

## Evaluating drought risk in data-scarce contexts. The case of southern Angola

Natalia Limones, Javier Marzo-Artigas, Marcus Wijnen and Aleix Serrat-Capdevila

### ABSTRACT

This paper pursues a methodological objective, developing and validating a structured approach for the recognition of areas under the highest levels of drought risk, suitable for data-scarce environments. The approach is based on recent scientific outcomes and methods and can be easily adapted to different contexts in subsequent exercises. The research reviews the history of hydro-meteorological drought in the south of Angola and characterizes the experienced hazard in the episode from 2012. Also, it intends to portray the socioeconomic vulnerabilities and the exposure to the phenomenon in the region to fully comprehend the risk. A list and map of these areas at high risk are two of the main outputs of this work. The results demonstrate that most of the region experienced a severe multi-year meteorological drought that was intensifying at the time of writing this paper, and that the majority of its impacts started immediately after the rainfall anomalies appeared. Last, the study confirms that the set of indicators used reveals different facets of vulnerability, leading to different drought vulnerability profiles in the south of Angola and, consequently, to several varieties of priority areas prone to distinctive impacts.

**Key words** | Angola, drought, exposure, hazard, risk, vulnerability

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### HIGHLIGHTS

- A methodology is presented to assess the components of drought risk that is suitable for data-scarce environments.
- This methodology can help inform decision making, relief action and development initiatives and prioritize areas to concentrate the efforts.
- The approach was applied and validated for the case of the severe 2012–2019 drought in the south of Angola, a region increasingly prone to drought.

### INTRODUCTION

#### Background

The center, and especially the south, of Angola are suffering a severe drought from 2012 to the time of writing this paper (2019). Sporadic rains during this period brought some relief but were not enough to start the recovery. Some areas in southern Angola, as well as other parts of southern Africa,

recorded the driest season in 35 years in 2015/2016, a peak of severity linked to El Niño ([United Nations Development Programme 2016](#)).

From 2013 to 2016, between 76 and 94% of the populations of the provinces of Namibe, Cunene and Cuando Cubango were affected by the drought. According to the Post-Disaster Needs Assessment (PDNA) performed by the

United Nations Development Programme (UNDP), until 2016, there were 1,139,064 people affected by drought in Cunene (accounting for half of the impacted populations), Huila and Namibe.

The economic impacts for all sectors are estimated at over US\$749 million, adding up the effects in these three provinces, with the agriculture-livestock-fisheries sector being by far the most damaged. Apart from the directly monetizable losses, the PDNA acknowledges a rising trend in admission cases of malnutrition, of family abandonment, domestic violence, charcoal production and deforestation. The PDNA reports that about 80% of the existing boreholes were non-functional in 2016 due to water scarcity and disrepair in the three provinces.

Moreover, this devastating drought episode is not perceived as an isolated event. Scientific research reveals that the shift in seasonal rainfall patterns is one of the consequences of climate change that are already evident in the region, as well as the increased frequency of droughts (Dai 2011; Climate & Development Knowledge Network 2014), so Angola is looking into how to transition from a reactive approach to more preparedness and prevention approaches to drought and to build drought resilience across the south.

### Rationale, objectives and outputs

In this context, this research aims to review the history of hydro-meteorological drought in the region of the south of Angola, understood as a period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance (World Meteorological Organization 1992). This research will characterize the experienced hazard, with a special focus on the situation lived in the drought episode from 2012.

Also, it intends to portray the drought vulnerabilities of human populations, including their conditions of access to water supply. The exposure to the phenomenon is also analyzed to fully comprehend the risk. The final product of this is a map and a list of the areas under substantial risk in the region.

In parallel, this paper pursues a methodological objective, developing and validating a structured approach suitable for data-scarce environments that allows for the recognition of the areas under the highest levels of drought risk (see Figure 2).

In fact, the most significant challenge for characterizing risk in the study area is the lack of reliable ground information of enough spatial and temporal resolution to build the different components and to validate the results. Therefore, the developed framework is based on proxy variables, remote sensing products and targeted interviews.

The methodology can be easily adapted to different contexts in subsequent exercises and support the prioritization of areas in which to concentrate mitigation and resilience efforts by decision makers, donors and development partners, etc.

The approach aims to be uncomplicated but based on the most recent scientific outcomes and methods implemented for operational purposes.

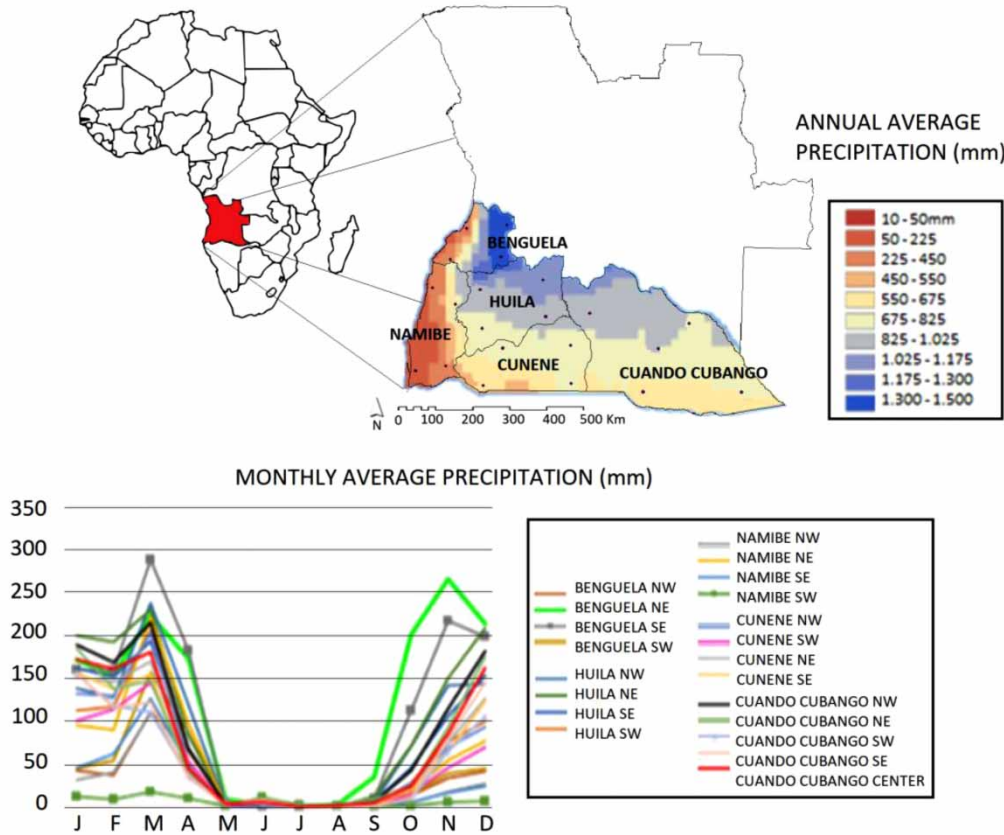
### Study area

The study encompasses the southern region of Angola, namely the provinces of Benguela, Cunene, Huila, Namibe and Cuando Cubango. It was selected according to the reported significance of the 2012–2019 drought impacts. It is a large and elongated region from 11.5 to 17.5°S and from 11.5 to 23.5°E (see Figure 1).

This area shows less socio-economic development than the remaining part of Angola; it is sparsely populated, and many rural communities are marginal. The mentioned provinces have a combined population of nearly 6.5 million, most of which is concentrated in Huila and Benguela. The rural population is about 65% of that figure.

In terms of climate and landscape, there is also a difference with respect to the rest of the country. These provinces fall within the arid and semi-arid agro-ecological zone in Angola that is characterized by desert, savannah grass and woodlands. Temperatures are milder on average than in the rest of Angola (Huntley 2019). It rains less than 800 mm per year on average in most of the south, but there are parts of the southern coast where it rains less than 200 mm (see Figure 1).

Although these total amounts of rainfall are significant, rainfall is not evenly distributed within the rainy season. As appears in Figure 1, some rain falls at the start of October and later at the end of the season in March/April. In between, the highest falls can occur anytime but are most frequent from January to March, especially in the parts



**Figure 1** | Study area, spatialized annual average precipitation and monthly regimes in 21 points of the area (marked in the precipitation map). *Data source:* Tropical Rainfall Measuring Mission Multisatellite Precipitation Analysis (TMPA).

more to the south. Also, year by year variability is very high and means rain totals are not predictable.

- exposure refers to the inventory of population and economic resources in an area in which drought may occur;
- vulnerability refers to the propensity of exposed elements such as societies to be impacted by drought.

## MATERIALS AND METHODS

The methodology developed consists of a series of steps that progressively allow narrowing down to the areas under the highest drought risk – and suffering the worst impacts – and to recognize the underlying causes.

The structure is based on the traditional definition of the degree of risk – used for example by the United Nations or the Intergovernmental Panel on Climate Change (IPCC) – as a combination of hazard, exposure and vulnerability (Cardona 2005; Cardona *et al.* 2012):

- hazard refers to the occurrence of a drought event that may have adverse effects on vulnerable and exposed elements;

The different phases of work are directed towards determining the parts of the region that stand out in these components of the drought risk.

There have been successive endeavors to develop indices to quantify these components systematically (Villholth *et al.* 2013; Kim *et al.* 2015; Dabanli 2018a, among others). For this study, a simple version that combines the magnitude of the hazard experienced in a specific (recent) dry run and the human exposure and vulnerability to drought is used to spot the areas in which to expect the most significant impacts during that run.

Most of these studies did not try to understand and address risk by connecting it to concrete past events damages and losses, except for a few attempts (Cardona

2005; Peduzzi *et al.* 2009) that did it mainly under a multi-hazard perspective. In contrast, this research relies on mapping analysis of region-wide indices to highlight both the zones at risk during a long ongoing drought and the most influential factors, comparing these results with the observed impacts. The stages undertaken are the following (see Figure 2):

1. hydrologic water availability assessment and description of the history of hydrometeorological drought in the region, focusing on the drought 2012–2019;
2. assessment of the socio-economic vulnerability to drought;
3. assessment of human exposure;
4. ground-truthing using the empirical evidence on drought impacts provided by local stakeholders.

