SPATIAL-TEMPORAL DISTRIBUTION OF DROUGHT IN THE WESTERN REGION OF PARAGUAY (2005-2017)

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ABSTRACT:

The Western Region of Paraguay is naturally dry which makes it vulnerable to almost permanent drought events. Hence, low cost drought monitoring is necessary. Therefore, an index derived from satellite image information was used for this purpose. The Normalized Difference Drought Index (NDDI) was used with the objective of studying the characteristics (temporal and spatial distribution) of drought in the Western Region of Paraguay from years 2005 to 2017 and relate drought point values of NDDI to the land use cover of the study area. Terra satellite's Moderate Resolution Imaging Spectro-radiometer (MODIS) sensor images were used for the calculation of NDDI. The driest month of all years (July) and the wettest month of all years (December) were averaged to analyze spatial tendencies. The NDDI was contrasted spatially with the Land Use Cover of the Western Region to pinpoint the location of the highest values. The year 2015 had the highest value of 0.9847 in agricultural land use in the Department of Boqueron. The NDDI was a good indicator of drought throughout the region and could be a complement for in-situ measurements.

KEY WORDS: NDDI, MODIS, land use, Paraguay, drought.

1. INTRODUCTION

The Western Region of Paraguay is characterized by a semiarid climate where cattle ranching is the largest economic activity. The main amount of precipitation occurs in the Eastern region of Paraguay, reaching more than 1,700 mm per year, while in the Western region it is less than 600 mm [1]. The North western section of the country is therefore more susceptible to drought events. [2] Drought occurs in high as well as in low rainfall areas. It is a condition relative to some long-term average situation of balance between rainfall and evapotranspiration in a particular area. Average rainfall does not provide an adequate statistical measure of rainfall characteristics in a given region, especially in the drier areas. Drought severity, too, is difficult to determine. It is dependent not only on the duration, intensity, and geographical extent of a specific drought episode, but also on the demands made by human activities and by the vegetation on a region's water supplies. Drought characteristics, along with its far-reaching impacts, make its effects on society, economy, and environment difficult, though not impossible, to identify and quantify.

NDDI was previously studied to be a good indicator of drought in a five-year study in the Great Plains of the United States compared to just using NDVI [3]. Another study of fifteen years [4]in a basin was made which found that NDDI was a good measure of drought in large surface studies. Furthermore, a study in Hungary [5] using MODIS imagery and NDDI concluded that the index is sensitive to land cover changes although it can overestimate drought. Still, it continues to be a good advantageous low-cost analysis tool.

Therefore, remote sensing provides low cost tools to analyze phenomena, such as drought, in a large geographical scale to serve as a complement to in situ data that might be missing or incomplete. Consequently, the main objective of this research is to study the characteristics (temporal and spatial distribution) of drought in the Western Region of Paraguay from years 2005 to 2017 and relate drought point values of NDDI to the land use cover of the study area.

2. METHODOLOGY

2.1 STUDY AREA

Paraguay is a small landlocked country located in central South America, bordered by Argentina in the south, Brazil to the east and northeast and by Bolivia to the north and northwest. The Paraguay River runs from north to south, dividing the country in two regions, the Eastern region, where most of its population lives and the majority of the economic activities take place, and the Western region, an extended plain where only 2 % of the population lives [1] (Figure 1).

