ESCUELA SUPERIOR POLITÉCNICA DEL LITORAL

FACULTAD DE INGENIERÍA MARÍTIMA Y CIENCIAS DEL MAR

"A computational script that calculates the Standardized Precipitation Index (SPI) for Latin America, using the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data base and crossing the SPI with two layers of spatial information: population density and land use."

INTEGRATOR PROJECT REPORT

Prior to obtaining the degree of:

INGENIERO OCEÁNICO Y AMBIENTAL

FREDDY DARWIN LÓPEZ SOLÓRZANO

GUAYAQUIL – ECUADOR

2018

ACKNOWLEDGEMENTS

My deepest thanks to CIIFEN staff that assisted me in the development of this project, to my tutor teacher as well, the always busy and caring, Ph. D. Mercy Borbor, and OF CURSE to ESPOL, you cost me seven years of my life, sometimes I even hated you, but I will still always carry you in my mind and soul, you made me the professional that I am.

DEDICATORY

This project is dedicated to my family. My mother that help me whenever I need it and keep me well fed during this years of demanding work in ESPOL. To my father that as well help me and teach me, in his own way, how to be man. To my little “Gona” that even as young as she is, is doing better than me, I’m proud of her.

EVALUATION COURT

M. Sc. Luis Miguel Altamirano Pérez
EVALUATOR TEACHER

Ph. D. Mercy Julia Borbor Córdoba
TUTOR TEACHER

DECLARATION

"La responsabilidad y la autoría del contenido de este Trabajo de Titulación, me corresponde exclusivamente; y doy mi consentimiento para que la ESPOL y CIIFEN realice la comunicación pública de la obra por cualquier medio con el fin de promover la consulta, difusión y uso público de la producción intelectual"

"The responsibility and authorship of the content of this degree work, corresponds exclusively to me; and I give my consent so that ESPOL and CIIFEN can make public communication of this work with the goal to promote the consult, diffusion and public use of the intellectual production"

Freddy Darwin López Solórzano

ABSTRACT

This report is the culmination of a cooperative project with the Centro Internacional para la Investigación del fenomeno de “El Niño” (CIIFEN) in order to satisfy or, putting in other words, solve CIIFEN’s problem on developing the first drought tool for their Impact-based Forecast and Warning Services (IFWS) initiative for agriculture areas and population density.

The problem was defined as follows: “The current CIIFEN’s drought tool, the Standardized Precipitation Index (SPI), has a spatial resolution of 1º by 1º that does not provide detail spatial information to develop an IFWS drought tools for agriculture areas and population density”.

To solve this problem was necessary a literally review to find precipitation sources (data) with a better spatial resolution than the one that CIIFEN currently has, as well a review to understand the theory behind the Impact-based Forecast and Warning Services. The results of this review were: Finding the precipitation Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data base and a better understanding of the IFWS in order to develop the droughts tools.

The solutions were: a computational script developed in R, a statistical language program, that computes the 3-months SPI and two IFWS methodologies developed in and for the open-source geographic information system QGIS (although it can be replicated in any GIS program), using the SPI as a droughts predictability tool. They consist in predicting where and how much (percentage) of agricultural area might be affected by a drought event; and how many people might be affected as well as, using CIIFEN's monthly precipitation forecast. To show the capability of the IFWS tools, it presents two examples in Ecuador, using CIIFEN's precipitation forecast for March, April and May of 2018.

The first example indicates that for the next seasonal period from March to May of 2018, the agricultural areas of Santa Elena, Guayas and El Oro might face a moderately dry event, according to the Forecast SPI calculated for that period of time, the approximate percentage of area that might be affected for the providences are: 48,52%, 4.63% and 0.58% respectively. The second one indicates for the same

providences as the first one that the approximate percentage of people who might be affected are: 59.92%, 17.40% and 3.14%, respectively.

It is recommended to verify the accuracy of these tools. It was not done in this project because the most recent CIIFEN's monthly precipitation forecasts available were the ones used in the examples, so I did not have the necessary inputs to estimates the accuracy of these tools but, as states by Singlenton (2012), in a similar study, the 3-moths SPI It is almost perfect reliably for the forecasting of drought and wet events[19].

TABLE OF CONTENTS

ABREVIATURES

WMO: World Meteorology Organization

SPI: The Standardized Precipitation Index

NDVI: Normalized Difference Vegetation Index

CHIRPS: Climate Hazards Group InfraRed Precipitation with Station

GIS: Geographic Information System

ENSO: El Niño/Southern Oscillation

IFWS: Impact-based Forecast and Warning Services

NMME: North American Multi-Model Ensemble

CPT: Climate Predictability Tool

MAE: Ministerio del Ambiente del Ecuador

MAGAP: Ministerio de Agricultura, Ganadería y Pesca del Ecuador

MAG: Ministerio de Agricultura y Ganadería del Ecuador

INTRODUCTION

According to the World Meteorological Organization (WMO, 1986)[1] *'drought means a sustained, extended deficiency in precipitation"*, while the UN Convention to Combat Drought & Desertification (1994)[2] it defines "*drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production system"*. In this study we refer to droughts as the natural hazard that results from low levels of precipitations for a considerable amount a time, impacting on human and environment activities, however, because of it slow and long-term impacts is not evident for the policy makers until may be too late; therefore, is necessary to develop methodologies for monitoring droughts.

This project is developed in collaboration with the Centro Internacional para la Investigación del Fenómeno de "El Niño" (CIIFEN), a nonprofit international organization created in 200, although It is mainly dedicated to monitoring variables related to the El Niño/Southern Oscillation (ENSO) phenomenon, it also has an extensive trajectory in vulnerability and risk studies and one of its achievements in this area, It is its own drought monitor, a drought monitor for Latin America (CIIFEN's monitoring domain) that observes variables such as: precipitation, evaporation, soil moisture and equivalent water height and also two drought indicators: the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI) (CIIFEN, 2018)[3]. So far what they in their drought monitor is a conventional warning of the variables and indicators (For example: A map of Latin America showing the precipitation anomaly of May of 2017) but CIIFEN, being a member of the WMO, is following as goals the latest WMO's guidelines (López et al,2008)[4] and one of the headlines of those explicitly says: "It is no longer enough to provide a good weather forecast or warning, people are now demanding information about what to do to ensure their safety and protect their property" that's why the WMO suggests its members to incorporate the Impact-based Forecast and Warning Services (IFWS) in their activities.

As previously mention, CIIFEN has the SPI indicator as one of its drought monitor products but the spatial resolution, of 1° by 1°, its presents as a problem to develop the IFWS because the IFWS requires a better spatial resolution. So, the spatial resolution of the current CIIFEN's SPI is the problem and genesis of this project and it consists basically of two tools:

1- A computational script developed in the statistical programming language R, that can calculate the 3-months SPI and because the goal is to have much detail information of droughts, the CHIRPS precipitation data, that has a spatial resolution of 0.05° by 0.05°, was use as input for the calculation. The output of the script is a geo-tiff raster with the spatial resolution that CHIRPS has. To show the capability of this tool, it presents an example in Ecuador, using CIIFEN's precipitation forecast of March, April and May of 2018.

2- The second are two IFWS tool, developed in and for the open-source geographic information system QGIS (although it can be replicated in any GIS program), that uses the SPI as a droughts predictability tool, and it consists in predicting where and how much (percentage) of agricultural area might be affected by a drought event, as well as how many people might be affected, using CIIFEN's monthly precipitation forecast. To show the capability of this IFWS tool, it presents an example in Ecuador, using CIIFEN's precipitation forecast of March, April and May of 2018.

It is important to point out that these tools were developed for CIIFEN, because the goal in this term's integrator curse was to develop a product for a client. It also important to point out that these tools are delimited exclusive to the area of Ecuador and the SPI's computational script is as well limited to compute the 3-month SPI, but CIIFEN can easily replicate them for the rest of Latin America and different periods of months.

The main objective of the project is to develop the first tool to the CIIFEN's initiative, give them an IFWS drought tool with the spatial resolution capable of monitoring local events.

