Are siren alerts effective tools for risk management in France?

Johnny Douvinet[1], Anna Serra-Llobet[2], Esteban Bopp[1], Matthias Kondolf[3], Mathieu Péroche[4]

[1] UMR ESPACE 7300 CNRS, Avignon University, Avignon, F-84000, FRANCE
[2] Institute of International Studies, University of California Berkeley, 94701, USA
[3] Department of Landscape Architecture & Environmental Planning, University of California Berkeley, USA
[4] UMR GRED, University of Montpellier Paul-Valéry III, Montpellier, F-34000, FRANCE

Correspondence to: Johnny Douvinet (johnny.douvinet@univ-avignon.fr)

Abstract. *Alert sirens have been an important component of the emergency alert system in France since the mid-20th century, intended to warn the population in the event of sudden of rapid-onset hazards (be they natural hazards such as flash floods, industrial accidents, or terrorist attacks). However, for sirens to work effectively, the authorities much use them, and people must both hear them and understand their meaning. Thus, we assessed the effectiveness by mapping the distributions of sirens across France, overlaid on detailed populations maps, and found that large urban areas are well covered by sirens, while rural areas poorly. From interviews, we found that authorities are often reluctant to issues alerts because of potential negative reaction if they issue a false alarm. Our surveys of hundreds of residents showed that most residents trusted sirens (more than other potential means of communicating impending risk), but many did not recognize the siren sound nor correctly interpret its meaning. We studied the behaviour of people in response to a siren alert during a civil security exercise and found the most people simply continued their prior activities, even when he clearly heard the siren, and even when they later acknowledged steps that should have been taken to avoid danger. The current siren system in France (NAN) will be replaced by a new (SAIP) effective 2022. While sirens can be important components in emergency management, we recommend that the gaps in their coverage of the population be addressed, and that sirens be augmented by other technologies such as cell-phone alerts (CBC or Location-Based SMS).*

1. Introduction

1.1. Background

As symbols of traditional alerting disseminators (Sorensen and Sorensen, 2000; Sättele et al., 2016; Mathews et al., 2017; Goto and Murray, 2020), sirens are intended to alert people to danger related to sudden or rapid events (earthquake, terrorist attack, tsunami, flash flood). Sirens are still the only means of alerting an entire population, day or night (Zunkel, 2015; Mathews et al., 2016; Landry et al., 2019), provided sirens are close enough to be heard by all (Paul et al., 2003). Sirens are implemented to produce collective but also individual reactions (Cazanave, 2010). They also allow authorities to quickly advise people and to implement countermeasures in a short time (Douvinet, 2020). Sirens do not give time for hesitation and do not provide a comprehensive message (Reed et al., 2010; Zunkel, 2015; Mathews et al., 2016). Their effectiveness is based on the implicit assumption that the population understands what is expected from them in the event of a siren alert (Linsday, 2011). For example, in regions of North America prone to tornados, a siren during tornado season is widely understood to indicate an impending tornado, and it is widely assumed that the alerted population understands the need to take shelter. These "outdoor warning sirens are a unique part of the tornado warning dissemination process, since one siren may alert thousands of people, even if they are not watching or listening to any type of commercial broadcast" (Coleman et al. 2011). However, where the population is less informed about possible risks (e.g., from flash flooding) or where the siren may be activated for more than one risk, they may be less effective and the behavior expected from the population (stay, leave,…) more ambiguous.

In France, sirens have been deployed since the end of World War II (DGSGCG, 2013; Vogel, 2017). Previously, in the Middle Ages, priests were the only ones authorized to ring the church bell to alert the local population (Maillard, 2001). But this "power of alert" was transferred to the services of the State after the end of World War II, as attested by an order signed in 1954 by General de Gaulle. It led to the creation of the National Alert Network (1954-2010), based on electronic sirens and deployed to alert people in the event of aerial threats. A few years later, the order of January 7th 1959 defined the responsibilities of the authorities responsible for the NAN activation (mayors and prefects). The decree of May 8th, 1973 expanded the use of NAN sirens in the event of nuclear, bacteriological and chemical risks, in relation to the development of the nuclear program during the 1970s in France. In 2010, a total of 4,291 NAN sirens were deployed over 2,647 municipalities. But due to their age and increasing occurrence of failures in siren activation, in 2010 the French Ministry of Interior began to establish a new network, SAIP (Système d'Alerte et d'Information des Populations in French), with a target date of 2022. The siting of new SAIP sirens was guided by 3 objectives: 1) to connect sirens together in a single network, using encrypted email messages and complying with current security standards; 2) to activate the 5,531 sirens with a unique software (developed in 2012-2014 by Airbus Defense and Space, and successfully tested and verified in 2015); 3) to improve the location of sirens, to reach a maximum number of people in 1,743 risky areas.

