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### ► To cite this version:

Vassili Kypreos, Guillaume Lacquement, Emilie Lavie, Wolfgang Ludwig. The vulnerability of irrigation associations to the decrease of water resource. A case study in Roussillon. *Total Environment Advances*, 2024, 28 p. 10.1016/j.teadva.2024.200096 . hal-04421728

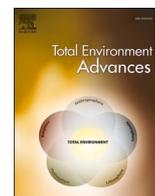
**HAL Id: hal-04421728**

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Submitted on 30 Jan 2024

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# The vulnerability of irrigation associations to the decrease of water resource. A case study in Roussillon

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## ARTICLE INFO

### Keywords:

Adaptation  
Strategy  
Collective  
Qualitative software  
Water

## ABSTRACT

This work proposes an analysis of the vulnerability of irrigation associations to climate change and its effects on the decrease of water resources in the Têt watershed, one of the three coastal rivers of Roussillon (France). However, this work is not directly interested in the forms that these adjustments take, but in their construction process and their relationship with the geographical space in which they take place. By taking into account the organization of the geographical space, the objective is to account for the role of the modes of access to the water resource on the effectiveness of the strategies of Association Syndical Autorisée (ASA)<sup>1</sup> to the reduction of the water resource. This entry reveals different areas that influence the effectiveness of adaptation strategies. The characteristics of those areas, both physical and social, are comparable to roots of vulnerability that guide the effectiveness of the adaptation process. The territorial characteristics influence the adaptation process and account for more or less vulnerable spaces. The logics of action and strategies are then territorialized.

The adaptation strategies of the ASAs are examined through an empirical survey of 12 associations presidents. The interviews were transcribed and then loaded into a qualitative analysis software. It appears that all the strategies of the ASAs have the objective of ensuring access to the water resource for their users. However, there are distinctions in the way the associations respond to this objective. Securing access to the water resource appears to be a factor in reducing the vulnerability of the associations to the hazard, but does not solve the risk. The results show that strategies are also influenced by formal and informal relations between presidents and institutions. The combination of these levers makes it possible to characterize associations that are more or less vulnerable to water decrease.

## 1. Introduction

The adaptation and vulnerability of agriculture to the impacts of climate change is a subject that is gaining ground in both research and public action. However, this subject can be approached in many different ways.

Some studies analyze how representations and perceptions influence farmers' vulnerability and adaptation strategies (Brondizio and Moran, 2008; Marega et al., 2019). Other works focus on the governance and its links with vulnerability or farmers' adaptation strategies. Or are adopting an empirical approach to analyze the effectiveness of adaptation strategies or to highlight the elements that will constrain or promote

actions (Biesbroek et al., 2013; Mortreux and Barnett, 2017; Fedele et al., 2019; Kypreos et al., 2020). Finally, the increasing use of computer tools is opening up quantitative studies and modeling in order to measure vulnerability or forecast adaptation scenarios (Holzkämper, 2017; Zaatra, 2021).

However, perceptions and representations do not necessarily leads to actions (Niles et al., 2016). Moreover, quantitative studies and models may not represent the real vulnerability of the farmers, nor allow us to understand the process of vulnerabilization for the farmers in time (Metzger et al., 2004; Turner, 2016). This justifies the adoption of territorialized and qualitative approaches to understand why a system is vulnerable and how it adapts (Moser and Ekstrom, 2010; Wise et al.,

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<sup>1</sup> The ASAs (in french: Associations Syndicales Autorisées) are irrigation communities.

2014; Adamson et al., 2018).

Some studies attempt to link territories to levels of vulnerability in order to highlight the role of location effects on vulnerability (Adger, 2003). Some of the location effects studied in those works are the collective action that characterizes some territories. In the context of climate change impacts, WN. Adger (De Rosa et al., 2022) and S. P. De Rosa (Wannowitz and Garschagen, 2023) highlighted the role of social capital, network and the flow of information in the individual and collective adaptations' strategies. In this way, they suggest that the collaborative effort can help adapt to the impacts of climate change and to manage natural resources (Bouarfa and Molle, 2020).

However, in some cases, the collective action is deemed unsuited to contemporary uses, particularly for the agriculture. In addition, the modernization of agriculture and irrigation systems has led to the abandon of collective irrigation systems (Soulis et al., 2020) and of canal networks diverting surface water, in favor of groundwater drilling. But, in some cases, the modernization of irrigation has not resolved conflicts of use or reduced pressure on water resources (Head, 2010). In fact, overall pressure on the resource is increasing as a result of demographic growth, increasing urbanization, intensification of agriculture and diversification of water uses, as well as institutional management of the resource, which imposes controls on withdrawals. As a result, these pressures reduce the legitimacy of agricultural uses. This pressure on water resources is even greater in the *hot-spot* regions of climate change. In these regions, the intensity of the expected changes intensifies the risk of unavailability of water for all users. This put pressure on the spaces and activities that have developed through the use of water resources.

In addition to that, it has been believed that adapting agriculture to climate change was only a question of capital and technics (Ostrom, 1990; Adger et al., 2009). Nevertheless, it appeared that the adjustment of uses goes beyond those parameters, and also involves other social and territorial processes. In this context, the study of collective action in developed countries (Bouarfa and Molle, 2020) is gaining renewed interest through qualitative and contextualized approaches, in order to analyze the extent to which it constitutes a sustainable lever for adaptation to water scarcity.

In the Pyrénées Orientales (France), the Têt watershed is characterized by original management and sharing of water resources, involving 187 ASAs. These associations share water resources between their members within an irrigation perimeter. The watershed is thus divided into zones of water abundance and scarcity. The climatic, hydrological and social contexts question the capacity of ASAs to face the hazard of water resource decrease, and the risk of water scarcity.

In the framework of this work, this capacity of adaptation is understood as the implementation of a collective strategy that will ensure water service to members of the association. Using semi-directive interviews recorded, transcribed, and then processed by qualitative analysis software, the associations' adaptation strategies are analyzed. The objective of this work is to identify factors that reduce or reinforce the effectiveness of adaptation strategies and to link these factors to the characteristics of the territory. Furthermore, this work raises the question of the adaptive capacity of irrigation associations according to the types of access to water resources. Compared to an unsecured water resource, does a secure resource reduce vulnerability in the event of a decrease in water levels, or does the effectiveness of collective action tend to ensure minimal vulnerability regardless of the mode of access to the water resource? Linking strategies to hydro-agricultural spaces identifies territories of vulnerability and risk.

This work hypothesizes that (1) considering the climatic, hydrologic social context, securing water resource improves the adaptability of the ASA in the context of decreasing water resources, and it decreases the vulnerability of the farmers. The more secure the water resource is, the more water service can be provided. However, (2) if the service is not provided, then the ASA farmers-members individualize their water resource access.

The first part lays the conceptual and geographical foundations for

this work. Next, the methodology of fieldwork and use of qualitative analysis software is outlined. The results are exposed in the fourth part and discussed in the fifth. In this last part, we compare the results with the previous research of the first survey conducted in 2019 and exposed previously. This last part discusses the role of collective action in adapting to environmental issues (Ostrom, 1990; De Rosa et al., 2022) and try to highlight a social limit of adaptation to climate change (Adger et al., 2009). This work completes the Ccr\_tet project.

## 2. Material and methods

### 2.1. Geographical and conceptual approach

The concept of risk has been refined since it emerged with the physical paradigm in the 1950s. Early research presented risk as a consequence of the action of a physical phenomenon (hazard) damaging a human system (Magnan et al., 2014). From the 1980s onwards, the social dimension of risk was introduced (Ercole and d', Thouret, J.-C., Dollfus, O., Asté, J.-P., 1994). Risk is then considered as the consequence of the action of a hazard on more or less vulnerable human systems (Pigeon, 2002; Veyret and Reghezza, 2006). Vulnerability is composed of two modalities: the sensitivity to the hazard (the propensity of a human system to be affected by a hazard) and the exposure to the hazard (the location of the human system in a place where the hazard can materialize). To decrease its vulnerability, the human system adjusts both modalities. This adjustment corresponds to the adaptation process (Ara Begum et al., 2022).

However, the ability of a human system to adjust may be constrained by socio-political, cultural, or economic factors. These are vulnerability factors that form a set of drivers, barriers, or dependencies that are considered the roots of human system vulnerability (Biesbroek et al., 2009; Biesbroek et al., 2013; Magnan and Ribera, 2016) (Feola, 2013; Ribot, 2014; in Eitzinger et al., 2018). In the most radical dimension of adaptation, addressing the roots of vulnerability is the only process that can strongly reduce the vulnerability of an issue (Biesbroek et al., 2009). Studying the process of constructing adaptation strategies, and not their final form, helps to highlight these factors (Ara Begum et al., 2022). However, risk, vulnerability, and adaptation are increasingly cross-cutting social phenomena, making them complex to interpret. Even if many quantitative indicators are interfering in the adaptation practices (Zaatra, 2021), qualitative information are necessary for highlighting territorialized vulnerability factors that (Rebotier, 2015; Leone and Vinet, 2006; Reghezza-Zitt, 2015; Adger et al., 2009).

