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Operationalizing urban resilience to floods in embanked territories - Application in Avignon, Provence Alpes Cote d'azur region

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Abstract :

Over-urbanization coupled with a climate change has led to an increase in urban floods, both in frequency and intensity. Faced with growing uncertainties, managers are struggling to find appropriate risk management strategies. Alongside traditional risk management strategies, the concept of Urban Resilience is embedded in political discourses, international and local strategies. However, this concept remains still very abstract for a lot of actors, a buzzword difficult to operationalize. The objective of this work is to concretize urban resilience to floods by proposing a spatial decision support tool co-built with urban managers. The proposed methodology is a holistic approach integrating three indicators of resilience applied to the Avignon rase study (Provence Alpes Cote d'Azur Region).

Highlights

► This article proposes a methodology to operationalize urban resilience in the face of flood risk. ► For this purpose, the methodology was built with the urban services of the case study city in order to facilitate the understanding and integration of the concept of resilience among urban strategies. ► The originality of the methodology is based on a significant use of open data and open access tools. ► The resilience approach was designed to be as holistic as possible in order to adapt to a systemic approach to the territory.

Keywords : Urban floods, Urban resilience, Climate change, Decision-support tool

1. Introduction: An increase in floods in urban areas

1.1 Urban floods

The current context of climate change, leading to an increase in natural disasters of about 2% / year over the past fifteen years (Catastrophes Naturelles-Observatoire permanent des catastrophes naturelles et des risques naturels, 2016), associated with the increase in people and goods in urban areas, has considerably weakened cities. Among these disasters, flood risk seems to be the most problematic (Vinet, 2010), constituting 47% of climate-related disasters over the period 1995-2015 (UNISDR and Center for Research on the Epidemiology of Disasters (CRED), 2015).

In total, the EM-DAT (Emergency Events Database) recorded an average of 318 natural disasters in 2017, affecting 122 countries. While the number of deaths in developed countries has decreased in response to this risk, 2017 is the second most costly year (Center for Research on the Epidemiology of Disasters (CRED), 2018). Regarding risks, floods are still the most expensive natural disaster, which could reach 100 billion euros/year by the end of the century (Barroca et al., 2013) in Europe. This is mainly due to the increasing concentration of goods and people in urban areas.

1.2 An increased urban population

This accelerated mutation (Beaud, 2000) has led humanity to reach 7.55 billions of people. This increasing mainly urban population, 50% of people living in urban areas (Serre, 2016; Zevenbergen et al., 2010) (Zevenbergen et al., 2010), is problematic related to the risk of flooding in the city. The rapidity of this phenomenon, urban areas having increased from 10% in the 90s to 50% in only two decades (Meerow et al., 2016), weakens the territory because cities are not prepared or equipped to handle the needs of such a concentration of population. This, for lack of available land space, is coming to settle in areas at risk (Barroca et al., 2006). Thus, one disaster out of three concerns cities with more than 500,000 inhabitants (Dauphiné and Provitolo, 2013). What can we do when in France, ¼ of inhabitants and 1/3 of employments are settled in flood areas? (Gonzva et al., 2015) This urban growth is poorly controlled and contained by local developers and politicians. New neighborhoods are emerging, with no adequate equipment, in risky areas such as flood-prone, polluted, unhealthy areas. With cities occupying only 1% of the world's territory (Dauphiné and Provitolo, 2013), developed countries have never concentrated more value per square kilometer (Albouy, 2002) than at present. This concentration of population on such a small portion of the territory has increased the spatial and social vulnerability via the exposure of the stakes (Adger and Brooks, 2003). Indeed, it seems logical to consider that the more a population and its stakes are concentrated on a small area, the greater the damage will be. A flood in an uninhabited area will not be considered and apprehended in the same way as in an urban area (Mitchell, 1999). It is no longer just natural disasters that impact cities, but urbanization that leads to over-vulnerability, an anthropic vulnerability (Pidgeon and O'Leary, 2000), leading to a melting pot of opportunities for risk amplification (Mitchell, 1999). Urban risk is therefore composed by vulnerability and exposure (Cardona et al., 2012) such as urban concentration which is therefore seen as an aggravating factor in risk management. If we take the example of the 2001 attacks, only 1% of buildings in New York were destroyed (Dauphiné and Provitolo, 2013) while human losses were very heavy because of the high density. This density also complicates emergency services, which may be hindered by the over-occupation of the territory. In these urban spaces we observe the increase in natural risks but also the creation of new forms of risk (Mitchell, 1999; Reghezza, 2006). The interconnected architecture of economic, social, political, commercial, administrative, etc. activities in modern cities and a globalized world tend to create an interdependence of networks (Helbing, 2013), whether formal (technical networks) or informal (social interrelations). The most frequently cited example is the 2005 disaster in New Orleans (Pescaroli and Kelman, 2017), following the passage of Hurricane Katrina in August 2005 (Kelman, 2007). The hurricane and the storm wave have resulted in 1,833 fatalities. Because of the interdependent networks, secondary events have occurred such as the destruction of vital utility networks, the creation and diffusion of pollution and the loss of strategic areas (Moynihan, 2009). The return to normal has been extremely complicated, particularly because many services had been destroyed such as electricity services (3 million citizens without electricity for several weeks) , transport networks (reducing the capacity to deliver food), communication networks (3 million customers without phone), but also critical infrastructures such as emergency services and hospitals, leaving hundreds persons without basic supplies (Knabb et al., 2005). In this case, it is not only a natural hazard that has occurred, but a natural hazard that impacted an anthropic reality and vulnerability, because of an interdependent urban world and activities. The interdependence then plays the role of a risk diffusion factor. According to the concept of the cascading effect (Nones and Pescaroli, 2016; Pescaroli and Kelman, 2017; Pescaroli and Nones, 2016; Serre and Heinzlef, 2018) that is to say a chain reaction causing impacts in one territory, some areas are affected by the flood, even if they were not located directly in the risk zone. Networks then act as vectors of risk propagation (Lhomme et al., 2013). Societies and systemic territories are therefore deeply vulnerable to potential functional disruptions due to a crisis (Boin and McConnell, 2007). Thus, if natural hazards persist (earthquake, flood, hurricane, avalanche, etc.), it is transformed by a social hybridization (Reghezza, 2006), by the actions and practices of man on its environment. The hazard is then modified by urban practices, urbanizations, and citizens (Ale, 2005; Reghezza, 2006). Thus, while natural hazards are not new, their impacts are evolving due to urban movements, urban growth and urban structural changes (Reghezza, 2006). Faced with this rapid urbanization and the emergence of these new risks, managers have to manage a series of uncertainties (Steen and Aven, 2011). These uncertainties, linked to climate change (Adger and Brooks, 2003; Gonzva, 2017) , to urbanization, to the complexity of the systems (Lhomme et al., 2013), to the emergence of new actors and new risks, complicate the management of urban risks. Faced with these increased uncertainties (Gersonius et al., 2013), the answers provided by scientists and managers are also in transition. Formerly risk-oriented management (Dobson et al., 2016), it tends today to integrate the concepts of vulnerability and resilience, taking more into account the systemic aspect of a territory.

The goal of this paper is to defend the theory that the vulnerability concept may have some limitations, both on the theoretical field and practical strategies, whereas the resilient concept is more adapted to a visionary policy approach (Serre and Heinzlef, 2018). We will define in a first part the conceptual resilience concept and its limitations in concrete applications. In a second part, we will describe how we designed a resilient decision support tool, thanks to a research-scientist collaboration and managers of the territory, with a localized application in Avignon.