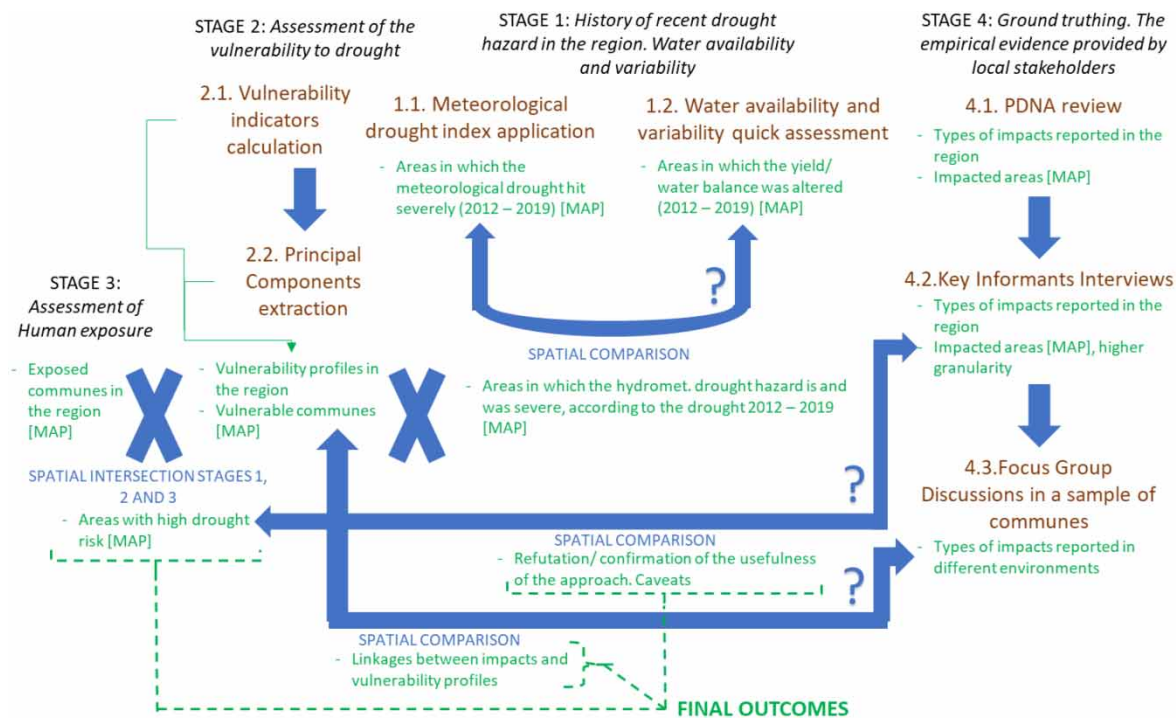
The methodology relies heavily on remotely sensed and modeled information. It is built on available global datasets for the physical hazards parts in step 2, considering the scarcity of hydrometeorological data in Angola from the post-colonial times. On the other hand, exposure and

vulnerability have been evaluated thanks to a Geographical Information System (GIS) – supported analysis of local statistical data sets and modeled information sources.

### History of recent drought hazard in the region. Hydrologic water availability and variability

This part of the research aims to provide an understanding of the hazard component from the perspective of the drought experienced from 2012, to help identify the most adequate water infrastructure option and to design water sector investments.

Unlike other research in which the authors construct comprehensive composite indices that combine magnitude and frequency of occurrence of droughts throughout a time series, in order to evaluate the overall hazard posed by drought in a particular point (Shahid & Behrawan 2008; Rajsekhar *et al.* 2015; Dabanli 2018b), in this study the intention is simply to characterize the influence of the last drought sequence in the region. It is essential to determine where meteorological drought has recently hit with



**Figure 2** | Stages of the research methodology. The sub-stages are numbered and labeled in brown, the transition steps between sub-stages are marked with letters and symbols in blue, the results of each of the parts are in green letters and marked with 'MAP' when the result is also a cartographic product. Please refer to the online version of this paper to see this figure in color: <http://dx.doi.org/10.2166/wcc.2020.101>.

significant intensity and duration and where the phenomenon is getting increasingly more threatening; this will later allow for testing if the impacts have evolved in a proportionate way and what is the influence of the measured vulnerability in the process.

The Drought Exceedance Probability Index (DEPI) is used for this analysis. DEPI is a modification of the ISSP (known by its French name: *Indice Standardisé de Sécheresse Pluviométrique*) developed by Pita (2000). DEPI is an index based on the calculation of cumulative monthly rainfall anomalies, in a similar way to the standardized Precipitation Index (SPI) of McKee (McKee et al. 1995) or the SPEI (Vicente-Serrano et al. 2010). However, in this case each monthly DEPI score represents the empirical probability of exceedance of the level of drought experienced in that month.

The index calculation is performed through the following successive stages. In the first stage, the rainfall anomalies of each month of the series (AP) are calculated using the expression:

$$AP_i = P_i - P_{MED_i} \quad (1)$$

where  $P_i$  = precipitation of the month  $i$ ;  $P_{MED_i}$  = median precipitation of the month  $i$  for the whole study period.

The index uses the median to determine surpluses and deficits because it is considered more suitable than the average for highly variable meteorological regimes (Pita 2000).

In the second stage, cumulative rainfall anomalies are calculated from the first month of the series. As soon as a negative anomaly is found, a dry sequence starts and therefore the accumulation is restarted in that particular month.

After that restart, the addition of anomalies continues month by month. Such a dry run ends when the cumulative anomalies become positive again after subsequent accumulations. In this wet run, anomalies continue to be added until a new negative rainfall anomaly is found. Obviously, at that point a new dry sequence starts, which is calculated following the same method.

The methodology is, therefore, a continuous addition of surpluses that stops whenever there is a negative anomaly, which precisely allows for prioritizing such an anomaly (this avoids the effect of drought minimization very

common in many indices, resulting from the accumulation of positive anomalies, which in many climates are substantially bulkier than the negative ones as there is no upper limit for precipitation, but zero is the lower one).

Consequently, the calculation of this second phase corresponds to the expression:

$$APAC_1 = AP_1 \quad APAC_i = \sum_{j=r}^i AP_j \quad i > 1 \quad (2)$$

where:  $APAC_i$  = rainfall cumulative anomaly of the month  $i$ ;  $r$  = the value marking the start of the dry run and follows the expression:

$$r = \max \{k: 1 \leq k \leq i, AP_k < 0, APAC_{k-1} \geq 0\},$$

Note that, if  $AP_i < 0$  y  $APAC_{i-1} \geq 0$ , then  $r = i$  and, as a result  $APAC_i = AP_i$ , marking the beginning of a new dry sequence.

Finally, in the third stage it is necessary to sort the series of cumulative rainfall anomalies calculated in the previous stage from lowest to highest, namely, from the months with the largest negative cumulative anomalies, or deficits, to the months with the largest positive ones, or surpluses. This is necessary to obtain the empirical probabilities of exceedance corresponding to each month of the series. Once sorted, the formulation of the DEPI requires that the probability of exceeding the event observed in each month is calculated, using the plotting positions method designed by Weibull:

$$P_{exced_{APAC_i}} = DEPI_i = M_{APAC_i} / (n + 1) \quad (3)$$

where:  $P_{exced_{APAC_i}}$  = empirical probability of exceedance of the month  $i$ , namely, the DEPI of the month  $i$ ;  $M_{APAC_i}$  = position of the rainfall cumulative anomaly of the month  $i$  in the sorted series, from lowest to highest cumulative anomalies, being:  $M = 1$  the largest negative cumulative anomaly or largest observed deficit,  $n$  = total number of months in the series.

Therefore, the DEPI for a given month is literally the probability of exceedance attributable to its cumulative rainfall anomaly, calculated as described above. This implies that it is a standardized value and comparable between

different series. Also, being a probability value, it contains an estimate of the hazard, with DEPI values below 0.5 indicating significant accumulation of anomalies (not likely to be exceeded) and therefore droughts, more severe as they approach 0.

The essence of the index, and its fundamental sign of identity over other similar ones, is that it restarts the calculations of cumulative anomalies whenever a new dry month ( $APi < 0$ ) arises in the context of a surplus period (with  $APAc_{i-1} \geq 0$ ). This ensures easy interpretation and identification of dry runs of different lengths from a straightforward single calculation of the index. SPI or SPEI require multiple time scales to reflect the different durations of the dry runs. This can be an advantage to reveal the multi-scalar nature of drought. *McKee et al. (1993)* illustrated this feature through consideration of usable water resources including soil moisture, ground water, snowpack, river discharges, and reservoir storages. The lag from the arrival of water inputs to availability of a given usable resource differs and that is why drought indices can be linked to a specific timescale to be useful for monitoring of different usable water resources (*Vicente-Serrano et al. 2010*). However, using different time scales is not practical for a study like this that needs to compare the evolution of a single dry run (onset, duration, intensity, etc. of the last drought) across multiple locations.

There are currently few rainfall stations in the region and their records are not continuous, but they have been used to test the usefulness of satellite rainfall estimates. Consequently, the Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) product, by NASA and the Japan Aerospace Exploration Agency, has been used as input data.

TMPA was selected because it performs accurately in the south of Angola if compared to data from the Global Precipitation Climatology Project (GPCP), the Climate Prediction Centre Morphing Technique (CMORPH) and Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) (*Pombo et al. 2015*). Also, TMPA has high temporal (3 h) and spatial ( $0.25^\circ$  pixel) resolutions, which makes it perfect for counting on monthly rainfall series.

