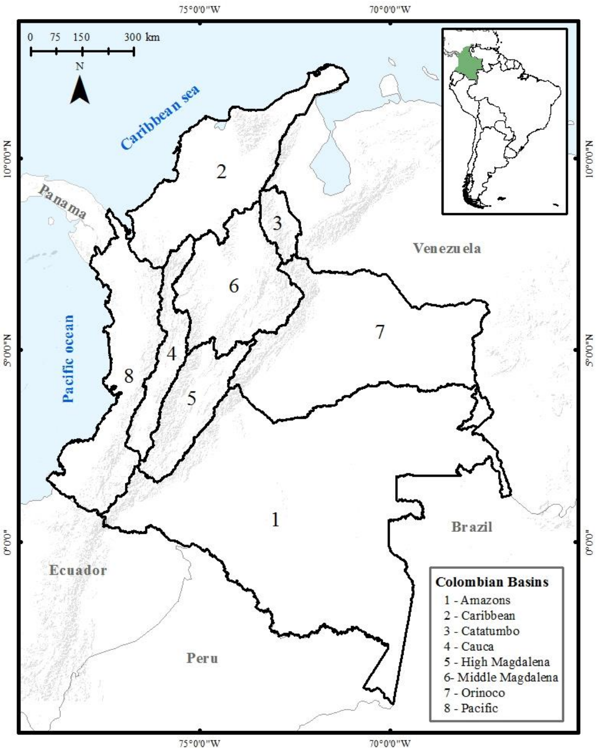

Figure 1. Colombian basins based on IDEAM (2010a).

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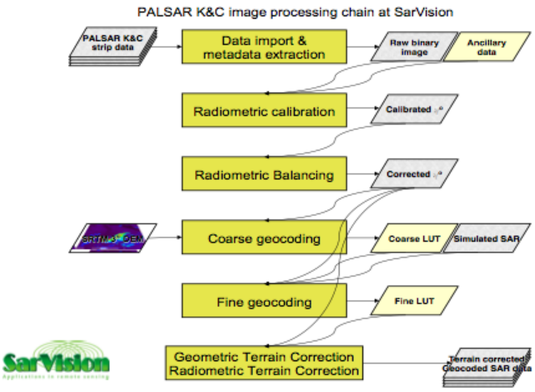
2.3 Frequency flooding map

2.3.1 Image processing: A dense time series of the Alos PALSAR FBS and FBD-HH radar (50 m) was used to generate a flood frequency map of the whole Colombian continental territory. This map presented the number of times each pixel was detected to be flooded during the study period (2007-2010). Two main classes are shown in the map: the open water class and the flooded under the canopy class.

In total 168 strips of the Alos FBD and FBS were processed covering the Colombian territory. A total of 7 coverages over the whole territory were completed for the period between 2007 and 2010. Single look complex (SLC) Strips were processed using Gamma software following the processing steps showed in Figure 2. Detail processing can be found in Quinones (2013).

Five Alos PALSAR –HH mosaics at 50 m resolution were created for the whole country. Each of this HH mosaics was filtered and classified using ENVI classification techniques.

Each classified map showed two classes, corresponding to open water and flooding under canopy. A flood frequency map was created integrating the information for these maps.



a.

Figure 2. Processing process carried out to each FBD- FBS Alos PalSAR SLC strips.

2.3.2 Validation process: IDEAM carried out the validation process of each of these classified mosaics. Although the flooding map was generated for the all the Colombian continental territory, the validation process was made for 19 representative windows in strategic areas of the country.

Six main steps were followed during the validation process: (i) at the initial stage, the information was tested by Colombian landscape experts from IDEAM, IAvH and SarVision. They visually validated different well-known areas of the country, (ii) a stratified random sample was designed for the accuracy assessment following the Olofsson *et al* (2013) and (2014) methodology, (iii) samples were revised and compared with both high-resolution radar and optical images, (iv) matrix error evaluation, which is a cross-tabulation of the remote sensed data against the verified reference, (v) estimating area and uncertainty and (vi) confidence intervals.