2. Resilience, an urban flood management concept

2.1 Definitions of Resilience

For the past twenty years, the resilience concept has been the showpiece of risk management. However, its multidisciplinary use makes it a polysemic concept. Michel Rutter is comparing it to a new Rorchach test that would allow different actors to project their interpretations (Ionescu, 2012), and transform it into a buzzword (Davoudi et al., 2012; Shaw et al., 2014; Weichselgartner and Kelman, 2015). From the Latin word *resilientia* (*re*, back; *salire*, jump), the term resilience is used for the first time by Francis Bacon in his latest work, Sylva Sylvarum or Natural History, to describe the 'bouncing' noise made by the echo. The first meaning, given by the English language, of the word resilience thus means "to rebound", "to recover". Formerly used it in the physical field, then in the psychiatric field, the resilience concept is defined by Holling as the capacity of an (eco)system to absorb disturbances, to recover after a major disruption and to restart activities (Holling, 1973). Adapted to risk management, resilience can be defined as "*the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner (…). The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need*" (UNISDR-United Nations International Strategy for Disaster Reduction, 2009). The resilience concept highlights the idea that disturbance is not necessarily negative but on the contrary is fully involved in creating a new model by supporting the idea of innovation, learning, rebound and change (Folke, 2006). The distorted system must be able to evolve, adapt (Bahadur et al., 2010; Carpenter et al., 2001; Folke et al., 2010), recover from (The Rockefeller Foundation, 2015), absorb changes (Chelleri, 2012; Gunderson and Holling, 2002) and persist. It is therefore a proactive capacity that the system has to develop in order to react in the face of the flood, developing learning ability (Vale and Campanella, 2005; Zevenbergen, 2016; Fuchs and Thaler, 2018) and anticipation abilities (National Academies (U.S.), 2012).

2.2 Theoretical position

The resilience concept can operate at different temporal scales, usually following the different steps of a disaster (Fuchs and Thaler, 2018). Some authors consider that resilience approach must be done after a shock, evaluating the resilient components post-crisis (Saunders and Becker, 2015). However, some studies emphasize the idea that resilience must be considered as a *continuum*, beginning by a preimpact phase (including preparation strategies) and going to a post-impact phase (mitigation measures) (Fuchs and Thaler, 2018). This study considers that resilience is a process inherent to the internal system functioning (Serre and Heinzlef, 2018). Therefore there is no need for a shock to express system's resilience, this capacity (or capability (Provitolo, 2012)) could be pre-existing a crisis. Resilience characteristics can exist and be identified a-chronically and constitute a potential for resilience. Resilience is therefore considered as pre-existing (Fig.1) or developing characteristics in such a way as to make the system flexible, adaptable, elastic in the face of shock, so as to prepare, survive and redevelop an activity after the crisis by learning from failures or successes. This scientific positioning makes possible to analyze urban resilience as a continuum (Fig.1), highlighting proactive capacities that the urban system must develop in order to (re)act in the face of the disaster, thereby developing learning and anticipation skills. Resilience is therefore no longer a skill that can be observed only after the crisis, but rather a concept that would define a learning process (Brand and Jax, 2007; Davidson-Hunt and Berkes, 2002; Gunderson and Holling, 2002) via a culture of risk (Laganier, 2015) over the long period of time during which the shock would only be a trigger and reveal the intrinsic capacities of the system. From this point of view, resilience and vulnerability are no longer in opposition but participate in the definition of the inherent characteristics of the systems. The shock will then make it possible to highlight these resiliences and/or these vulnerabilities. Nevertheless, these characteristics can be revealed by the shock. Resilience factors can then be identified a-chronically, over a long time (Damien Serre, 2011) in order to study and develop resilience potentials (Reghezza-Zitt et al., 2012; Serre and Heinzlef, 2018). Resilience always refers to a return to an acceptable balance, whether pre-existing or new.

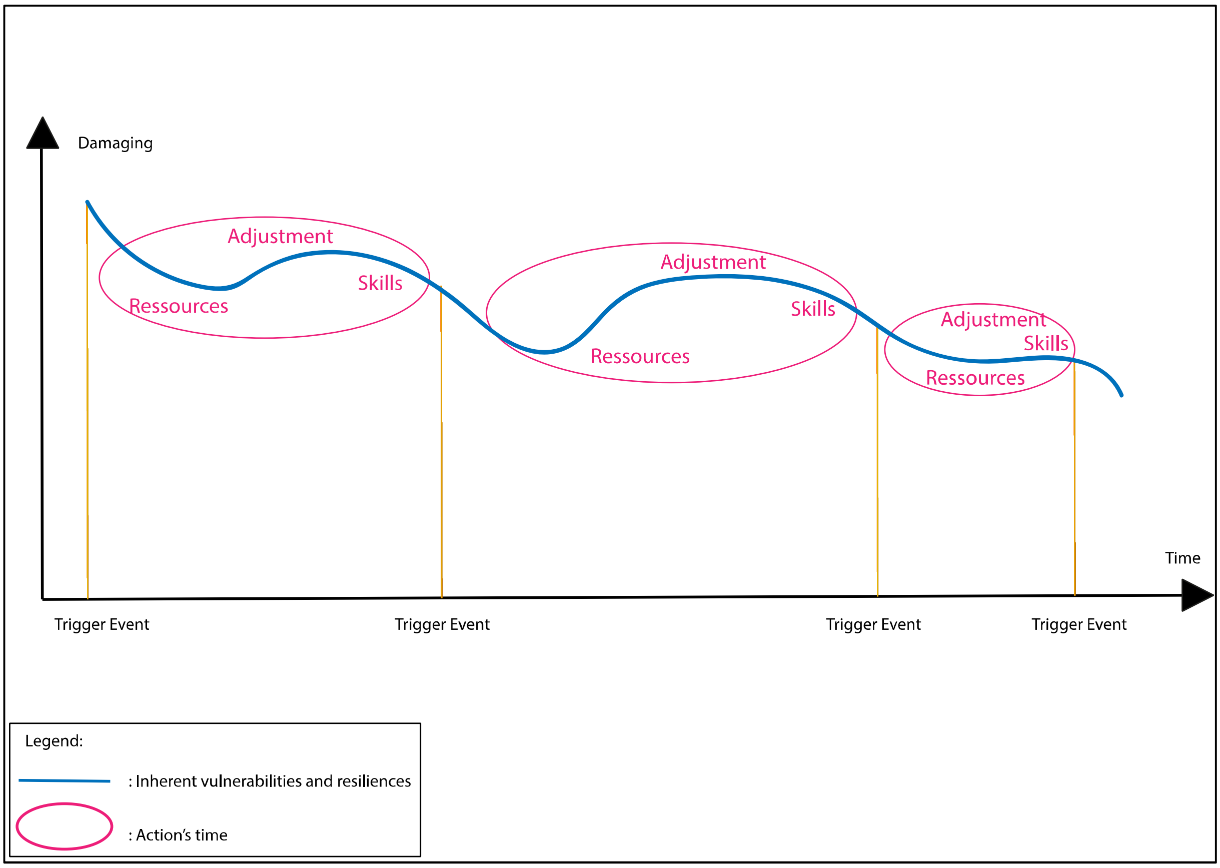

Figure 1: Resilience process on a long term

This concept refers to technical, urban, architectural, political, economic, social, management, environmental innovations in order to (re)question our risk management systems and approaches. This injunction to innovation perfectly suits our complex and evolutive urban world. Nevertheless, and despite a significant increase of the resilience concept (Meerow et al., 2016) in urban risk management, concrete advances still have to be made. Perhaps due to its over-use (Fuchs and Thaler, 2018; Weichselgartner and Kelman, 2015), few practical integration of this theoretical concept have been made (Klein et al., 2003). Furthermore, the majority of nowadays' studies are essentially turned around a technical-organizational resilience (Koks et al., 2015; Lhomme et al., 2013; Serre, 2016; Toubin et al., 2015; Bozza et al., 2018) but without taking into account its social dimension. The goal of this research is to reconcile urban, technical and social resilience by facilitating the understanding of this concept and more precisely its integration in urban planning policies and urban risk management. To operationalize resilience, this work is aiming at co-creating a spatial decision support tool with urban managers in order to integrate the theoretical concept into urban practices and flood risk management policies.