The DEPI drought index has been applied to the TMPA monthly values from January 1998 to January 2019 for all

the cells of the region. The evolution of the drought index from 2012 to the time of writing this paper was examined in detail in all the cells, but only the 21 points distributed across the region that appear in *Figure 1* are plotted in the figure to facilitate interpretation by the reader.

To endorse the described drought analysis and check the recent evolution of the water availability, a very simple account of the monthly precipitation minus the actual evapotranspiration (P-ETa) has been performed at medium spatial resolution – a pixel of  $0.25^\circ$  – and covering the entire region. Different studies consider the result of P-ETa as a reliable proxy to the yield or the produced runoff per unit watershed area at the monthly level (*Guerschman et al. 2008; Weiss 2009*).

This analysis also uses satellite data. Actual evapotranspiration gridded series are obtained from the GLEAM (Global Land Evaporation Amsterdam Model, available at [www.gleam.eu](http://www.gleam.eu)). TMPA has been used for rainfall estimates here as well.

The full monthly series P-ETa from 2003 to January 2019 were obtained for all the pixels of the region and subsequently some statistics were calculated for understanding the normal regimes and what is different in the most recent regimes (from 2012 to 2019). These results confirm the areas experiencing significant deficits in their water availability. Simulating other hydrological variables like soil moisture or discharge in the sub-basins of the region and applying a broader array of drought indices to them could provide a broader understanding of the hazard component (*Shamshirband et al. 2020*). These simulations could be built based on free access reanalysis global datasets of hydrological variables. These enhancements were not included in the methodology for the current research due to the impossibility of finding any ground information for calibration and validation, so the final hazard characterization presented in this research is simple and useful for these types of no ground data environments.

### Assessment of the vulnerability to drought

Understanding the structural characteristics of the environment and society is key to rating their susceptibility against natural threats like droughts. Faced with the same hazard, one community could be resilient while another

could suffer important impacts. In developing countries like Angola, high vulnerability to drought is a factor that constitutes a constant threat to livelihoods and, eventually, to meeting the most basic needs.

Although there are heterogeneous visions and ways of understanding the concept of vulnerability, the perspective of this study is to consider that vulnerability is the state that exists within a system before it encounters a hazard (Brooks 2003). According to the definition by the Intergovernmental Panel on Climate Change, vulnerability is the propensity or predisposition to be adversely affected. Within this paradigm, vulnerability can be defined, in turn, as a function of sensitivity and coping capacity, following the approach of studies such as Shahid & Behrawan (2008).

For this study, different factors have been considered to characterize sensitivity and coping capacity to drought (see Table 1), following the set of variables measured and validated by Luetkemeier & Liehr (2018) in the Cuvelai basin. The choice of indicators was conditioned by the availability of data, but the main elements considered in specialized literature could be included thanks to the existence of the recent reliable and exhaustive National Census of Angola.

There is a solid body of recent research using analogous vulnerability components and tackling the assessment with similar granularity, from applications at the continental level in sub-Saharan Africa (Ahmadalipour & Moradkhani 2018), to others at the country and sub-country levels in China (Simelton *et al.* 2009; Zhao *et al.* 2020), South Africa (Jordaan *et al.* 2018), Romania (Dumitrascu *et al.* 2018) or Irán (Sharafia *et al.* 2020).

In Angola, the provinces are divided into municipalities, which in turn are subdivided into communes. The commune is the basic administrative unit for the selection of areas at risk in this study and for the calculation of the indicators in this stage, because it is the most desegregated spatial entity with publicly available Census information.

Outlier households in vulnerable communities may have an array of alternative livelihood options and vice versa: in some communes, positive indicators could be hiding vulnerable situations, but there is no data with finer resolution available.

To populate the indicators, the team digitized the variables referring to population density, age and gender

structure of population, typologies and size of households, access to drinking water, education level and use of technologies that appeared in the Census survey reports for the 130 communes of the south.

On the one hand, the 10% of the communes with the highest score of each indicator are highlighted. Principal component analysis was applied to extract a lower number of underlying – potentially meaningful – factors, along the lines of similar vulnerability assessments found in recent literature (Žurovec *et al.* 2017; Kim *et al.* 2018), assuming that some of the 11 socio-economic indicators used are interdependent. The scores of each commune in the different factors have also been analyzed.

### Assessment of human exposure

Depending on the authors, exposure is a separate element (Carrao *et al.* 2016) or is understood as one of the subcomponents of vulnerability (IPCC 2014). Other authors understand drought exposure as the frequency and severity of the drought events (Brown *et al.* 2016), under the definition of what is commonly categorized as the hazard component. A very interesting definition based on the previous is provided by Mosquera-Machado & Dilley (2009), which describes exposure as a measure of the population-weighted hazard, indicating the probability of people experiencing it.

In fact, most of the recommended proxies point to a measure of the population subject to the phenomenon, regardless of where this factor is placed within the components of the risk.

For the purpose of this work, exposure is understood as a dichotomous factor, and only almost uninhabited areas are considered not exposed.

According to oral communications, in the south of Angola, people living in sparsely populated areas – which is a large proportion of the territory – walk daily not less than 5 km for the development of their vital or economic activities. If that radius is used as a threshold, it is necessary to have a minimum of 6.5 people per square kilometer to achieve at least an average of 500 inhabitants in potential frequent contact.

For the communes below that threshold, the authors have analyzed the population clusters in them, thanks

**Table 1** | Indicators used to characterize sensitivity to drought and coping capacity in the study region

	Factors	Indicator	Original variable considered to build the indicator	Data source
Sensitivity	Water	IND1: Water source unreliability	Main source of drinking water (%). Luetkemeier & Liehr (2018) methodology is applied. The analysis of the seasonal changes (wet-dry) of the combination of sources used in the communes indicates their reliability levels	Angola Census 2014 (INE)
		IND2: Water unsafeness	Main source of drinking water (%). Census establishes a differentiation between safe and unsafe water source types. Based on this classification, each water source has been scored according to its (un)safeness, with a 0–1 score. Then, each score is multiplied by the percentage of the commune relying on that type of water source and added up per commune	
		IND3: Financial dependence	Main source of drinking water (%). Source types that require financial inputs: boreholes and tanker trucks. Logically, boreholes are the least weather related water supply option and are more reliable, but only if there is capacity for maintenance, which does not seem the case for the region	
		IND4: Water demand	Average household size in the commune was taken as a reference for water demand as a more relevant measure of population density for large communes with empty lands, a very frequent case in southern Angola	
	Livelihood	IND5: Livestock density	Livestock per square kilometre	Food and Agriculture Organization (FAO) (2007)
		IND6: Practise of agriculture	Households that practise agriculture (%)	Angola Census 2014 (INE)
	Social	IND7: Rural exodus	Sex ratio or masculinity index@@@Exodus normally means more sensitive families. However, if absent family members work in non-rural or non-agricultural jobs and have independent income to share, the family becomes less vulnerable, so the direction of the influence needs to be proven for south Angola	
Coping capacity	Energy	IND8: Energy endowment	Use of electricity (%)	
	Human capital	IND9: Work force	Population between 15 and 65 years old (%). Higher rates imply more ability to diversify activities, move or stay in appropriate health conditions, among other copying advantages	
		IND10: Education level	Literacy rate (%), is used to evaluate the productive wealth embodied in skills and knowledge	
	Physical capital	IND11: House walls' material	Wattle and daub (Pau-a-pique) built houses (%), relying on the building materials as proxy to the assets that a commune counts on	

to two complementary sources of population spatial information:

- Density grid maps of the WorldPop collection ([www.worldpop.org/](http://www.worldpop.org/)), created following the methodology

described in Stevens *et al.* (2015), with a resolution of about 100 m in the study area.

- Density grid maps of population in Namibe, Cunene and Huila, created by the NGO Development Workshop by digitalization of houses from high-resolution Digital

Globe images available in Bing and Google Earth (Calunga *et al.* 2015).

If there is not at least a population hotspot exceeding 1,000 inhabitants, normally corresponding to the head of the commune, the commune is considered not sufficiently exposed.

### Ground truthing. The empirical evidence provided by local stakeholders

As the dedicated literature points out, drought indicators of all types need to be ‘ground-truthed’, i.e. compared with information representative of the local drought conditions or impacts, which are ‘observable losses or changes that occurred because of drought’ (National Drought Mitigation Center 2019). Some drought monitors recently created even include reported field evidence of agricultural or hydrological drought (Bachmair *et al.* 2016; Van Loon *et al.* 2016).

For this study, the team benefitted from several sources to test the combined results of the previous two stages qualitatively.

### PDNA review

First, the team resorted to the publications delivered for the 2016 PDNA. However, one of the major reported challenges in creating the PDNA was the lack of fine granularity statistics and the inconsistencies and gaps in the information collected from different sources (UNDP 2016).

### Key informants interviews

In the absence of a comprehensive database of reported impacts at detailed scales, a second step was needed, based on iterations and feedback loops between actors and researchers. A network of local partners was made available in the provinces of the south and headed by the *Fundo de Apoio Social* (FAS). A total of 21 representatives from FAS, Unicef, Civil Protection, Fire Department, *Instituto Nacional de Recursos Hidricos* and FAO staff members working on the ground in the south of Angola met the research team in successive Key Informants Interviews to

discuss the impacts of the 2012–2019 drought, revolving systematically around the following topics:

- start of the drought, intensity and duration;
- most affected areas. For the authors to consider that an administrative entity has been significantly impacted it had to be repeated by >75% of the informants;
- geographical differences in the phenomenon;
- main affected sectors and significant impacts throughout time, challenges they face;
- drivers of resilience in the areas that cope better.

It continued with a presentation of the outcomes of the two screening analyses aimed at finding the areas with the highest hazard, exposure and vulnerability levels, in order to discuss the relevance of the measured parameters and confirm the accuracy of the results. It was essential to follow this order so that the results of the researchers’ analyses did not influence the discourse of the consulted individuals.