2.3.3 Correlation analysis between the thematic map and the flooding map: A spatial correspondence analysis was made between the identified wetlands of the thematic map with the flooding areas detected by radar. All flooding frequency was reclassified to a value of 1. Then, the comparison was done without taking into account the type and frequency of flooding. The processing was performed in ArcGIS 10.1.

2.4 NDVI MODIS map

2.4.1 NDVI MODIS acquisition and pre-processing: The products MOD13Q1 from MODIS Terra Sensor were downloaded from the NASA website http://reverb.echo.nasa.gov. To cover the territory of Colombia six tiles were required (h10v07-v08-v09; h11v07-v08-v09). In total 138 images for each tile were acquired from 2007 to 2012. The NDVI band of all images were imported in ERDAS IMAGINE 2010. Afterwards a layer stack was built with all NDVI images guaranteeing the time sequence. In this sense, the first image in the stack (band 1) is from January 2007 and the last one (band 138) is from December 2012. The process was performed for all the tiles to finally create a mosaic. The same procedure was done for the quality band.

2.4.2 TIMESAT processing: The NDVI image stack for Colombia was converted to binary data format with the same quality stack. The TIMESAT 3.1 (Eklundh and Jönsson 2012) program parameters were adjusted on pilot windows for the monomodal and bimodal regions of Colombia (IDEAM 2005). The selected mathematical function to adjust the NDVI profiles was Savitzky-Golay. Pixel with clouds or without processing were excluded from the analysis.

2.4.3 Imagery classification and multitemporal analysis: A TIMESAT output file was imported to ERDAS IMAGINE and its values rescaled to digital numbers (0-255). The ISODATA clustering unsupervised classification ran from 30 to 120 classes. Based on divergence statistics criteria, the most adequate number of classes was chosen (de Bie et al. 2011, Ali et al. 2013). The classes associated with wetlands were identified and assessed among the main hydrological Colombian basins.

2.4.4 Wetlands characterization using MODIS NDVI information: The NDVI annual profile of each class was assessed to assign to which land cover correspond. Next, it was calculated the NDVI classes distribution on wetlands from the thematic map, and finally a comparison within basins was done.

2.5 Hydroperiod of Colombian basins

A characterization of the main watersheds in Colombia was created based on hydroperiods. The hydroperiod is the seasonal pattern or the level of a wetland and is the wetland's hydrologic signature (Mitsch and Gosselink, 2000). From hydrometeorological gauging stations distributed along the country with recording for the period between 1974-2012, was possible to identify the season and variability of the discharge and precipitation. This analysis articulated hydrographic zoning (IDEAM, 2013) and relief allowing the characterization of regions with similar hydroperiods.

3. RESULTS

3.1 Wetlands thematic map

The map shows two classes: (1) identified wetlands which refer to wetlands where information from one or more criteria is accurate for the ecosystem detection, and (2) potential wetlands ecosystem that are areas vulnerable of flooding or transformed wetlands by natural or anthropic causes. These areas might have a lack of information due to the scale (1:100.000), fieldwork limitations (e.g. access difficulties, number of samples) or remote sensing constrains (e.g. clouds, topography).

This study focused on class 1 (identified wetlands) which are water bodies, or areas with hydromorphic soils and hydrophytic vegetation that present temporal flooding, and are adapted to particular wet regimes. It is estimated that Colombian inland and costal wetlands' area is around 18'000.000 ha (Figure 3), marine wetlands are not included. The Orinoco and Amazons basins have the highest percent of wetlands, 38.3% and 31.9% respectively, followed by the Caribbean (13.0%) and the Pacific (11.4%). The high and middle Magdalena area correspond to 0.6% and 3.8% overall area. The basins with less area are Cauca (0.9%) and Catatumbo (0.2%). The accuracy of this detection is the subject of an ongoing assessment.

Furthermore, the relevance of the areas detected as class 2 (potential ecosystem of wetlands) stands out for environmental planning and risk management (12’000.000 ha approximately). However, they are out of the scope of this paper.