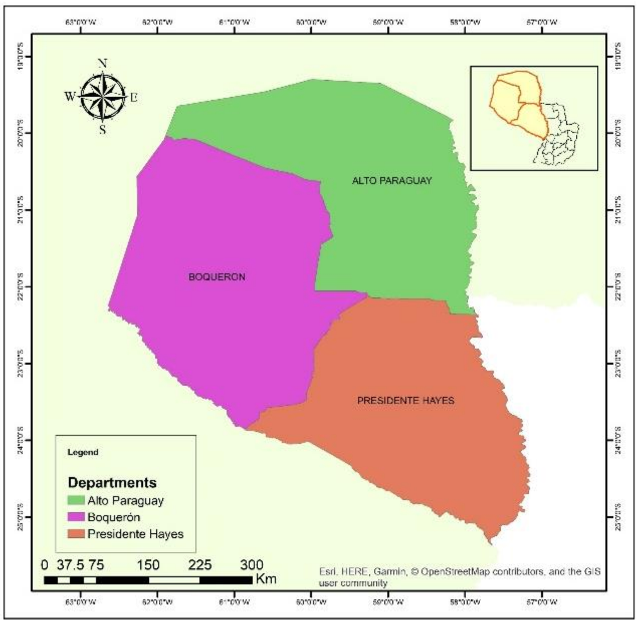

Figure 1. Political Division of the Western Region of Paraguay.

It has been presented in previous studies [6] that the Paraguayan western region is under pressure over the international food demand of meat production and the alarming expansion of agriculture and deforestation. This is seen in the map (Figure 2) where the majority of land has been categorized as agricultural use.

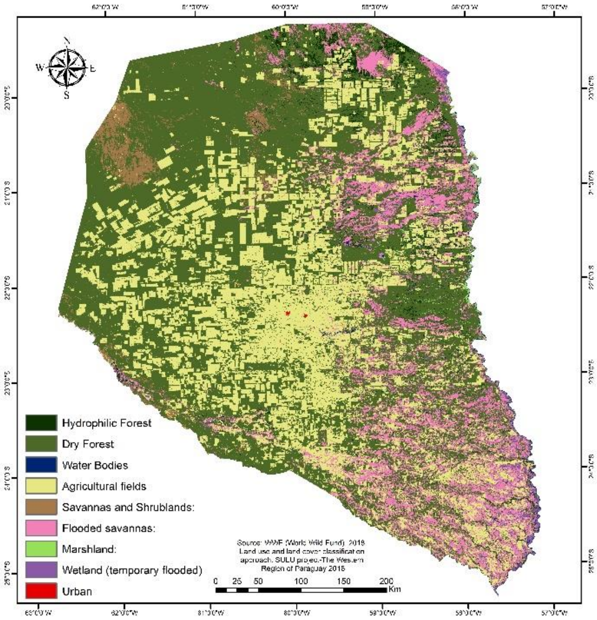

Figure 2. Land Use, land cover of the Western Region of Paraguay.

2.2 IMAGE PROCESSING

For this research MODIS 16-day 250-meter surface L3 Global MOD13Q1A images were used. In addition, a water mask MOD44W 250-meter resolution was downloaded. Both were obtained from the NASA Earth Explorer site (https://earthexplorer.usgs.gov). MOD13Q1 MODIS Images were downloaded from 2005 to 2017. Considering July as the driest month and December as the wettest month of all the study years. MOD44W water mask images were downloaded from year 2005 to 2015 only one per year. 2015 water mask was used to calculate the index for the year 2016 and 2017.
Two scenes that covered the main study area were used. Tiles MOD13Q1h12v10, MOD13Q1h12v11 and MOD44Wh12v10, MOD44Wh12v11 for the water mask. NDVI, NIR (near infrared) and MIR (middle infrared) bands of MOD13Q1 were needed as well as the water mask for the calculation of the spectral index of interest. Images were processed as follows:
(1) Data from the MODIS tiles (h12v10 and h12v11) were mosaicked. Images of July (2005-2017) and December (2005-2017), later were projected to the coordinates of the study area. (2) All images were introduced in Model Builder of ArcGIS 10.3 to automate the process of calculation of NDDI. The water mask was used to extract the water of all indexes to diminish the possible noise in the final result. (3) NDVI and NDWI were calculated automatically with equations 1 and 2

$$NDVI = \frac{(\mathrm{IR-R})}{(\mathrm{IR+R})} \quad (1)$$

Where: IR: Infrared
R: Red

$$NDWI = \frac{NIR\ -SWIR}{NIR\ +SWIR} \quad (2)$$

Where: NIR: Near Infrared
SWIR: Short Wavelength Infrared

*Using the MODIS satellite, the SWIR band was replaced by the MIR (Middle Infrared) of the MOD13 images.