### Focus group discussions in a sample of communes

Lastly, several half-day meetings took place in the headquarters of the government of a sample of areas recognized as those under the highest levels of risk in previous stages of the work. The intention was to continue refining the comparison between estimated degrees of risks and observed impacts.

In all the cases, a group of 10–15 members of the communities participated in each of the sessions, benefiting from snowball sampling. The head of the local government, several farmers and herders’ representatives from the different communes, a member of the government dealing with water supply and another one involved in livestock and agriculture management were systematically present.

The researchers used a more targeted and detailed line of questioning to guide the discussions about: i) the socioeconomic and environmental characteristics of the municipality and the communes that condition resources management and water supply, beyond what can be concluded from the census data; and ii) the nature, degree and distribution of impacts suffered from 2012 in each of the communes within the municipality. In this case, the

team facilitated Focus Group Discussion (FGD), guaranteeing all the participants offered their individual views.

Recent literature on risk assessment compiles similar experiences on enhancing the indicators approaches to evaluate drought risk with qualitative interviews on previous drought impacts and risk perceptions. In particular, works like Colorado Water Conservation Board (2013), McNeeley *et al.* (2017) and Ndiritu (2019) have proved the robustness of the mixed-methods approaches designed as the one performed in this research, particularly when these assist in ground-truthing quantitative drought analyses.

## RESULTS AND DISCUSSION

### History of recent drought in the region. Hydrologic water availability and variability (stage 1)

The application of the DEPI drought index to the TMPA monthly rainfall series corroborates that the five provinces have suffered moderate to severe meteorological drought from 2012 to 2019, but also that there are differences in the temporal evolution and intensity of the phenomenon that varied gradually across the territory (see Figure 3). That gradualness confirms that the spatial variability of drought in the area is limited enough to allow for realistic and comprehensive interpretations with only a few points or pixels per province, in line with the findings of dedicated research (Bonaccorso *et al.* 2003; Martins *et al.* 2012; Wang *et al.* 2019), even if the index was applied to all the pixels in the region.

The southern part of Benguela has suffered drought from 2012, while the north has experienced it for the last two years of the analyzed series. In general, the phenomenon is getting more intense in this province.

The entire provinces of Huila and Cunene have been experiencing a creeping drought from 2013, being extremely intense from 2016 – an agricultural campaign from which all the consecutive rainy seasons have been anomalously dry until the date of this research – and worsening over time.

The highlands of Namibe, which correspond to the eastern part of the province, have been facing a gradually increasing drought from 2012, relatively parallel to the evolution of the drought in Huila or Cunene, while in the coastal

areas – the western half – the drought has appeared intermittently throughout that period. Moreover, the phenomenon is getting more and more intense in the eastern highland, while the coast seems to be recovering.

Last, Cuando Cubango has faced more intermittency than the rest of the region. The eastern part of the province has been steadily recovering since 2017, while the western part has a sustained deficit in rainfall that evolved similarly to that of its neighboring provinces.

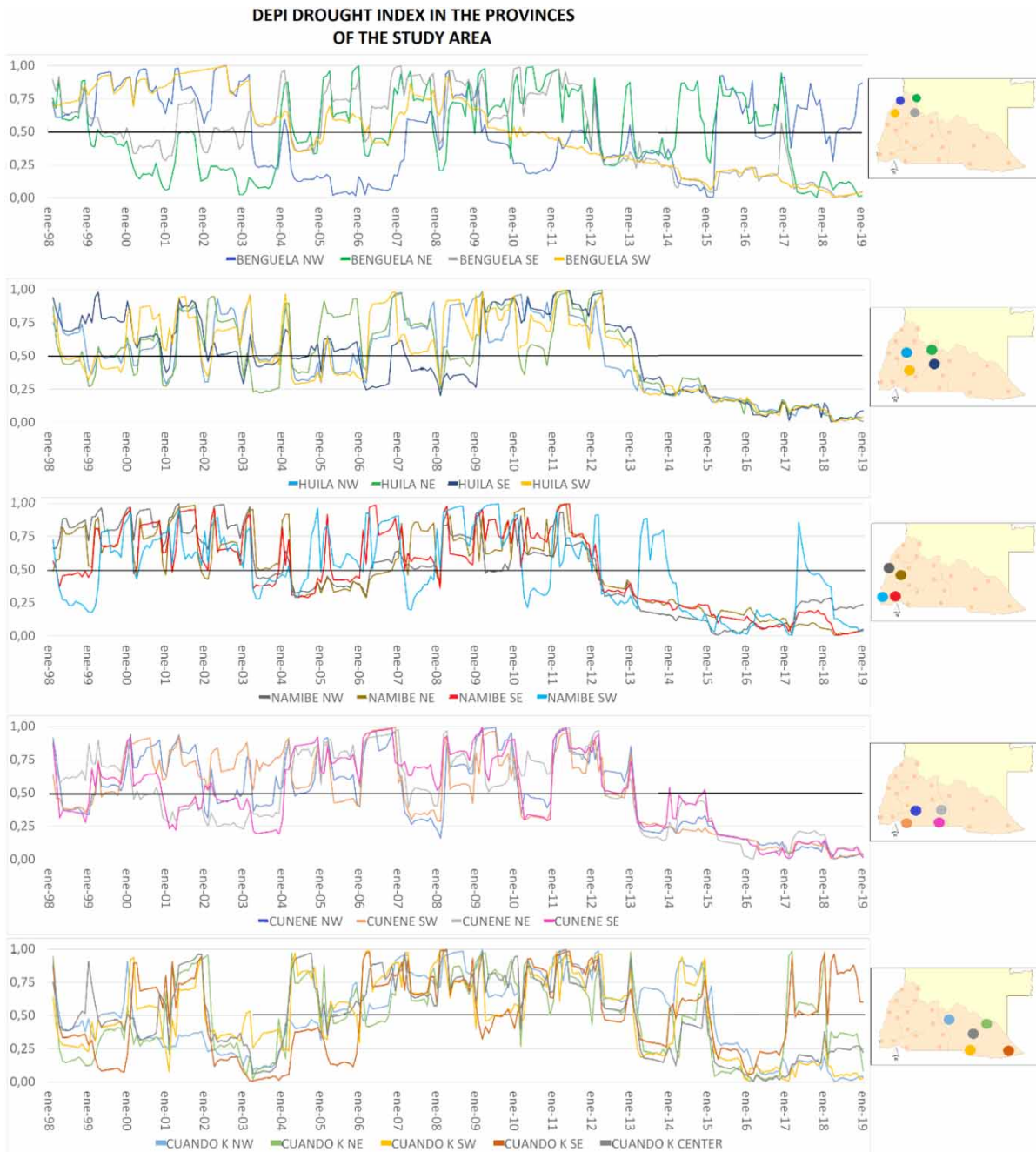
All this proves that the drought has hit more continuously in the geographical central core of the region and, in addition, in most of it the deficit continued to accumulate until the end of the studied period, hence the severity of the event is gradually growing.

In addition, the account of the monthly precipitation minus the actual evapotranspiration (P-ETa) points to the same problematic geographic areas. Not only are the parts of the region previously mentioned as most affected by the meteorological drought from 2012 to 2019 those with the lowest values of produced runoff per unit watershed area in normal conditions (see Figure 4), but also these are the zones that have experienced the most significant reductions in their yields during the studied drought (see Figure 5).

The largest negative anomalies in yields are concentrated in the wet months, which are the only ones in which production of runoff is possible in most of the region (according to Figure 4), especially from December to March. Again, these deficits are particularly substantial and continuous in the central core of the region: the entire provinces of Huila and Cunene and the adjacent halves of the other provinces. These areas registered average deficits beyond 50 mm of yield per month in the rainy seasons of 2012–2019, which undoubtedly jeopardized their water security.

This confirms the sub-area of the region that has experienced the worst hydrometeorological conditions during the last recorded drought: the provinces of Huila and Cunene, the western part of Cuando Cubango, the south of Benguela and the eastern part of Namibe. For the purpose of this work, this represents the physical magnitude of the hazard and the exposure for this drought event.

Figure 6 is the cartographic product of this stage. The edges of the area harshly affected by the phenomenon

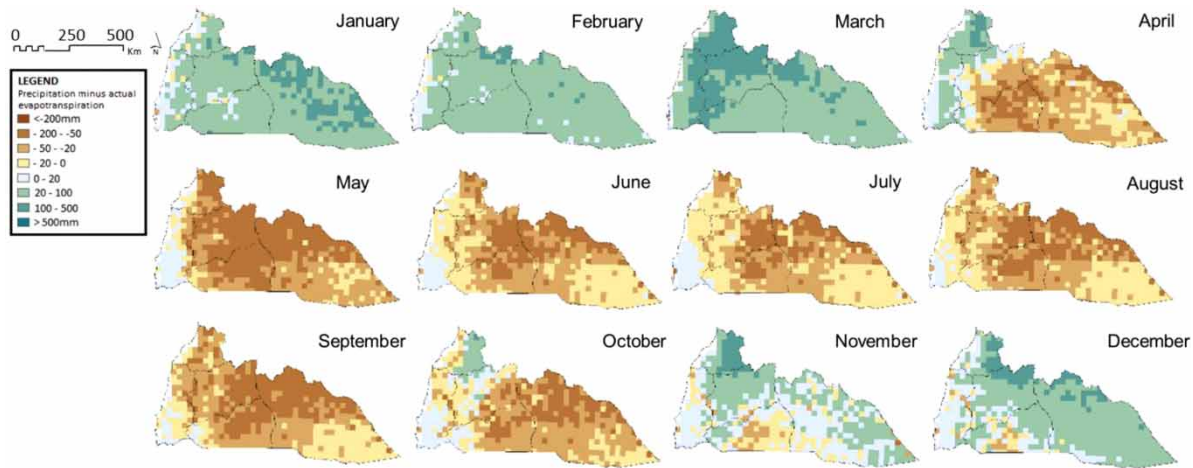


**Figure 3** | Temporal graphs depicting the evolution of the Drought Exceedance Probability Index (DEPI) for 21 points of the region, distributed across the five considered provinces. Values between 0.5 and 0 indicate drought, more intense as the DEPI values decrease.