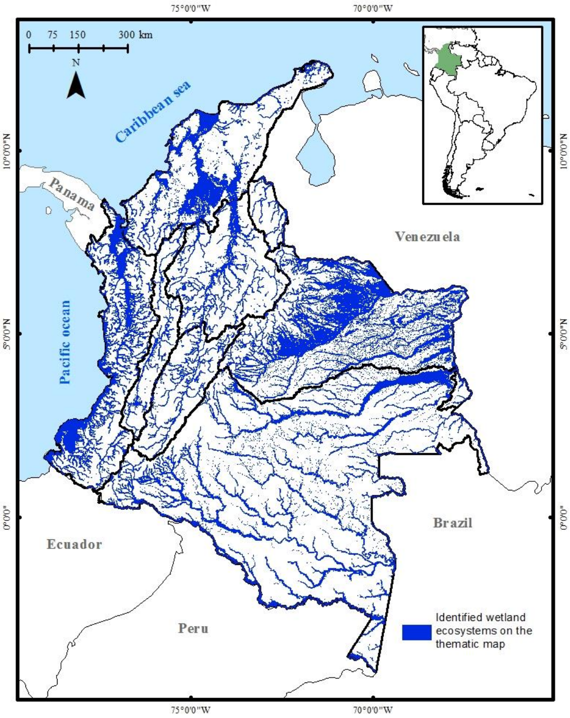
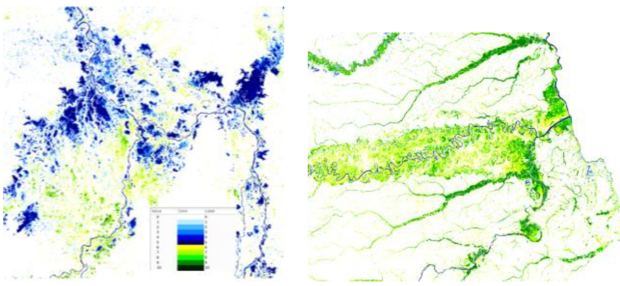


Figure 3.Wetlands identified in the thematic map at 1:100.000 in the continental territory of Colombia

3.2 Frequency flooding map

The frequency flooding map shows how many times radar detected flooding at a 50m of pixel within 5 observations. A window on the Mojana region in the north of the Magdalena basin is presented to illustrate the flood frequency map (Figure 4). Colours on the legend indicate the two main classes on the map. Open water (blue) and flood under canopy (green). Shades on the colours indicate the number of times a pixel was detected flooded. The higher the shade of the colour the higher the flood frequency.



a. b.

Figure 4. Frequency flooding map for the a. Mojana region (above) and the b. Mataven region (below). The darker the colour the higher the times the area was detected as flooded.

Flooded forest dominates in the Amazon, Pacific and Orinoco basins. Conversely, open water flooding predominates in the Caribbean and Magdalena’s (higher and middle) basin. Information for Catatumbo and Cauca is not conclusive considering that their detected area is low as well as the spatial correspondence with radar (Figure 5).

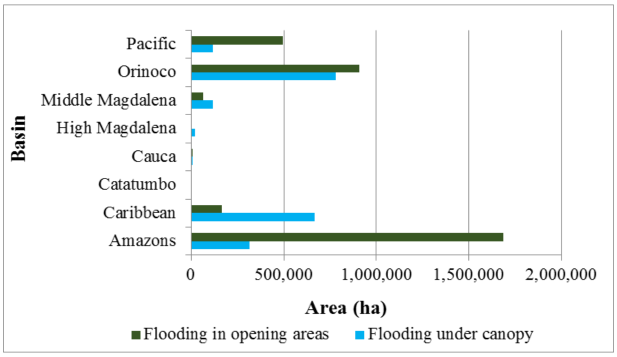


Figure 5. Area detected by radar of opening areas and under canopy in each of the Colombian basins.

For the validation process three classes were mapped from each SAR mosaic in the analysed timeline; (i) class 0: non-flooding, (ii) class 1: flooding in open areas and (iii) class 2: flooding under canopy. Hereafter a frequency-flooding map was the product that merged the information of the 6 observations. It presents information from each flooding pulse (observation) per pixel. Therefore, it is possible to read the number of times that flooding was detected in a single pixel was during the time analysis. This product was validated, by reviewing 11307 samples and the map had an overall accuracy of 85%. Higher accuracies were associated to flat terrains and mirror waters and the main errors were associated to the category of flooding under canopy, especially in areas with relieve.