In this report, it will be found:

A literature review in CHAPTER 1, with the theory behind the SPI, IFWS, CHIRPS and CIIFEN's monthly precipitation forecast. In CHAPTER 2, the methodology that was used to compute the SPI and IFWS's drought tool. In CHAPTER 3, the results and discussion of both examples and tool. The conclusions and recommendation of the overall project and finally, the annexes where the complete code for the 3-month SPI calculation is found.

CHAPTER 1

1. LITERATURE REVIEW

This chapter presents a definition of droughts, a brief history of the development of the SPI, the standard timescales or modes that SPI has and what they mean in terms of droughts. It also presents a description of the CHIRPS precipitation data base that was used, the CIIFEN's monthly and seasonal precipitation forecast, the theory behind the IFWS. Finally, a description for the agricultural areas and population density of Ecuador.

1.1. Definition of droughts

Because drought affects many natural and human activities, countless definitions have been developed. The causes behind this are multiples. Drought occurs with varying frequency in almost all regions in the world. Drought's impacts also vary spatially and temporally, depending on the societal context of drought, therefore trying to find or elaborated a universal definition is an unrealistic expectation. So, what it going to follow next are two conceptual definitions:

According to the World Meteorological Organization (WMO, 1986)[1] *'drought means a sustained, extended deficiency in precipitation"*.

The UN Convention to Combat Drought & Desertification (1994)[2] it defines "*drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production system"*.

1.2. SPI

1.2.1. Introduction

There have been many drought indices developed over the years by meteorologists and climatologists. The variety and complexity of these indexes are broad and as shown by Hayes (2007)[5] in his article, they go from a simple calculation like the percentage of normal precipitation to more sophisticated indices such as the Surface Water Supply Index. However, Americans researchers McKee, Doesken and Kleist realized in 1993 that a drought index no only needs to be simple, it also needs to be easy to calculate and statistically relevant, so with that in mind they developed the SPI. The SPI (McKee et al., 1993, 1995)[6][7] is a powerful and flexible index that only requires precipitation as an input parameter.

These index allows a specialist to establish the intensity of drought or wet events at any period of time for any place that has rainfall records. Its greatest strengths are analyzing wet and dry periods for witch it needs at least 20-30 years of monthly values, with 50-60 years (or more) being ideal (Guttman, 1994) [8]. The intensities of the events are categorized according to the Table 1(McKee et al., 1993, 1995) [6][7], the positive values of SPI indicate wet events and the negatives dry events, being 2.0 or more and -2 or less the extremes, respectively.

The algorithm is freely available, it can be found in the publication of the developers and in many other publications, but for this project the WMO's algorithm, that's in their user guide(WMO, 2011)[9], was used, because, as previously mentioned, CIIFEN is a member of the WMO.

Scale		
	2.0+	Extremely wet
	1.5 to 1.99	Very wet
	1.0 to 1.49	Moderately wet
	-.99 to .99	Near normal
	-1.0 to -1.49	Moderately dry
	-1.5 to -1.99	Severely dry
	-2 and less	Extremely dry

Table 1: SPI scale **Source:** McKee et al. (1993) [6]

1.2.2. Strengths and Weaknesses

SPI's strengths and weaknesses can be summarized as follows (WMO, 2012) [9]:

Strengths

- It is flexible: it can be calculated for multiple periods of time, from weeks to months.
- SPIs of short periods of time like 1-, 2- or 3-month SPIs, can provide early warning of drought, which helps for decision-making.
- It is a standardized index so that allows for comparisons between various locations in different climates.

Weaknesses

- It only uses precipitation.
- It does not evaluate other wet factors such as the evapotranspiration and that means that this index does not fully provided a good evaluation of wet events.

1.2.3. Interpretation

The SPI time flexibility has been already described but statistically, 1–24 months is the best practical range of application (Guttman, 1994, 1999)[8][10].

The time periods or SPI modes recommended are 1, 3, 6, 9, 12 and 24 months (Guttman, 1994, 1999) and those reflect the impacts of drought, needed by several decision-makers. Soil moisture and meteorological conditions are very sensible to short timescales precipitation anomalies, for example 1 to 6 months, whereas stream flow, groundwater and reservoirs are sensible to longer-term precipitation anomalies, 6 months up to 24 months or even longer. So, for example, the 1- or 2-month SPI can be used for meteorological drought, a range from 1-month to 6-month SPI for agricultural drought, and 6-month to 24-month SPI or more for hydrological drought.

The standard SPI timescales or modes are described below:

Overview

All the SPI modes compare the precipitation for the timescale selected with the same timescale over the historical data set. For example, a SPI of 3-month at the end of May of 2010, compares the accumulated precipitation since March to May of 2010 with all the past totals for that same period.

1-month SPI

A 1-month SPI reflects short-term conditions. It helps to monitor meteorological drought in soil and crops, particularly in growing season.

3-month SPI

The SPI in these mode helps to identify moisture conditions and provides a seasonal overlook of the precipitation. In primary agricultural regions, this SPI might be more effective in emphasizing available moisture conditions.

6-month SPI

The 6-month SPI help to identify medium-tern trends in precipitation. At these timescale the SPI can be very helpful in identifying patterns in the precipitation between seasons.

9-month SPI

The 9-month SPI offers an indication of inter-seasonal rainfall. Droughts regularly take more than 6 months to develop. -1.5 values (or below) of SPI, in these timescales, typically indicates that drought is having a significant impact on agriculture and may be affecting other sectors as well.

12-month up to 24-month SPI

The SPI in these modes helps to identified rainfall patterns in a large period of time. The precipitation patterns in these long-term periods are the accumulative result of short-term periods, the longer SPIs tend to gravitate away from zero indicate that is taking place a wet or dry event. At these timescale the SPI is usually link to stream flow, reservoir levels, and even groundwater.

1.3. CHIRPS

CHIRPS is a 30+ year quasi-global precipitation[11], only land, precipitation dataset, developed to support the United States Agency for International Development Famine Early Warning Systems Network. It covers 50°S-50°N and all longitudes, it has records starting in January of 1981 to near-present. CHIRPS incorporate satellite data with a spatial resolution of 0.05° by 0.05° with in-situ station data to create gridded precipitation time series.

1.4. CIIFEN's Precipitation Statistical Forecast

Note: *CIIFEN's forecast official publication, to date of redaction of this report, is not yet published but it was used in this project by CIIFEN's request to develop the first tool in theirs IFWS initiative, but because I want to write a brief description of this forecast I asked to be instructed in one of the forecast's runs and that is what is described below.*

CIIFEN's monthly and seasonal precipitation forecast is a high resolution, 0.05° by 0.05°, with a spatial domain that covers all Latin America. It is calculated with CPT, a computational statistical tool using, as input parameters, the monthly and seasonal precipitation forecast of the NMME (a coupled model from US and Canada modeling centers: NOAA/NCEP, NOAA/GFDL, IRI, NCAR, NASA, and Canada's CMC) and the previously describe CHIRPS precipitation dataset.

The outputs of CIIFEN's forecast that were used in this project are shown in Figure 1.

The first one corresponds to the "observed" seasonal precipitation forecast for March to May of 2018 and the second one corresponds its statistical probability.