3. Measuring and mapping urban resilience to floods

3.1 State of the art

Several researchers have attempted to calculate the propensity of a society and / or territory to experience shock, and its intrinsic abilities to recover. Cutter revolutionized social vulnerability by creating its index - SoVI - to examine the spatial distributions of social vulnerability to natural disasters. Its application, tested on the US territory, is intended primarily for an audience of territorial managers to improve planning practices. Indicators have been categorized into social resilience, economic resilience, institutional resilience, resilience infrastructure and community capital, to provide a global view of social and spatial interactions. Following this data, a global vulnerability map was produced in the US, with high social vulnerability (over 20%), moderate social vulnerability, and low social vulnerability (less than 20%) (Cutter and Finch, 2008).

More recently, Norwegian researchers have developed a natural hazard vulnerability indicator for Norway (Opach and Rød, 2013). This indicator stems from the realization that urban designers have difficulties in territorializing vulnerability in terms of space and population. Their tool, ViewExposed, has integrated various hazards present on the territory of Norway, floods, landslides, storms and avalanches. To quantify this vulnerability of territories and populations to the risks, the scientists worked on the "integrated vulnerability" (IntVI), the linking of the exposure to a risk and the capacity of the local populations to resist it. In addition to the exposure index, social vulnerability was taken into account, with various sub-indicators, socio-economic vulnerability (unemployment and demographic trends, viability of the municipality, socio-economic status, qualifications, etc.) and the vulnerability of the built environment (lifelines, aging of buildings, density of facilities). This tool was designed for a public of professionals, local elected officials but also for the local populations.

While these tools have been designed around the concept of vulnerability, others address resilience in order to map it. These works are valuable avenues for reflection to work on the implementation of the concept of resilience on the territory. However, this analysis of urban resilience is essentially based on the technico-organizational prism (Toubin, 2014). A functional study of the city to measure or improve its resilience often seems to be the most obvious. Because of their broadcasting capacity, networks are regularly subjected to this analysis. A case study in Dublin was carried out with the aim of developing a GIS prototype to analyze different characteristics of resilience, the absorption capacity (i.e. the capacity of a network to function in spite of events disruptive), recovery capacity (i.e. the ability of a network to return to service as quickly as possible) and lastly resilience (Lhomme et al., 2013). The objective was to facilitate the integration of the theoretical concept with the managers' practices. The final mapping classifies the city into different areas of resilience, depending on their ability to return to service after the crisis.

More systematically, Suarez has devised a global index to measure the spatial resilience of a territory, with indicators as diverse as modularity, tightness of feedbacks, social cohesion, innovation and organizational diversity (Suárez et al., 2016). Most of the indicators that have been defined are composed of a social, economic, institutional and physical dimension.

These studies work at the urban scale of the city and / or agglomeration, but some researches have chosen to study buildings to measure potential resilience. Nguyen focused on measuring the resilience of households to floods by asking people about their homes based on architectural and material characteristics (Nguyen and James, 2013). This methodology has been reused and deepened in Norway to create a guide on how to prepare for climate and weather events that may affect individual homes based on building and geographic characteristics (Johansson et al., 2016).

Although important for our research, these studies highlight the limitations of a vulnerability / resilience approach. Each of these studies highlighted the difficulty of jointly studying the vulnerability and resilience intrinsic to territories and urban populations. Moreover, among these few lines of thought cited, key examples in this work, many are essentially turned around a technico-organizational resilience, without taking into consideration its social dimension. The objective is therefore to facilitate the understanding of the notion of resilience, and especially its integration into management and planning policies, at the crossroads of urban, technical and social resilience. This work aims to operationalize resilience by creating a spatial decision support tool that integrates the theoretical concept into urban practices and flood risk management policies. Through its joint construction with urban services, as well as through its holistic approach, this work seeks to combine the different approaches already established, while deepening the concept of resilience by studying these components at once social, technical and urban.

The objective of this work is therefore to address resilience in all its complexity, in all the components that make up the territory, to operationalize it through spatial mapping, but also to measure the impact of new urban projects on territorial resilience. The proposed work is therefore carried out at two scales, the spatial scale of a city and the scale of the urban project (Balsells et al., 2015), in order to concretize the international injunctions of resilience (The Rockefeller Foundation, 2015).

3.2 A holistic methodology for resilience to floods assessment

3.2.1 Resilience indicator modelling

Our research highlights the idea that the resilience approach must be concentrated on both multiple social and territorial dimensions and interactions. Our goal is to understand and to point out the characteristics which could decrease or increase urban resilience. Bearing in mind that resilience is considered as an ability, a capability of a society or a territory to plan for, adapt, absorb, recover from, learn, evolve, we tried to select some inherent traits which would participate to develop a resilience territory.

Over the last decade, the use of indicators has been increasingly developed in risk management as they may measure or/and operationalize variable to describe an extraordinary phenomenon (Øien, 2001). Indicators are valued because of their ability to integrate large amounts of information in an easily understandable form, making them valuable communication tools and instruments of action (Freudenberg, 2003). They can assume different kind of functions, simplify the data without losing sight of the role they play as an important communication tool specifically for policy making and public communication (Cutter et al., 2010). In this research, we developed several indicators, themselves divided into specific variables, in order to study both inherent vulnerabilities and resilient characteristics of a society and a territory. It is established here that these variables indicate a potential for resilience in order to revive a social, economic, urban, and systemic activity after a shock. These indicators have been built after a translation of the Baseline Resilience Indicators for Communities (BRIC) methodology (Cutter et al., 2008; Singh-Peterson et al., 2014) and constitute a hierarchical resilient index (Tate, 2012) constructed on the basis of three indicators of urban, social, technical resilience (Fig. 2), a city being composed by populations, networks, environment, infrastructures, buildings etc. (Lhomme et al., 2010).