The higher spatial correlation between the thematic map (class1) and the frequency flooding map is observed in lowlands. In other words, the Caribbean, Amazons and Pacific exhibit the highest correspondence with the radar detection (Figure 6) where are also most of the largest wetlands complex.

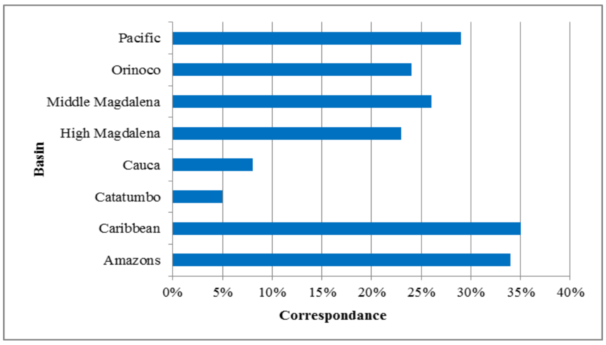


Figure 6. Spatial correspondence between the wetlands thematic map and the flooding map.

3.3 NDVI MODIS wetlands map

The NDVI map was found to be the most adequate with 45 classes based on the average separability and minimum separability criteria (Estupinan-Suárez and Florez-Ayala, 2014). The classes behave differently within basins Therefore, they represent different type of wetlands ecosystems which are mainly separated by temporal characteristics. The analysis of NDVI classes was focused on the characterization of the identified wetlands in each basin and highlight their features based on their temporal trend.

In general, class no. 1-4 detects sea water and glaciers, from class no. 5 to no. 19 the NDVI map is showing water bodies. It was observed that the classes on the 20-29 range have a good correspondence with wetlands on highland, predominates with the *Paramo* ecosystem detection. Classes from 30 to 39 identifies temporal flooding, Orinoco wetlands cover (42%) is dominates mainly by classes 37,38 and 39 which are associated to temporal shrub swamps and flooded savannahs .The evergreen vegetation is classified on the latest classes higher than no. 40 (Table 1).

Colombian basins	**Percent of pixels in a no. of classes range (%)**				
	1-9	**10-19**	**20-29**	**30-39**	**40-45**
Amazons	0.43	1.14	1.63	2.66	94.55
Caribbean	5.71	11.59	4.69	10.93	67.09
Catatumbo	1.95	0	0.4	8.53	89.12
Cauca	0.26	0.5	1.91	8.83	88.50
High Magdalena	2.2	6.95	8.55	22.51	59.80
Middle Magdalena	0.76	4.79	11.51	4.79	78.30
Orinoco	0.16	0.58	0.72	42.92	55.61
Pacific	2.08	1.19	1.79	6.53	88.41

Table 1. NDVI classes frequency range by basin

When the NDVI MODIS classes are analysed separately temporal differences of the wetlands are shown. For example, the dominant NDVI water mirror profiles of the Pacific and Caribbean lakes differ. In the Pacific, the opening flooding are classified as no. 13, 18, 19 while in the Caribbean as class no. 10, 12 and 16. The evergreen classes also present outcomes to separate. The hypothesis is that this separation is caused by different temporal regimes on the index. The basins with more than 80% of evergreen classes also exhibit important patterns. The Amazons is clearly dominated by class no. 44. Pacific and Cauca which are neighbour basins have similar trends, the predominant classes are 43 and 44, but Pacific also has a significant participation of class no. 40 and 45 (Figure 7). Catatumbo has an specific trend, distributed from higher to lower classes frequency as 44, 45, 43 which shows a particular composition.

Figure 7. Percent of NDVI MODIS classes in Colombian basins. Solely from classes no. 40 to 44

The use of NDVI MODIS to detect wetlands is constrained due to their spatial resolution and optical properties. Its potential relies on its high temporal resolution that shows the temporal annual dynamic of shrub swamps and opening water bodies. In very dense vegetation, like flooded forest, its use was reduced to the main rivers and riparian vegetation.