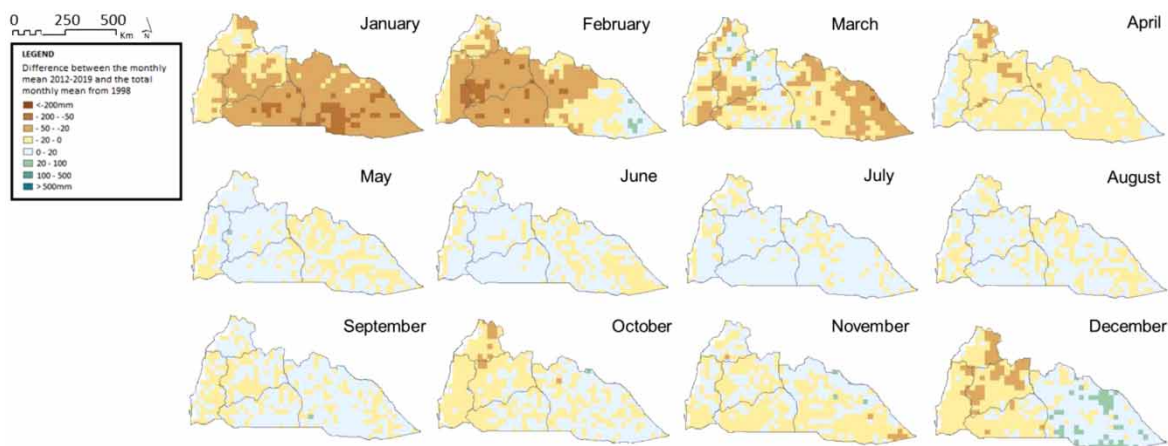
were delimited interpreting intensity, duration and evolution of the DEPI index in each pixel for 2012–2019. They also coincide with the edges of the area with the highest average anomalies in yield in that period.

### Analysis of the vulnerability to drought. Choice of the potential targets (stage 2)

Despite having used a set of indicators that account for different facets of the vulnerability to drought, the values



**Figure 4** | Average monthly precipitation minus actual evapotranspiration for the entire region based on the grids of monthly values from 1994 to 2019.



**Figure 5** | Difference in the average monthly values of precipitation minus actual evapotranspiration in the period 2012–2019 and those average monthly values calculated from the entire period (1994–2019).

of some of them are significantly correlated, even among the indicators expressing sensitivity with the coping capacity ones, as shown in Table 2. The strongest connections are found mutually among the practice of agriculture, the unsafeness of the used drinking water sources and the energy endowment (inverse).

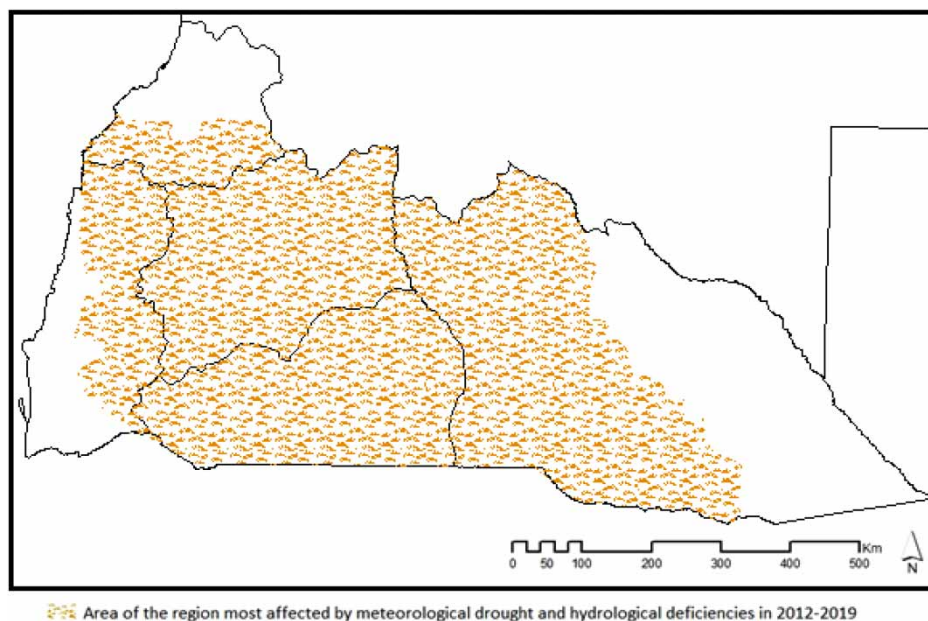
Social sensitivity, expressed by the indicator (7) on rural exodus, gives independent information about the communes in the region. Likewise, among the sensitivity indicators describing water access and use, the water demand patterns indicator (4) – based on the size of the household – is not correlated with the rest either.

Sixty-three per cent of the communes are in the lower decile of at least one of the applied sensitivity and coping

capacity indicators, showing the complexity and variety of difficulties experienced in the majority of the region (see Figure 7). This percentage decreases to 13% of the communes in the last decile of more than two indicators at the same time, indicating that there are areas with structural deficiencies of a varied nature.

Principal component (PC) analysis performed with the scores of the original 11 indicators yielded six factors that explain 85% of their variability (see Table 3).

Figure 8 shows the variables represented by the components and a map of the commune scores for each of the six. The ten different colour categories represent the scores deciles.



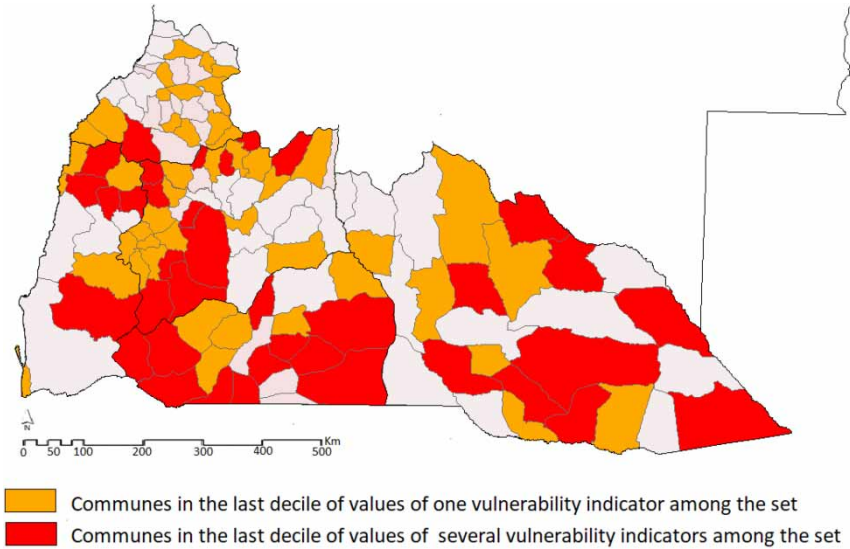
**Figure 6** | Area of the region most affected by the meteorological drought and hydrological deficiencies during the period 2012–2019.

**Table 2** | Pearson correlation among the vulnerability indicators

Correlation among the indicators (Pearson R)	IND2: Water unsafeness	IND3: Financial dependence	IND4: Water demand	IND5: Livestock density	IND6: Practise of agriculture	IND7: Rural exodus	IND8: Energy endowment	IND9: Work force	IND10: Education level	IND11: House walls' material
IND1: Water source unreliability	0.32	-0.28	0.14	0.50	0.30	-0.38	-0.38	-0.29	-0.11	0.19
IND2: Water unsafeness		-0.45	0.10	0.06	0.69	-0.16	-0.69	-0.34	-0.57	0.54
IND3: Financial dependence			-0.06	-0.01	-0.31	0.36	0.18	0.29	0.12	-0.04
IND4: Water demand				0.11	0.07	0.08	0.10	-0.03	0.03	0.34
IND5: Livestock density					0.02	-0.26	-0.07	-0.26	-0.12	0.02
IND6: Practise of agriculture						-0.23	-0.75	-0.43	-0.49	0.37
IND7: Rural exodus							0.14	0.39	0.13	0.10
IND8: Energy endowment								0.38	0.60	-0.41
IND9: Work force									0.26	-0.15
IND10: Education level										-0.49

The factor loadings are relatively unambiguous. As intended, the spatial patterns of the principal components encompass the most relevant patterns observed for the indicators scores individually. The vulnerability profiles they represent are interpreted as follows:

- Principal component 1 (PC1), which explains about 36% of the total variance, has high loading associated with electrical energy endowment (0.42) and a negative correlation with water unsafeness and the practise of agriculture (both loadings amount to 0.4). This was

