Vulnerability and resilience to drought in the Chaco, Paraguay

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4 Vulnerability and Resilience to Drought in the Chaco, Paraguay

Abstract: This chapter presents an innovative methodology to identify and characterise the vulnerability and resilience to drought in ten indigenous communities (*comunidad*) in Chaco, Paraguay. The first part studies meteorological drought through the analysis of average daily rainfall over the last 38 years. The second part analyses vulnerability (V) on the *comunidad* scale. The third and final part analyses resilience (R) on the *comunidad* scale. The main sources used are the survey conducted for the Participatory community diagnosis (2014), from which 18 indicators have been chosen to measure exposure (E), sensitivity (S), and adaptive capacity (Ac) according to the equation V = (E * S) / Ac. We ascertain that rainfall in the driest areas of the Paraguayan Chaco varies cyclically in relation to the meteorological phenomena of El Niño and La Niña. The operative consequence of this phenomenon is that in the Chaco, drought may be predicted with enough forewarning to launch an early warning in the driest areas. Furthermore, we highlight that the most vulnerable *comunidades* are also the most resilient. This demonstrates that the various projects undertaken to strengthen resilience have so far benefited the most vulnerable communities and therefore the drought defence has been well directed.

Keywords: Vulnerability, Drought, Climatic analysis, Resilience, Climate change, Indigenous communities, Chaco, Paraguay

4.1 Introduction

This chapter analyses drought experienced by ten indigenous communities (*comunidades*) of the Chaco region in Paraguay, their vulnerability and resilience.

The Paraguayan Chaco (257,000 km^2, 43% of the national territory) covers almost a quarter of the Great American Chaco, a region that extends as far as Argentina and Bolivia (1.1 million km^2) on a sedimentary basin at the foot of the Andes (Pasig 2005; PSAC 1998) (Figure 4.1). The Paraguayan Chaco is located between the Paraguay River

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Figure 4.1: The Great American Chaco (pink) in the context of Latin America (elaboration E. Ponte).

to the East and Pilcomayo to the South. From an administrative point of view, it is divided into three regions (Boquerón, Alto Paraguay and Presidente Hayes), which are in turn divided into 15 districts. Only 2.5% of the population of Paraguay lives in the Chaco (density 0.5 inhabitants/km^2) and is made up of indigenous groups (33% of the Great American Chaco population), Mennonite colonies (14% of the Great American Chaco population), and creoles (53%) (PNUMA 2013; Pacheco 2012).

The climate is characterised by two seasons: dry from May to October and rainy from November to April. Drought and flooding characterise the climate of Paraguay, the summer is long, hot and wet, while the winters are short, mild and dry, but frost may occur between June and August (Grassi *et al.* 2005).

The majority of rainfall is convective, produced by storms or series of storms common from spring to autumn (Pasten 2007). Temperatures can reach 45° C and the long periods of drought block the economic development of this region and broaden its marginalisation compared to the economic and financial centres in the south-west of the country. According to the literature (Grassi *et al.* 2005; GTZ 2005; PNUMA 2013; USAID 2007), western Paraguayan Chaco is drier than that to the east. Annual overall rainfall in central Chaco is on average (1960–2010) 1,000 mm, while in western Chaco it is 1,500 mm. Nonetheless, rainfall in the latter has been less than 450 mm in 13 years out of 40.

Nunez *et al.* (2009) have shown how in Paraguay the effects of climate change (CC) caused by global warming consist of rising temperatures, especially during the spring.

In the Chaco, where the indigenous populations survive on agriculture and sheep farming, climate trends have significant impact: the indigenous communities are less prepared to deal with this type of occurrence (Vila 2010; IPMPCC 2011). Drought in the Chaco is a transitory anomaly that is characterised by an insufficient availability of fresh water for plants, animals and humans.

Among water resources studies developed in the sector from the 1970s on, IDAEA (2012) highlighted how the biggest problem for the Chaco is the lack of fresh water. In this vast area it is rare to have underground water, but when it is there, it is so salty as to render it unusable for humans and animals (Pacheco 2012).

The aim of the chapter is to characterise atmospheric drought and assess the vulnerability and resilience of ten indigenous communities of Paraguayan Chaco.

The method used is simple, but innovative, and contributes to demonstrating the relationship between global and local climate phenomena. In effect, we based it on an integrated analysis of the hydrological data and risk evaluation. Based on the Standard Precipitation Index (SPI) as indicated by Khan *et al.* (2008) for the study of drought and the impact of rainfall on agricultural areas, and carrying out an evaluation of those parameters distributed over the territory, we were able to identify the most arid areas and the wettest areas in the territory studied. Finally, the analysis of the thermal sea temperature anomaly models obtained by the NCEP-NOAA oceanic data assimilation system (Behringer and Xue 2004) enabled us to define a connection between the annual variations of the humid and arid areas with El Niño cycles. This evaluation has allowed us to introduce, in the risk evaluation model, a variable of exposure to drought that is, in addition to the population size, also a function of the physical phenomenon. The inclusion of this variable facilitates an effective improvement of the risk evaluation model and resilience. The most obvious application is the possibility of replicating this analysis in similar situations, and adapting it to the information available. Another interesting possibility would include using this analysis to carry out specific impact studies.

The following paragraphs present the innovative methodology of meteorological, vulnerability and resilience analysis, followed by the results obtained. Finally, in the conclusions, we set out some suggestions to develop future strategies.

4.2 Methodology

4.2.1 The Analysis of Vulnerability

Vulnerability may be defined as a "function of the climate variation to which a system is exposed, of its sensitivity and its ability to adapt" (IPCC 2001). Consequently, the components of vulnerability are:

- Exposure (E), which is defined as "The nature and degree to which a system is exposed to significant climatic variations" (IPCC 2001). In our case, the hazard is represented by the meteorological drought.
- Sensitivity (S), which describes "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (IPCC 2001).
- Adaptive capacity (Ac), which defines "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2001), in our case five indicators are used.

The first two components of vulnerability represent potential impact while the last one indicates the measure in which the impacts may be attenuated.

These components are linked in the equation: V = (E * S) / Ac

Each component is measured by indicators (Brant 2007), which may vary depending on the time scale and the systems involved (social, economic and biological) (Smit and Wandel 2006). Often, vulnerability is ascertained as the starting point for the study of resilience.

This approach also allows monitoring vulnerability over time, though it is limited by the subjectivity of the selection, the variables considered, and the availability of data (Luers *et al.* 2003). The final considerations will therefore refer to the potential impacts of the drought forecast on the short- and long-term in accordance with the pre-existing scenarios of CC (Knutson *et al.* 1998). In the instance of the Chaco, we used 18 indicators from the Participatory Community Diagnosis (COOPI, OXFAM / PCI, ACH 2014), considering the data available.

The component E (exposure) included the impact of CC on the system, as explained below. For the study area, the system of liquid precipitation and drought that makes the system vulnerable represent the CC affect. Therefore, in this study, the analysis of drought is considered, supplemented by a detailed analysis of all other indicators that comprise the vulnerability analysis.