(4) Next, they were used to calculate NDDI with the following formula

$$NDDI = \frac{\mathrm{NDVI-NDWI}}{\mathrm{NDVI+NDWI}} \quad (3)$$

Where:
NDVI: Normal Difference Vegetation Index
NDWI: Normal Difference Water Index

(5) Once NDDI was calculated for July (2005-2017) and December (2005-2017) they were normalized to -1 to +1 values using a correction factor (a mathematical division of each image with the value 32768) to be better later interpreted. (6) All images were clipped to the area of interest. In this case all the western region of Paraguay. (7) They were then averaged, taking the images of July and December of each year to have only one representative map of drought to be analyzed. (8) They were classified according to the values in Table 1. This classification has been adapted from the USDM (United States Drought Monitor) [7]. (9) The highest values were extracted considering the land use soil map (Fig 2) and then ascertained with satellite images of that year and location.

NDDI Value	Drought Category
-1 – 0	Waterbody / No Drought
0.0-0.1	Abnormally Dry
0.1-0.2	Moderate Drought
0.2-0.3	Severe Drought
0.3-0.4	Extreme Drought
0.4-1	Exceptional Drought

Table 1. NDDI based Drought Classification

3. RESULTS

The most severe spatial extension of extreme drought according to NDDI were during the years 2010 (Figure 3) and 2016 (Figure 5). On the other hand, the highest value of NDDI was found in the year 2015 (Figure 4), followed closely by 2010. Both results were found in the use of agricultural land and in the same region in the department of Boqueron.

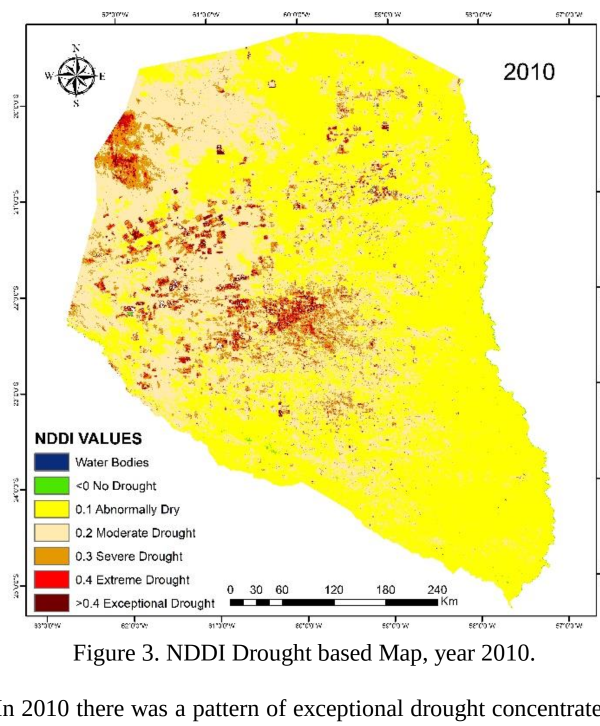

Figure 3. NDDI Drought based Map, year 2010.

In 2010 there was a pattern of exceptional drought concentrated in the center of the area and moving towards the northwest in its

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Primary publication at IEEE Xplore: https://doi.org/10.1109/LAGIRS48042.2020.9165664

majority. There were some points scattered in the northeast that went from severe to exceptional drought.