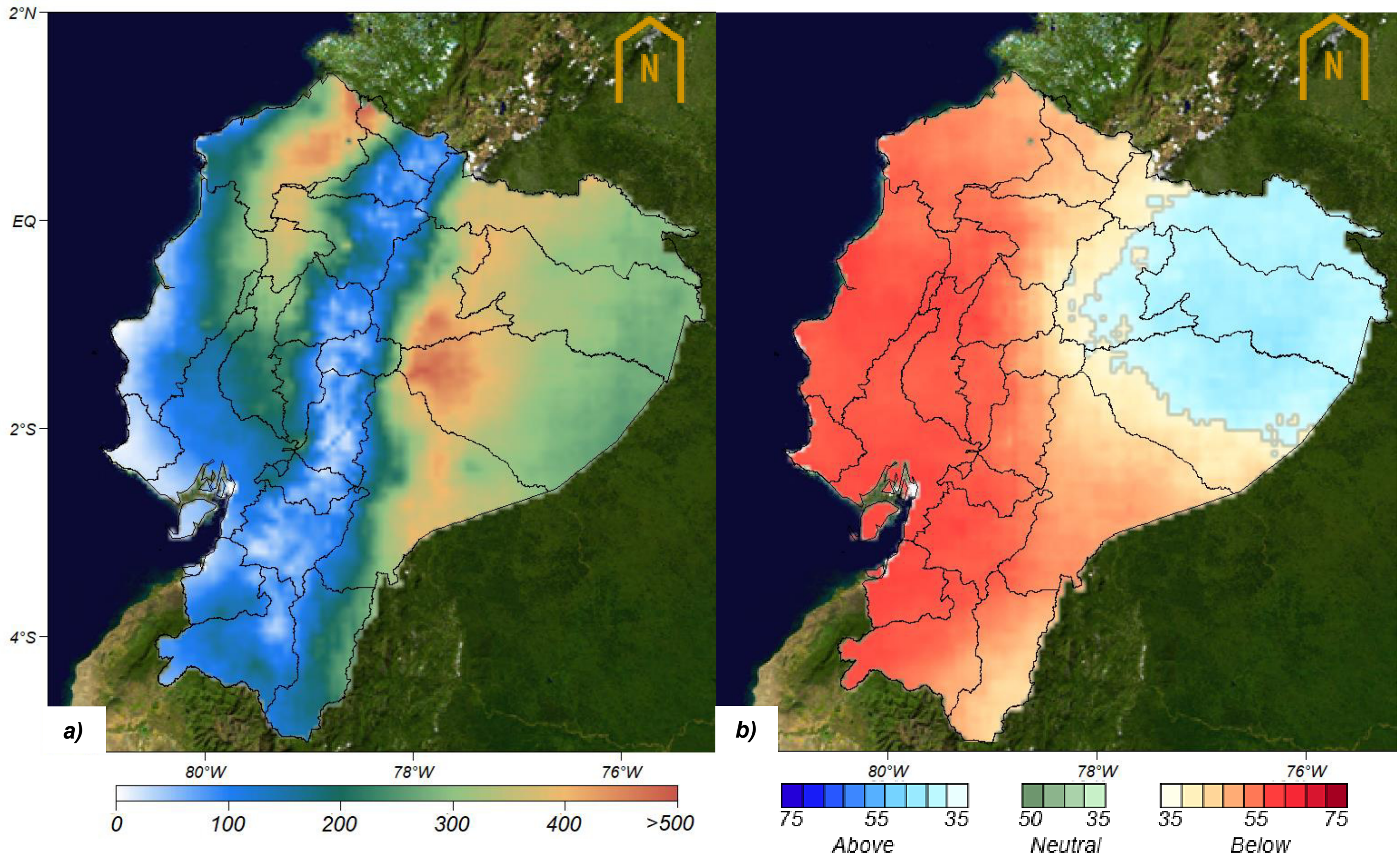


Figure 1: a) Seasonal Precipitation forecast (mm/month)
b) Statistical Probabilities (%)
Both for March to May of 2018

Source: CIIFEN

1.5. IFWS

The WMO published in 2015 a set of guidelines[12] to a new approached for warning services, the IFWS. It is recommended that all Meteorological and Hydrological center, such as CIIFEN, consider the potential benefits of providing impact-based warnings services. The central difference between a conventional weather warning and an impact-based warning is the inclusion of vulnerability of people, livelihood and property with consideration of any kind of hydro-meteorological hazard. That means, warning about the impacts that weather triggers, rather than the weather itself. Migrating to an impact-based paradigm involves many complex factors, because these types of warnings are not only driven by the hazards themselves, but also by their locations and timing.

So, because this is project related to droughts the Table 2 show two brief examples, in terms of droughts, between a conventional forecast warning and one Impact-based warning, to show the differences.

Warning	Example
General forecast	Seasonal statistical forecast shows below normal levels of precipitation in Ecuador.
Impact-based warning	A 45% of the agricultural areas in Ecuador's Amazon region could suffer a severe drought event according to a seasonal precipitation statistical forecast.

Table 2: Examples of warnings **Source:** Based on WMO (2015)

1.6. Ecuador: Agricultural areas

In 2015 MAE and MAGAP (now MAG) published the results of theirs cooperative project "Proyecto para la generación del mapa de cobertura y uso de la tierra del Ecuador Continental 2013-2014, escala 1:100.000"[13]. It consisted in a geographical identification and classification of the land use in Ecuador, such as: Forests, shrub and herbaceous vegetation, and agricultural areas.

The agricultural areas, which are the interest of this project, group many types of crops (Table 3).

Levels	Crops
Annual crops	Rice, quinoa, corn, amaranth, wheat, chocho, canola, soy and potato
Semi-permanent crops	Banana, tamarillo, naranjilla, uvilla, sugarcane artisan and industrial
Permanent crops	Avocado, coffee, blackberry, orange, cocoa and African palm
Grassland and Agricultural mosaic	Grasslands and the agricultural mosaic are groups of cultivated species that are mixed together and cannot be individualized

Table 3: Crops **Source:** MAE & MAGAP (2015)

The official map of coverage and land use of Ecuador is in **Annex A**

1.7. Ecuador: Population Density

In 2010 was the most resent population census in Ecuador made by the Instituto Nacional de Estadisticas y Censos (INEC), whom, amount other things, estimated the population density of every providence in Ecuador. In Table 3 are shown the calculation of the population density by providence, using INEC's census date.

Providences	Area Km^2	Population N° Habitants	Population Density N° Habitants/ Km^2
AZUAY	8309.58	712,127	86
BOLIVAR	3945.38	183,641	47
CAÑAR	3146.08	225,184	72
CARCHI	3780.45	164,524	44
COTOPAXI	6108.23	409,205	67
CHIMBORAZO	6499.72	458,581	71
EL ORO	5766.68	600,659	104
ESMERALDAS	16132.23	534,092	33
GUAYAS	15430.4	3,645,483	236
IMBABURA	4587.51	398,244	87
LOJA	11062.73	448,966	41
LOS RIOS	7205.27	778,115	108
MANABI	18939.6	1,369,780	72
MORONA SANTIAGO	24059.4	147,940	6
NAPO	12542.5	103,697	8
PASTAZA	29641.37	83,933	3
PICHINCHA	9535.91	2,576,287	270
TUNGURAHUA	3386.25	504,583	149
ZAMORA CHINCHIPE	10584.28	91,376	9
GALAPAGOS	8010	25,124	3
SUCUMBIOS	18084.42	176,472	10
ORELLANA	21692.1	136,396	6
SANTO DOMINGO DE LOS TSACHILAS	3446.65	368,013	107
SANTA ELENA	3690.17	308,693	84

Table 4: Population Density **Source:** INEC (CPV-2010) [14]

Of Table 4 is important to point out the numbers of the providences Santa Elena, Guayas and El Oro, because as shown in CHATER 3 those providences are of interest of this report, so: Santa Elena has 308,693 habitants in an area of 3690.10 square kilometers, giving a population density of 84 habitants per square kilometer. Guayas has 3’645,483 habitants in an area of 15430.5 square kilometers, giving a population density of 236 habitants per square kilometer and finally, El Oro has 600,659 habitants in an area of 5766.68 square kilometers, giving a population density of 104 habitants per square kilometer.

CHAPTER 2

2. METHODOLOGY

This chapter presents: the climatological baseline and the reason because it was selected, the SPI algorithm and the methodology to compute it in R and finally, the methodology of the two impact-base forecast drought tools developed for the agricultural areas and population density of Ecuador.

2.1. Climatological Baseline (1981-2010)

The climatological baseline selected to calculate the SPI was 1981-2010. It was chosen mainly for two reasons:

- The precipitation data set, CHIRPS, it is complete and has records since 1981[11]
- The WMO[15] explicitly says about climatological normal in one of iis guides: “Using a more recent averaging period results in a slight improvement in predictive accuracy for elements that show a secular trend”.