### 2.2. Characterization of the hazard

The Mediterranean basin is considered a climate change hot spot (Giorgi and Lionello, 2008; Tuel and Eltahir, 2020; Ara Begum et al., 2022) because of the severity of the expected changes in precipitation and temperature. On average, temperatures are already increasing by 1.3 °C compared to 1880–1920 when temperature increase was at 0.85 °C globally (Guiot and Cramer, 2016). These changes are likely to be more severe during the rainy seasons due to an increase in winter droughts (Raymond et al., 2018).

In the Têt valley (Pyrénées Orientales) between 1960 and 2018, the average temperature increased by 1.54 °C and precipitation decreased by 18 % (Lespinas, 2008; Labrousse et al., 2020). Relating these parameters to changes in stream flow using the Qpike hydrological index and the drought index, we found that climate change has reduced the surface water resource by 25 %. In addition, climate forecasts to 2100 in the case of a 4.3 to 4.5 °C warming and a 10 to 16 % decrease in precipitation were modeled (Labrousse et al., 2020) using the GR2M hydrological model. These findings suggest a decrease in Têt river flows of around 85 % over the period (Labrousse et al., 2020; Lespinas et al., 2014). Although these forecasts must be treated with caution due to the constantly changing parameters of the models, as well as the extreme

scenarios, the trend towards a further reduction in Têt flows is confirmed. These umbro-thermal trends modify the hydrological regime of rivers, contracting low-water flows, reducing the recharge of alluvial aquifers and accentuating the hydric stress.

### 2.3. Presentation of the field

The Têts' watershed area is 1 400 from the lower alluvial plain to the river's source in the Carlit massif in Cerdagne. The waters of the basin are regulated by several hydraulic infrastructures.

Bouillouses' dam is operated since 1910 and is managed according to the Lanoux convention (1953) which allows the provision of 15 millions  $m^3$  of water from July 1 to October 1 at a flow rate of  $3.08 m^3/s$  to the Têt river to support irrigation. Vincas' dam has a volume of 25 millions  $m^3$  and was built in 1976. Its functions are to control floods and store water for irrigation. This last function is allowed only if the filling of the dam reaches a predetermined level (regulation of July 31, 1987). In addition to the two dams, the lake of Villeneuve de la Raho allows for securing water resources for a part of the associations. Built in 1977 by the diversion of the waters of the Têt from the canal of Perpignan and its main function is irrigation with 15,6 million  $m^3$  available. Those dams are managed by the «*Société Hydro-Electrique du Midi*» (SHEM). But those infrastructures are only the last built ones of a complex hydraulic system built since the 8th century. At the beginning of Middle Ages, the communities, lords and abbays started building canals derivating the water from the Tet river. Those canals are still existant and reached the number of 180 and have a cumulative length close to 1000 km.

These canals, and the irrigation perimeters they serve, are managed by 187 ASAs that share the water resource on irrigation perimeters through canals. The ASAs are public Establishments of an Administrative Nature (EAN). They are financially autonomous to fulfill a mission of general interest under the control of the State or local authority. The operation of the association is composed of several bodies: the owners' assembly; the syndicate, which ensures the administrative operation of the association; the president and the vice-president who are appointed by the syndicate. The president is the authority in charge of the day-to-day management of the association. Although the operation is the same for all the associations, their types of access to the water resource are different.

- The associations whose irrigation perimeters are located along tributaries of the Têt in Conflent, Cerdanya, and Capcir: their water supply is dependent on hydrological factors (precipitation/snow/resurgences). Those ASA will be qualified as: mountainous ASA.
- The associations whose irrigation perimeter is located near the thalweg between the Bouillouses and Vinça dams: these associations have their water supply secured by the Bouillouses dam: Those ASA will be qualified as ASA in the piedmont.
- The associations whose irrigation perimeter is located downstream of the Vinça dam: these associations have their water supply secured by the dams of Bouillouses and Vinça. Those ASA will be qualified as: ASA in the plain

The previous survey made in 2019 in the same watershed (Kypreos et al., 2020) showed the influence of the territory on adaptation strategies of the farmers. Indeed, this prior survey was focusing on the individual strategies of the farmers. Those strategies are splitted in two logics of response to the water decrease. The first one, called «palliative» aims to, temporaly, counter the water decrease without changing the farming system. The second one, called «adaptative» conceive changes in the territorial roots of the farming system. These involve a change in collective and institutional strategies for the valorisation and water governance. Considering the fact that the Têt watershed is characterized by an intense and ancient collective mobilization of the water ressource through the ASAs, the current study seeks to highlight the extent to which collective strategies support or hinder individual strategies.

The decrease in water resources is forcing the ASAs to develop strategies to ensure water service to their members. However, the access to the resource is not the same for all associations. Some ASAs have their resource secured by hydraulic infrastructures while others depend on hydrological and climatic factors. To study the associations' adaptation strategies, one must locate collective strategies, firstly in the irrigation perimeters, and secondly, in the hydro-agricultural space that delimits the discharging basin (Fig. 1). This allows for territorializing of collective strategies and risk.

### 2.4. Semi-structured interview

The qualitative approach allows a better analysis of the adaptation strategy understood as a non-linear and univocal cognitive process (Anadón and Guillemette, 2007; Kypreos et al., 2020). Indeed, the objective of this approach is the understanding of the actions and reflexions of the individuals (a collective in this work) in the construction of adaptation strategies to climate change. It was therefore decided to use semi-structured interviews. The individuals surveyed are the presidents of the associations. They are the bearers of management authority, they have decision-making power, and are one of the vectors of the voice of the members of the association. It's a strategical actor that can inform us objectively about the strategy of the ASA. The syndicat would give the same informations but it's compsoed by many members. Interviewing the syndicat would be then more time-consuming for the same information given. In addition to that, interviewing the owners' assembly is incompatible with the survey considering the fact that some of the owners are the farmers interviewed in the survey of 2019. They have an opinion about the collective strategy, but are also following their individual strategy. This could biased the information about the collective one.

The narratives obtained correspond to the adaptation strategies. We hypothesize that the vulnerability factors we are looking for are revealed in these narratives. To achieve this, the interview must be guided by an interview grid constructed according to the purpose of the study and the research hypotheses.

#### 2.4.1. The different grid constructed to collect and analyze the qualitative information

The interview grid aims to guide the interview to collect the narratives of the ASA presidents. The grid is constructed in four parts. The first cares about the past and current operating of the ASA, the second about the confrontations with the hazard, the third about how the confrontations were resolved, and in the last part, which factors interfered in the resolution. The parts are then detailed to specify the information sought. For the first part, the number of members, the surface area, the state of the hydraulic network, the economic balance, and the evolution of withdrawals specify the operating status of the ASAs. The second part focuses on the type of hazard encountered by the association. The third part focuses on the tools used to resolve the crisis. They can be an arrangement between users modifying the sharing of the resource within the ASA or between ASAs; tariff modification, or a more rigorous application of the water turn. Institutional and technical levers exist. Canal contracts, management plans, or statutory modifications are solutions recommended by public policies to support the ASAs in the face of a decrease in resources. The use of agricultural hydraulics and the modernization of the irrigation network, the tubing of canals, or other water-saving tools are levers to face the hazard. Finally, the factors involved in the flexibility of the resolution of the hazard are searched in the fourth part. Those factors can be association's internal or external social resources.