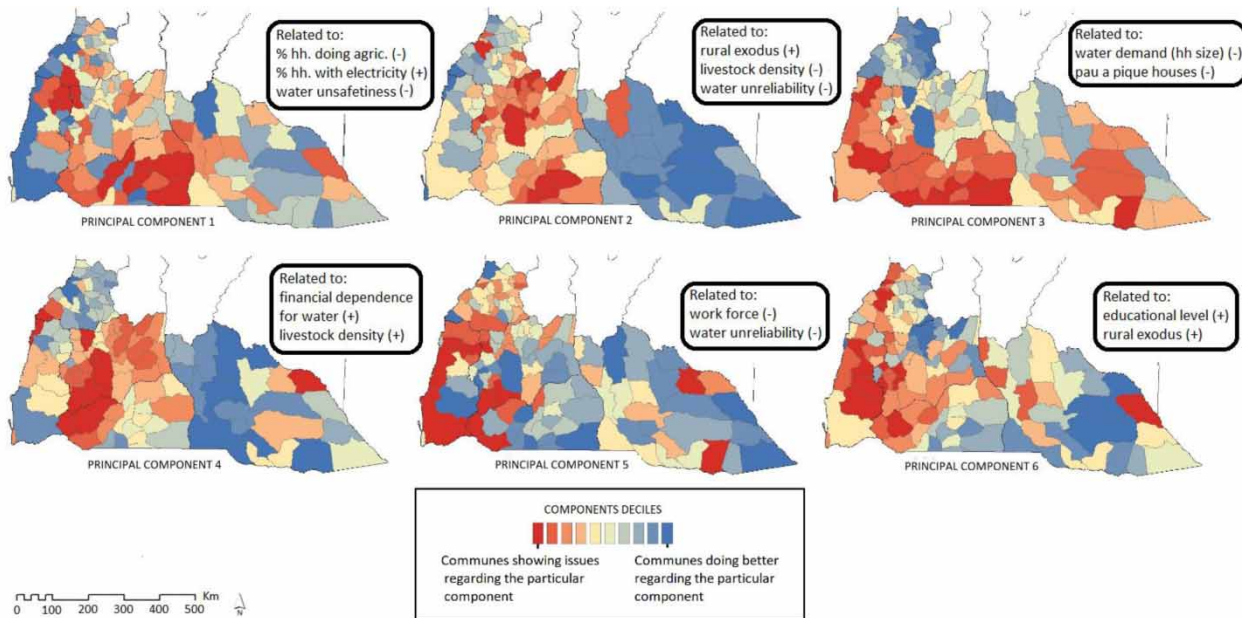


**Figure 7** | Communes in the last decile of values in the different vulnerability indicators. Marked in yellow are those that stand out in just one indicator; marked in red are the communes performing poorly in several of them. Please refer to the online version of this paper to see this figure in color: <http://dx.doi.org/10.2166/wcc.2020.101>.

**Table 3** | Variance of the vulnerability indicators that is explained by the extracted principal components

Variance explained by the principal components	PC1	PC2	PC3	PC4	PC5	PC6
Proportion of variance	0.356	0.167	0.108	0.1	0.069	0.052
Cumulative variance	0.356	0.524	0.632	0.732	0.801	0.853

expected due to the abovementioned strong correlation among these three indicators. This component is clearly related to the infrastructure development of the communes and the urban–rural dichotomy of the study area. In southern Angola, agriculture is mainly subsistence and rainfed, and a high percentage of the commune relying



**Figure 8** | Mapping of the deciles where each commune belongs for each of the six principal components identified (dark red meaning high vulnerability scores for that principal component and vice versa). Please refer to the online version of this paper to see this figure in color: <http://dx.doi.org/10.2166/wcc.2020.101>.

principally on this activity means fewer resources to engage in more profitable livelihood options like live-stock raising.

- A different dimension of this urban–rural duality can also be identified by *PC3*, characterized by its correlation with water demand (a sensitivity to that indicator of 0.75) and house walls' material (0.43): in urban areas, both the household's size and the percentage of houses built using the wattle and daub (*pau-a-pique*) technique are significantly smaller. This component depicts poor rural areas with economic activity diversity, and which do not stand out either in livestock keeping or in crop farming predominance. This is the case for almost the entire provinces of Cuando Cubango and Namibe, which register significant issues regarding *PC3* but show opposite behavior regarding *PC1* in most of their communes.
- Cunene is the subregion where both factors (*PC1* and *PC3*) have lower component values, with the exception of the capital.

*PC2* and *PC4* identify the communes with high livestock density (with predominance of water demanding animals like cattle, but also goats) and facing problems accessing drinking water. The issues are different, though:

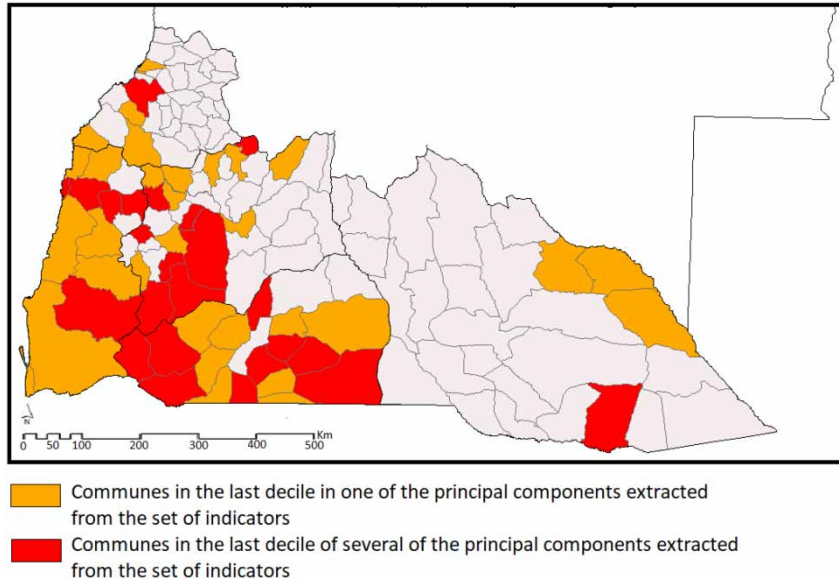
- Regarding *PC2*, these difficulties are related with unreliable sources (factor loadings in that indicator of 0.42), which dry up quickly. Therefore, it is not surprising that the communes with worse *PC2* scores are in the parts of Cunene and Huíla where drinking water is mainly obtained from cacimbas, hand-dug wells, and chimpanças, small artificial ponds, according to the data. Those water sources are not drought-resistant which, added to the predominance of livelihoods based on water demanding livestock, designates communes with a high vulnerability to the phenomenon.
- *PC4*, on the other hand, identifies the pastoral communes with financial dependence to obtain water, mainly located in the southwest of Huíla and the northwest of Cunene (high sensitivity to that indicator, with loadings of 0.67). In these cases, the population relies heavily on drilled boreholes for all their uses because the hydrogeological circumstances favor it. These devices can be instrumental to mitigate drought because they guarantee

a more stable supply, are less immediately dependent on the rainfall conditions, but require adequate governance mechanisms and capacity for operation and maintenance, otherwise they fail to provide these communes with the significant amounts of water they demand given their livestock density. This is a recurrent problem in the region. There is another hotspot for this component in some coastal communes of Namibe, where most of the households rely on tanker trucks to obtain drinking water and the rest on boreholes, both cases requiring community or domestic financial inputs, which are not always available. This is the most noteworthy issue for the population in this province, partially due to its aridity and the absence of permanent water bodies.

- Interestingly, according to *PC5* and *PC6*, the coping capacity of the communes in the eastern part of Cunene province is significant because of a strong young population and workforce (in *PC5*, that variable has a loading of 0.75), significant masculinity rates and a higher educational level (*PC6* has sensitivities of 0.44 and 0.63 to these two indicators, respectively). Most of the communes of Namibe perform poorly in these two components and are in the opposite situation.

Logically, the indicators and the principal components lead to a similar set of recurrently highlighted communes (see [Figure 9](#)).

Some authors construct composite indicators to quantify vulnerability, combining the different dimensions and individual indicators ([Naumann \*et al.\* 2014](#); [Murthy \*et al.\* 2015](#); [Luetkemeier & Liehr 2018](#)). For this work, the authors suggest a more parsimonious and qualitative solution that is able to provide a spatially differentiated representation of relative vulnerability: a selection of communes is made, according to their persistent poor performance in indicators and principal components, without giving weight to any of them or assigning a final blended score to the communes. The hypothesis is that if an area scores low in more dimensions of the used framework for measuring vulnerability, then it can be considered under a broader and therefore greater risk. The posterior stage of validation is used to test if this approach exposes the most impacted areas of the region during the drought from 2012 or if, on the



**Figure 9** | Communes in the last decile of values of the six principal components. Marked in yellow are those that stand out in just one principal component; marked in red are the communes performing poorly in several of them. Please refer to the online version of this paper to see this figure in color: <http://dx.doi.org/10.2166/wcc.2020.101>.

contrary, separate principal components or indicators reveal more accurately the propensity to be affected by drought.

Twenty-four communes were found systematically in the lowest deciles of indicators and principal components (see Table 4). They are part of 16 different municipalities, mainly in Cunene, Huila and Namibe.

### Human exposure to the phenomenon and overlay with the previous results (stage 3)

There is a total of 30 communes (23 of them in Cuando Cubango) that do not meet the required population standards to be considered sufficiently exposed to be ranked as a priority area.

**Table 4** | Initial list of priority communes based exclusively in the vulnerability study

Communes	Times repeated in the indicators	Times repeated in the PCs	Municipality	Province	Communes	Times repeated in the indicators	Times repeated in the PCs	Municipality	Province
Mongua	4	3	Cuanhama	Cunene	Chinquite	3	1	Camucuio	Namibe
Chiange	4	2	Gambos	Huila	Dinde	2	2	Quilengues	Huila
Evale	4	2	Cuanhama	Cunene	Kalonga	2	2	Cuvelai	Cunene
Kafima	4	2	Cuanhama	Cunene	Kihita	2	2	Chibia	Huila
Chimbemba	3	2	Gambos	Huila	Kusse	2	2	Caconda	Huila
Chingo	2	3	Camucuio	Namibe	Lola	2	2	Bibala	Namibe
Chitado	3	2	Curoca	Cunene	Naulila	3	1	Ombadja	Cunene
Kunjamba	4	1	Mavinga	Quando Kubango	Neriquinha	3	1	Rivungo	Quando Kubango
Ombala yo Mungu	3	2	Ombadja	Cunene	Onkokwa	2	2	Curoca	Cunene
Otchinjau	3	2	Cahama	Cunene	Oximolo	3	1	Cuanhama	Cunene
Shiede	3	2	Namacunde	Cunene	Tchipungo	2	2	Tchipungo	Huila
Caitou	2	2	Bibala	Namibe	Virei	2	2	Virei	Namibe

Crossing the three assessments, it is possible to reduce the list of 24 vulnerable communes by removing five of them: Kunjamba and Neriquinha in Cuando Cubango, Kalonga and Oximolo in Cunene and Virei in Namibe, because they are either in the part of the region not severely affected by the physical phenomenon or only sparsely inhabited (see overlay in Figure 10). The resulting 19 communes are identified as those suffering the highest levels of risk in the region.