3.4 Hydroperiods regions on Colombian's basin

Seventeen regions were identified based on hydroperiods. Figure 8 shows the geographic positions of the respective data collection points. The diagram bars show the hydroperiod for Colombian rivers, these curves represent the discharge fluctuation (m^3/s) during the annual cycle between 1974 and 2012.

One of the largest hydrographic areas of Colombia corresponds to the Amazon, with a mean annual flow of $26800m^3/s$ where it is possible to find floodplains, madreviejas, marshes (small and medium size) and flooded forests. These wetlands are characterized by a monomodal hydroperiod with high values between May and June. The importance of the Amazon region is also because it has one of the RAMSAR sites the Laguna de la Cocha, located in the upper basin of the Putumayo River at an elevation of 2700 meters. Also some of the rivers of the Amazon region are born near the Colombian Massif such as Putumayo and Caqueta river.

The Orinoco basin in Colombia has a monomodal hydroperiodo, with high flows between the months of June and July. The Chingaza lacustrine system is an important site for RAMSAR and it is found in this region. In the Orinoco the wetlands can be flood plains in winter, madreviejas and permanent ponds.

Within the Magdalena River basin there are tree identified regions. The first is High Andean, which has a monomodal hydroperiod with a maximum flow value in July. Downstream the second region is Hight Magdalena, the hydrological regime is bimodal with peak flow in April and November, where there are large expanses of flooded land for rice cultivation and some hydroelectric dams. The third region is Middle Magdalena, the hydroperiod is still considered bimodal as observed in the Arrancaplumas station with peaks in May and November and a mean annual flow of 1277 m3/s over Magdalena River.

The Eastern Andean region is monomodal hydroperiod, some important wetlands in the region are Fuquene and Cucunuba Lagoon. Thanks to the physical and geographical conditions together with the contributions of the rivers of the East Andes to the Middle Magdalena region, there is a transition from monomodal to bimodal hydroperiod.

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The Lower Magdalena region is characterized by a system of marshes and floodplains at the confluence of Magdalena, San Jorge and Cauca rivers (*depression momposina*). Even though the upper regions are monomodal the lower Magdalena has a monomodal trend as the Caribbean region that has a clear monomodal hydroperiod. The most important wetland in this region is the Cienaga Grande de Santa Marta RAMSAR site (RAMSAR, 2014). The Catatumbo River basin drains into the Gulf of Maracaibo and the hydroperiod is marked by two seasons of high flows in May and November.

Cauca River is divided into three regions of similar hydroperiods. The first is the Higth Cauca with monomodal regime. Then the Valle del Cauca with a bimodal regime and flow peaks in May and November. The Middle Cauca has one of the sites of RAMSAR international interest wetland complex the Otún Lagoon. According to the values recorded at the station SAN JUAN in Nechí region the hydroperiod is monomodal with highs flow in November with an average annual flow of 487 m^3/s.