4.2.1.1 Methodology for Analysing Drought

To study drought in the Chaco, the SPI (Standardized Precipitation Index) was used, as recommended by the World Meteorological Organization (WMO 2012). This index measures probability relating to rainfall. The SPI is based on the probability of recording a given quantity of rainfall. The probabilities are standardised so that an index of 0 indicates the quantity of average rainfall. The index is negative in situations of drought, and positive for rainfall. The more arid or wet the conditions, so the index becomes more negative or positive. The SPI is calculated by the NCDC (National Climatic Data Center) on different time scales – from one to 24 months – with the aim of bringing forth variations both for the short- and long- term[15].

We decided to calculate the SPI for various points. From the NOAA (National Oceanic and Atmospheric Administration) website, we selected the weather stations that have continually recorded daily rainfall data for at least 20 years between 1949 and 2013. To choose the stations, a circle with a 250 km radius was traced with the meteorological station of Pozo Colorado as its centre (59° 18' 22" W, 23° 32' 43" S), and all 15 stations that fell within it were considered. Six stations showed incomplete or anomaly data (rainfall absent for months at a time or anomalous rainfall) (Figure 4.2). All rainfall data (recorded every six hours) was gathered from January 1, 1975 to December 31,2013 and monthly rainfall was calculated.

Once this phase was completed, the monthly, three-monthly, six-monthly and annual SPI were calculated. At this point, graphics were drawn up with the annual and six-monthly SPI (wet and dry seasons) to have an initial idea of its main variations and trend.

Subsequently, SPI maps were drawn up to show the variation of the index over the past 40 years. Following this, the six-monthly SPI was calculated for the dry season (from May to October) and for the wet season (from November to April).

4.2.2 The Analysis of Resilience

Resilience is defined as the ability of a system, a community or a society potentially exposed to risks to resist, absorb, encounter and recover from the effects of a hazard in a timely and effective manner, also through the conservation of its basic structures and functions (UN-ISDR 2009). This ability is determined by the degree to which the social system is able to increase its ability to learn from past disasters, increasing protection and reducing risk (African Development Bank *et al.* 2004).

Resilience is the opposite of vulnerability; the higher the level of resilience of a community, the lower its vulnerability. In other words, the probable impact of drought would increase the danger (measured, for example, by the number of people exposed and/or by the frequency and seriousness of the drought) and therefore the vulnerability of a community would be higher. Nonetheless, the drought risk of a community decreases as its resilience increases.

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15 http://www.ncdc.noaa.gov/.

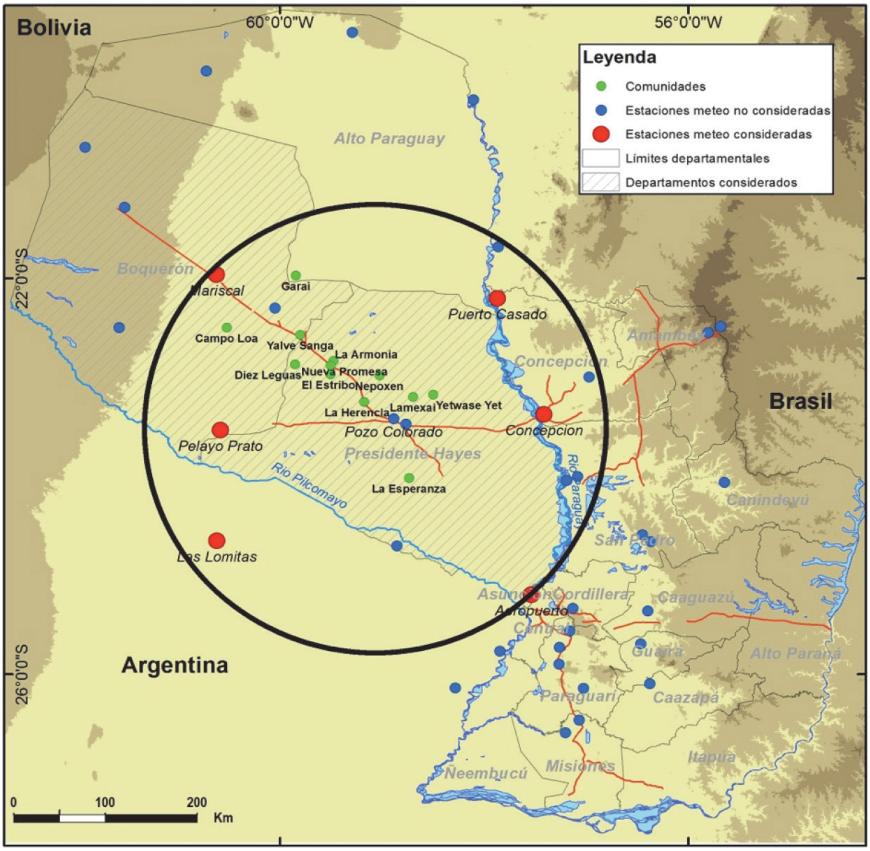

Figure 4.2: Paraguayan Chaco. Study area (circled) showing the comunidades (green dots), the weather stations considered (red dots) and those not considered (blue dots) (by E. Ponte).

Considering that communities are unable to reduce their exposure to drought, attention must therefore be focussed on looking for ways to reduce vulnerability and increase resilience. In fact, the resilience approach focuses attention on the components of a system and how they relate to each other (Berkes *et al.* 2003). But it is important to underline that resilience is not synonymous with adaptation (Walker *et al.* 2006). In fact, in some cases, high adaptability can unintentionally lead to a loss of resilience capacity.

The sources of information used are the Participatory Community Diagnosis and information gathered on site during a mission (April 2014). The main difficulty related to the tracing of representative indicators of resilience available for all the *comunidades* of the study area.

4.3 Characterisation of Atmospheric Drought

Although it may be considered a rare and causal event, drought is a component of climate. This is verified throughout almost all climatic zones, but its characteristics vary greatly from one region to the next (UN-ISDR 2009). Drought in itself is not an emergency situation, but it becomes such due to its impact on the population (UN-ISDR 2003).

Drought is "a dangerous physical phenomenon that may cause the loss of human life, injury or other effects on health, damage to property, loss of means of survival and services, social and economic disintegration and environmental damage" UN-ISDR (2009).

We can distinguish four types of drought: meteorological, agricultural, hydrological and socio-economical (UN-ISDR 2009). Meteorological drought is a natural event that has climatic causes that differ from region to region. It may also be defined as a lack of rainfall for a prolonged period of time, which is translated into a lack of water for a variety of activities. Agricultural, hydrological and socio-economic drought affects human and social aspects, especially the interaction between the climatic characteristics of meteorological drought and the human activities that depend on rainfall to provide enough water and products to satisfy social and environmental needs. This chapter reflects mainly the meteorological drought of the Paraguayan Chaco considering the strong impact on the indigenous population.

The United Nations Convention to Combat Desertification (UNCCD) and in part also the United Nations Framework Convention on Climate Change (UNFCCC) are particularly aimed at reducing the risk of drought.