2.2. SPI Algorithm

Thorn (1966)[16] discovered that the gamma distribution fits well to a climatological precipitation record. The gamma distribution is defined in the equation 2.1:

$$g(x) = \frac{1}{\beta^{\alpha} * \Gamma(\alpha)} * x^{\alpha-1} * e^{-x/\beta} \quad (2.1)$$

For x ≥ 0, otherwise g(x) = 0,
where:

$\alpha > 0$	α shape parameter
$\beta > 0$	β scale parameter
$x > 0$	x precipitation sum
$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy$	$\Gamma(\alpha)$ the gamma function

Computation of the SPI involve fitting a gamma probability density function to a given frequency distribution of precipitation sums for a data set. Then, the gamma parameters, alpha (α) and beta (β) parameters, are estimated, accordingly to the SPI mode selected (1 month, 3 months, 9 months, etc.) for all the climatological baseline.

Thorn (1966)[16], states as well that the optimal way for estimating the α (2.2) and β (2.3) parameters is by using the maximum likelihood method:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{\frac{4A}{3}}\right) \quad (2.2)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \ (2.3)$$

Where:

$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$

$\mathrm{n} =$ Number of precipitation observation

Then, the shape and scale parameters are used to determine the cumulative probability of a precipitation data set for the selected SPI mode. The cumulative probability equation is:

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\hat{\beta}^{\hat{\alpha}} * \Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx \ (2.4)$$

Letting$t = -x/\hat{\beta}$, this equation becomes the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^x t^{\hat{\alpha}-1} e^{-t} dt \ (2.5)$$

Since the gamma function is not defined for x=0 and the data may have zeros, the cumulative probability equation will then be:

$$H(x) = q + (1-q)G(x), \qquad (2.6)$$

where:

q probability of no-precipitation

The probability of q is calculated:

If m is the number of zeros in the precipitation data set (n). Thorn (1966)[16] expresses that q can be calculated by m/n.

Finally, the cumulative probability (2.6) is transform to the standard normal distribution, obtaining the SPI.

This algorithm then was implemented in R, a statistical programming language, to create a script that easily computed the SPI of 3-months for May of 2018, using the historical CHIRPS precipitation data since 1981 to 2017 and CIIFEN’s monthly precipitation forecast for: March, April and May of 2018. The complete computational script is in **Annex B** and was based on a guide developed by Joint Research Centre (Singleton and Vogt, 2011) [17].

2.3. Impact-based Forecast Warning drought tool

2.3.1. Geo-data preparation

To start a methodology in and for any kind of GIS program, first, the shape files must be in the same coordinate geographic system, properly labeled, the area of the polygons, and a common field. All the previously states are to not causes any problems and to optimize the process.

2.3.2. Methodology

The methodology described below require a midlevel understanding of GIS programs.

a) Load all the files to the GIS interfaces, the SPI file, the target shape file (such as: agricultural areas or population density) and the selected geographical level (such as: providences or parishes).
   The target shape file in the one that we want to know how much and where is going to be affected by droughts.
b) The SPI raster is transform to a vector shape file and then, using an intercept tool, is intercepted with the target shape file, in some cases it might be required to make another interception, but in this time with the geographical level shape file. The result in this step is the "where" of this methodology.
c) To have the "how much" of this methodology, the polygons of the shape file resultant of the step c) must be dissolved (using the dissolve tool) because usually in this step you might have multiples separate polygons.
d) The resultant polygon in the step d) is again intercepted with the polygons of geographical level shape file, to have the area affected divide by the geographical levels and then calculate the area of those polygons, using a field calculator.
e) Join the tables of the shape file resultant in the step e) with the ones of the geographical level shape file by using the common field, to copy the field area on to the geographical level shape file and export it to save it as a new shape file.
   Note: *The step d) and e) had to be done to the polygons of the original target shape file to have the total area.*
f) Finally, compute the percentage of area affect by a drought event, using the shape file in step e) and the original one.

CHAPTER 3

3. RESULTS

In this chapter are shown the results for the examples mentioned in Charpter 2: the 3-months SPI forecast and the ones for the IFWS drought tools, as well as a discussion of them.

3.1. 3-months SPI forecast

The output result, Figure 2, of the calculation of the 3-month SPI forecast for May 2018 calculation shows that almost all Ecuador´s area might have near normal precipitation conditions, with a slightly tendency towards a wet event in the north central Sierra area and the Amazon providence of Napo (1), and a slightly tendency towards a dry event in the providences: Manabí, Santa Elena, Guayas and El Oro (2).

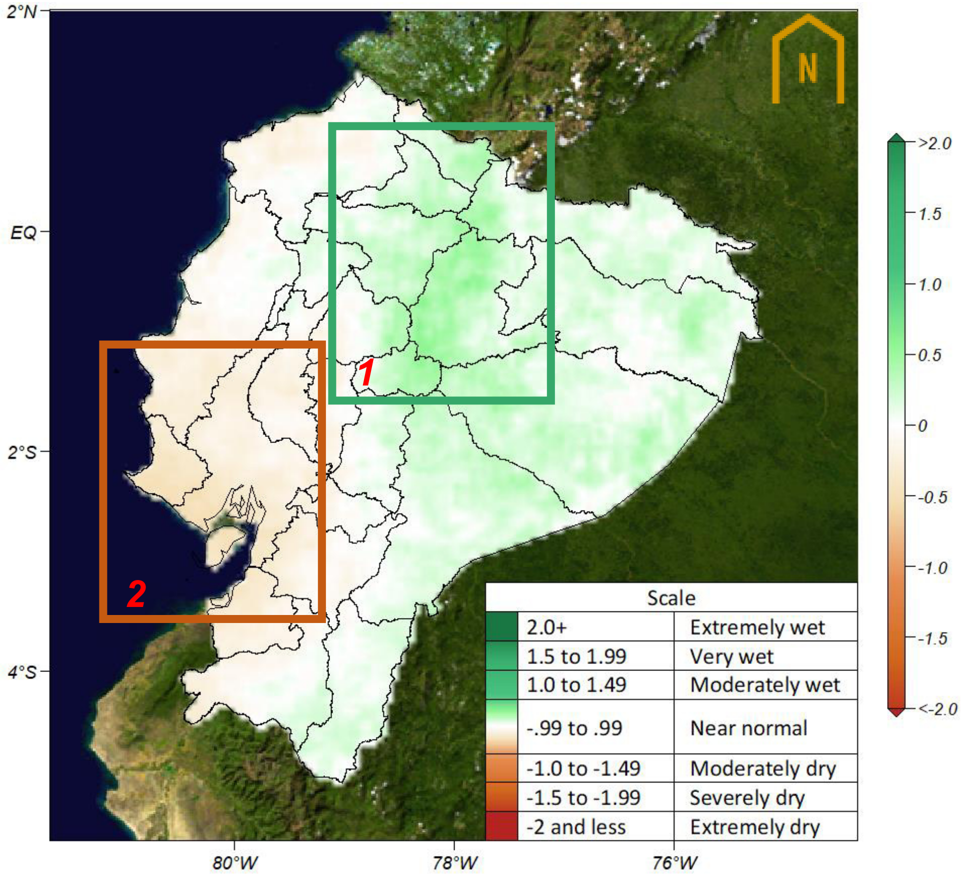


Figure 2: SPI forecast May 2018 for Ecuador **Source:** Author

3.2. Providences with high probabilities of a drought event

With a manipulation of the output SPI result, the areas with high probabilities of a dry event were isolated (Figure 3), showing that the event that might take place is a Moderately dry one (according to Table 1), on the following providences: Santa Elena, Guayas and El Oro.