This contribution has been peer-reviewed.
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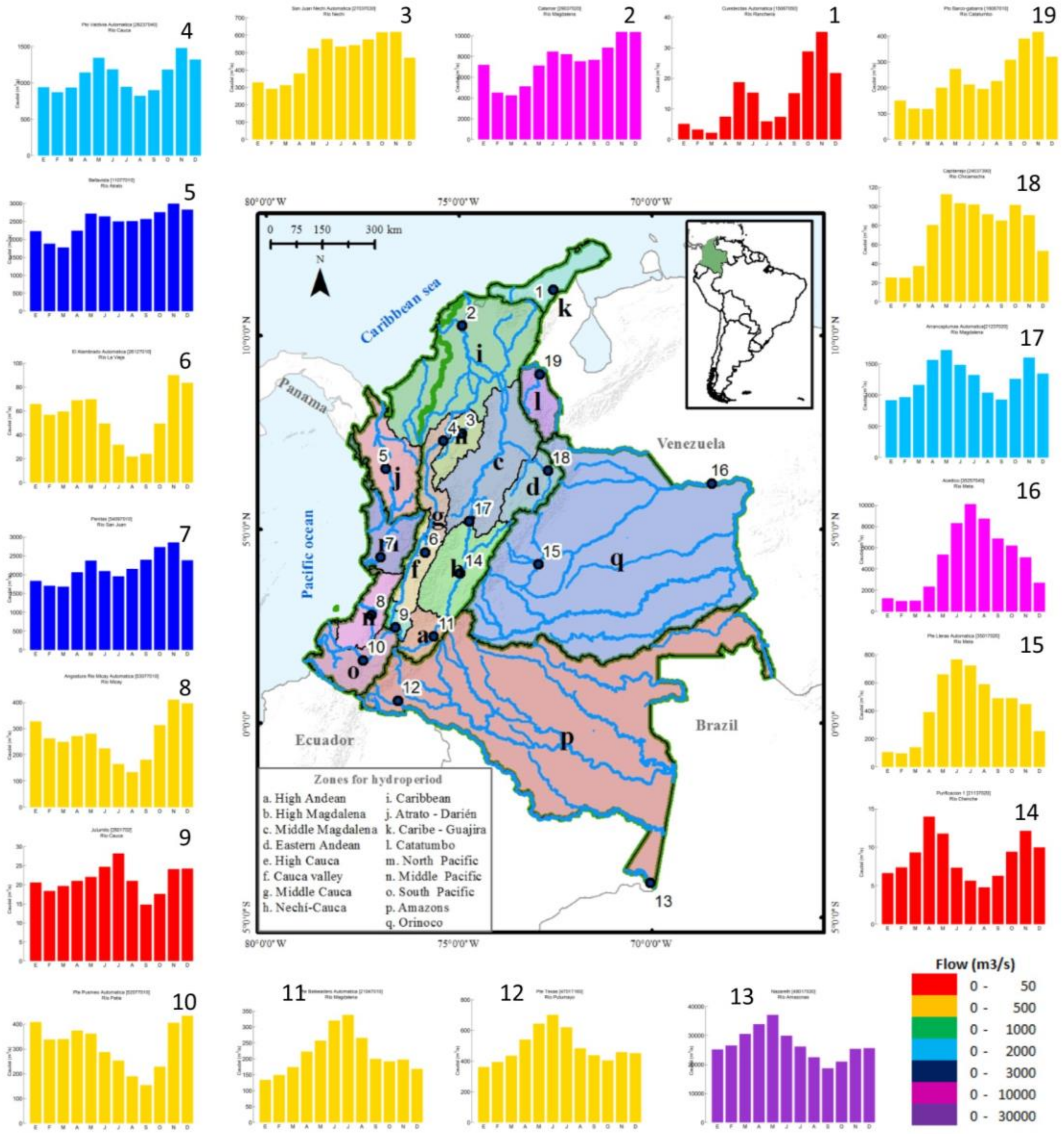

Figura 8. Hydroperiods of the hydrological zones of Colombian basins a based on flow multiannual data (1974-2004) of hydrological stations. Number indicates the geographical position of data collection points.

In Colombia the precipitation regime is heterogeneous. The region with higher precipitation is de Pacific, but the most important discharge are in the Amazon, Orinoquia and Magdalena. The Pacific region shows three hydroperiod, in the northern river basins in San Juan and Baudo (wetland of Delta Baudo River interest RAMSAR) with bimodal hydroperiod at high flow rates in the months of March and November. In the Mid and South Pacific the hydroperiod is monododal with seasonal high flow rate in November.

4. DISCUSSION

Colombia has recognized the importance of wetlands when it became a party of RAMSAR convention since 1998 and later on the legislation through a National Policy of Wetlands in 2002. By that time it was estimated an area of 20.000.000 ha for inland wetlands (MADS, 2002). But only until 2012, after the extreme flooding of *La Niña* event, a wetlands map iniciative begun. The wetlands thematic map presented in this article identified the ecosystem based on basic official national geophysical layers that were assessed and refined by thematic experts. The mapping criteria were selected on workshops with researches and discussed environmental government agencies and are consistent with national data availability. During all the process, it was sought to incorporate the high variability of Colombian wetlands.