The main objective of the analysis is to verify the trend of drought in recent years in the study area, and to evaluate the possibility of predicting it in advance.

The distribution of rainfall throughout the year (the Figure 4.3 shows the rainfall index derived from a dataset developed and maintained by NOAA) shows that the months with most rainfall are November, December, January and February (Ip11, Ip12, Ip01, Ip02), while the driest months are June, July, August and September (Ip06, Ip07,

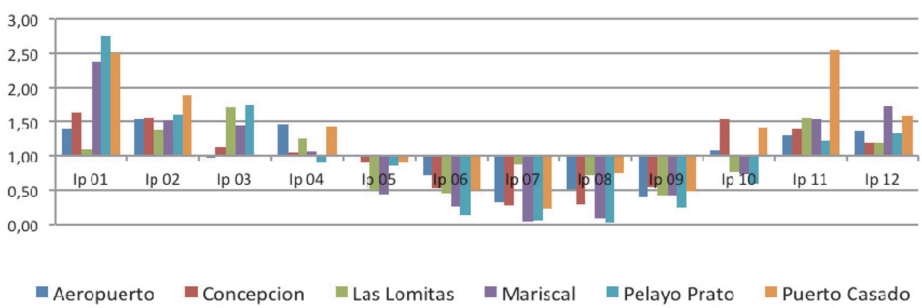

Figure 4.3: Paraguayan Chaco. Rainfall index for the six stations (source: NOAA).

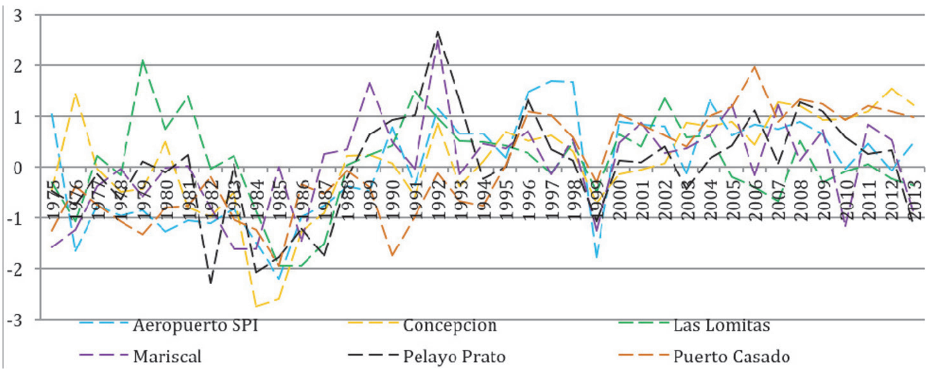

Figure 4.4: Paraguayan Chaco. Variation of the SPI for the six stations analysed.

Ip08, Ip09). The graph also reveals how drought is accentuated by the fact that for a good eight months of the year (from March to October), average monthly rainfall is less than 100 mm, and decreases to 50 mm from June to September.

The trend of the SPI for the six stations considered (Figure 4.4) may be summarised as follows:

- 1975–1984: slight increase in drought
- 1985–1994: slight decrease in drought
- 1995–2004: decrease in drought
- 2005–2013: decrease in drought

Observing the graph of the annual average SPI, we can note how anomaly values have been recorded in some years compared to the trend of the previous years: this is the case in 1992, a particularly wet year, or in 1999 which was very arid.

The next step is to understand whether the variations observed on the SPI maps have been influenced by global meteorological phenomena such as El Niño or La Niña.

These phenomena occur in the central Pacific Ocean. The former is characterised by warming and the latter by a cooling of currents. When the waters are warming (El Niño), the pressure of the western Pacific is high and when the waters are cooling (La Niña), the pressure of the western Pacific is low. These phenomena condition the rise of rainy phenomena in a large part of North and South America.

We used the annual climatological map[16] obtained using data averages from 1975 to 2013 (Figure 4.5). The map shows – according to the scale of colours from red to blue – the average variations of the sea temperatures.

16 http://www.cpc.ncep.noaa.gov/products/GODAS/

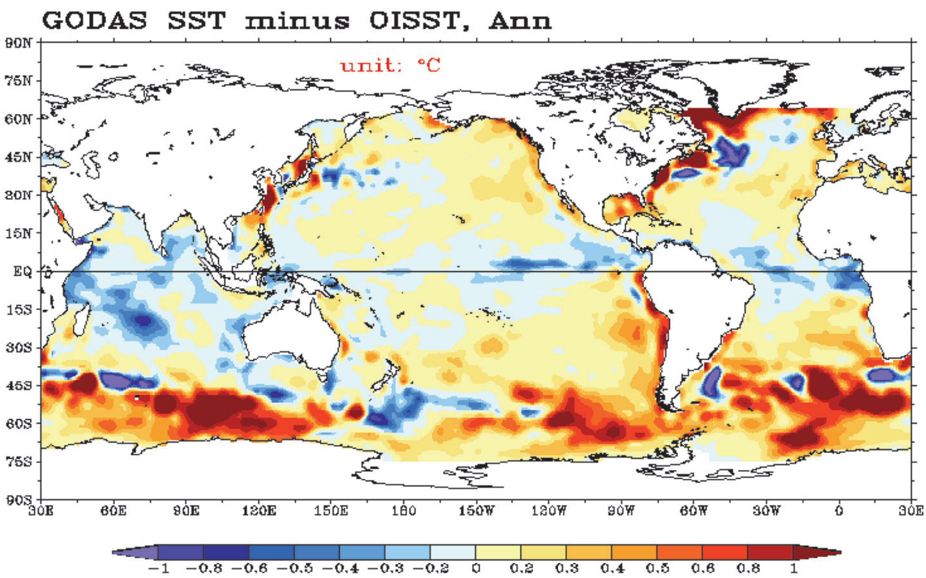

Figure 4.5: Average variation of the sea temperatures (1975/2013) (source: NOAA).

Subsequently, three different years were taken as examples, one per type of SPI map: 2003 (uniform map), 2013 (map with wet area to the south) and 1987 (map with wet area to the north).

4.3.1 Neutral Situation

To demonstrate this case, we have taken the year 2003 as an example. The SPI map (Figure 4.6.a) highlights a standard coloration if we exclude the area to the east where there is a very slight variation. This means that in 2003 there was minimal variation in humidity (violet colour, variation between 0 and 0.5), which was uniform throughout the territory under study.

If we observe at the same time the 2003 map of the Sea Surface Temperature (SST) (Figure 4.6.b), we can see how this differs little from the annual climatological map (Figure 4.5).

This similarity between the two maps can be explained by the fact that when there is no considerable variation between the annual climatological map (Figure 4.5) and the annual SST map, (Figure 4.6) we will have a uniform SPI map (Figure 4.6) and therefore there will be a minimal and uniform drought variation within the territory under consideration.