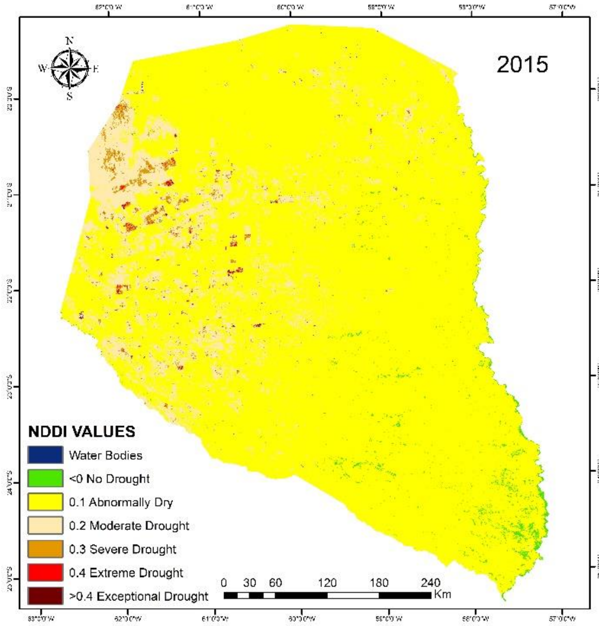

Figure 4. NDDI Drought based Map, year 2015.

In the year 2015 areas with exceptional drought were distributed mostly in the Northwest similar to year 2010. Although the severity of cases seems to be lessened in comparison. In this case, visual interpretation is an important tool that sometimes could be misleading without further data analysis of the spectral index. As an example, the extension of drought in the year 2015 (Figure 4) does not seem to be quite extreme. Nevertheless, it was the year where the highest value of NDDI was found. Every so often, not finding an aggravation in the extent of an index such as NDDI, does not mean that high values cannot be found in the area.

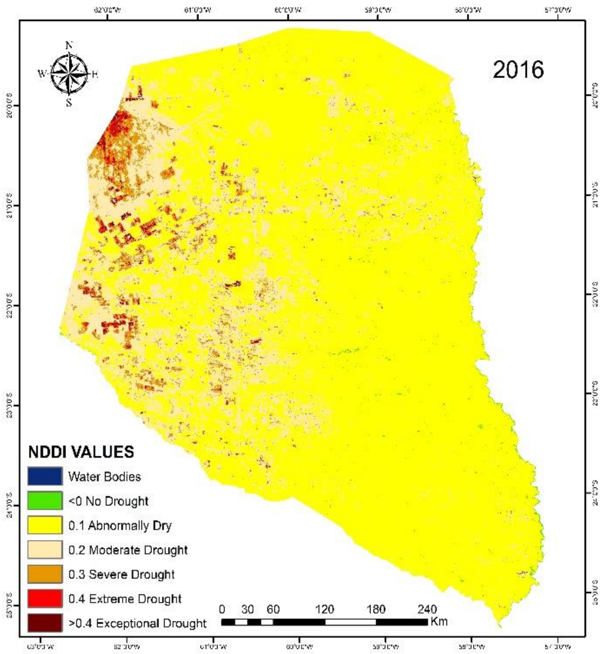

Figure 5. NDDI Drought based Map, year 2016.

The year 2016 had a visually high extension of drought. Even though the highest value of the series was not found in this year, it is important to notice the predominance of the pattern of exceptional drought similar to the year 2010. The area where exceptional drought coloration is prevalent is in the Northwest.

In all previous years of the series there was an extension of abnormally dry conditions typical of a semi-arid region such as the Western Region of Paraguay. A frequency of exceptional drought concentrated in the middle and northwestern area. Natural formed sandbanks are found northwest of the region; this could explain the natural predominance of drought in that area as shown in all maps studied.

Drought Category	**2010**	**2015**	**2016**
Waterbody / No Drought	1.24%	4.48%	1.13%
Abnormally Dry	30.65%	38.73%	24.51%
Moderate Drought	18.41%	51.25%	60.29%
Severe Drought	35.15%	4.58%	10.70%
Extreme Drought	9.76%	0.73%	2.39%
Exceptional Drought	4.79%	0.23%	0.98%

Table 2. Surface Distribution of Drought by category in percentage.