#### Ground truthing. The empirical evidence provided by local stakeholders (stage 4)

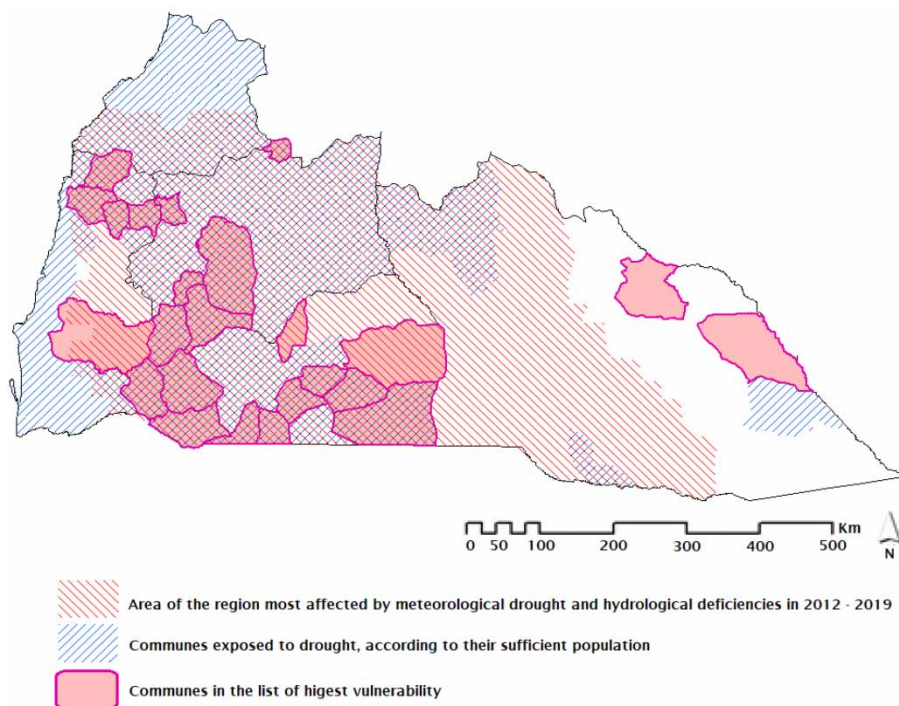
The PDNA performed in 2016 for Angola restricts the focus directly to Namibe, Huila and Cunene provinces, claiming repeatedly in the text that the most notable impacts were experienced in them and that, every year from 2012, these three provinces alone contained more than 75% of the population affected by the drought in Angola. Livestock deaths reported were exceptional in Cunene (240,000), Huila (150,000) and Namibe (110,000). Losses in the three

provinces were calculated based on the reduced production of cereals and other crops, milk and meat. In total there were Angolan Kwanzas (AKZ) 15.8 billion in losses in Cunene, once again the highest among the three provinces, amounting to AKZ 14.7 billion in Huila and AKZ 3.1 in Namibe.

Despite these valuable findings, the PDNA does not go to a more detailed geographic scale than the provincial level and there is a lack of comprehensive databases or formal records, so the work from this point focused on reaching the maximum resolution possible with the help of the feedback from a network of local partners.

The first round of local experts and stakeholders consultations through successive key informants interviews confirmed the need to give priority to the provinces of Cunene, Huila and Namibe, in that order. It was fully unanimous (100% of the sample).

Seventeen of the key informants were able to provide a list of municipalities suffering the most severe impacts and receiving continuous government and donor support: Gambos and Chibia in Huila; Bibala, Camucuio and



**Figure 10** | Spatial intersection of the most vulnerable communes, listed in Table 4, the area of the region most affected by the meteorological drought during the period 2012–2019, displayed in Figure 6, and the 100 exposed communes in the region.

Namibe municipality in the homonymous province and Curoca, Ombadja, Namacunde and Cuanhama in Cunene (see Figure 11). These municipalities were repeated by 12 or more informants (>75% of the sample). However, the team could not obtain solid feedback referring to the administrative level of detail of the communes.

In any case, the authors could ratify the list obtained based on the analyses of vulnerability and drought hazard, since 15 of the 19 listed (79%) priority communes were contained in the informants' enumeration of municipalities (Figure 11).

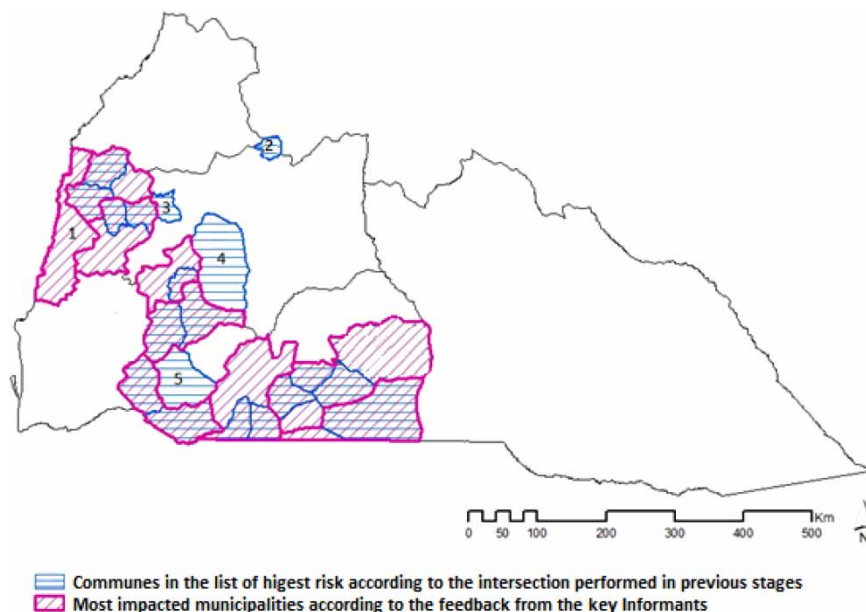
Only the Namibe municipality was cited by the informants and not detected by the performed analyses. Its three communes stood out less than other areas in terms of recent hazard and vulnerability. The fact that extraordinary impacts are reported in them denotes structural water security issues that need to be addressed, beyond just drought risk, especially their already mentioned reliance on tanker trucks. According to oral communications by FAS and successive confirmations in the field, these trucks tend to use water bodies and aquifers that are far inland, in areas that were registering a more severe deficit than the Namibe coastal ones in the time of the study.

Building from the results, the second round of consultations was organized in the headquarters of the six municipalities that contained a higher number of identified priority communes and were confirmed by the key informants: Gambos in Huila, Camucuio in Namibe and Curoca, Cuanhama, Ombadja and Namacunde in Cunene. Focus group discussions were also held for the three communes within these municipalities not categorized as priorities, in order to check if they registered less impact.

Table 5 and Figure 12 show a summary of the reported main hurdles and drought impacts experienced from 2012 in the visited communes, according to the responses and the raised issues in the FGD.

Self-reported drought measures are considered more valid if the self-assessment of drought of people living in proximity is similar (Hunter *et al.* 2013). Figure 12 shows the sample impacts are geographically consistent, especially among communes that are close and stand out in similar indicators, like Gambos and Chimbemba in Huila, or the area from Shiede to Mongua in Cunene.

Apart from the information summarized in the table and map, the main result from these consultations was the confirmation that the total of the cases and respondents in the