The interview analysis grid is based on the interview grid. It structures the information obtained during the survey for the analysis in the qualitative analysis software. The grid classifies the information into three levels: categories, properties, and modalities. The categories correspond to the four parts of the interview grid. In this work, these

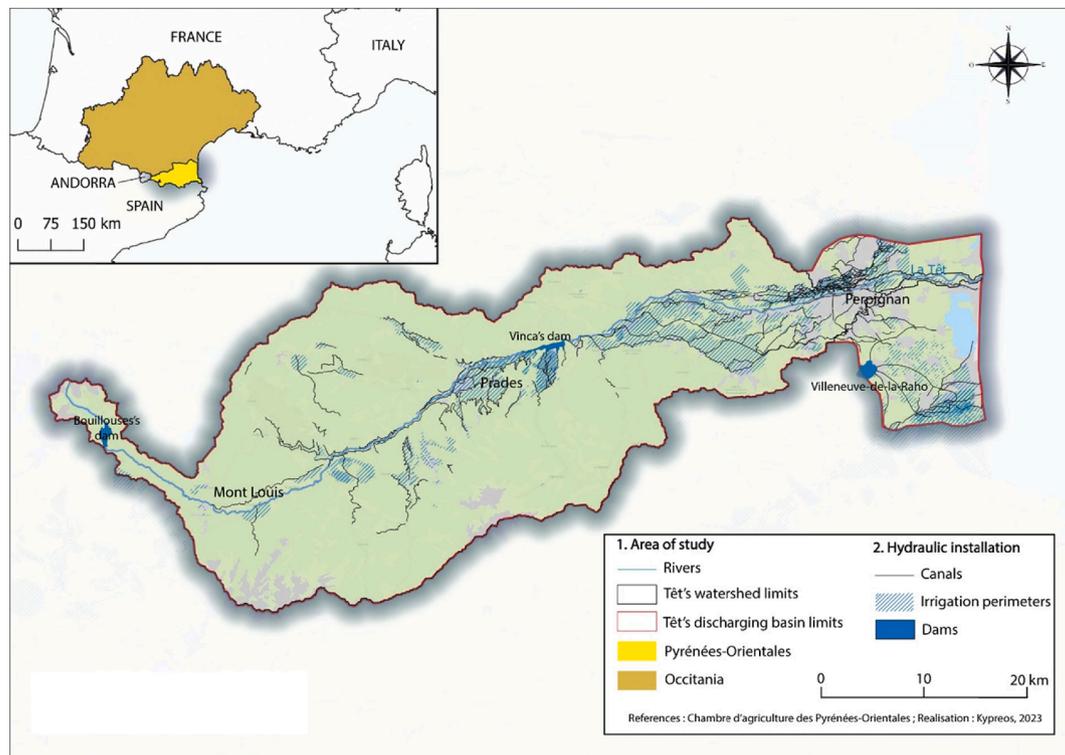


Fig. 1. The hydro-agricultural territory of the Têt discharging basin.

categories correspond to the components of risk situations. These categories are broken down into properties. The properties describe the situations of the ASAs in the face of risk and classify the information with a view to their precision. The third level is the modalities which specify the properties. It is the level that classifies the information contained in the operators' narratives. The modalities are the fine scale of the risk situation (Fig. 2). To identify the vulnerability factors among the modalities, it is necessary to translate the interview analysis grid into computer language to analyze the interviews in the qualitative analysis software. The coding grid is the final step in the process of collecting research material. This grid is constructed in the qualitative analysis software only based on the modalities. Thus, all the modalities of the interview analysis grid are transcribed into codes of the same name in the software. These codes are used to code the interviews in the software.

The coding stage consists of assigning a code to a portion of text, like a tag. Thus, according to the information carried by this portion of text, it will be assigned a code. The information that makes up the fine scale of the risk situation (the modalities) becomes codes in the qualitative analysis software. The codes carry qualitative information. Once this step has been completed for all the documents, the software reads the interviews not as a series of words, but as a series of codes. This makes it possible to systematize the processing of qualitative information by the computer tool, to gain objectivity, and maximize the analysis of the interviews.

To obtain coding and interview grids that are faithful to the realities of the field, they are updated according to the field data. Modalities (and codes) can be added to specify risk situations that had not been identified when the grids were constructed. There is then a continuous back and forth between the grid and the field to ensure its operability.

#### 2.4.2. Sampling of ASAs' presidents

Before interviewing the presidents, a sample of ASAs was developed in cooperation with an expert from the Chamber of Agriculture. The selection criteria are:

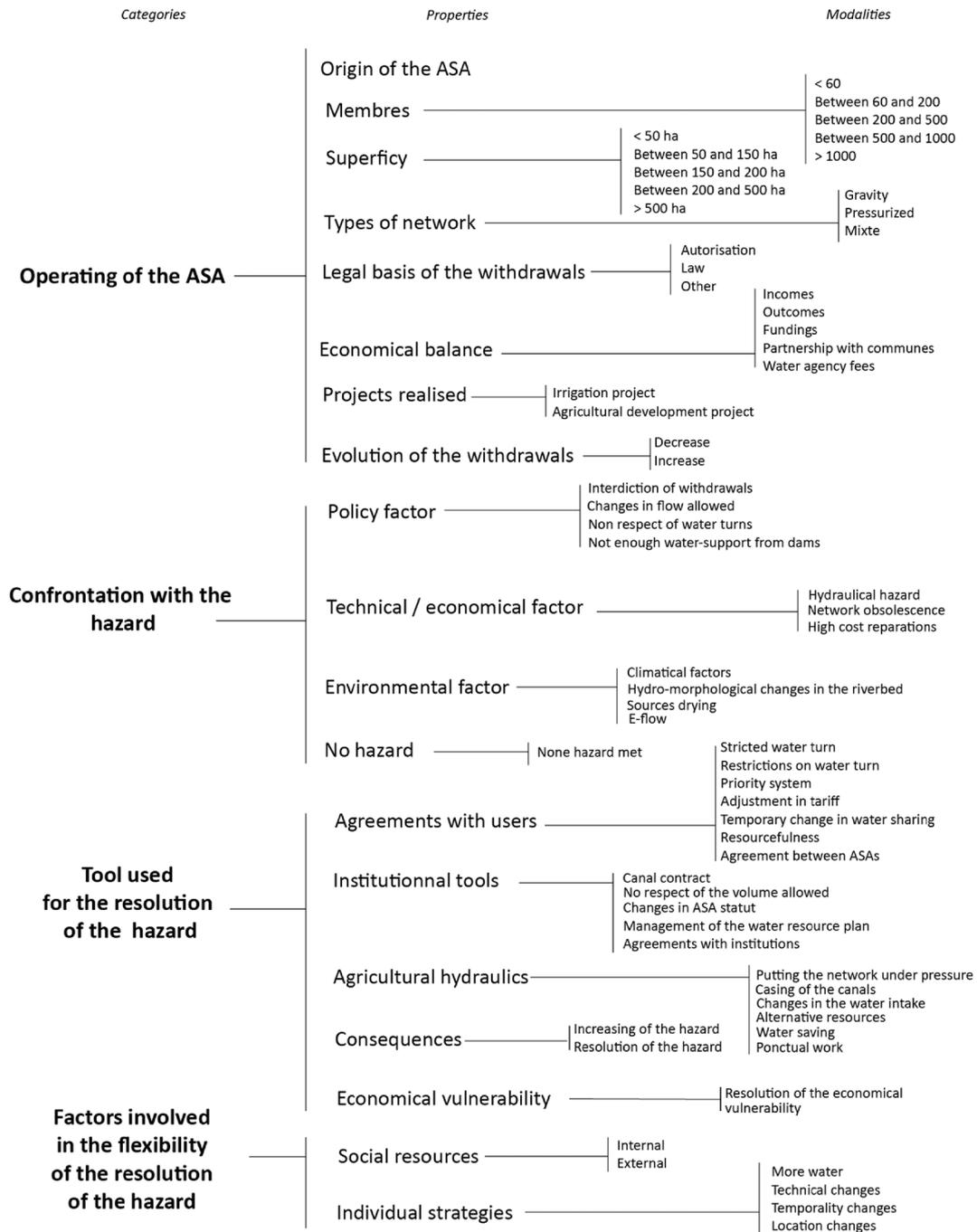
- ASA locations in the plains, piedmont, and mountains;
- Associations active from the point of view of water resource management (i.e. involved in projects to modify their hydraulic network);
- Associations of various sizes;
- Associations in conflict with water resource management authorities.

These criteria were derived from empirical thinking related to the first survey. The goal is to obtain a representative sample of the issues faced by the ASA. The issues selected are economical (many ASA are in a precarious economic balance, which disturbs their management of the water resource); statutory (many mergers, unions, and even dissolutions of ASA have been noted in the study area), and political (some ASA presidents may find themselves in conflict with institutions or management structures at various scales, particularly the Water Agency or even the Departmental Directorate of Territories and the Sea (DDTS)). The surveys were conducted with the presidents of the ASA that represent the population of our sample. 12 presidents were contacted: four presidents of ASAs in mountainous areas and eight presidents of ASAs whose water resources are secured by dam recharge. In this last category, we distinguish two sub-groups: the first group is composed of ASA in the piedmont (4 ASA presidents concerned) and the second groups the ASA in the plain (4 ASA presidents concerned).

#### 2.5. The qualitative analysis assisted by computer

##### 2.5.1. The choice of the qualitative analysis software

Qualitative research can be manual or software-assisted. Computer-Assisted Qualitative Data Analysis Software (CAQDAS) increases the objectivity of qualitative research while adopting epistemological scientific rigor (Oliveira et al., 2016). Its use accompanies the researcher in their reflexion and analysis of qualitative data. Using "codes," which are tags that classify qualitative data, these software programs systematize the analysis of qualitative data. Several approaches to qualitative analysis determine the types of research and use of software (Louart, 2020).