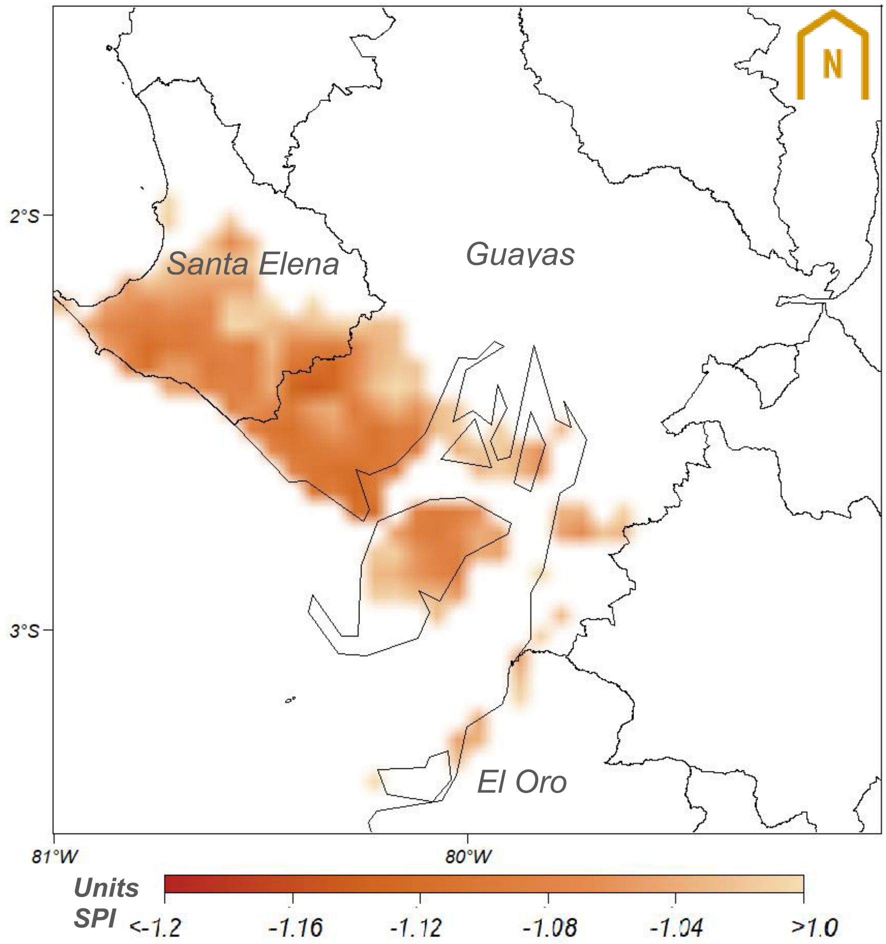


Figure 3: Providence with a high probability of a Moderately dry even. **Source:** Author

So, Figure 3 shows that the providence that might have a higher risk and vulnerability facing a Moderate dry event is Santa Elena, followed by Guayas and a smaller portion of El Oro.

3.3. Agricultural area

Using the geo-information of MAE and MAGAP about land use and crossing it with the SPI, I was able to predict a percentage of Agricultural area that might be affected by a Moderately dry event.

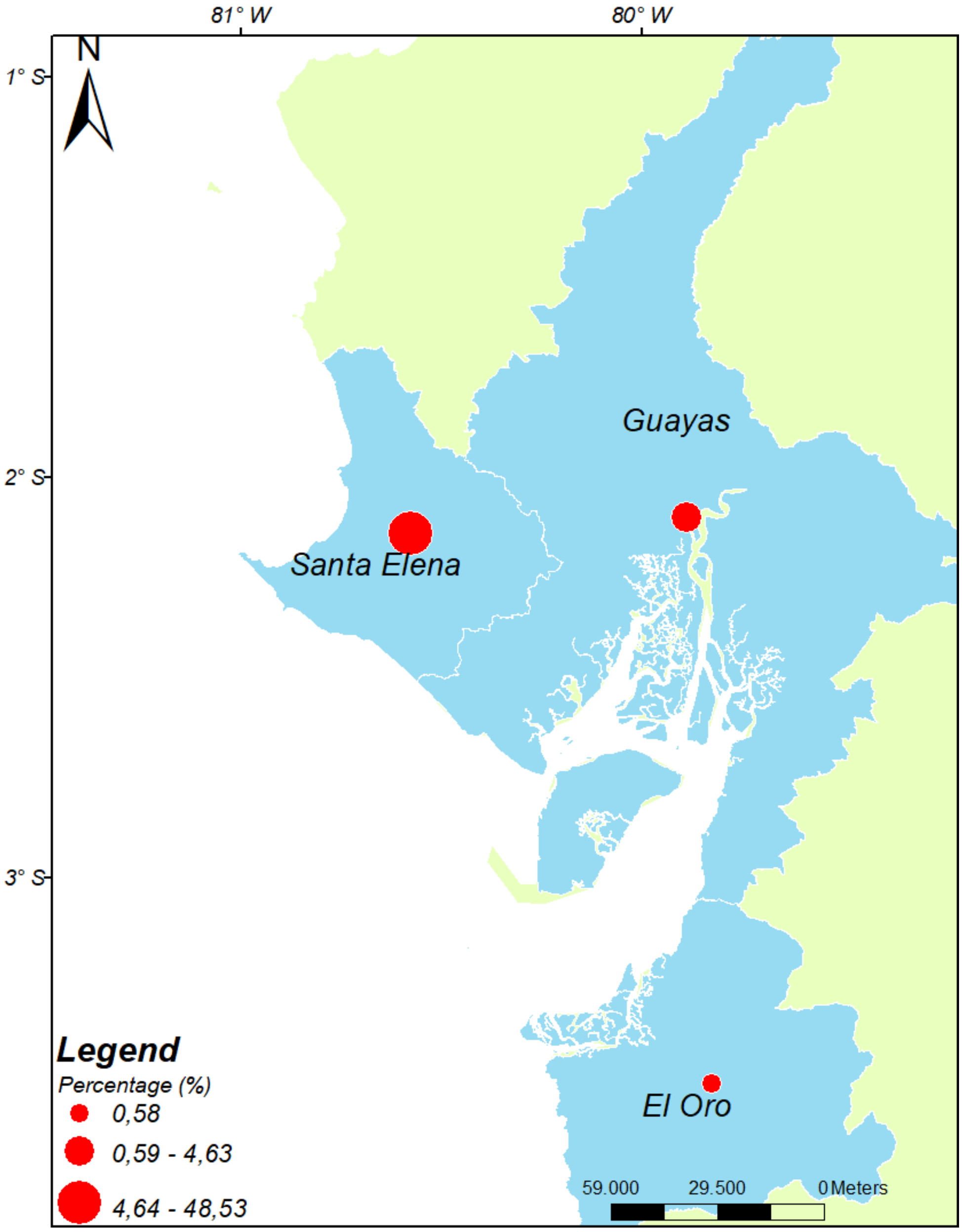


Figure 4: Providence with a high probability of a Moderately dry even. **Source:** Author

The providence (Figure 4) with the higher percentage of area that be affected is Santa Elena with a 48.52% and them, with less percentage, is Guayas with 4.63% and finally, El Oro with a 0.58%. To see the extensions of agricultural area that will be affected, check **Annex B.**

3.4. Population density

Using the geo-information of INEC[18] about the last census and crossing it with the SPI, I was able to predict a percentage of people that might be affected by a Moderately dry event.