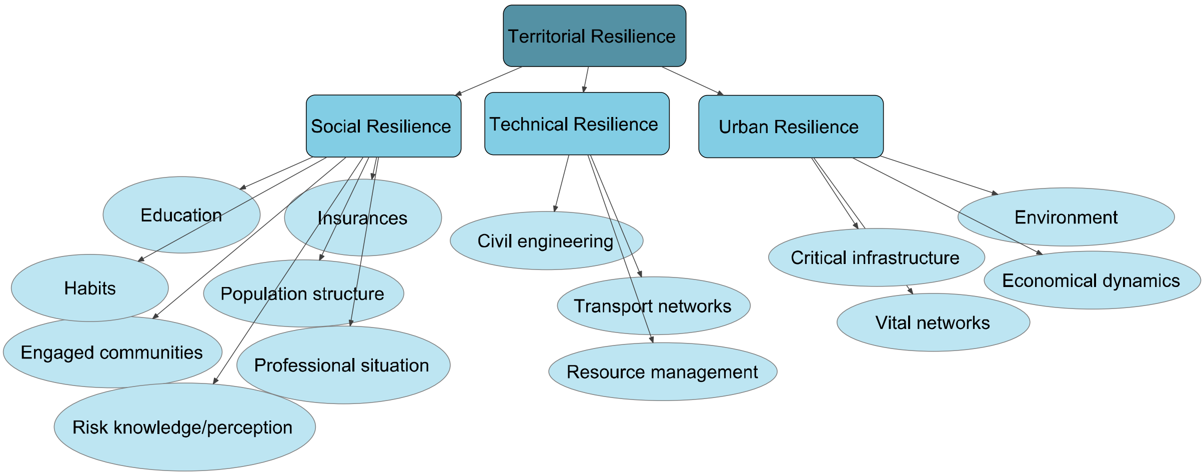

Figure 2: Resilient hierarchical index

a) Social resilience

It is maybe the most sensitive indicator. Social resilience can be defined as the capacity of a population to adapt and recover from disturbances (Hutter and Lorenz, 2018). Many factors can allow a social entity to proactively act, react and redevelop activities or interactions, such as the age (Cutter et al., 2010), the political investment (The Rockefeller Foundation, 2015; Voss, 2008), the socioeconomic status (Flanagan et al., 2011), the risk knowledge and perception, diversity etc. We understand in this study social resilience as a social community resilience (Wilson, 2013) and not individual resilience (Hutter and Lorenz, 2018). Following the Bourdieu's conception, we consider that social resilience is a multiple concept, based on few variables as personal dispositions and habits, knowledge and perception and educational qualification (Bourdieu, 1984). The main idea is to pay more attention to the capacities, capabilities and resources of a population in order to proactively adapt components to a potential disturbance (Hutter and Lorenz, 2018; Serre and Heinzlef, 2018). We should not forget that population revitalizes territory after a crisis, and that social resilience may create the difference between vulnerability and resilience (Hutter and Lorenz, 2018).

b) Technical resilience

We understand as technical variables all the material components interconnected such as urban networks. Transport, gas, electricity, water networks (their age, their ability to resist, absorb, recover from (Serre, 2016) are integrated into this indicator). Indeed, recent researches highlight the impact (negative or/and positive) of the urban networks during and after a crisis. They are essential to the good functioning of a city, connecting more and more people and territories and, in this way, offering a variety of resources and opportunities but they also may create interdependence situations (Serre and Heinzlef, 2018). They may, by their interconnection characteristics, propagate the floods beyond geographical and functional border (Boin and McConnell, 2007), and by this way, the failure (Lhomme et al., 2010). Although they are essential to create dynamics, relationships, opportunities, they also create vulnerability on a territory. One single failure may create cascading effects affecting the whole city, because of the reticular urban system (Serre and Heinzlef, 2018). For this indicator, we developed the methodology of the DS3 Model (Serre, 2018), which defined three characteristics to analyze the resilience of urban networks: resistance, absorption and recovery capacities.

c) Urban resilience

We consider that the urban resilience indicator includes all urban dynamics - physical such as buildings (age of buildings, density, functionality) or critical infrastructure - or virtual dynamics such as economic dynamics, evaluated by the creation or disappearance of new commercial properties. For instance, for the critical infrastructures, we measure their influence of the field of action. Critical infrastructure can be defined as the infrastructure which concentrates all the functions which are necessary for the good functioning of a territory and its population (Pescaroli and Kelman, 2017). They are defined “critical” because in a situation of crisis, their potential destruction could weaken all the organization of a territory (Galland, 2010). They may be natural (water supply for instance), built (energy, telecommunication, transport networks, etc.) or virtual (cyber information for example) (Serre, 2018), but none exhaustive list exists. However, they are part of the territory and hence are a precondition to develop methods to assess resilience (Brauner et al., 2018).

We established few variables to understand the urban resilience degree, taking into account critical infrastructures (fire, police, defense forces) influence area, the health access (Norris et al., 2008; Opach and Rød, 2013), the density of social housing (Johansson et al., 2016), the touristic dynamic (Tierney, 2009) and the economic dynamic (creating new companies, keeping old ones).

3.2.2 Turning the concept of resilience into practice

Because of its multiple origin (Alexander, 2013) and its multiple use across disciplines, resilience still struggles today to become clear, operational and part of practical strategies (Weichselgartner and Kelman, 2015). Because of its multiple levels of meaning, interpretation and definition, measure resilience is an important challenge and led to a very little attention from scientific studies to the need of resilience operational indicators (Carpenter et al., 2001). Most of the research that tends to define resilience is based on technical approaches (Lhomme et al., 2013; Serre, 2018, p. 3), particularly around networks and/or critical infrastructures. This is why this research focuses on the need to understand urban resilience in its entirety, in order to understand all the potential resilience of each element that contributes to the construction of the territory, through a precise definition of variables, indicators and treatments that can be reproduced by local actors.

The variables of each indicator were based on an analysis of a scientific review in order to analyze the different social (age of the population, level of education, knowledge of risk, etc.), urban (urban structure, economic dynamics, state of structures, etc.) and technical elements which participate in the territory’s reality. Thanks to the indicators’ methodology, it is possible to explore social, urban, technical phenomena and to determine which area is more or less resilient by a comparative work.

Once the selection indicators work has be done (Fig.3), we chose to use Open Data in order to make this methodology as generic as possible. By this way, the approach will be “*unsurpervised*” (Jovanovic et al., 2018) and reproductible. 90% of the data set is from INSEE or SIREN, French open data website, and 10% are sensitive data from the case study’s territory.

Figure 3: Resilience flow chart – from theory to practice approach

In order to calculate resilience, we chose to study the impact of each variable on overall resilience, as each variable can have a negative or positive effect. What determines this impact is the ratio of the variable to the overall data. As an example, if there is a high rate of houses built between 1970 and 1994 compared to the total of built houses at the IRIS scale, the impact will be negative because such houses are, for instance, more vulnerable to damages and likely economic losses. (Mileti, 1999). For each variable established, we therefore estimated the impact it would have on overall resilience (Cutter et al., 2010). All raw data acquired via INSEE were therefore transformed into comparable ratios using percentages. This standardization was essential to avoid the problems inherent in pooling different units of measurement, since our variables were delineated in a number of statistical units, ranges and scales. Our results ranged from -1 to 1. Once these ratios were calculated, it was necessary to determine their impact on overall resilience. Does this variable have a positive or negative impact on resilience? It was also necessary to consider the potential impact changes depending on the timing of a flood. Usually, scientific studies calculate variables with a linear min-max scaling, a X-min/max-min type (Cutter et al., 2010). But as we wanted to compare several years, analyze the impact of each variable on the global resilience and vary the overall value of the resilience per indicator, we have chosen to use linear regression for several reasons:

- First, linear regression introduces the hypothesis that the values of Y depend on those of X, i.e., assume that knowledge of the values of X predicts the values of Y. We knew the value of the ratio (i.e. the value of the variable), we had to determine the value of resilience. It is therefore a forecasting model and the objective is to minimize the forecast error, i.e. the distance between the observed values Yi and the values Y*i estimated by the relation X+b. This choice also makes it possible to estimate the effect of one or more variables on another by controlling for a set of factors. For example, in educational science, the effect of class size on children's academic performance can be assessed by controlling by the socio-professional category of the parents or by the location of the school. Under certain restrictive assumptions, this effect can be considered as a causal effect. Adapted to resilience, we can therefore determine the effect of the value of the variable (for example the value of the number of people aged 25 to 39), on a potential overall resilience. Indeed, in statistical learning, linear regression is considered a supervised learning method used to predict a quantitative variable.

-Second, the visualization, thanks to the resilient curves, helps into the decision-support process. Indeed, the use of curves graphically expresses the vertical variation of the line for a horizontal displacement of a positive unit.