Kypreos, Lacquement et Authier 2020

Fig. 2. Interview analysis grid: tree structure or matrix of categories, properties and modalities.

The MAXQDA software allows for a wide variety of material analysis due to its many tools and supported document formats. Its properties allow the researcher to explore their research material through manual analysis and not an automatic one, as in the case of the equivalent software IRaMuTeQ (Saillard, 2011). The manual analysis allows greater freedom of reflexion and analysis from the researcher. Finally, MAXQDA allows both an inductive and hypothetical-deductive approach, which is not the case with other CAQDAS (ATLAS or Nvivo). Given that the objective of this work is neither to create nor verify theories (Anadón and Guillemette, 2007; Garreau and Bandeira-

de-Mello, 2008; Moscoso, 2013), MAXQDA software is relevant to conduct this work. Furthermore, its use in recent qualitative studies reinforces its use in this work (Kuckartz and Rädiker, 2019).

### 2.5.2. MAXQDA software and its tools

This work attempts to link the adaptation strategies of ASAs to the hydro-agricultural area and their characteristics. The goal is to identify territories that are more or less vulnerable by analyzing the adaptation strategies of ASAs. But how can we compare 12 strategies? Once the interviews have been transcribed, loaded into the MAXQDA software,

and coded, they can be analyzed. Two tools are used for this: the code map and the code matrix.

A coded map is a tool proposed by the MAXQDA software which sorts the codes and locates them on a 2-dimensional plane using a multidimensional positioning (PCA). The codes are more or less distant from each other and grouped into clusters. The sharing of codes between clusters is done based on co-occurrences between codes. Thus, if a portion of text has been coded several times by several codes, then these codes are grouped in a cluster. The more co-occurred the codes are, the more close and clustered they will be. The software reads them as similar and regroups them in clusters. Isolated codes are not selected by the software. This requires reflexive coding to maximize co-occurrences. To do this, it is necessary to resituate the coded information in the context in which it is evoked.

Once the sorting between codes is done, they are grouped by cluster. By regrouping similar codes in a cluster, we can synthesize a cluster by all the codes that are composing it. The codes being qualitative information (the modalities), they correspond to real factors that are intervening in the strategies. They can be translated as actions and the clusters as context of actions common to the 12 interviews. Like a mechanism, the clusters are gears and the actions that compose them are screws that will more or less make the gears work. All of this makes up the common mechanism for the construction of ASA's president strategies.

Once this common mechanism is identified, it is necessary to identify which actions are vulnerability factors according to the geographical locations of the ASAs. To do this, the mechanism is tested according to the geographical location of the ASAs. This last step is verified using the "code matrix" tool. The interviews of the three groups of ASA were constructed according to the modes of access to the water resource. The option "calculation of the size of the symbols in relation to the column" is activated to calculate the frequency of the factors in the interviews. The result is a table where the frequencies appear as square figures of varying sizes and colors. The result can also be in numerical form with the frequency displayed instead of the square figures. To make the result more readable, it was decided to combine the two graphical renderings and to display only the vulnerability factors considered representative of the distinctions between groups. The differences in frequencies between groups reflect the differences in strategies and in localization.

By reducing the twelve strategies to one common process, and comparing that process across association groups, we can link adaptation processes, vulnerability, and space.

### 3. Results

The objective of this work is to highlight the role of hydro-agricole area (and their geographical dimensions) in the adaptation strategies. By looking at the process of strategy construction, we seek to know how and to what associations are adapting. Do associations face drivers or barriers that decrease the effectiveness of their strategies toward the hazard? Are these drivers and barriers related to characteristics linked to the territories where the ASA are located?

#### 3.1. Identification of the common strategies' construction mechanism

The coding grid was initially composed of 63 codes. The code map tool selected only 41 codes that are non isolated. They are shared in 5 clusters to which a random color was assigned. It was also decided to represent the links between codes only from 3 overlapping codes. Thus, this highlights more clearly the relationships between the actions and their contexts in the presidents' discourses.

The statistical treatment grouped the factors that refers to the agricultural development and the extension of the associations' irrigated

perimeters as part of the strategies. It was decided to name the context of action «agricultural development» (green color). In the yellow context of action, actions undertaken to maintain the e-flow<sup>2</sup> are grouped (water saving, casing, prohibition of abstraction, reserved flows). This gave the title to this context of action. In the marine blue context of actions, multiple actions to manage the risk of resource depletion are referred. These actions range from the use of hydraulics to the non-compliance of water turns, and refer to actions taken internally by the association. This context of actions has been named «internal management of the hazard». The light blue context of action highlights frequent actions by presidents to resolve the hazard. These actions appear to be based on arrangements between institutions and ASAs. The red context of action is composed of the single action «economic vulnerability resolution». It has been named by the same title as the factor that composes it. This refers to the association's concern for economic balance in responding to the hazard (Fig. 3). Actions and their context are building the mechanism of the strategies' construction. This illustration is created by the software. Because of the research material being in french, their translation to the english through the software is not possible. The contexts of actions in legend are added in a second time on a illustration software.

Association presidents build their strategies based on these five contexts of action. Together, these contexts allow us to understand the framework of the president's actions. In addition to sorting out actions from specific situations, this tool also highlights the common actions that make up the presidents' strategies. Within these common actions, the role of resources external to the associations in the strategies seems to be more important than other factors.

Faced with the hazard of diminishing water resources, the association presidents' reflexion is framed by 5 contexts of action composed of different actions. However, this tool does not highlight the geographical influence on the strategies. This influence is analyzed using the "code matrix" tool. This will make it possible to account for the most frequent contexts and actions in the farmers' discourse, based on the 41 codes selected by the previous tool.

#### 3.2. Comparison of the mechanism of strategies construction between the ASAs

The mechanism of construction of the strategies is compared between the groups in the «code matrix" tool. After observing the frequencies of the 41 actions identified by the «code map", it was decided to represent only 16 that had more differences in their occurrences for each group. These 16 codes are representative of the distinctions between groups, but also of their importance according to the common strategic construction mechanism (importance revealed by the thickness of the segments resulting from these factors). However, the objective is not to limit the study to these 16 codes but to allow the reader to visualize some results of the software.

The tool will make it possible to compare the frequency of the actions by a group of ASAs. If the actions are unequally mentioned between groups, and if they influence the way of adapting to the hazard, these actions are vulnerability factors. To verify this, the tool allows the manipulation of the qualitative information tagged with the actions.<sup>3</sup> Thus, each action is linked to a portion of the interview that can be used as verbatim. This makes it possible to detail the context in which the actions were evoked in the narrative, and thus to know if the actions and contexts have the same meaning for the 12 presidents. The quantitative frequency analysis is complemented by a qualitative analysis to understand how the geographic context influences the strategies (Fig. 4).

Using the verbatim for each action provides insight into the context

<sup>2</sup> Environmental flow.

<sup>3</sup> The codes in computer language, have been translated as actions to analyze the results from the tools. Yet, the qualitative information hold by the codes, are then holded by the actions.