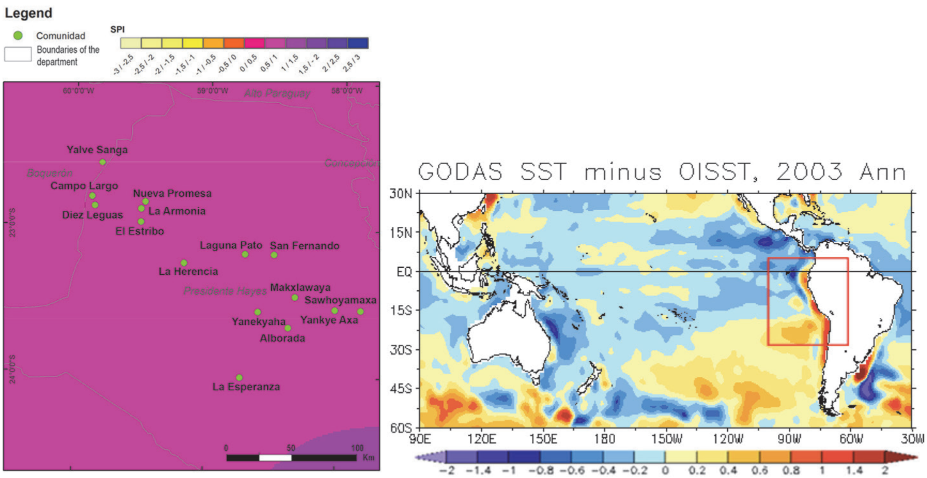

Figure 4.6: SPI in the Chaco in 2003 (left) and SST in 2003 (right).

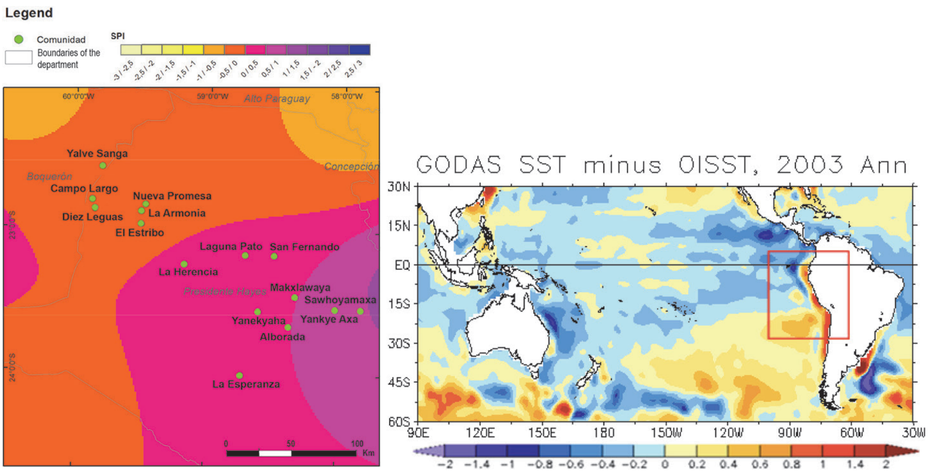

Figure 4.7: SPI in the Chaco in 2003 (left) and SST in 2003 (right).

4.3.2 The La Niña Situation

To demonstrate this case, we have used the year 2003 as an example. Observing the SPI map (Figure 4.7), we can see how there is a more arid area concentrated towards the North with points of variation that go as low as –1. This means that in 2013 there was a negative humidity variation to the north (orange colour, variation between –0.5 e –1) and a positive one to the south (violet colour, variation between 0 and 1).

If, at the same time, we look at the 2013 SST map (Figure 4.7), we can see how this differs from the annual climatological map (Figure 4.5) in two aspects: the presence of a wide cold area (in blue) at the centre of the Pacific Ocean and the almost complete absence of a warm front on the coasts of Ecuador and Peru.

This is what occurs to cause La Niña.

4.3.3 The El Niño Situation

To demonstrate this case we have used the year 1987 as an example. The SPI map (Figure 4.8) highlights a more arid area concentrated to the south (yellow) with points of variation that reach –1.5. The 1987 SST map (Figure 4.8) differs from the annual climatological map (Figure 4.5) in the absence of cold area (light blue) in the zone to the south of Panama, and in the consequent further extension of the zone to the north of Ecuador. This occurs with El Niño.

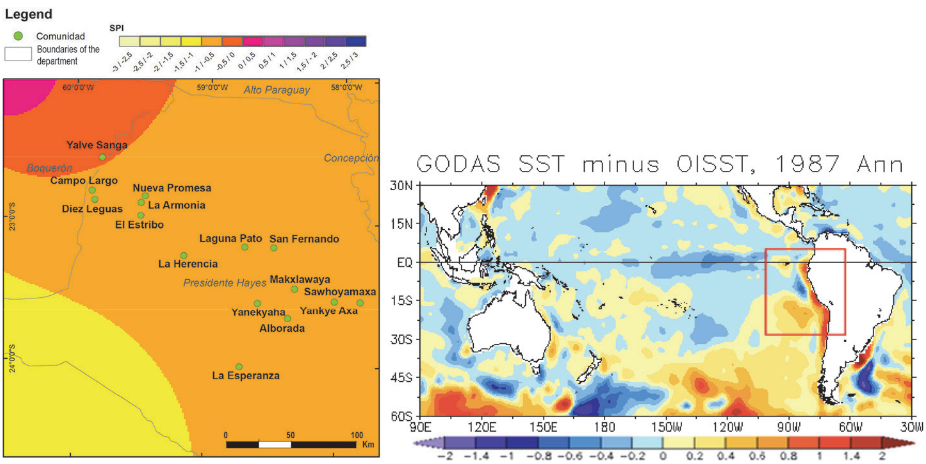

Figure 4.8: SPI of the Chaco in 1987 (left) and SST in 1987 (right).

4.3.4 Final Considerations

The three analyses reported above demonstrate the existence of a close relationship between the variation in temperature of the Pacific Ocean near the coasts of Ecuador and Peru, and the variation in SPI in the Chaco. These variations in temperature of the Pacific Ocean are influenced by the climatological phenomena of El Niño and La Niña. These phenomena can now be predicted and this may serve to warn the Chaco regarding those areas in which drought may occur in the subsequent months.