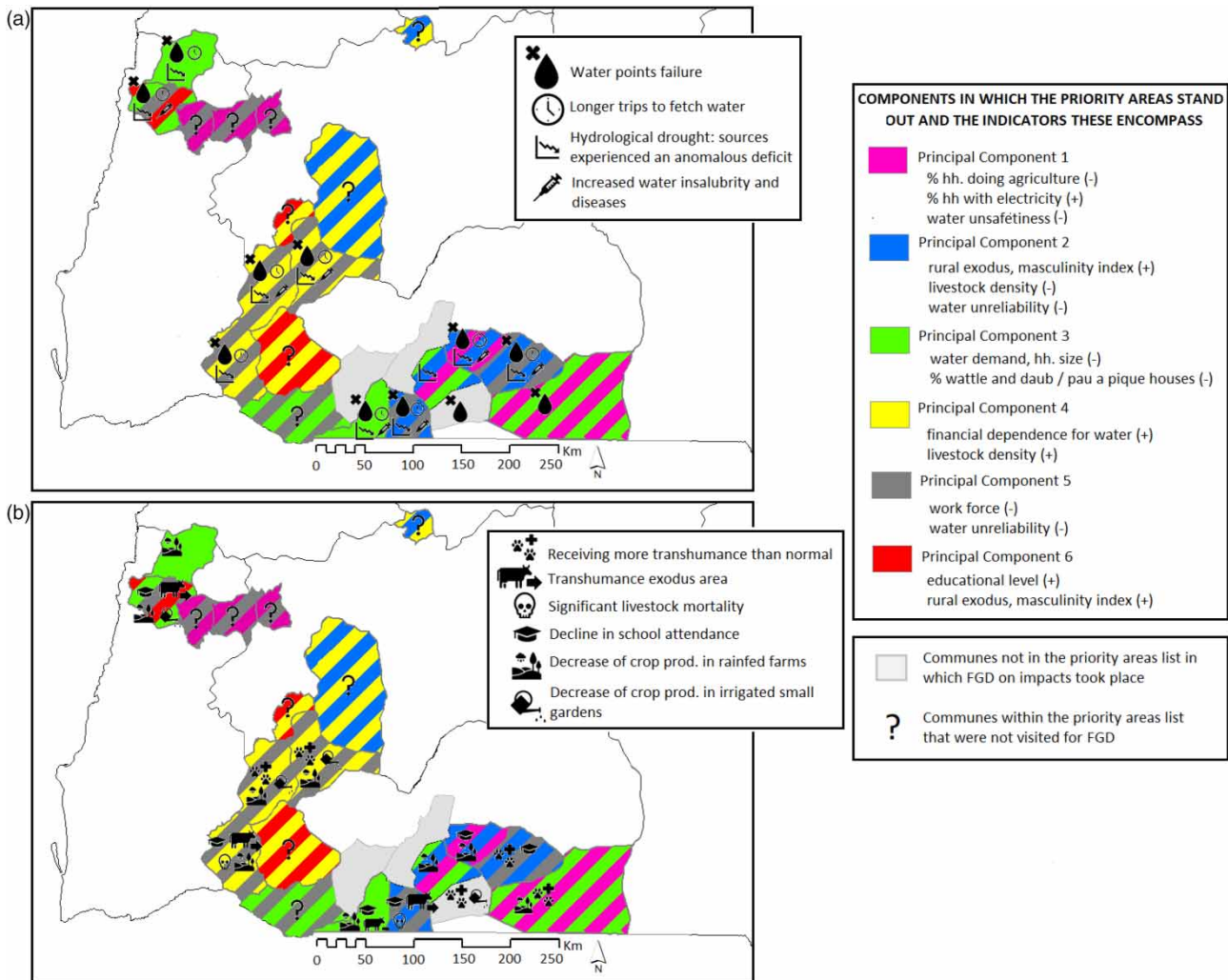


**Figure 11** | Map of the most impacted municipalities created with the feedback by key informants and the degree of adjustment to the communes highlighted by the present study. Namibe, number 1, is the only listed municipality that does not contain any identified priority commune. On the contrary, 2: Kusse, 3: Dinde, 4: Tchipungo and 5: Otchinjau are communes not contained in the list of municipalities by the key informants.

**Table 5** | Self-reported drought impacts and structural main issues recognized for each of the sampled priority communes

	<b>GAMBOS COMMUNE (AKA CHIANGE) GAMBOS MUNICIP.</b>	<b>CHIMBEMBA</b>	<b>CHINGO CHINQUITE) CAMUCUIO MUNICIP.</b>	<b>MAMUE (AKA OMBALA Y. MUNGU OMBADJA MUNICIP.</b>	<b>XANGONGO</b>	<b>NAULILA</b>	<b>HUMBE</b>	<b>EVALE CUANHAMA MUNICIP.</b>	<b>ONDJIVA</b>	<b>KAFIMA</b>	<b>MONGUA</b>	<b>SHIEDE NAMACUNDE MUNICIP.</b>	<b>ONKOKUA CUROCA MUNICIP.</b>
<b>Structural issues identified or reported</b>													
Water points not georeferenced	X	X	X	X	X	X	X	X	X	X	X	X	X
Points not repaired due to a mix of lack of technical capacity, spare parts and financial capacity	X	X	X	X	X	X	X	X	X	X	X	X	X
Lack of knowledge of water points functionality			X								X		
Significant dependence on cacimbas	X	X	X										X
Significant dependence on chimpanças				X		X		X		X	X	X	
Significant dependence on water trucks													X
<b>Self-reported drought impacts</b>													
Water points failure	X	X	X	X	X	X		X	X	X		X	X
Longer trips to fetch water	X	X	X	X	X	X		X		X			X
Hydrological drought (sources experienced an anomalous water deficit)	X	X	X	X	X	X		X		X	X		X
Increased water insalubrity and diseases	X	X	X		X	X		X		X			
Receiving more transhumance than normal	X	X							X	X		X	
Transhumance exodus area			X		X	X							X
Significant livestock mortality					X								X
Decline in school attendance			X	X		X		X		X			X
Decrease of crop production and crop failure in rainfed farms	X	X	X	X		X		X			X	X	X
Decrease of crop production and crop failure in irrigated small gardens	X	X	X						X				

*Note:* The columns in bold are the communes for which a FGD was held as a control group, since they do not belong to the priority list. Information compiled in the focus group discussions.



**Figure 12** | Self-reported drought impacts as per Table 5. (a) Water supply, water quality and water resources management impacts; (b) main impacts on social and economic activities. Background symbology represents the indicators and principal components in which the priority areas showed the worst scores.

priority areas identified (100%) experienced what they perceived as an exceptionally long and intense drought and suffered significant impacts. All of them – with no exception – reported that most of the impacts included in the summary table started immediately after the DEPI drought index initiated its decline in each of the areas (see Figure 3), while the failure of the water points tapping groundwater generally happened after, when drought persisted beyond approximately six months. This proves the value of meteorological indices as anticipation of posterior hydrological issues and their full usefulness to determine the onset of the struggles for communities relying mainly on livestock and rainfed agriculture (Hunter *et al.* 2013; Hahn 2018;

Erfurt *et al.* 2019), which is the case for the great majority of rural areas in southern Angola.

The visited areas that were not in the authors' list of high drought risk communes reported significantly less impacts, mainly due to the access of their population to more reliable and safer water sources.

It is not possible to extract many evident patterns from the performed inventory of self-reported impacts, however:

- in general, high scores in the water sources unreliability and water unsafety indicators and the components encompassing them (PC1, PC2 and PC5) matched with the areas reported as the most impacted, showing that

these are among the most urgent aspects to tackle in order to increase resilience in the region;

- areas with a higher percentage of their population dedicated to agriculture and without reliable sources, not even for drinking purposes, depend mainly on rainfed crops. As expected, these areas reported more agricultural losses than the rest;
- on the other hand, there are communes that stand out in PC4, with a predominance of sources that require financial inputs, particularly boreholes, since their environment does not allow for surface water or shallow groundwater use. These communes counted on those boreholes for keeping more livestock and irrigating some plots in the prosperous times. These are drought resistant sources if well managed, but the parts of the region that combine such borehole predominance with low education level or low work force – namely, those standing out also in PC5 or PC6 – record higher rates of water point failures. Consequently, the communes combining remarkable values in those PCs are the parts of the region with more reported cattle anomalous movements due to the drought and those with noteworthy losses in small irrigated lands. Examples of this are Gambos, Chimbemba or Onkokwa.

The results neither allow for rejecting indicators or components or to fully demonstrate the higher importance of any of them. Indeed, different indicators, components and a combination of them captured different types of vulnerabilities to drought, linked to the distinct rural profiles inside the region, and were proven to lead to devastating impacts.

## CONCLUSIONS

It was possible to describe the evolution of the last drought and delimit the areas in which the physical event was more severe. Also, different drought vulnerability profiles were revealed in the south of Angola and the communes under the worst conditions of sensitivity and coping capacity to confront the phenomenon were identified.

The ground-truthing used confirmed that the set of indicators offers information on different facets of vulnerability, leading to several varieties of priority areas that have

registered distinctive impacts during the studied drought. For a new study area, the procedures could be maintained, but the set of indicators would have to be tested and adjusted to the specific socio-economic and environmental contexts.

That stage also confirmed the list of communes under high risk that resulted from the combination of the areas delimited in the vulnerability and the past physical hazard assessments. Therefore, it is a data undemanding, straightforward methodological procedure that can be replicated for drought recovery or emergency relief actions targeting in information-scarce regions.

However, for planning proactive action, the hazard characterization performed here should be adjusted to depict the historical behaviour of droughts in the study area. A more comprehensive hazard index can be built combining the frequency, intensity and length of the droughts in the historical series of the DEPI index (Shahid & Behrawan 2008; Rajsekhar *et al.* 2015; Dabanli 2018b).

In summary, this research elaborated a flexible stepwise methodology that can be adjusted – for example, to assess or develop scenarios of future risk in the country – and generated a map of areas that are under high drought risk in the south of Angola.

The research presents some shortcomings and aspects for improvement:

- The study did not allow for linking vulnerability components or vulnerability profiles with types of impacts, with the few exceptions mentioned in the results.
- In the set of indicators, there are missing variables that would have been valuable to define the vulnerability in the context of the south of Angola. A key example is the rate of water point failure, which is a widespread issue and appears as a main driver of conflicts and impacts related to water access. This data is not compiled systematically and the used indicators of capacity (work force, educational levels, etc.) can only be considered proxies to predict where in the region infrastructure operation and maintenance would be a relevant limitation.
- Despite the fact that the last available census data was used, some crucial information became outdated quickly, such as the domestic water supply sources, which were improved in some visited communes.

- The commune spatial scale has limitations, for large communes the average and totals used in this study are of lesser significance. The described methodology would yield more realistic results if applied to data about settlements, which is unfortunately not available for Angola.
- The ground-truthing is at all steps qualitative and based on self-reports. However, in such a data scarce region, it was impossible to collect validation information about the evolution of agricultural or pastoral activities during the times of the drought, nor about other socio-economic variables.
- The focus group discussion took place in three communes that were not in the list of those priority ones under the highest risk: Xangongo, Humbe and Ondjiva, but a broader and more widespread control group would improve the validation process. A major drawback is not having had the opportunity to verify the impacts on the ground in the few communes that appeared in the list but were not explicitly confirmed by the key informants.

For complementary research, the ground-truthing will be broadened beyond the sample used in this piece of work, also covering areas in which the hazard is lower, in order to test which of the components of the risk plays the central role in explaining the impacts.

The expansion of this study to the entire territory of Angola – benefitting from the countrywide census information – could serve as a proactive measure to delimit the areas under risk before a major drought hits, verifying that the indicators used here apply to the reality of the whole country and crafting a comprehensive hazard index from the DEPI historical series. This would help to target resilience building activities and development operations in an objective manner.

Further attempts should experiment with modifications like assigning the values of the indicators or the components to each of the cases and combining or adding them, as an alternative to the straightforward ranking of the communes performed in this research.

## ACKNOWLEDGEMENTS

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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