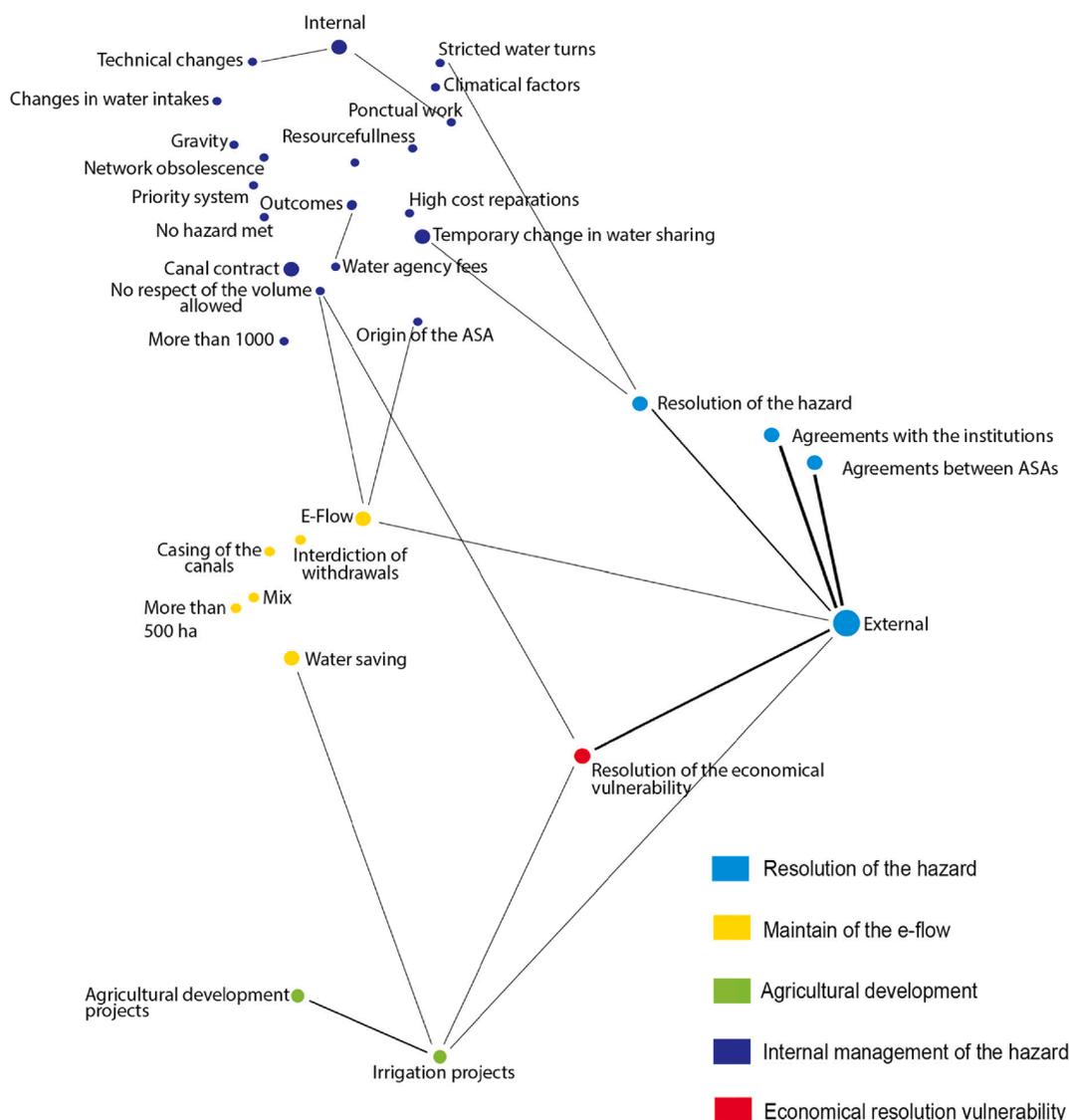


Fig. 3. Identification of the common process of strategy construction based on context of action.

in which the action was mentioned. The differences in frequencies between the groups support the idea of a geographic distinction of the actions. This distinction is clarified by the use of verbatim. For actions with the same frequency, the verbatim will detail the context of their use. In other terms, a same frequency of action in the narrative does not mean a same univocal action. Presidents could refer to a same action but in different contexts which can be negative or positive.<sup>4</sup> For these actions, the geographic distinction is potentially based on differences in the context that leads to the actions, which may be different from one group to another.

### 3.3. Identification of the distinction between the ASAs by categories

#### 3.3.1. Category: Monitoring of the ASAs

The decrease in withdrawals is unevenly mentioned between presidents. The analysis of the verbatim shows a geographical distinction of the action. In the case of the ASA in the plain and in the piedmont, water-saving and agricultural development policies are linked to the decrease

<sup>4</sup> For example, a president can talk about an helpfull external social resource when his colleague can talk about a non helpfull one. Both of those actions would be coded as “external” but yet, the context would be different.

in withdrawals. This is shown by the modernization of collective and individual irrigation networks as well as by the extension of irrigation perimeters. As said by a president from an ASA in the plain “Drip irrigation is easier and water consumption is reduced [...]. Fishing requires water and this has allowed us to irrigate more surface area”. For the ASA in the mountains (as well as some in piedmont), the decrease in withdrawals is linked to social changes due to fewer users “In the valley [...] it has been replaced by breeding and breeding requires less water” (from an interview with a president from an ASA in the mountains). Presidents of ASA in the piedmont are sharing the same point of view “Afterwards, there are also social changes, there are fewer and fewer farmers, and we don’t water all winter”.

All the presidents mention the economic balance of their ASA. However, the means to achieve this are geographically distinct. The associations secured by dams seem to have more recourse for partnerships with the communities to achieve this balance (use of the ASA canals for the management of rainwater runoff, for example). However, the economical situation for the mountainous ASAs seems more complicated as the presidents seems to struggle to maintain the economic balance of the associations “We have considerably increased our fees, but we are the same as before. Because now the Water Agency takes 1500 € per year, we have the administrative office that takes 1400 € per year, and we have insurance that takes up to 700 € per year. So in fixed costs, we

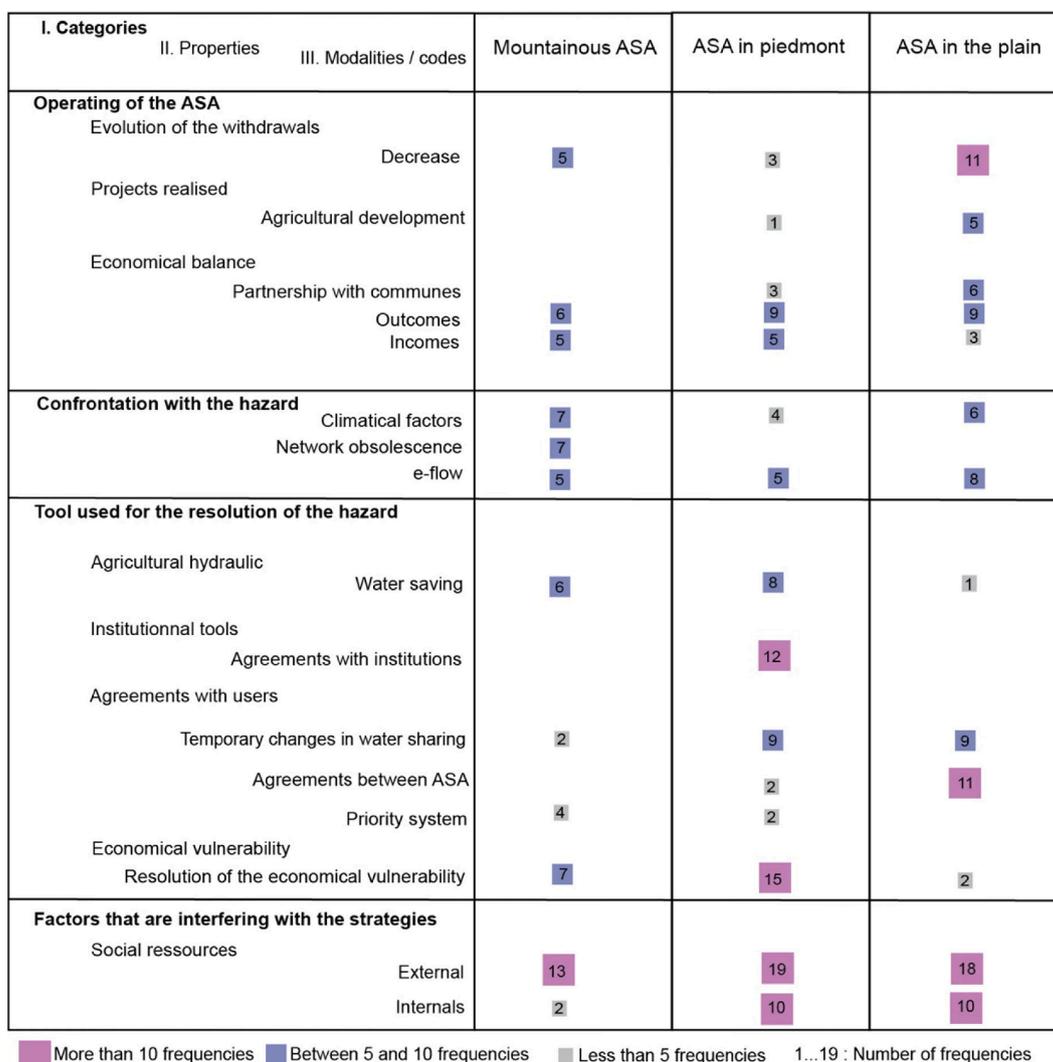


Fig. 4. Comparison of the frequencies of the 16 actions in each group of ASA presidents' interviews.

have almost double what the costs were 10 years ago”.

Although all the presidents try to maintain a balanced budget, the presidents of ASA in the mountains do not have strategies for partnerships with communities to increase their revenues. They are more exposed to budget imbalances. These imbalances, accompanied by social upheavals in mountain societies, prevent them from modernizing their networks, and from having agricultural development policies. The economic balance is therefore a root of social vulnerability that leads to geographical distinctions in the functioning of the ASAs.