Based on these considerations, two thematic maps have been drawn up for each scenario (neutral, Niño, Niña). The first map represents a division of the drought by

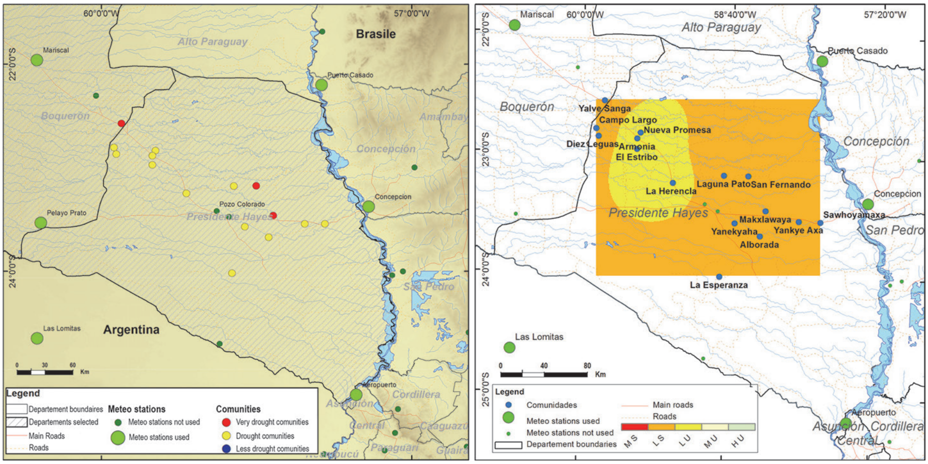

Figure 4.9: Paraguayan Chaco, neutral case: comunidad by level of drought (blue-humid, yellow-not very arid, red – arid) (left) and map of drought (right) (by E. Ponte).

comunidad while the second covers the entire territory. In Figure 4.9.a., which refers to a neutral scenario, the arid *comunidades* are represented with a red point, while those less arid and more humid are represented with yellow and blue dots, respectively. In Figure 4.9.b the arid areas are represented in red and humid ones in blue.

Observing the two figures given above, it can be noted as in the case of a neutral situation there is a general uniformity among the different Communities that appear to be mainly drought.

Regarding the scenario of La Niña, the situation changes. It seems obvious in both figures that a clear separation is found among the wetlands southeast, slightly damp areas in the centre, and driest areas in northwest.

Finally, regarding the scenario of El Niño, the situation is reversed, as in a mirror. It may be noted in both figures, as in this case, the wetlands are northwest, the little moist areas are in the middle and the driest areas are southeast.

This analysis, completed by the maps (Figures 4.10 and 4.11) outlined for the situation of Niña and Niño, covers a gap in literature, which does not present studies in drought in Paraguayan Chaco, and constitutes a starting point for future analysis. Alternatively, analyses of this type linked to national and regional evaluations of drought via the SPI are present in literature (Bonaccorso *et al.* 2003; Livada and Assimakopoulos 2007; Labedzki 2007; Michaelides and Pashiaridis 2008; Khan *et al.* 2008), demonstrating the current state of this type of research.

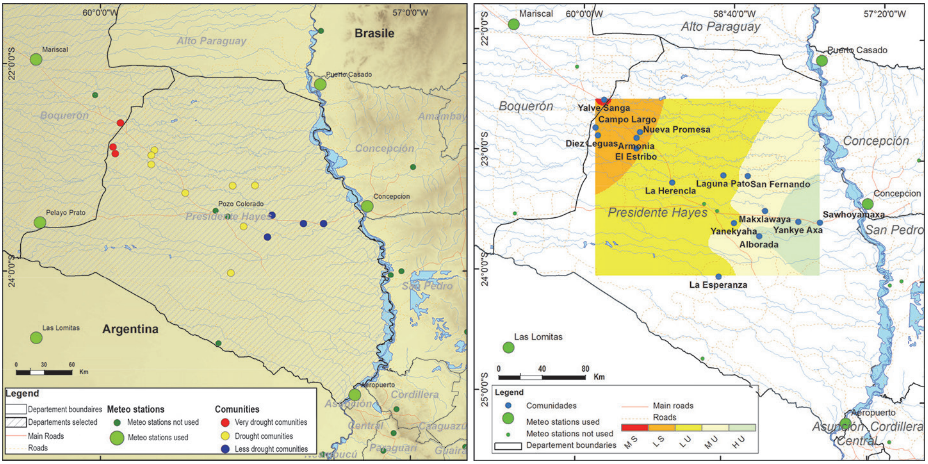

Figure 4.10: Paraguayan Chaco in the case of Niña: Comunidad by level of drought (left) and map of drought (right) (by E. Ponte).

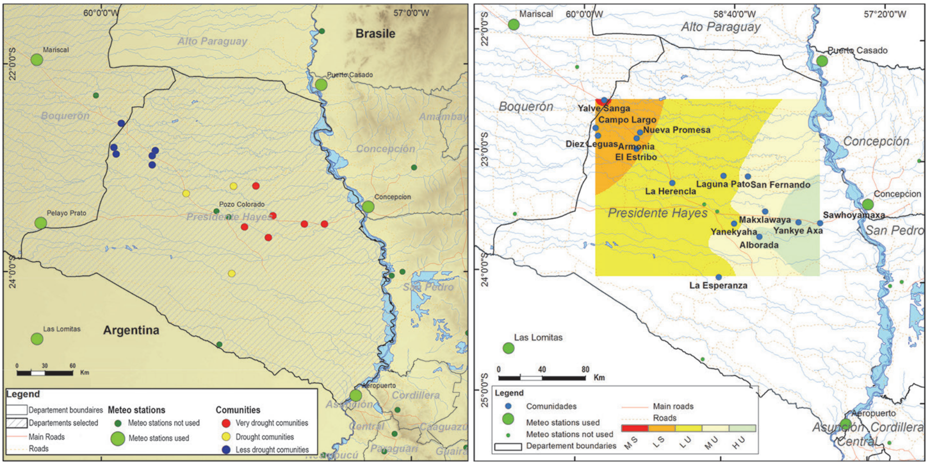

Figure 4.11: Paraguayan Chaco in the case of Niño: Comunidad by level of drought (left) and map of drought (right) (by E. Ponte).

4.4 Vulnerability to Drought

As mentioned in Section 2.1, vulnerability is measured through some indicators with the following equation: V = (E * S) / Ac; where V = vulnerability, E = exposure, S = sensitivity, Ac = adaptive capacity

The main source for developing this work phase is represented by the Participatory Community Diagnosis (PCD) (COOPI *et al.* 2014). This survey represents the systemisation of documented experience and gathers the methodological proposal of the Chaco consortium, made up of the following non-governmental organisations (NGOs): COOPI-Cooperazione Internazionale, Oxfam Intermon, Pro Comunidades Indígenas (PCI) and Acción Contra el Hambre (ACH). The availability of this resource has allowed us to identify and carry out activities for the preparation and mitigation of the vulnerability of 12 indigenous communities in order to deal with drought in Paraguayan Chaco.

Firstly, all the questions asked within the PCD were analysed, and subsequently questions that may be associated with one of the indicators of vulnerability (E, S, Ac and R) were identified (Table 4.1). Quality criteria were then applied for the selection (WRI & GIZ 2011). In this way, the following were identified:
- 2 indicators for exposure
- 7 indicators for sensitivity
- 5 indicators for the adaptive capacity
- 4 indicators for resilience (see chapter 5)

In this phase, we develop the analysis of exposure, sensitivity and adaptive capacity in order to determine a numeric value that may allow us to establish the value of vulnerability of each *comunidad*.

Table 4.1: Indicators chosen to determine vulnerability (source: COOPI *et al.* 2014).