The largest complex of Colombia wetlands are located in lowlands which are mainly isolated areas and with lack of data as is the case of Amazon, Pacific and Orinoco regions. Radar detected that the flooding area under canopy is higher than in open areas. The flooding under canopy is associated predominantly to flooded forest in areas with high mean precipitation values as the Amazons and Pacific. This was also reaffirmed with the MODIS NDVI map results that showed a dominance of 95% of evergreen forest in the wetlands of Amazons. The radar information from Alos PalSAR is able to give a new dimension for the wetlands management in Colombia due to identifications of the flooded under the canopy which changes the management strategies that until now have been focus in the water mirrors.

The area of wetlands in Cauca, Catatumbo, High and Middle Magdalena were underestimated at the assessed scale. Firstly, the majority of wetlands on these basins are smaller than the cartographic scale (25 ha) which might be explained by the dominance of steep relief. For that reason, this information has to be seen together with the Colombian wetlands inventory to avoid misrepresentations. Complementary, Cauca and Magdalena basin hold a large percent of the country population and have been exposed to strong transformation process.

The frequency-flooding map generated with radar images constitutes an important flood analysis tool for the country, since this information provides consistent and accurate data as a monitoring baseline tool of aquatic ecosystems, as well as proper flooding information. The spatial correspondance found between the thematic map and the flooding map was lower than the reported initially by Quinones et al. (2014). This could be explained because the first analysis used the high and very high potential areas of the wetlands thematic map. Otherwise, this survey was solely focused on the identified wetlands without including potential areas. In this sense, it is necessary to explore if the areas detected by radar that correspond to potential wetlands ecosystem can be classified as identified wetlands, mainly in lowlands where radar detection is more accurate.

In addition, it is recommended that a comparison be carried out between the 50 m frequency flooding map and the 100m product (also obtained in the wetlands project) that has less spatial resolution but more observations. This could have a major number of dates that fall into the rainy season. Therein, to work with more captures of flooding could improve the correspondence between the flooding frequency maps and the thematic wetlands. Moreover, radar exposed limitations detecting mangroves, if this drawback is solved is expected that the correspondence with costal boundaries basins increase.

MODIS NDVI data has a high potential to characterize wetlands taking into account the temporal trends of vegetation and water mirrors. However, the developed methodology limits its detection to the largest water bodies. The use of more bands and the comparison between images from the dry and rainy season as suggested by Landmann et al. (2006) has still to be explored.
This study was centred on the identification and characterization of wetlands, and turns into an opportunity to accomplish Ramsar compromises adopted by the country on the convention

5. CONCLUSSION

The large extension of Colombian wetlands, their diversity and complexity requires high human and technological efforts towards the generation of proper information for decision makers. In this sense, products derived from remote sensing turns into a valuable input, guaranteeing uploaded data for wetlands management programs, conservations strategies and risk management.

The outcomes shown on this paper are unique for the country. The thematic map has a biogeophysical approach considered landforms that accumulates water, hydromorphic soils and hydrophytic vegetation which are evidence of temporal or permanent flooding. The L band-radar (Alos Palsar) of the frequency flooding map provided valuable information specially when detecting flooding under canopy, since this information it's very difficult to detect by other sensors. However the reliability of the data is higher in flat areas. The MODIS NDVI map brought out information of the separability of wetlands including temporal information of water and vegetation. Moreover, characterization of hydroperiods at different basis zones shows the high variability of patterns and features of wetlands.

In brief, the resulting maps bring out a more complete understanding of wetlands, they included the spatial and temporal ecosystem dynamics and are a first attempt to link the hydrological information with geophysical layers integrated on the thematic map, and satellite imagery for the whole country. This frame that includes different approaches and data sources also has provided guidelines for risk management strategies and might be considered as a baseline for a wetlands monitoring program. Finally, it is recommended to develop a multi scalar approach, looking at detailed scales for small wetlands identification and at large scales to understand the spatial and temporal dynamics of wetlands complex located mostly in lowlands.

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