### 3.3.2. Category: Confrontation with the hazard

The confrontation with the hazard is not the same according to the geographical localizations. Although all the presidents perceive a decrease in water resources “climatically”, but also linked to the e-flows, the presidents of the ASA in the mountains also include the obsolescence of the hydraulic network in their confrontation with the hazard “Since there is less water, the water-intakes are moving, so there is less water going ... We have to leave 150 L per second of e-flow. Now we have this obligation and it makes it more difficult to get the water into the canals [...] the Sahorre mining site do the maintenance once a year. After that, we don't touch the canal much because we can't afford it. The budget of ASA is not high, if we have a canal breaking, the ASA can't pay the reparation costs by itself”. For the other groups of ASA, the hazard is linked to climatical factors and to the e-flow “they lowered the e-flow. Today we are 1.2 m3 per seconds. They wanted to lower it below 1 m3 seconds, it was negotiated to 1.5 and today it's

1.2 [...] they want to lower it, but we explain to them that it is not possible” (from a ASA president in the plain).

All the presidents mention the risk of a decrease in water resources and have been confronted with it. But mountain associations are facing more factors related to the hazard than other associations. This increases their exposure to the hazard.

### 3.3.3. Category: Tool used for the resolution of the hazard

Association presidents use the same tools to respond to the diminishing water resource. These tools can be internal to the association but also external. The internal tools correspond to a whole range of actions to manage water demand (agricultural hydraulics, temporal and spatial modification of water sharing between users, etc.). “When there are leaks, we patch them up, we do work to fix them” (from a president from an ASA in the mountains). The presidents of ASA in piedmont and plain can reduce the withdrawals when they can “We can afford to reduce our withdrawals a little... It's almost invisible for the owners”, “It has already happened to us to restrict and preserve the biological flow”.

The external tools bring together a whole network of influence and knowledge between ASA presidents, or between ASA presidents and institutions. These can be formal relationships between association presidents and institutions, or informal networks between presidents and members of other organizations. The frequencies of these actions in the interviews are not the same across association groups.

The agreements between institutions only concern the ASAs in the

piedmont. In the event of a quantitative decrease in water resources, it appeared that the presidents of the associations call on the Bouillouses dam so that the Société Hydro-Electrique du Midi (SHEM) makes low-water support releases “*We work in coordination with the Departmental Directorate, which manages the releases from the Bouillouses dam so that we have a practically regular flow*” (from an interview with a president from an ASA in the piedmont).

The agreements between ASAs concern mainly the ASA in the plain, and to a lesser extent those in the piedmont. These arrangements modify the sharing of water between associations according to the needs of each association. A president in the plain explained this strategy “*We have never had any problems because we all work together, all the canals share the resource [...]. What we do between canals is pass water to each other. All the canals communicate and we can transmit water from one canal to another [...] internally we have the implementation of water turns and afterward, if it is not enough, we can pass in water turns by canals [...]. There is a lot of frequent and regular work, and every year we meet to share the resource so that everyone has water to make their canal and their perimeter work*”.

The two previous types of agreements were not mentioned by the presidents of the mountainous ASAs. When referring to external tools, these presidents describe a system of priority. This system consists of giving priority to certain activities in times of crisis. It brings together all the economic activities that use the water resource (hydroelectric dams, fish farming, agriculture, etc.), and then the elected officials who decide which economic sector and users will be supplied with water. “*We will start from the principle that everyone is impacted; but in reality, fish farming and drinking water supply have priority [...] we have a kind of steering committee that includes farmers, the three mayors, the president of the association, fish farming and hydroelectric plants. A first meeting in June to report on the situation, and then we often meet and even more often in case of crisis*”.

The analysis of the actions frequencies and the verbatim highlights the different margins of manoeuvre for resolving the hazard between the groups. All the presidents mention more or less the same internal tools. Their use is aimed at ensuring water service to users in the event of a crisis. However, the assurance of this service and the effectiveness of the response to the hazard is conditioned by the associations’ external tools. In the event of a crisis, the ASAs in the piedmont call on the institutions and managers of the Bouillouses dam to support the flows of the Têt river with water stored in the dam. The ASAs in the plain provide a water service by exchanging volumes of water among themselves. These relationships are distinctive to these two groups and allow them to provide water service to users. In contrast, the external tools of the mountainous ASAs aim to prioritize certain sectors of activity to the detriment of the association’s members. This factor is distinctive but does not ensure an efficient water service. By not having access to stored water, nor any other ASA with which water volume exchanges are possible, the ASAs in the mountains are more exposed to hazards than others.

### 3.3.4. Category: Factors that are interfering with the strategies

External social resources to the associations can hinder strategies. This is particularly the case in the plain, where the analysis of the verbatim highlights the institutional obstacles faced by the associations. These obstacles are opposed to the development projects of some associations “*The DDTM helps less and less, whatever the project is*”, “*we don’t understand why the DDTM is putting a stop to this [...] we are the ones who are going to be penalized the most*”.

For internal resources, the actions are more numerous for the ASAs in the piedmont as well as in the plain. Each ASA pursues its internal management according to the objectives and issues of the members “*The association is a public institution and it is not supposed to cut off water to urban dwellers to give preference to farmer s; it must serve its members in the same way*.” (From an interview with a president from an ASA in the plain). Yet, the objectives of the members, and their water consumption, can be outside the competences of the presidents “*The pressurized networks are on demand, which means that the water we serve is that which is*

*requested by the farmers. If they do not also make the effort to manage the land more finely, then we do not have control*”.

The external factors that influence the strategies are mainly institutions or individuals that will hinder or facilitate the strategies of the ASA. In the case of individuals, it is interesting to note that presidents do not have control over the individual strategies. The objective of ASA presidents is to keep the association in operation as well as to ensure water service to members. The competences of the ASAs end at the member’s parcel.

### 3.4. Synthesis of the comparison of the strategies by groups of ASA

The use of different tools does not make it possible to identify different drivers of adaptation strategies. The concern to ensure user access to water resources is common to all the ASAs. This is the only driver of adaptation strategies. However, there are distinctions in the way associations respond to this objective (Fig. 5).

The ASAs in the mountains are more exposed to the risk of a decrease in water resources for both climatic and technical reasons. In addition, the agricultural population is decreasing and the operating costs of the ASAs are increasing. This accentuates the budgetary imbalance of the associations. The maintenance of the irrigation network is constrained and this contributes to the risk of a decrease in water resources. In addition, activities and populations are changing. Farmers are no longer the only users of the resource. Other activities such as tourism, hydro-electricity, fish farming and private use are leading to a diversification of water withdrawals. The management of the decrease of the resource thus passes mainly by a modification of the sharing between sectors of activities and not between members of the association. This penalizes some farmers who then find themselves without access to the water resource. Secondly, maintenance work, or even makeshift work based on informal collaboration between members of the association, attempts to maintain access to the water resource. These associations are the most vulnerable of the sample. The roots of the vulnerability of these associations seem to be linked to their geographical location as well as the socio-economic context of mountain communities. These roots in turn generate distinctive vulnerability factors that will reduce the associations’ ability to adjust to the hazard. Thus, beyond a higher exposure to climate change than other associations, territorial factors related to the functioning of mountain societies in their space make these associations less able to adapt to climate change.

The ASAs in the piedmont are confronted with a hazard mainly due to climatic factors. However, the management of the hazard takes a different form than the mountain associations. The availability of the water resource is maintained because of the collaboration between the association presidents and the SHEM who are bound by the Lanoux agreement. At the same time, the associations compensate for the economic uncertainties by diversifying their services to the communes. This makes it possible to maintain a balanced budget and thus to finance maintenance, modernization and water-saving work. Despite this, in the event of a decrease in the resource, a modification of the sharing of water in time and space between members can take place. All of this helps to maintain the availability of water resources to the most vulnerable members. This strategy is effective as the hazards have never led to water shortages. In the sample, these are the least vulnerable associations because they put in place different levers that ensure resource availability and can activate others that would further reduce vulnerability. Although these ASAs are also facing socio-economic changes that decrease their profitability (the root of vulnerability), their ability to adjust is less constrained than the previous ASAs. Water storage and the Lanoux Agreement are two key vulnerability factors in the ability of the ASAs to adjust.