#	Classification	Information
1	Exposure	Persons
2	Exposure	Drought analysis
1	Sensitivity	Distance from the paved road in km
2	Sensitivity	N. of people dedicated to self-consumption agriculture
3	Sensitivity	Time required to reach the nearest shops
4	Sensitivity	Duration of supplies of grown foods
5	Sensitivity	Transportation
6	Sensitivity	Types of soil: sandy, clay, other
7	Sensitivity	Availability of land to grow
1	Adaptation	Health centre
2	Adaptation	Agricultural tools
3	Adaptation	*Tajamar*
4	Adaptation	*Aljibes*
5	Adaptation	*Tanques*
1	Resilience	Community centre: yes or no
2	Resilience	Communications facilities: telephone, radio, other
3	Resilience	Existence of a community organization
4	Resilience	N. of people in the community with formal employment and medium-term

In the following sections, specific information for each indicator is given, including a rationale analysis of what it represents, and why it was chosen as an indicator.

4.4.1 Analysis of Exposure

Exposure to drought is expressed by both the physical phenomenon (drought) (DE) and the amount of population exposed (PE).

For the definition of a coefficient that may characterise the exposure to drought, based on the analysis presented in paragraph 2, indicators have been considered for the three scenarios presented: neutral situation, El Niño and La Niña (Table 4.2). In the first case, the SPI is between 1 and –1 throughout the area of interest. In the event in which we are in a Niño situation, there are humid areas to the north, with SPI values that may reach 2.5/3, and more arid zones to the south, with values that may reach –1/–1.5. Finally, in a Niña situation, we have humid areas to the south and more arid zones to the north, with values that may differ by as much as 2/3 points for the SPI value.

To define the correct coefficient to the *comunidades* in the three scenarios possible, the drought maps of the three scenarios have been used.

Table 4.2: Paraguayan Chaco. Coefficients of reduction to analyse drought.

Comunidades	Coefficients
Drought Comunidades	1
Less drought Comunidades	0.5
Humid Comunidades	0.1

In this case, the return time of the drought has been evaluated based on the connection between extreme events and the El Niño-Southern Oscillation (ENSO) cycle. In fact, there is a strong link between the extreme event, and consequently between the probability of occurrence and the ENSO cycle (see paragraph 3). As the ENSO cycle has a variable time deadline, it has been decided to simulate the probability of a disastrous event occurring based on the evaluation of the state of drought of the individual communities. This evaluation may be conducted while considering the ENSO cycle, and may be used both to develop the analysis as well as future forecasts. Consequently, the PE index has been assigned a numeric coefficient which comes within the calculation of the value of exposure (E). As can be seen in table 2, this value increases as the drought increases.

On the other hand, regarding the population affected, the information gathered from the PCD was used (COOPI 2014). Classes from 0.25 to 1 (Table 4.3) were defined.

Table 4.3: Paraguayan Chaco. Coefficients of reduction for the number of people in the comunidad.

Comunidad	Households	People per household	People	Coefficient
	n.	n.	n.	
Armonia	142	2.16	348 [a]	0.25
Campo Loa	321	4.78	1,563 [a]	1
Diez Leguas	306	3.95	1,210	0.75
El Estribo	468	3.71	1,736 [a]	1
Garai	35	1.85	65	0.25
La Esperanza	311	3.96	1,230 [a]	0.75
La Herencia	538	3.55	1,912	1
Lamenxai	149	4.8	716	0.5
Nepoxen	219	4.19	918	0.5
Nueva Promesa	240	3.33	800 [a]	0.5
Yalve Sanga	671	2.72	1,830	1
Yetwase Yet	61	4.36	266	0.25

[a] N. households * Average n. of components per households.

Finally, to determine the value of exposure of the various *comunidades*, we used the algebraic sum of these two elements: E = DE + PE.

4.4.2 Analysis of Sensitivity

In order to determine sensitivity, seven different indicators were used, divided into two groups: an economic one (ES) and a physical one (PS). It thereby follows that:

S = ES + PS

Regarding economic sensitivity, the five questions associated with the indicators considered to analyse economic sensitivity, are:

– *Distance from the paved road (km) (ES1 indicator)*. For each *comunidad*, a distance in kilometres has been identified to represent the distance of all the *aldea* (villages) which make up the Ruta Transchaco. Three groups have been identified: distance between 0 and 10 km (coefficient 0.1, minimum sensitivity), distance between 10 and 40 km (coefficient 0.5) and distance over 40 km (coefficient 1, maximum sensitivity).
– *Population dedicated to self-sufficiency (indicator ES2)*. The higher the percentage of population affected, the higher the sensitivity, as in the event of rought, it will be harder to react (0 and 25, sensitivity coefficient 0.25; 25 and 50, sensitivity coefficient: 0.5; higher than 50, sensitivity coefficient: 0.75).
– *Time necessary to reach shops (ES3 indicator)*. The times indicated start from 100 minutes for those *comunidades* that are nearest to the shops (sensitivity coef-

ficient 0.25), from 100 to 200 minutes in the intermediary range (sensitivity coefficient 0.5), and over 200 minutes for those *comunidades* that are furthest from shops (sensitivity coefficient 0.75). The distances are to be considered undertaken by foot.

– *Period during which the population uses cultivated foods (ES4 indicator)*. This indicator, important in evaluating how sufficient the cultivated products are to cover annual food demand, is expressed in months. The values obtained range from 3.9 in the case of Campo Loa (sensitivity coefficient 0.25) to 1.3 in the case of La Esperanza (sensitivity coefficient 0.75) (Table 4.4).
– *Means of transport (ES5 indicator)*. In the event of emergency, having motorcycles and cars available can drastically reduce the population's sensitivity. The more transport a *comunidad* has, the lower the vulnerability. The values are attributed according to the following classes: a single means of transport available coefficient 1, two 0.75, three 0.5 and four 0.25.

Table 4.4: Coefficients used for ES4 indicator.

Comunidad	Time (months)	Coefficient
Armonia	2.2	0.5
Campo Loa	3.9	0.25
Diez Leguas	2.6	0.5
El Estribo	2.6	0.5
Garai	1.7	0.75
La Esperanza	1.3	0.75
La Herencia	3.5	0.25
Lamenxai	2.8	0.5
Nepoxen	2.6	0.5
Nueva Promesa	2	0.5
Yalve Sanga	3.2	0.25
Yetwase Yet	3	0.25

Regarding physical sensitivity, on the other hand, the two indicators considered are:
– *Type of soil: sandy, clay or other (PS1 indicator)*. This indicator expresses in general terms the agricultural type of soil: a clay land (sensitivity coefficient 0.1) is more suitable for agriculture than sand (sensitivity coefficient 1), which has a high capacity for water filtration and dries more easily. Clay land is given a lower value than sand as it is believed that in land with clay soils, agricultural activity is more developed. This results in a higher use of water for irrigation with a relative increase in the impact of the parameter on the vulnerability to drought of the *comunidades*.
– *Land available for cultivation (PS2 indicator)*. Those *comunidades* that do not have land for agriculture, such as Armonia and Garai, have been assigned a coefficient

of 1; those that have land (Campo Loa, Lemenxai) the coefficient used is 0.1. In this case the possibility of cultivating land is considered positive for the population due to the possibility of having products for survival.