Therefore, in order to calculate the resilience, we made the choice to use a linear equation of type X+b. The regression line of Y as a function of X introduces the hypothesis that the values of Y depend on those of X, that is to say postulate that the knowledge of the values of X makes it possible to predict the values of Y. It is therefore a forecasting model and the objective is to minimize the forecast error, i.e. the distance between the observed values Yi and the values Y * i estimated by the relation Y * = aX + b. In this case, y= resilience indicator and X= resilience variable. It is said that the variable Y is the dependent variable or variable explained and that variable X is the explanatory variable. The values of X represent a resilience curve, with X0= resi0 and X1= resi 100 which evolve depending on the positive or negative impact of the variable on resilience. These values make it possible to situate the variable on a growth curve or of a decrease in growth. The resi 0 corresponds to the starting point of the curve and the resi 100 to its point of arrival. Each variable is therefore placed on a positive or negative curve, following its impact on the territorial resilience. For example, if we take the proportion of young people in the territory, if this variable is higher than the old people (older than 65 years old for example (Cutter et al., 2014)), we consider that they will be more resilient. Therefore, we can conclude that this variable will increase the global resilience. This definition of the parameters corresponds to a unique form of deviation for each variable, thus making it possible to vary the overall value of the resilience per indicator. This choice can be explained by the will of analyze resilience in a multi-year comparison and an approach using Min and Max (Cutter et al., 2010) (which would not have been similar from one year to another), wouldn't be valid. If the value of the resilience curves is different for each variable, the weighting is 1 for all variables (Holand et al., 2011). This choice of single weighting is explained by the desire to avoid disparities between the variables (Fekete, 2009), some of them being sensitive and subjective (% of foreign people, level of education, etc.).

3.2.3 Spatial and temporal scales

Spatial and temporal scales have an essential role to play into the measure of resilience (Emrich and Tobin, 2018). Indeed, in a interdependent world context, risks have exceeded their previous geographical and temporal limits and therefore become transboundary catastrophes (Ansell et al., 2010; Pescaroli and Alexander, 2016). This new risks, systemic risks, don’t have statistically independent failure anymore but, in the contrary, have interdependent failures because of the interconnected system components. In this case, a localized failure could have unimaginable and potentially disastrous effects and unbounded damages (Helbing, 2013). Indeed, a flood will impact its local territory (major riverbed for instance), but because of the interconnected networks or urban activities, it may exceed the physical limits of the floodplain area. For example, an indirect financial impact (Ansell et al., 2010) of a flood in Paris could impact international relations with New York, for example, on a global scale. A modern crisis is also over classical time dimensions. The terrorist attack on US soil in 2001 is a good example to understand the crisis effects felt on several years at different levels (financial, political, social crisis). A single crisis, composed of several sub-elements, can therefore have effects that can appear at different time scales. In order to integrate this specificity of modern disasters, we have established an analysis with a precise geographical and temporal limit. The spatial scale of analysis is local (Robinson and Carson, 2016) as this scale is easier to work with local actors in order to precisely answer their problems of management facing the risk of flooding. Thus, urban projects at the neighbourhood or macro-lot levels will be analysed in terms of their contribution to the intrinsic resilience of the neighbourhood. This scale of neighbourhood or urban project, so far little practiced (Balsells et al., 2015) allows to act directly on the territory, to innovate and to experiment new urban risk strategies. As a result, the main scale of study chosen to assess urban resilience is as accurate as possible, i.e. at the IRIS scale. This scale is located between the 200 × 200 grid (INSEE) and the District Council. Each computation is therefore multi-scalar but also multi-temporal. As the disaster is limited to a specific temporality, with a beginning and an end (Jigyasu, 2005), resilience risk management has to integrate the temporal reality. Indeed, the resilience to risks must be imagined according to a multi-temporal paradigm, to act before the crisis, i.e. to anticipate (urban planning); and to recover from the event (to rebuild, to restore an activity, to adapt) as a continuum (Emrich and Tobin, 2018; Serre and Heinzlef, 2018).

3.3 Avignon pilot site

As we said, we wanted to operationalize urban resilience to a local scale, in order to make this concept clearer and easier to use. Concrete work on resilience cannot be envisaged without a specific study area and subject to the risk of flooding. It turns out that the Provence Alpes Côte d'Azur region suffers from the consequences of flooding every year. Each event raises the question of the territorial strategy to adopt with regard to events that will be increasingly frequent and severe according to IPCC forecasts. However, elected officials, local leaders and decision-makers are sometimes powerless over the strategies of territories to be developed both in the short term and in the long term. At the same time, urbanism operations continue, without properly integrating this dimension of risk, and these operations are in fact long-term. Given the regional context linked to floods and urbanization issues, it is urgent that local decision-makers and planning professionals can therefore integrate resilience strategies into their planning choices, their urban programming choices and their architectural choices. It is therefore to respond to these tensions and uncertainties that a collaborative approach with the actors of the city of Avignon has been put in place, in order to co-construct a resilience strategy.

3.3.1 Collaborative Approach to implementing resilience concept

Concrete work on resilience cannot be envisaged without a specific study area and subject to the risk of flooding. The current research project is based in the Provence-Alpes-Côte d'Azur regional area (Fig.4) (PACA), and more precisely in Avignon (Fig.5), city subject to flood risk (Rhône-Durance confluence). Well known for either its flash flood, usually unpredicted, fluvial flood (the unpredicted Durance river), the area is submitted to flood uncertainties.

Figure 4: Map of the south of France, source: Géoportail

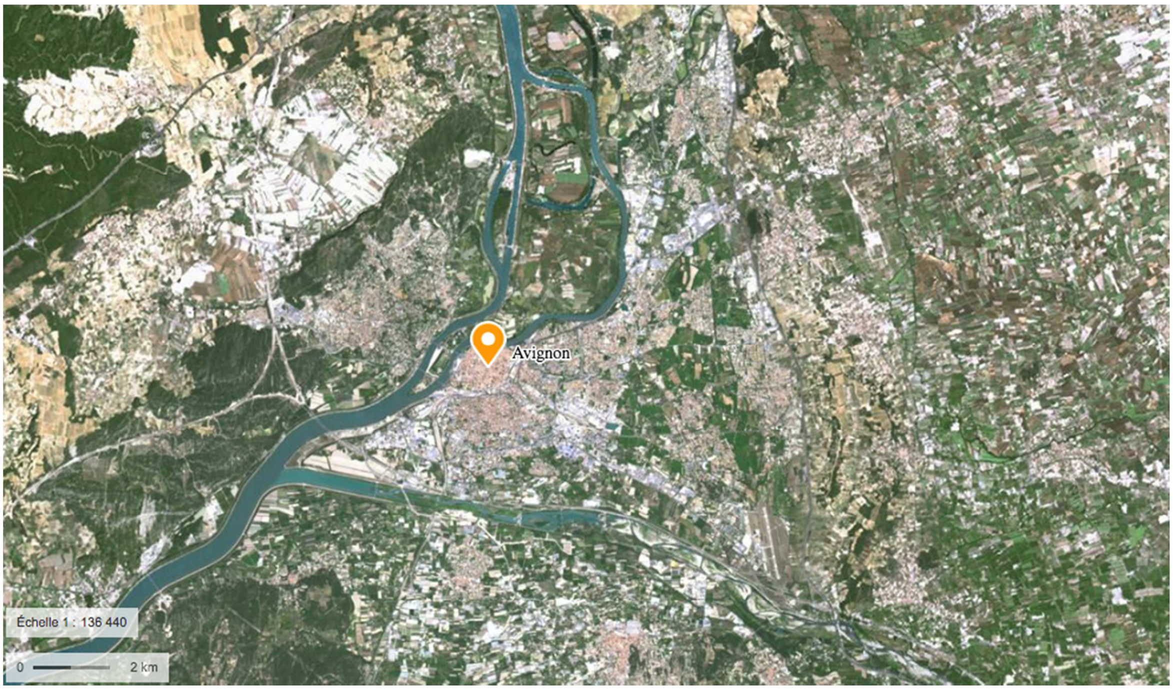

Figure 5: Avignon's localisation, source Géoportail

In terms of stakes, the Preliminary Flood Risk Assessment on the Avignon Flood Risk Territory (TRI) estimates:

- about 400,000 people the permanent population in flood-prone areas (in the envelope approached potential floods) - 67% of the estimated total population of the TRI,

- and about 185,000 jobs in flood-prone areas - 76.2% of the number of jobs

total identified within the TRI. (Directive Inondations Bassin Rhône-Méditerranée, 2014)

In 2010, it was estimated that in Avignon 768 inhabitants and a maximum of 606 jobs are affected in the case of a frequent flooding scenario and 73820 inhabitants for a maximum of 72198 jobs are affected in the case of an extreme scenario (Fig.6) (Direction régionale de l'Environnement, de l'Aménagement et du Logement (DREAL PACA), 2014). With important, but rare (the latest important one was in 2003), floods, the risk culture, the prevention strategy, the resilience operationality are questioned in Avignon.

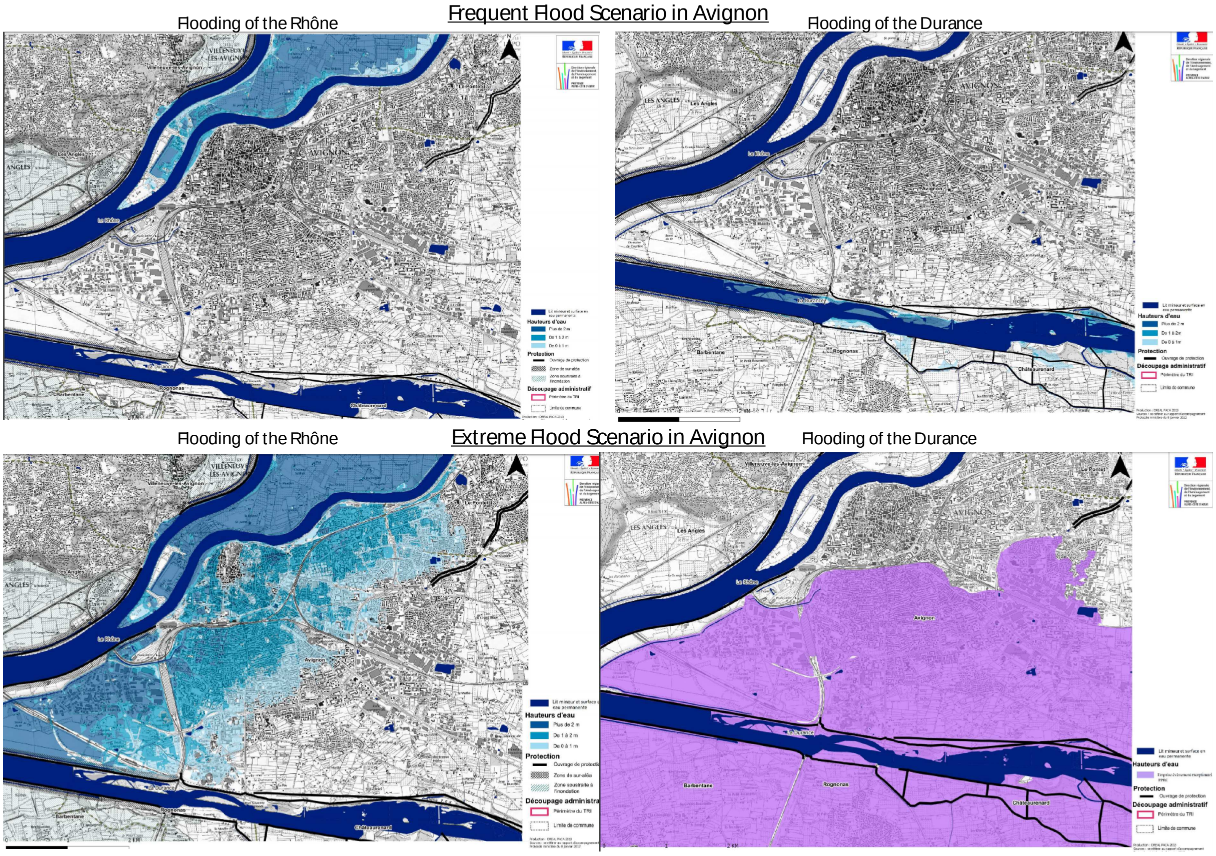

Figure 6 : Frequent and Extreme Flood Scenarios in Avignon scale, inspired by © DREAL PACA

Facing exponential physical and social issues, the City needed a decision support-tool in order to integrate and adapt the resilience concept into urban practices. This need is represented by a collaborative work, a partnership with the urban and technical services (GIS) of Avignon. The goal of collaborative approaches is to structure a complex problem in a transparent manner (Mustajoki et al., 2004) to enhance mutual understanding of stakeholders and consensus. The co-construction of expert and local knowledge can reduce complexity, take into account the interests, the needs and point of views of everyone, but also promote acceptance and appropriation of solutions to facilitate decision-making. The implementation of urban resilience as a combination of good management of resources and services, coherent urban planning and taking into account the risks and possibilities of adaptation is also part of the need to involve multiple stakeholders (Serre and Heinzlef, 2018; Toubin et al., 2015). Furthermore, the main goal of this project is to include the concept of resilience in the very beginning of any urban project and strategy. In this perspective, to build a vision co-constructed by the different actors makes more legitimate and relevant the reflection on a territory (Desthieux, 2005; Terrin, 2014). More specifically, on such a complex subject as urban floods with so many uncertainties, a collaborative approach enriches knowledge and perceptions on a complex and abstract topic and it sensitizes and motivates each person who has and will have a role to play (Toubin, 2014). These characteristics facilitate the implementation of adaptation strategies (Frommer, 2011).

In this case study, the collaboration is particularly illustrated by the exchange of so-called sensitive data, although 90% of the data are Open Data (INSEE or SIREN), and the co-construction of the tool by using a Data Management Engine (ETL), the Feature Manipulation Engine, used by the GIS service of French cities. By paying particular attention to using the same processing tool as French communities, the accessibility of the tool is reinforced, as it does not require specific learning that would lengthen access time but also considerably reduces its use. Maps and analysis are done with QGIS.

3.3.2 Main results of the case study

Preliminary resilient results illustrate a potential of resilience independently of a specific flood scenario (level of water, precise temporality, material or human losses) but following a disaster temporality – before, during and after a crisis. The indicators allow to independently map each variable and each indicator (Fig. 7, Fig. 8), but also to condense them to create an overall index of resilience. For instance, Figure 7 has been built thanks to social resilience variables, as populationon structure data (age of population, INSEE data); professional situation (INSEE data); habits (INSEE data); education (INSEE data), etc. These variables have been aggregated in order to map a global social resilience indicator for a scenario "during crisis". Following the same methodology, Figure 8 has been built on urban resilience variables such as buildings' characteristics (construction date, SIREN data), location of critical infrastructures (SIREN data), economic dynamics (business creation and closure, SIREN data), etc. These variables have been also aggregated in order to map a global urban resilience indicator for a scenario "during crisis". The local scale chosen as well as this dissociation between variables and indicators makes it possible to analyze precisely the components that accentuate or diminish the resilience.