Finally, the ASAs in the plain have different hazard management. Gathered under the Association of the Canals Downstream Vinça (ACDV), their collaboration is facilitated. In the event of a decrease in water resources, this collaboration leads to “exchanges” of water

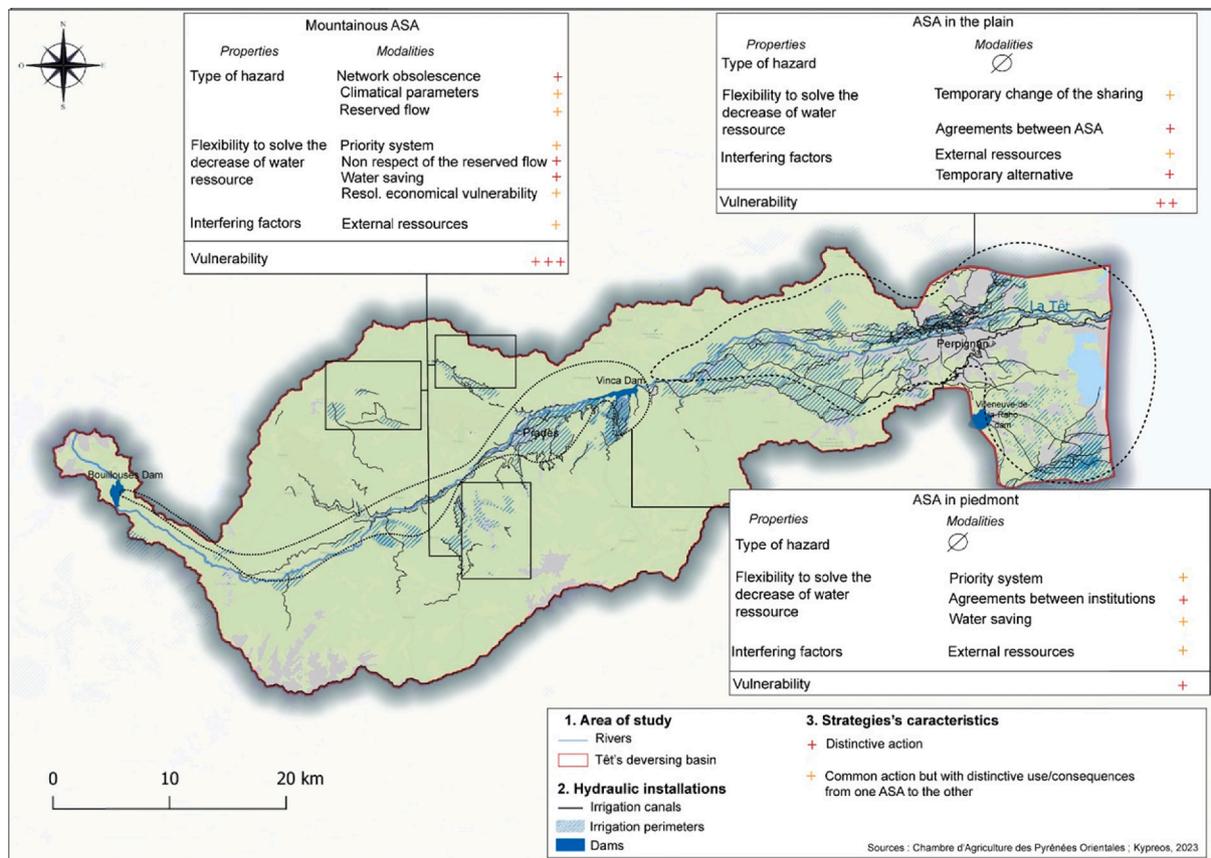


Fig. 5. Typology of the adaptation strategies implemented by the ASA in the discharging basin of the Têt according to the mode of access to the water resource.

volumes between associations according to the needs of their members. In addition, internal levers within the associations can be mobilized, such as modifying the sharing of water among members. The combination of internal and external levers has not prevented crises, which were mentioned with concern by the presidents. Indeed, the re-supply of the canals and the river from the water stored in the Vinça dam is more uncertain than the re-supply from the Bouillouses dam. The main branches are already modernized and yet, the river flow reaches levels that can prevent water supply of the canals. This is making these associations more vulnerable than the previous ones because the water needs are changing (in the case of pressurized networks, the water must be maintained under pressure, and the farmers must irrigate in a quasi-continuous manner), the irrigation perimeters are extended and the strategies may not be sufficient against the water shortages. In addition, there is strong competition for shared water both to accommodate new populations and to meet the needs of other economic sectors, including tourism. The roots of their vulnerability are linked to socio-economic changes that lead to an increase in the number of water users, as well as confrontations with institutions. The latter are increasingly interfering with the ASAs, which are seeing their adjustment capacities reduced. In addition, the insufficient filling of the Vinça dam due to the decrease in water resources prevents the use of the stored water to support irrigation in the summer period. This makes up the last root of the vulnerability of these ASAs.

These adaptation processes make some groups of associations more vulnerable than others. Having a secure water resource can mean less exposure to water resource depletion. The physical dimension of access to water resources is important in the vulnerability of associations. However, this does not mean that associations with a secure resource have effective strategies. The effectiveness of strategies depends on tools and formal or informal social relationships between ASAs's presidents or with ASAs's presidents and institutions. When those tools are combined,

they make it possible to distinguish territories that are more or less vulnerable.

All of these tools, both internal and external to the associations, have only one objective: to provide water service. The individual strategies from a previous survey can be compared to the collective strategies in this survey to test the second hypothesis.

#### 4. And if the water supply is constrained? Discussion on the individualization of irrigation and on the confrontation of ASA's strategies with farmers ones

The analysis of 27 individual strategies of farmers for the decrease in water resources allowed us to identify two main drivers for adaptation: economic constraints and climate (Niles et al., 2016). Two strategies for the hazard have been identified: palliative and adaptive strategies. The former provides a one-time remedy to a risk of a decrease in water resources, while the latter adapts the socio-economic functioning of the farm on a long-term basis to a decrease in water resources. The former is mainly oriented towards the resolution of the economic vulnerability experienced by the farmer while the latter aims to resolve an economic and climatic vulnerability.

However, the characteristics of the Pyrénées Orientales is exposing the farmers to economic vulnerability. Because of the MP<sup>2</sup> platform,<sup>5</sup> the localization of the department, and the department's import-export

<sup>5</sup> This platform is composed of 3 strategic infrastructures: the Saint Charles platform, Boulou and the commercial port of Port-Vendres. Together, these three infrastructures, which are supported by European development funds for the purpose of intensifying trade, have led to an increase in the presence of foreign foodstuffs (especially fruit and vegetables) (mainly from Spain and the southern shore of the Mediterranean) in the territory.

policy favor competition with European and non-European agriculture. The analysis of commercial trade of the Directorate General of Customs shows an increasing in the importation of foreign agricultural products since 2009. The market is clogged with agricultural products, mostly from Spain and Morocco. The main consequence of this offer of products from regions with different productivity is a direct or indirect competition between producers. This favors the negotiation of purchase prices between farmers and large scale distribution. According to a more or less strong dependence between the farmers and the activities related to commercialization, the negotiation of prices can lead to a low profitability for the farmers creating a context of economical vulnerability (Niles et al., 2016).

The practices to respond to the economical vulnerability of farmers have to deal with climate change and the decrease of water resources. By ensuring a water service, the ASAs accompany the farmers' strategies. However, if the water is not ensured, it would constrain the agricultural production of the farmers. This constraint would favor cases of economic vulnerability that will lead to the development of a strategy from the farmers. In the case of constrained water services, this could lead farmers to emancipate themselves from collective associations in order to control their access to the water resource and to ensure the farm production. The individualization of farmers' irrigation is a scenario that would modify the risk of water shortage by decreasing the efficiency of the collective management. This scenario is currently underway in the basin (Fig. 6).

In some ASA perimeters, the use of individual drills reaches 75 % of total water withdrawals. By using the 27 strategies of the previous survey, it appears that collective irrigation is being abandoned in favor

of individual irrigation. This is motivated by a technological obstacle (gravity canals do not allow pressurized irrigation), constraints of access to the water resource (water turns, summer service cuts) as synthetized during an interview "I am in association perimeter but i have a drill too. The stream It's impossible to have water by the canal, there is never any water. ... I would have to clear the brush, especially since I can't use weed killer, otherwise I'll be in jail and no one will pay to use the brushcutter. So I made a drill". In addition to that, the competition between farmers and the modernisation of the farming practices motivate the use of pressurized water as illustrated by the use of drip irrigation. Despite being a water saving technology, drip irrigation needs a constant access to water (Souliis et al., 2020) "We're doing this to reduce our water consumption, the goal being to do sequences of irrigation. So we do half-hour irrigation sequences, we do it 5, 6, 7 times a day. We make small contributions to always maintain water to the roots so that they can always pump".

The increasing variability in water availability due to climate change, and the water needs of farmers, may accelerate the individualization of the water access and the loss of efficiency of the collective strategies. This situation is making some ASA presidents in the plain to worry "If the restrictions are more frequent and more important, it is because there are different strategies or lack of strategies [...] I know that the elected officials and the members would not accept to have a water turn and stations that are cut off three days here and four days there [...] I am afraid that we will no longer be able to make water turns...". In the meanwhile, some farmers openly talked about way of overpassing a constrained water access "You know, if the farmers need water, they will find it... There are some who say that they will drill a discreet drill and we will not tell anyone".