4.4.3 Analysis of the Adaptation

To prepare for drought, the following is necessary: monitoring of the indicators identified, an evaluation of the vulnerability and initial investments to plan adaptation (Engle 2009). Not only can this proactive approach contribute to reducing poverty, it also represents one of the most suitable tools for dealing with climate change. No direct parameters measure the process of adaptation in itself (UKCIP 2011), so *proxy* indicators are used.

For this study, those measures have been identified that are carried out by the population to adapt to drought. Also in this case, the main source for developing this analysis is the Participatory Community Diagnosis (COOPI *et al.* 2014).

The indicators identified are:

- *Health centres (Ac1):* in order to obtain a coefficient, the number of health centres for each community has been connected to the number of inhabitants thereby obtaining an amount of people per health centre. This number is then assigned a coefficient of adaptation: 0.1 for amounts above 1,000 inhabitants per health centre (minimum adaptation) and 0.8 for amounts lower than 500 people per health centre (maximum adaptation).
- *Agricultural tools (Ac2):* ranging from manual tools such as spades and hoes (minimum adaptation) to motorised ones such as tractors (maximum adaptation).
- *Tajamar (Ac3) (Figure 4.12.a):* this is a small dyke that collects rainwater in an artificial reservoir 2 to 3 metres deep. The bottom of the reservoir is covered in clay (Garcia *et al.* 2008). The water collected is then pumped out with a windmill into the canals that reach the surrounding villages. The untreated water is used to water animals and for washing. The tajamar have a water volume that varies from 5,000 to 100,000 litres (Table 4.5).
- *Aljibe (Ac4) (Figure 4.12.b):* holds rainwater collected from roofs. The water inside the tanks is protected. Nonetheless, the quality of the roofs of the houses must be studied accurately to guarantee the best possible collection (Junker 1999). This device is, in general, used both for community buildings, churches and schools (volume can be above 20,000 litres) as well as for homes (volume between 3,000 and 5,000 litres).
- *Tanque (Ac5) (Figure 4.12.c):* collect rainwater from roofs in plastic containers (volume up to 5,000 litres) and allow for a better control of water hygiene.

Table 4.5: Paraguayan Chaco. Coefficients used for the Ac3 indicator.

Comunidad	Litres	Litres/person	Coefficient
Armonia	51,600*	148	0.8
Campo Loax	43,100	28	0.1
Diez Leguas	74,400	61	0.4
El Estribo	112,120	65	0.4
Garai			
La Esperanza	64,000	52	0.4
La Herencia	52,500*	27	0.1
Lamenxai	20,000	28	0.1
Nepoxen	191,000	208	0.8
Nueva Promesa	109,400	137	0.8
Yalve Sanga	77,500	42	0.1
Yetwase Yet	7,200	27	0.1

Figure 4.12: Paraguayan Chaco, April 2014. Aljibe (left), tajamar (centre) and tanque (right) (photo by E. Ponte).

These measures increase the adaptation of the population in the event of drought in that they are able to provide a considerable amount of water. The adaptation coefficients are, therefore, expressed based on the calculated relationship of litres available per person (information presented in the PCD).

The coefficients of adaptation that have therefore been considered range from 0.1 (minimum adaptation) to 0.8 (maximum adaptation).

4.4.4 Results

In the case of the neutral scenario (Table 4.6 and Figure 4.13), a general uniformity of vulnerability emerged with eight out of 12 *comunidades* with a vulnerability between 2.5 and 7.5 in a scale from one to 10. The remaining four *comunidades* (Garai, Nueva

Table 4.6: Paraguayan Chaco. Vulnerability for the neutral scenario.

Comunidad	Ef	Ep	ES1	ES2	ES3	ES4	ES5	PS1	PS2	Ac1	Ac2	Ac3	Ac4	Ac5	V
Armonía	0.1	0.25	0.1	0.8	0.2	0.5	0.2	0.5	1	0.8	0.8	0.8	0.8	0.4	**0.6**
Campo Loa	0.1	1	1	0.5	0.5	0.2	0.8	0.1	0.1	0.4	0.1	0.1	0.4	0.3	**5.4**
Diez Leguas	0.1	0.75	1	0.5	0.5	0.5	0.8	1	0.1	0.1	0.4	0.1	0.1	0.4	**6.8**
El Estribo	0.1	1	0.5	0.2	0.8	0.5	0.8	0.5	0.1	0.4	0.4	0.1	0.4	1	**3.3**
Garai	0.1	0.25		0.2	0.8	0.8	1	0.3	1	0.1	0.4	0.8	0.8	0.4	**1.2**
La Esperanza	0.1	0.75	1	0.2	0.5	0.8	0.8	0.5	1	0.8	0.4	0.4	0.1	0.4	**3.9**
La Herencia	0.1	1	0.1	0.2	0.2	0.2	0.5	0.5	0.1	0.4	0.1	0.1	0.1	0.4	**3.6**
Lamenxai	1	0.5	1	0.2	0.5	0.5	0.2	0.5	0.1	0.4	0.1	0.1	0.4	0.4	**6.4**
Nepoxen	0.1	0.5	0.5	0.5	0.2	0.5	0.5	0.5	0.5	0.8	0.8	0.1	0.8	0.4	**1.3**
Nueva Promesa	0.1	0.5	0.1	0.5	0.5	0.5	0.8	0.3	0.5	0.4	0.8	0.1	0.4	0.4	**1.8**
Yalve Sanga	0.1	1	0.1	0.5	0.5	0.2	0.5	0.5	1	0.1	0.1	0.1	0.1	1	**5.2**
Yetwase Yet	1	0.25	1	0.8	0.8	0.2	0.8	0.5	0.1	0.1	0.1	0.4	0.4	0.4	**7.5**

Figure 4.13: Paraguayan Chaco, 2014. Charter of synthesis of the vulnerability of the comunidades for the neutral scenario (by E. Ponte).

Promesa, Nepoxen and La Armonia), had a vulnerability index of less than 2.5. There was, therefore an absence of *comunidades* with vulnerability values of over 7.5.

In the event of the scenario characterised by La Nina, most of the more vulnerable zones appeared to the west (Campo Loa, Yalve Sanga and Diez Leguas) with a value higher than 7.5. Only La Speranza to the south had a vulnerability index of over 5. All the remaining *comunidades* had a vulnerability index lower than 5.

In the case of El Niño, only La Esperenza had a vulnerability index higher than 7.5. With the exception of the *comunidades* of Garai, La Armonia, Nueva Promesa and Nepoxen which had a vulnerability index lower than 2.5, in all other cases all the *comunidades* had, in this scenario, vulnerability indexes between 2.5 and 7.5.

Observing all three scenarios together, we can see how the case of La Niña is the most critical in that drought affected the *comunidades* wherein there was already a more problematic situation. In fact, in this case, three *comunidades* have extreme vulnerability (coefficient higher than 7.5) while, for the El Niño scenario, just one *comunidad* had extreme vulnerability.