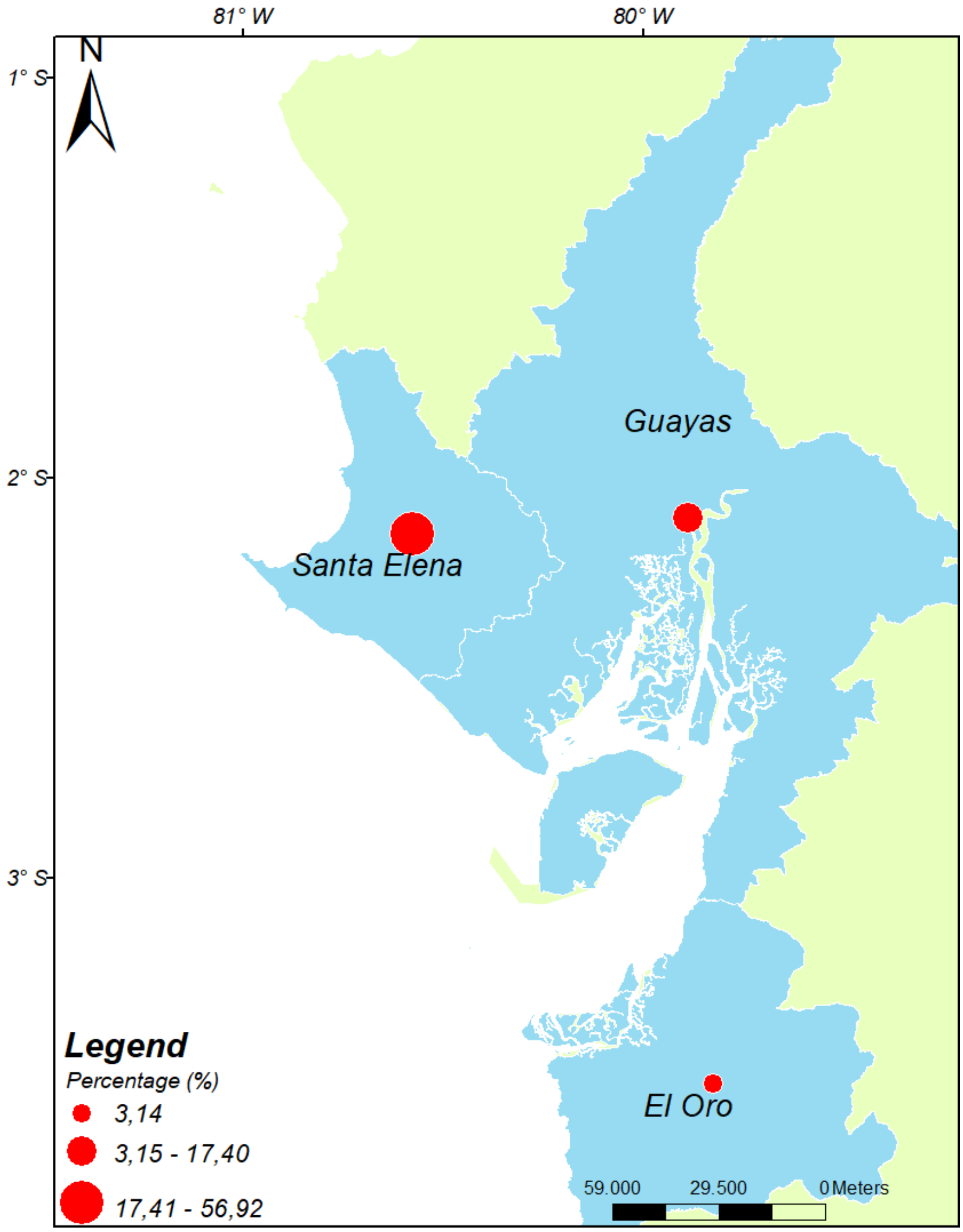


Figure 5: Percentage of people that might be affected by Moderately dry even. **Source:** Author

The providence (Figure 5) with the higher percentage of number of habitants that might be affected is Santa Elena with a 59.92% and them, with less percentage, is Guayas with 17.40% and finally, El Oro with a 3.14%.

CONCLUSIONS AND RECOMENDATIONES

Conclusions

Calculating the SPI for CIIFEN's domain was not done in this project because of my computer capabilities, to do that calculating is required more computer capabilities.

It is to be seen the response of this forecast tools but as states by Singlenton (2012), in a similar study, the 3-moths SPI It is almost perfect reliably for the forecasting of drought and wet events[19].

The providence with the higher risk and vulnerability towards a Moderately dry according with the forecast SPI is Santa Elena, whit its 48.52% of agriculture area and 59.92& of people, that might be affected.

The geographical category selected for the examples was providences, but it could be more useful to CIIFEN to use a smaller category such as, parishes, but the methodology will be the same.

Recommendations

It is recommended to verify the accuracy of these tools. It was not done in this project because the most recent CIIFEN's monthly precipitation forecasts available were the ones used in the examples, so I did not have the necessary inputs and time to estimates the accuracy/errors of these tools.

With minor changes to the R script, CIIFEN can compute the SPI for all their domain, but doing it by block or they can adapt this code to one of their computer serves to calculate it all at once, for that I recommend using Parallel Processing.

BIBLIOGRAPHY

[1] WMO. (1986). Report on Drought and Countries Affected by Drought During 1974–1985.

[2] UN Secretariat General. (1994): United Nations Convention of Combat Drought and Desertification in Countries Experiencing Serious Droughts and/or Desertification, Particularly in Africa.

[3] CIIFEN. (2018). Monitoreo de Sequias. [Online]. Available on: http://crc-osa.ciifen.org/index.php?option=com_content&view=article&id=149&Itemid=589

[4] P. López, R. Martinez and A. Regalado. (2009). CIIFEN-Primeros 5 años [Online]. Available on: http://www.eird.org/publicaciones/CIIFEN-esp.pdf

[5] J. Hayes, C. Alvord and J. Lowrey. Drought Indices. From Intermountain West Climate Summary.July, 2007.

[6] T.B. McKee, N.J. Doesken and J. Kleist. The relationship of drought frequency and duration to time scale. In the Eighth Conference on Applied Climatology, Anaheim, California, 17–22 January of 1993. EEUU, 1993, pp. 179–184.

[7] T.B. McKee, N.J. Doesken and J. Kleist. Drought monitoring with multiple timescales. In the Ninth Conference on Applied Climatology, Dallas, Texas, 15–20 January of 1995. EEUU, 1993, pp. 233–236.

[8] N.B. Guttman. On the sensitivity of sample L moments to sample size. Journal of Climate. pp. 7(6):1026–1029. 1994.

[9] World Meteorological Organization. Standardized Precipitation Index User Guide (M. Svoboda, M. Hayes and D. Wood). (WMO-No. 1090), Geneva. 2017

[10] N.B. Guttman Accepting the SPI: a calculation algorithm. Journal of the American Water Resources Association, 35(2):311–322. 1999

[11] Funk, Chris, Pete Peterson, Martin Landsfeld, Diego Pedreros, James Verdin, Shraddhanand Shukla, Gregory Husak, James Rowland, Laura Harrison, Andrew Hoell & Joel Michaelsen. "The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes". Scientific Data 2, 150066. 2015. doi:10.1038/sdata.2015.66 2015.

[12] World Meteorological Organization. WMO guidelines on multi-hazard impact-based forecast and warning services. WMO-No. 1150. Geneva. 2015

[13] MAE and MAGAP. Proyecto para la generación del Mapa de Cobertura y Uso de tierra del Ecuador continental 2013-2014, Escala 1:100.000: Anexo 1: Protocolo de leyenda temática de tipos de usos y cobertura de suelo. 2015.

[14] INEC (2010). Censo de Población y Vivienda (CPV-2010). [Online]. Available on: http://www.ecuadorencifras.gob.ec/documentos/web-inec/Tabulados_CPV_2010/12_DENSIDAD_POBL_PROV.xls

[15] World Meteorological Organization. WMO Guide to Climatological Practices. WMO-No. 100. Geneva. 2011.

[16] H. C. S. Thorn. Some Methods of Climatological Analysis. WMO Technical Note Number 81, Secretariat of the World Meteorological Organization, Geneva,Switzerland, 53 pp. 1966

[17] A. Singleton and J. Vogt. (2011). Annex A: Calculation of SPI with "R". Joint Research Centre. [Online]. Available on: https://circabc.europa.eu/webdav/CircaBC/env/wfd/Library/working_groups/i%20-%20CIS%20activities%202001-2015/scarcity_drought/drought_indicators/standardized_precipitati/IndicatorFactSheet_SPI%20v4_2011-08-11_Annex%20A_Computing%20SPI%20with%20R.pdf

[18] INEC. Cartografia Digital. [Online]. Available on: http://www.ecuadorencifras.gob.ec//cartografia-digital-2010/

[19] A. Singleton. (2012). Forecasting Drought in Europe with the Standardized Precipitation Index. Joint Research Center. Joint Research Centre. [Online]. Available on: https://ec.europa.eu/jrc/sites/jrcsh/files/lbna25254enn_0.pdf