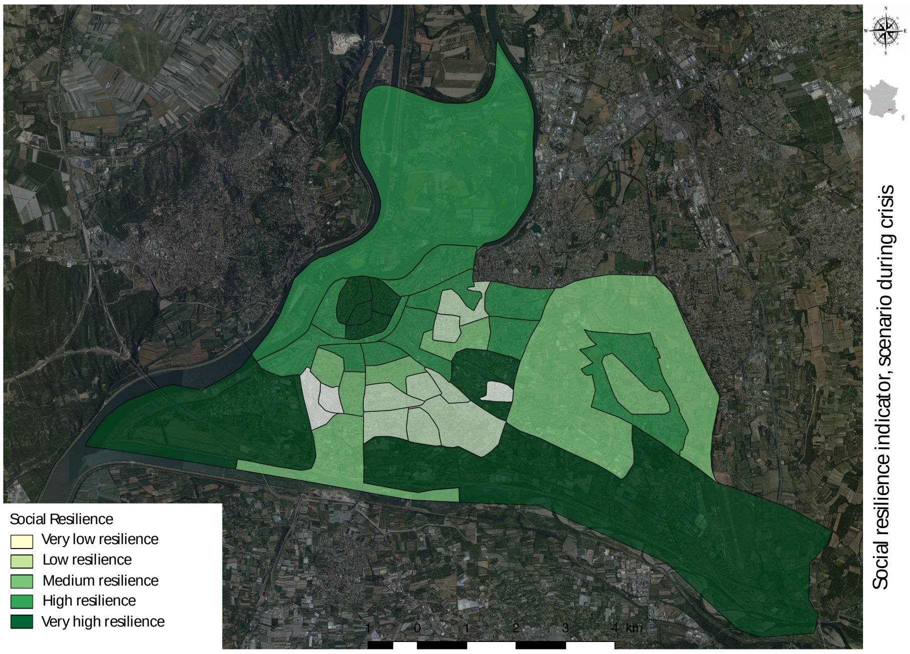

Figure 7: Social Resilience- Scenario During flooding event

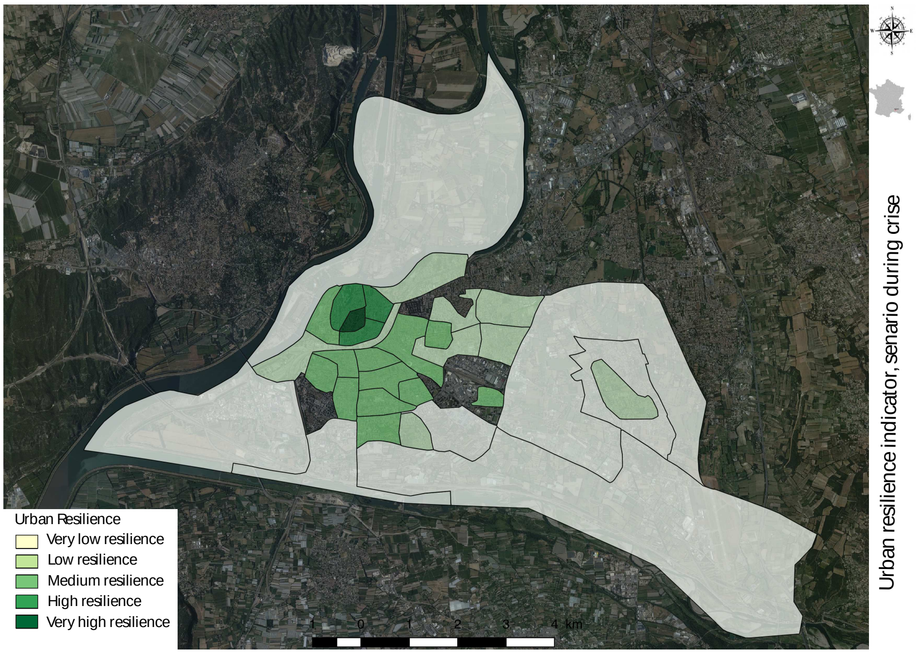

Figure 8: Urban Resilience- Scenario During flooding event

To interpret our results, we created histogram in order to analyze the statistical repartition of data (Fig. 9, Fig. 10).

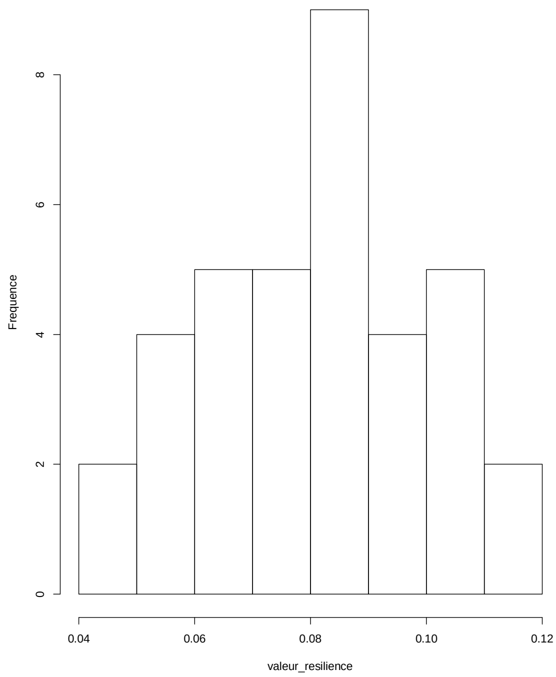

Figure 9: Histogram Social Resilience- Scenario During Crisis – High propension of 0.08 value (high medium value of social resilience)

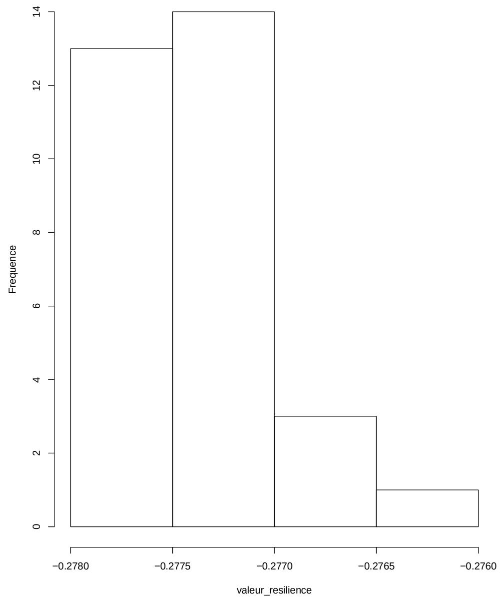

Figure 10: Histogram Urban Resilience- Scenario During Crisis- high propension of low urban resilience value

We can see that on a scenario “During Crisis”, there are more than 8 occurrences of the value 0,8, an average social resilience, unlike the urban resilience whose average is very low, under the step of medium resilience value. It seems that during a crisis scenario, social resilience is higher than urban resilience. These results may lead to a change of mind, of consciousness of urban managers and policy makers.

These maps are showing an objective resiliency, independently of a specific risk. Finally, with the idea of measuring the existing resilience but above all the impact of future floods on the dynamics of the city, it was interesting to locate spatial projects spatially during the period 2015–2020. These are as varied as the rehabilitation of some roads, as the creation of a tram line or new eco-neighbourhoods, but each of them participates in a structural and landscape renewal of the city. The next steps will be to apply these indicators on a smaller scale, the urban project scale, in order to advice and test these results to create a resilient urban project.