The Western Region has a natural dry ecosystem as previously mentioned, which might give an explanation to the distribution of drought presented in Table 2. As well, the year 2010 had the highest surface area distribution of severe drought in the three years. This corresponds to a drought event registered in 2008-2009 that might have extended for a longer period of time. In the years 2015 and 2016 the majority of the area is dominant by moderate drought.

Exceptional drought was not widely distributed. However, spotting its location can help identify the land use cover most vulnerable to drought as seen in Figure 6.

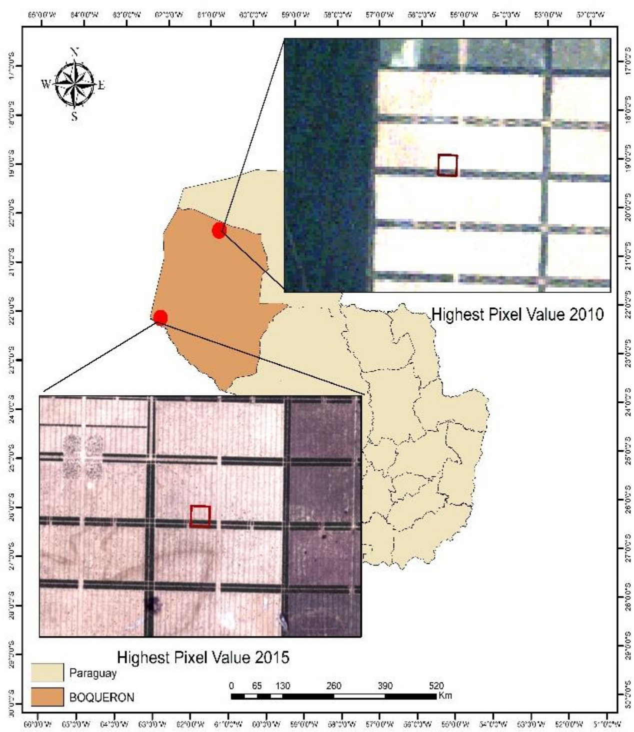

Figure 6. Exceptional Drought values geographical allocation.

The image used as control for the position of the highest NDDI value was Sentinel 2 from December 3rd, 2015. In the same way, a Landsat 5 TM 229/74 from July 29th, 2010 was used for that

year's control. The highest pixel value for 2010 and 2015 were in agricultural land use as observed in Figure 6. 2015 recorded a value of 0.9847, followed closely by 2010 with a recorded value of 0.9692, both values represent exceptional drought.
A similar result was found in Vietnam. Considering land use and several spectral indexes [8], authors studied extensively from 2001 to 2016 a series of spectral indexes, amongst them was NDDI. They considered different uses of soil. NDDI had a better correlation with a crop land use than a forest vegetation use. They concluded that NDDI was a better indicator of drought in cropland areas than any other land use they studied. That being so, it could explain why both values presented here had been found in agricultural land use. Another reason might be the soil being overused for cultivation or grassland. The Western area is commonly used for consecutive planting, leaving areas without vegetation coverage causing the soil to dry. This would likely impact on the satellite response to such phenomena, making it easier for them to detect droughts or abnormally dry areas.
Other authors in Thailand [9] studied NDDI related to land coverage. They divided their study in two years. One year was influenced by ENSO and another one was not. The NDDI was strongly associated with the lack of precipitation and land use changes, in the year affected by ENSO. As it is in this research in the Western Region of Paraguay, drought can be easily found in agricultural land because of a lack of natural vegetation in the soil. Another reason is because soil is left bare, exacerbating its loss. This might also explain the high values found specifically in two croplands that were left with no vegetation.

4. CONCLUSION

The patterns of drought observed were mostly located in the northwestern area of the study region. Due to a rapid expansion of agriculture and deforestation, this area has a high vulnerability to recurrent periods of severe to exceptional drought.

NDDI was a good indicator of drought throughout the region. NDDI could be a good complement for indexes measured on site with precipitation and temperature data. It has the advantage of providing immediate results in shorter periods of time than other indexes measured on site that require longer periods of time to be calculated and a larger input of data.

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