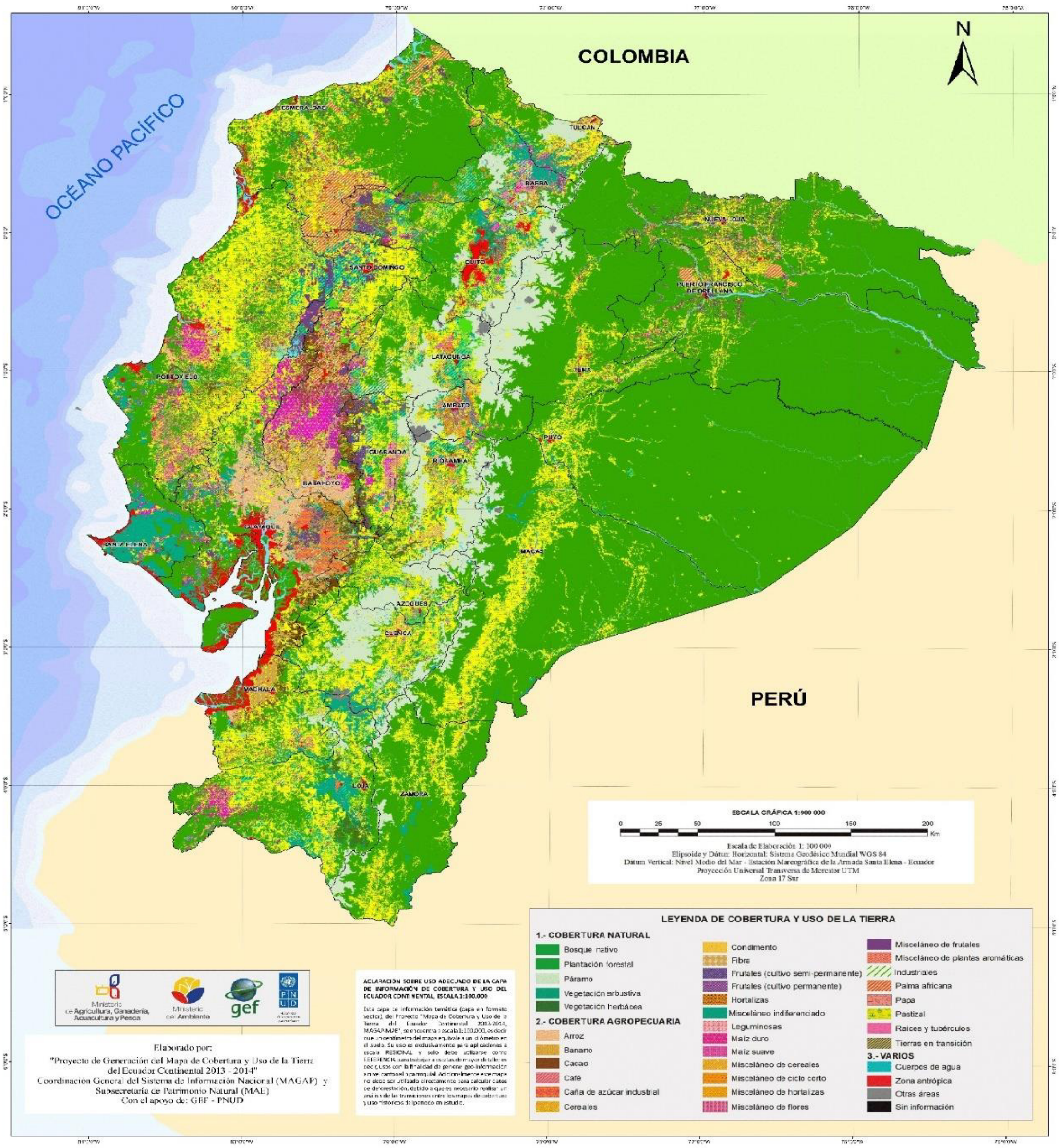
ANEXOS

A1: Map of coverage and land use in Ecuador

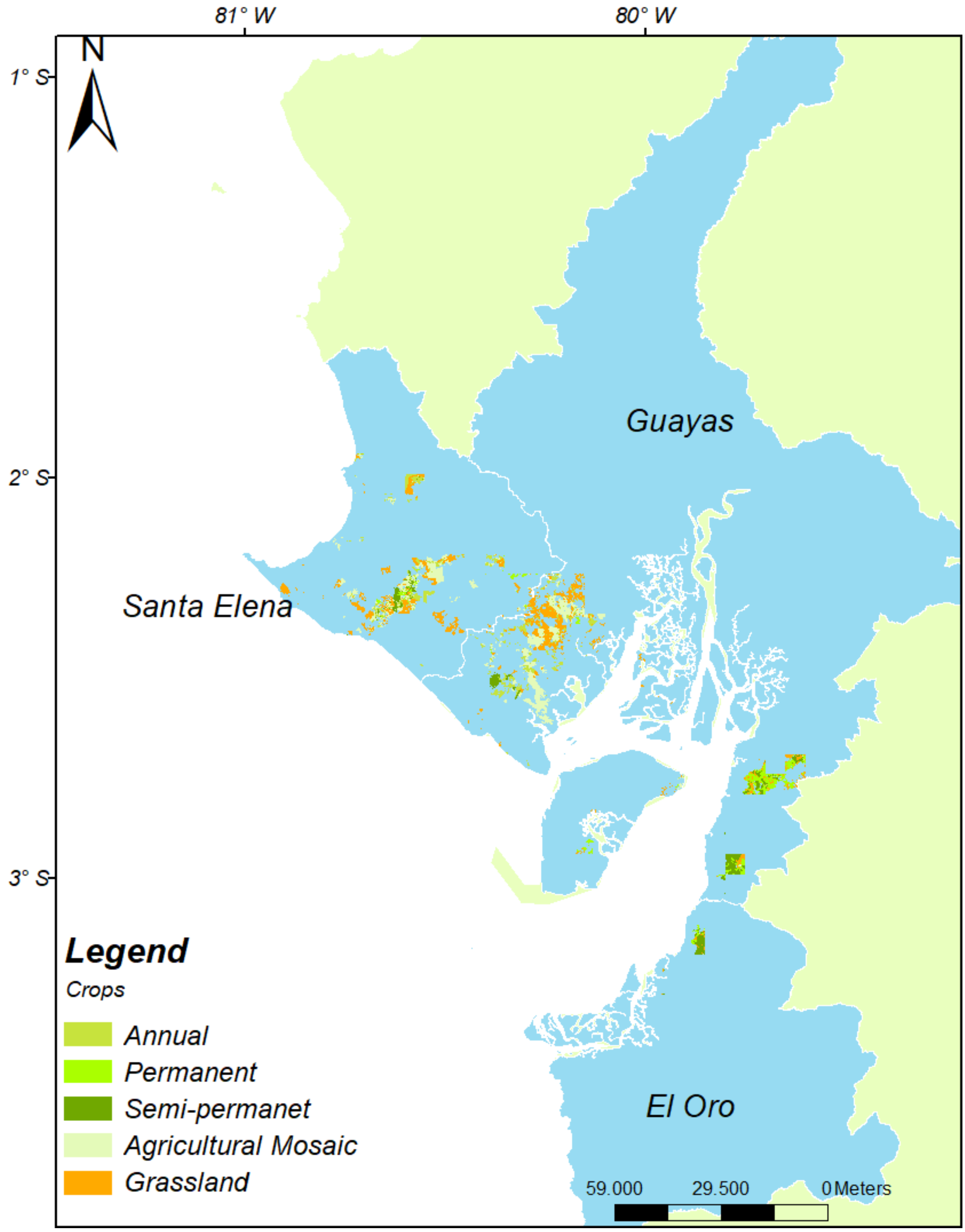
Note: This is a digital copy of the official map.