4. Discussion

The first Avignon results show that the intramural remains preserved by the flood management measures. Neighborhoods such as Barthelasse in the North or Courtine in the South-West are both neglected, unoccupied and little connected to urban dynamics. In case of flood these neighborhoods are vulnerable and of low priority. These results must therefore be put into perspective with the city's guidelines for urban planning by 2025. The Courtine district in particular is subject to an urban renewal project and will be our first case study. Indeed, the next step in our research is to translate the methodology into urban projects. The objective is to analyze the risk strategy taken into account by urban renewable projects. The challenge is to adapt resilience indicators built at the community level and transfer them to the urban project scale. In parallel with this step, we would like to test the holistic methodology on other cities of the PACA region, Cannes, but also on the French territory. Since 90% of the quantitative data is in Open access, it is possible to adapt this methodology to other territories, at least on all French cities, which are using INSEE data set. Thus, comparative work could lead to an exchange of feedback between different territories which could lead to a French resilience index. Furthermore, the choice of free-use tools or tools used by French collectivities makes the tool more accessible to urban services. Therefore, this methodology provides a holistic approach to analyze the resilience potential of an urban system. While the concept of resilience remains imprecise and subjective, this work allows to perceive resilience characteristics that a territory must develop.

The fact that this tool is co-constructed makes possible to directly integrate the needs and approaches of city managers. Unlike some case studies of resilience measurement (Fox-Lent et al., 2015; Serre et al., 2016, p. 3), this study does not apply its methodology *a posteriori* to a territory subject to a given risk, but starts by considering the integration of the specificities of the territory and especially its governance, a necessary step in a collaborative and participatory decision-making tool. The tool is therefore more in line with urban planners' risk practices and strategies. The concrete application on Avignon’s territory underlines the feasibility and usefulness of this kind of approach regarding the growing need of communities to acquire knowledge and a concrete tool in order to better understand resilience concept. The concept of urban resilience refers to multiple, transversal and interpretative issues requiring a transdisciplinary approach that allows the different actors of the city to be integrated from the design phase to the strategies of resilience. Recognizing by this very fact that there cannot be a single and correct answer to the question of urban risks, systemic and collaborative approaches make it possible to formulate and respond to the difficulties encountered by putting into perspective the different academic and practical knowledges of the actors. Moreover, this collaborative work guarantees acceptance and appropriation of a concept that is still abstract on many points.

The fact that each indicator and variable is measurable independently of each other makes it possible to point out the limits and fragilities of the territory. As a result, it is easier to advise planners on the measures to be taken to better prepare the territory for a crisis. These results are already used within the community, the city of Avignon thus having a new database of social resilience at local scale. With these new data, the city is creating a decision support tool to influence urban renewal projects to analyze the quality of social and urban life. The combination of these results should be of interest in understanding global resilience and building a strategy to increase urban capacity to cope with floods. This methodology could support decision-making by highlighting which characteristics or programs could enhance or decrease urban resilience.

Despite the significant contributions of this research, we faced a few limitations such as the genericity of the indicator of social resilience or genericity at the international level. Indeed, if 90% of the data is in open data, 10% are composed of answers to questionnaires, or from sensitive data belonging to the community. These data being non-reproducible, two conclusions are possible. It is either possible to leave out the variables that require these sensitive data, the representativeness of the resilience could not then be the same, or it is then necessary to accompany this methodology by a permanent agreement with the partner cities. A personal investment is then the condition *sine qua non* to acquire these data. With regard to international genericity, it is necessary to study data in free circulation in each state. The quality and the ease of obtaining them can then vary.

Another limitation concerns the tool used by managers, the Feature Manipulation Engine (FME). Although used on a large scale in French communities, this tool still pays off. Our next step is to study the feasibility of creating a QGIS plugin that would directly integrate our computer script and resilience processing.

The analysis, from the data transformation to the mapping of the resilience would thus be only on a tool in free circulation, free and downloading-free.

Finally, the last limit of a work that aims to clarify and operationalize resilience, as mentioned by (Bakkensen et al., 2017), is the bias in the definition and construction of measurement indicators. If there is not yet enough perspective and empirical validation when analyzing resilience over a long period of time and as a *continuum*, these studies may be more a useful screening-level tool in order to analyze, identify, resilience and vulnerability potentialities for further investigating and modelling in scientific communities than a final decision support tool for urban managers.

Although the concept of resilience is still vague and imprecise in many respects, the international work of various researchers and risk managers allows revealing characteristics that a territory must perform to improve its resilience level. This work has chosen to highlight the capacities inherent to a territory that can participate in the preparation, survival and relaunch of activities on a territory after a disaster, capacities that are declined according to the different temporalities of a flood. The study was thus able to develop an analysis adapted to the multi-temporal form of a crisis. This study should eventually make it possible to acquire a complete index on urban resilience, an index that is fully relevant to the urban needs of managers (The Rockefeller Foundation, 2015). This research also proposes a holistic methodology to improve urban resilience. It is based on a set of indicators constructed jointly by scientists and urban planners. This approach underlines the importance of having an integrated reflection on the concept of resilience, adapted to urban territorial complexity. A territory is composed of structural characteristics, buildings, interactions, environment, infrastructures, networks, economies, policies and populations. Applying the concept of resilience to urban dynamics must take into account all these elements and all the actors of a territory. Our methodology proposes to respond to this challenge by these indicators measuring inherent resilience and by collaborating with decision-makers. This research therefore highlights urban characteristics that can improve urban resilience and advises planners in their future decisions.

This research therefore proposes an integrated and holistic approach to resilience, both in the design of measurement indicators and in the collaborative approach methodology. The next lines of interest would be to apply the indicators constructed at the scale of the city to the scale of the urban project. Indeed, as mentioned in the article, the local level may be the key to integrating resilience into risk management strategies. Our next step is therefore to rework the variables of our indicators in order to apply them to the urban project scale, probably at a 200x200 grating scale. This future step would determine whether these new urban projects are contributing to the development of urban resilience, both at their own scale (or even at the neighborhood level) and at the community level. In addition, testing the methodology in other territories (French cities such as Cannes, or internationally) would validate and generalize the methodology.

After having built a methodology as holistic as possible, the tests on the territory of Avignon proved the usefulness of an integrated and global approach. Through the interest of the community for research on resilience, through their involvement in the exchange of data, through their socio-economic partnership and finally through the use of the very first results of the study, we can already say that the study provides interesting and relevant answers on the issue of resilience and its concrete application on flood-prone areas

5. Conclusion

This paper proposes a holistic methodology to improve urban resilience. It is based on a set of indicators built conjointly between scientists and urban planners. This approach emphasizes the importance to have an integrated reflection on the resilience concept, adapted to the urban territorial complexity. A territory is composed by structural characteristics, buildings, interactions, environment, infrastructures, networks, economies, politics, and populations. To apply a resilience concept to urban dynamics must take into account all these elements and all the stakeholders of a territory. Our methodology proposes to answer this challenge by its indicators measuring inherent resiliences and by co-working with decision-makers. This research highlights urban characteristics which may enhance urban resilience, advising urban planners in their future decisions. This research-practice partnership underlines the growing need for territories to acquire strategies and tools in order to operationalize urban resilience, but also demonstrates the feasibility and the usefulness of this kind of approach. In support of this argument, the city of Avignon already uses these new data set in order to build an urban well-being indicator. Moreover, following a request made by the Director General of Services of the city of Avignon, a demographic and social atlas of the community is ongoing, thanks to resilience data set.

To conclude, the application in Avignon attests that the tool is operational and that collaborative approaches are an essential issue to assess resilience. This research emphasizes the idea that resilience must be a part of urban planning in order to improve risk management. However, this study analyzes inherent urban resilience capabilities, without taking into account a precise water level. It would be interesting in the next steps to test and adapt it to precise water levels. Furthermore, to test this methodology on other territories, national (Cannes, France) or international (Mons, Belgium) would probably lead to an adaptation of these resilience variables. Yet, once this comparison work will be done, it would be innovative and challenging to provide a comprehensive index on urban resilience, index which makes sense in the international approaches and needs.

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