Until now, the collective strategies to ensure the water service were

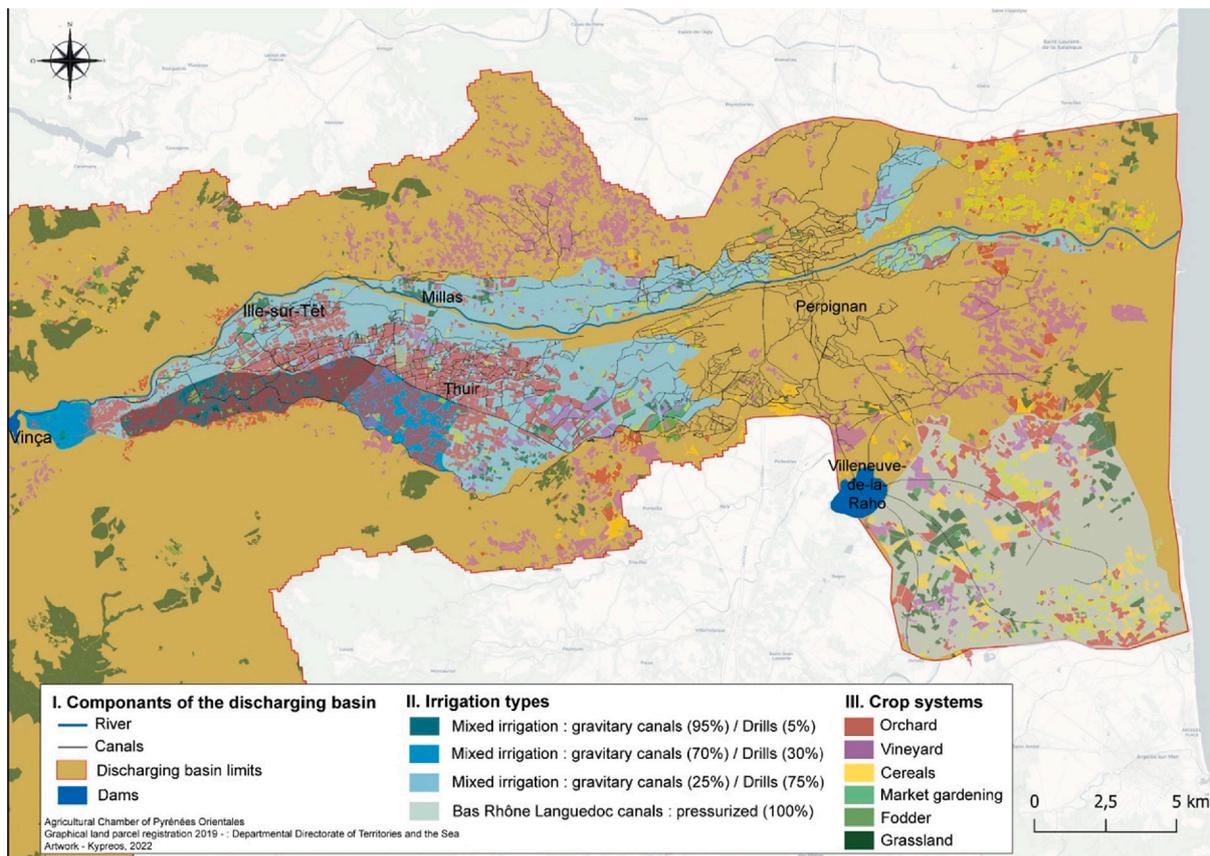


Fig. 6. Location of crop system and irrigation type in the plain. The canals networks and irrigation types localize the ASA perimeters. This maps shows that the crops systems irrigated by collective canals are in a minority area in comparison with the area irrigated by drills. Yet, almost all of the crop system located downstream Vinça are in a ASA perimeter. Those perimeters are mainly planted with orchards and market gardening. In those areas, the irrigation type is not linked to the crop system. It may be linked to the individual monitoring of the farms and to the economical context that they are facing. Oustide the ASA perimeters, the areas are mainly planted with vineyards.

efficient in the plain and in piedmont to ensure a water service to the farmers. However, there is already a individualization of the irrigation caused by many factors like modernization of the practices, uncertain access of water and needs of pressurized water. But the decreasing of water resource caused by climate change, and the uncertain access to water linked to it could aggravate this situation motivating individual strategies. Under the effect of economic and commercial barriers, the hydro-agricultural space could continue to be reorganized. This process could continue the modification of production systems and the loss of efficiency of the ASA.

These results are questioning the different adaptation strategies promoted by public policies in the region. On the one hand, agricultural policy strategies support the individualization of farmers so that they maximize their production tool (in part by means of *Climate-smart agriculture* practices) (Bureau d'études Oréade-Brèche, 2016; Head, 2010). However, agricultural policies are also aware of the assets of ASAs. Thus, agricultural policies also advocate maintaining or even increasing the number of ASAs on the territory. However, the individualization of agriculture is sometimes incompatible with collective operating methods in the event of a water shortage. This phenomenon is set to increase in intensity and frequency, given trends in the availability of water resources. Moreover, one of the levers for adapting agricultural policies is the creation of storage reserves. However, the results of this work show that adaptation is not determined only by the quantity of water stored, but by the ways in which this water is managed. Nevertheless, we must not fall into the trap of assuming that collective action is the solution to sustainable water resource management. The analysis of the interviews also showed that the collective pursues the trajectory of individuals, and it is indeed the sustainability of these individual trajectories that is called into question. On the other hand, environmental adaptation policies are defending the maintains of ecological flow at the minimum authorized level (1/10th of average flow), which has been below this level for several years. As illustrated in the interviews, this minimum flow may accentuate the pressure on the ASAs and on the farmers. This work is yet another argument in favor of a territorial adaptation strategy that transcends economic sectors, and in which uses (and businesses) are seen as invariable in time and space. Beyond a sector-based strategy, it's a territorial project that needs to be debated.

## 5. Conclusion

The first hypothesis is partially verified. Securing access to water resources appears to be an important factor in the vulnerability of associations and territories to the hazard. ASA in the mountains do not have a secure resource and are therefore more exposed to the risk of a decrease in water resources. However, securing the resource does not solve the risk. Social factors influence the ability of associations to respond to water scarcity crises and to adapt to climate change. Thus, the associations in the plain do not share the same social relations with institutions as the associations in the piedmont. Both of them are secured by dams, yet their strategies against water decrease are different. The risk is therefore not only a question of securing the resource but of a set of vulnerability factors internal and external to the associations. The social networks external to the associations are a significant lever in the resolution of risk. Thus, the relationships between association presidents, but also between association presidents and institutions, partly condition the risk. The ASAs strategies to the decrease in water resources do not only depend on a set of increasingly efficient techniques, but also on relations between individuals and institutions that together manage to reduce the vulnerability of the territories.

The second hypothesis has been verified. As public institutions, the associations must provide water services to their members. However, the inelasticity of water needs at the individual level is confronted with decreasing availability. Faced with this observation, individual strategies may tend towards individualization of access to the water resource.

This study analyzed the 12 presidents of irrigation associations using

the MAXQDA qualitative analysis software. The software maximizes the added value of the research material. It reinforces the multidisciplinary interest of this work by making it possible to identify territorial levers that accompany or hinder individual and collective strategies. It also makes it possible to account for the capacity of local societies to develop natural and social resources in a given area.

Moreover, this work takes into account the interweaving of individual and collective strategies. The ASAs support and reduce the vulnerability of farmers in the face of resource depletion. However, the ASAs also provides water service to farmers who face barriers and drivers to adaptation that may lead them to increase their dependence on the resource. In the case of constrained water service, individualization of access to the resource can take place. This individualization implies new forms of valuation of the resource that can take the form of technical or social resources. This modifies the risk equation for individuals and territories. Understanding individual strategies also means understanding the trajectory of collective strategies and the vulnerability of the territory.

In this way, our work provides further insights into individual and collective adaptation strategies to water scarcity in developed countries. It also adds to the bibliography on the social components of water scarcity. However, it doesn't just add to existing literature, it also introduces new elements, notably through the use of a CAQDAS. Indeed, these results have been put into evidence by means of computer software based on semi-directive interviews. In addition to that, this work leads to avenues of research on the relationships between societies and modes of valuing water resources through the concept of the hydrosocial cycle (Linton and Budds, 2014; Valadaud and Aubriot, 2019). Specifically in the study of the reorganization of hydro-agricultural spaces, in the prism of global changes.

## Fundings

This work was financed by the region Occitanie for the Ccr\_tet project: climate change and rurality.

## CRedit authorship contribution statement

**Kypreos Vassili:** Conceptualization, Investigation, Visualization. **Lacquement Guillaume:** Methodology, Supervision, Validation. **Lavie Emilie:** Supervision, Validation. **Wolfgang Ludwig:** Supervision, Validation.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kypreos Vassili reports financial support was provided by Occitanie Region.

## Data availability

The data that has been used is confidential.

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