MAPA DE COBERTURA Y USO DE LA TIERRA DEL ECUADOR CONTINENTAL

ESCALA 1:100 000, AÑO 2013 - 2014



A2: Agricultural Areas



B: SPI R Script

Note: *The SPI R guide on which my R script is based on, computes the SPI for a time series of one location, it is as if only computes the SPI for a meteorological station's precipitation record; but mine does it differently, it uses a time series of raster images and gives the SPI for the geographical domain of the raster images.*

```
###########################LIST OF VARIABLES###########################
##rr.1m: Multi-layer raster of monthly precipitation.                              ##
##rr.3m: Multi-layer raster of 3 months accumulated precipitation.                 ##
##s_mth: Month selected to compute the SPI.                                        ##
##dates_s_mth: Vector of dates of all raster images selected                       ##
##s_mth_rr.3m: Multi-layer raster of 3 months accumulated precipitation for        ##
##                    the month selected.                                          ##
##s_mth_baseline_3m:        Multi-layer raster of the climatological baseline for the ##
##                          month selected.                                        ##
##fun_fitdistr: Function that fits the gamma distribution to the climatological baseline.##
##gamma.parameters_shape: Raster of the gamma parameter "shape".                   ##
##gamma.parameters_rate: Raster of the gamma parameter "rate".                     ##
##fun_prob_zero: Function that computes the probability of zero precipitation of the ##
##                  selected month precipitation records.                          ##
##s_mth_prob_zero_3m: Multi-layer raster of the probability of zero                ##
##                    precipitation of the selected month precipitation records.##
##fun_s_mth_prob_3m: Function that computes the cumulative probability of          ##
##                        the selected month precipitation records.                ##
##s_mth_prob_3m: Multi-layer raster of the cumulative probability of the           ##
##                     selected month precipitation records.                       ##
##fun_s_mth_prob_adjusted: Function that computes the adjusted probability of the  ##
##                     selected month precipitation records.                       ##
##s_mth_prob_adjusted: Multi-layer raster of the adjusted probability of the       ##
##                     selected month precipitation records.                       ##
##fun_to_std_distr: Function that transform the adjusted probability to a standard ##
##                   normal distribution.                                          ##
##s_mth_spi_3: Multi-layer raster of the computed SPI for the                      ##
##                selected month precipitation records.                            ##
##################################NOTES################################
#####Developed by: Freddy López Solórzano                        Year: 2018        ##
#####e-mail: f.lopez@ciifen.org & fdlopez@espol.edu.ec                             ##
#####Based on the guide by: Andrew Singleton and Jürgen Vogt (2011)                ##
#######Guide web source: https://circabc.europa.eu/webdav/CircaBC/env/wfd/Library/ ##
###############          working_groups/i%20-%20CIS%20activities%202001-2015/      ##
###############          scarcity_drought/drought_indicators/standardized_precipitati/##
###############          IndicatorFactSheet_SPI%20v4_2011-08-11_Annex%20           ##
###############          A_Computing%20SPI%20with%20R.pdf                          ##
####R libraries require: Raster (v.2.5-8) and fitdistrplus (v.1.0-8).              ##
##################################CODE#################################
##                                                                                 ##
##                                                                                 ##
###Loading libraries:                                                              ##
##library("raster")       #Library's version: 2.5-8                                ##
##library("fitdistrplus") #Library's version: 1.0-8                                ##
##                                                                                 ##
##                                                                                 ##
```

```
##                                                                                   ##
###initializing a 449multi-layer raster for Ecuador's geographic extension           ##
##rr.3m_1layer<-raster(nrow=140,ncol=120,extent(-81,-75,-5,2),res=c(0.05,0.05))      ##
##values(rr.3m_1layer)<-NaN                                                          ##
##rr.3m<-stack(mget(rep( "rr.3m_1layer" , 449 )))                                    ##
##                                                                                   ##
###Selecting the Geo-tiff files and reading the dates                                ##
###Note: The tiff files were label as follow: "chirpsYearMonth". Example "chirps201401". ##
##prec_list<-list.files(pattern = ".tif")                                            ##
##dates<-substr(prec_list,7,12)                                                      ##
##rr.1m_list<-prec_list                                                              ##
##n.months<-length(rr.1m_list)                                                       ##
##                                                                                   ##
###Importing to R the tiff files and cutting it to Ecuador's geographic extension    ##
##rr.1m <- raster::stack(rr.1m_list)                                                 ##
##rr.1m <-crop(rr.1m,extent(-81,-75,-5,2))                                           ##
##                                                                                   ##
###Calculating of the 3 months accumulated precipitation                             ##
##for (k in c(3:n.months))                                                           ##
##{                                                                                  ##
##   rr.3m[[k]]<-0                                                                   ##
##   for (i in c(0:2))                                                               ##
##   {                                                                               ##
##     rr.3m[[k]] = rr.3m[[k]] + rr.1m[[k-i]]                                        ##
##   }                                                                               ##
##}                                                                                  ##
##                                                                                   ##
###Selecting the SPI month (May) to compute and extracting the respective records ##
##s_mth="05"                                                                         ##
##s_mth_rr.3m<-stack(rr.3m[[which(substr(dates,5,6)==s_mth, arr.ind = T)]]) #
##dates_s_mth<-dates[substr(dates,5,6)==s_mth]                                       ##
##n.years<-length(dates_s_mth)                                                       ##
##                                                                                   ##
###Creating the climatological baseline (1981 to 2010)                               ##
##s.y<-1981                                                                          ##
##e.y<-2010                                                                          ##
##s.idx<-which(substr(dates_s_mth,1,4)==s.y)                                         ##
##e.idx<-which(substr(dates_s_mth,1,4)==e.y)                                         ##
##s_mth_baseline_3m<-stack(s_mth_rr.3m[[s.idx:e.idx]])                               ##
##                                                                                   ##
###Fitting the climatological baseline to gamma distribution in order to obtain the  ##
###parameters "shape" and "rate"                                                     ##
##fun_fitdistr <- function(x)                                                        ##
##{                                                                                  ##
##  fitdist(na.exclude(x[x>0]),"gamma",method = "mle", lower = c(0, 0))$estimate     ##
##}                                                                                  ##
##gamma.parameters<-calc(x = s_mth_baseline_3m,fun = fun_fitdistr)                   ##
##gamma.parameters_shape<-gamma.parameters[[1]]                                      ##
##gamma.parameters_rate<-gamma.parameters[[2]]                                       ##
##                                                                                   ##
###Obtaining the probability of zero precipitation                                   ##
##fun_prob_zero<-function(x)                                                         ##
##{length(x[x==0])/length(x)                                                         ##
##}                                                                                  ##
##s_mth_prob_zero_3m<-calc(x = s_mth_rr.3m,fun = fun_prob_zero)                      ##
```

```
###Obtaining the cumulative probability for the non-zero precipitation         ##
###x=s_mth_rr.3m                                                                ##
###y=gamma.parameters_shape                                                     ##
###w=gamma.parameters_rate                                                      ##
###j=s_mth_prob_zero_3m                                                         ##
##fun_s_mth_prob_3m<-function (x,y,z,j)                                         ##
##{                                                                             ##
##   ifelse (x==0,j,pgamma(x,shape = y,rate=z))                                 ##
##}                                                                             ##
##s_mth_prob_3m<-overlay(s_mth_rr.3m,gamma.parameters_shape,                    ##
##gamma.parameters_rate,s_mth_prob_zero_3m,fun = fun_s_mth_prob_3m)             ##
##                                                                              ##
###Obtaining the adjusted probability (zero + non-zero precipitation)           ##
###x=s_mth_rr.3m                                                                ##
###y=s_mth_prob_3m                                                              ##
###z=s_mth_prob_zero_3m                                                         ##
##fun_s_mth_prob_adjusted<-function (x,y,z)                                     ##
##{                                                                             ##
##  ifelse (x!=0,z+(1-z)*y,NaN)                                                 ##
##}                                                                             ##
##s_mth_prob_adjusted<-overlay(s_mth_rr.3m,s_mth_prob_3m,                       ##
##s_mth_prob_zero_3m,fun = fun_s_mth_prob_adjusted)                             ##
##                                                                              ##
###Transforming the adjusted probability to a standard normal distribution to obtain ##
###the SPI                                                                      ##
##fun_to_std_distr<-function (x)                                                ##
##{                                                                             ##
##  qnorm(x)                                                                    ##
##}                                                                             ##
##s_mth_spi_3<-calc(s_mth_prob_adjusted,fun = fun_to_std_distr)                 ##
##                                                                              ##
###Finally, extracting the require SPI (May of 2018), assigning the respecting  ##
###geographic coordinate system and saving it in a Geo-tiff raster              ##
###Note: At this point the “spi_may” multi-layer raster has 38 layers, the first one being for ##
###May of 1981 and the last one for May of 2018.                                ##
##spi_may<-s_mth_spi_3[[38]]                                                    ##
##crs(spi_may)<-"+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0" ##
##writeRaster(spi_may, 'spi3_may_2018.tif', overwrite=TRUE))                    ##
###################################END##################################
```