4.5 Resilience

The resilience approach considers that flexible institutions capable of reorganising themselves are needed to address future climate change (Folke *et al.* 2002). In particular, in Chaco Paraguayo, the resilience can be viewed as the extent to which a local disaster management group is connected to the disaster risk policy, depending on the availability of the data. Together with the vulnerability systems analysed, the resilience would help to shed more light on social networks and how individuals interact.

4.5.1 The Indicators

At present, there is no outline of the strategies and projects undertaken to increase resilience (Birkmann *et al.* 2008).

The indicators of resilience and adaptive capacity are difficult to discern, and it is not easy to use a list of 'off-the-shelf' indicators (Brooks & Adger 2005) as they vary from entity to entity, even in the same locality. In this case, the choice of indicators starts with the definitions given, and is determined by the data availability.

Consequently, the information coming from the PCD was used (COOPI *et al.* 2014) (Table 4.7):

– *Community meeting centre (Res1):* these centres often coincide with churches (Anglican or Evangelical) where general community meetings are organised. Wherever these centres are present, the *comunidad* is given a coefficient of 1, otherwise the coefficient assigned is 0.1.

- *Means of communication (Res2):* when the *comunidades* have a telephone or radio, the coefficient is 0.5; if they have both the coefficient is 1.
- *Existence of community organisation (Res3):* the coefficients used are 1 where organisations are present, and 0.1 where they are lacking.
- *Number of people that carry out formal activities beyond their own aldea (Res4):* this indicator allows us to evaluate the population's ability to carry out a work activity that may not be dependent on the site and therefore exposed to drought. To establish the coefficient, we have calculated the percentage of the population dedicated to this activity. In this way, three classes have been defined: less than 5% coefficient 0.1; 5–10% coefficient 0.3; higher than 10% coefficient 0.5.

Table 4.7: Paraguayan Chaco. Calculation of resilience.

Comunidad	R1	R2	R3	R4	R
Armonía	0.1	1	0.1	0.3	**1.5**
Campo Loa	1	0.5	0.1	0.1	**1.7**
Diez Leguas	1	0.5	1	0.5	**3**
El Estribo	1	1	1	0.3	**3.3**
Garai	0.1	0.5	0.1	0.5	**1.2**
La Esperanza	0.1	1	1	0.3	**2.4**
La Herencia	1	1	1	0.3	**3.3**
Lamenxai	1	1	1	0.1	**3.1**
Nepoxen	0.1	1	0.1	0.3	**1.5**
Nueva Promesa	0.1	0.5	0.1	0.3	**1**
Yalve Sanga	1	1	1	0.1	**3.1**
Yetwase Yet	0.1	0.3	0.1	0.3	**0.8**

There is an important difference between *comunidades* regarding resilience: from 0.8 for Yetwase Yet (slightly resilient) to 3.3 for La Herencia and El Estribo (highly resilient).

4.5.2 Vulnerability and Resilience Compared

We have previously explained the link that exists between vulnerability and resilience. Having reached this point, it is therefore necessary to try and compare the values obtained for the various *comunidades* to see how they relate.

For the neutral scenario (Table 4.8) all the *comunidades*, with the single exception of Yetwase Yet which presented higher vulnerability (higher than 6), had also developed a value of higher resilience (higher than 3). For the opposite case, there is also a relationship: all *comunidades* which have minimum vulnerability (less than 3), have also developed a value of lower resilience (less than 3).

Table 4.8: Paraguayan Chaco, 2014. Comparison between vulnerability and resilience for the neutral scenario.

Comunidad	V	R	V-R
Armonía	0.6	1.5	< 0
Campo Loa	5.4	1.7	3.7
Diez Leguas	6.8	3	3.5
El Estribo	3.3	3.3	< 0
Garai	1.2	1.2	< 0
La Esperanza	3.9	2.4	1.5
La Herencia	3.6	3.3	0.3
Lamenxai	6.4	3.1	3.3
Nepoxen	1.3	1.5	-< 0
Nueva Promesa	1.8	1	0.8
Yalve Sanga	5.2	3.0	2.2
Yetwase Yet	7.5	0.8	6.7

4.6 Conclusions

This chapter shows the multiple vulnerabilities to drought of the indigenous populations of Paraguayan Chaco.

The exposure of the communities of the Chaco to meteorological drought is linked to El Niño and La Niña, which can be forecast in advance in order to give a drought early warning in the Chaco.

It could prove interesting to develop an analysis of water balance of the study area. In this way, carefully studying the various components of soil, under-soil, water resources available, we could better understand which components are lacking the most.

The analysis of vulnerability highlights how in all three scenarios considered, La Armonia is by far the least vulnerable community. This is mainly due to its high level of adaptation.

Contrarily, no *comunidad* is the most vulnerable under all three scenarios. We can, however, confirm that La Esperanza and Diez Lugas are the two *comunidades* with the highest values, even if in some scenarios they are equal to others.

Observing the data in more detail, it emerges that the important investments for adaptation (especially in providing *aljibe*, *tajamar* and *tanque*) are not presently enough to lower the population's vulnerability, which is some cases reaches high levels.

The links between vulnerability and resilience indicate a good strategy for resilience that has effectively helped the most vulnerable *comunidades*.

The choice of indicators has also been made from the viewpoint of predicting future analysis monitoring as advised by the literature on the subject (Ponte 2014, GIZ 2012). Specifically, regarding the analysis of resilience, it emerges that for the indicators, it is not possible to assess any important information such as the opportunity for planning, organisation, mobilisation, or mutual aid to the individual communities. This information would certainly be useful: in fact, it is one thing to have the tools available, another is to use them to effectively become more resilient.

The integration of possible new information could allow us to increase the precision of the study. In particular, passage of scale-adjusted information from *comunidad* to *aldea* could prove very interesting. In fact, numerous *comunidades* show many differences between the various *aldea* that they consist of: distance of infrastructure, tools available, activities carried out. It could also prove useful to consider how the strategies and national policies for resilience and adaptation are implemented in Paraguayan Chaco (GIZ 2012).

In considering the results of climate research, the existence of a national Early Warning System (EWS) on the manifestation of El Niño and La Niña would certainly be of great importance for the Chaco.

In fact, an EWS could increase the adaptation capacity of the system and reduce its vulnerability. Moreover, if the system was nationwide, this would help the poorest communities increase their adaptation capacity without having to invest their capital in the construction of reservoirs for rainwater harvesting. A careful analysis of the water balance at atmospheric precipitation levels (carried out using appropriate climate indices), a forecasting system of atmospheric events and a detailed vulnerability assessment at the Community level would lead to an effective and efficient EWS for water balance prediction and water crises management.

Finally, the obtained results confirmed that the methodology applied in the presented research demonstrated how it is possible to obtain significant analysis at a local scale, even if the starting point is a study of the Climatological factors elaborated at global scale.

We can therefore conclude that the study can be replicated in similar situations where there is an impact of drought on communities living in remote areas.

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