1.2. Research focus

In France, authorities still have confidence in sirens despite many limitations attested in the scientific literature (Garcia and Fearnley, 2012; Beccerra et al., 2013; Pappenberger et al., 2015; Daupras et al., 2015; Douvinet et al., 2017), and in National Senate reports (Vogel, 2017; Courteau, 2018). Despite many changes in the Ministry of Interior over the past 60 years, sirens still receive most of the funding allocated to alerting the population in France (83 million euros in 2010). Testing sirens (once a month in France) serves to remind residents the role of sirens (Creton-Cazanave, 2010), and a 2010 study indicated that 22 % of the French population well recognized the sound of alert sirens (Deloitte, 2014). However, the doctrine for activating sirens enacted in 1959, remain largely unapplied in mostly risky situations (Vogel, 2017). Over a period of 60 years, sirens have only been used four times: 1) during the 2014 Vidourle flash floods (3 deaths); 2) during the 2017 wildfires around Vitrolles, near Marseille (no victims, but 2,400 burnt areas and an estimated cost of 1.3 million euros); 3) during the 2019 industrial fire in Lubrizol, near Rouen (but only 2 sirens located in less than 500m. around the site); and 4) during the 2019 flash floods near Cannes (7 deaths). Nonetheless, there have been many dangerous situations in which sirens have not been activated, such as the 1969 dam failure in Malpasset, the 2005 landslides in southern France (Boudou, 2015), or the flash floods in Nîmes (1988), Vaison-la-Romaine (1992), Draguignan (2010), Cannes (2015), Trèbes (2018), or north of Nice (2020). And considering all the dangerous situations that could require siren activation (i.e. 3,226 municipalities have been the subject of a naturel disaster decree per year for floods over the period 1982-2018 for example; CCR, 2019), there has been very little use of the procedure. In part, this may reflect a reluctance to use sirens because of liability that may arise from a false alarm (such as in Bastia in 2005, face to a probable tsunami) and the related administrative penalties (2 years imprisonment and a fine of 30,000 euros) don't help either.

Authorities have tended to underestimate the benefits of other alerting tools (radios, SMS, social digital media, etc.). As a good example, the SAIP® smartphone application (which bears the same acronym as the future SAIP project for the modernization of the siren network), set up 8 days before the European Football Cup in June 2016, required a relatively light investment of 300k euros. Over a two-year period, the application was used only four times. In one case, the 2016 terrorist attack in Nice, the alert came 3 hours after the attack. In another case, the application sent a false alert (for the false attack on the Louvres museum in September, 2017). The French Ministry of the Interior finally decided to cancel the application on May 28th 2018, considering that it provided more disadvantages than benefits. The other approaches like Cell Broadcast (CBC), Located-Based SMS (LB-SMS) or alert tools related to the Internet of Things like connected watches or embedded objects such as cameras, etc.) have never been used in France, but have been used for alerts in other countries (Huang et al., 2010; Whitmore et al., 2015). These techniques can include informative messages to complement alarms specifying the nature of the dangers and recommending actions (Leo et al., 2015; Zunkel et al., 2015), thereby empowering the population by increasing their understanding of the threat (Becker and Bendett, 2015; Fajardo and Oppus, 2009; Jagtman, 2010) and facilitating good decisions during alarms (Bean et al., 2016; Zhang et al., 2004).

However, underlying the reliance on sirens is an assumption that people are able to identify, recognize, and deal with hazards or threats, whatever their origins or speeds. Previous studies have shown that few individuals are able to identify and understand dangers only by hearing the alarm (Lutoff et al., 2016; Daupras et al., 2015). The sound of the siren is "one sound on top of others" (Dedieu, 2009), and is added to the ambient noise, particularly in urban areas. Decision-making is complex under stress, because it involves cognitive and perception barriers (Becerra et al., 2013, Creton-Cazanave, 2010; Daupras et al., 2015). The interpretation of the sound depends on the knowledge and past experiences of each person concerned, but also on the training and information addressed upstream (CEPRI, 2011). In addition, these elements play a key role in the decision time, before the reaction time (Colbeau-Justin, 2002, Daupras et al., 2015). It is impossible to produce a signal that triggers automatic behaviors (Roux, 2006) and the adoption of reflex takes time. A clear difference remains in behavioral skills, between "I know what to do if something happens" and "I actually apply the instructions when a danger occurs" (Weiss et al., 2011). These lags prevail, independently of the type of the risk involved.

1.3. Main goal

In light of all the limitations mentioned above, the main goal of this paper is to answer the question: "*Are siren alerts effective tools for risk management in France?*" To answer this question, we have analysed three main factors related to (1) technical aspects regarding the current and future distribution of sirens, (2) institutional and governance aspects related to the authorities in charge of activating sirens, (3) perception and behavioural aspects regarding the population targeted to receive the siren alerts. In particular we wanted to answer the following questions:

1. *Where are the sirens of the National Alert Network (1950-2022) located in France? Where will the sirens of the future Population Alert and Information System (SAIP) be located in France? How well do they cover the targeted population, and finally can we observe changes, and why?*
2. *What is the role of sirens in management strategies in France? When and how are sirens used in France, and especially by the authorities? Are they really useful for these risk managers?*
3. *Do people recognize the sound of sirens? Do people understand the nature of the danger if a siren sounds?*
4. *Do people trust sirens? Do people trust in other alerting tools like smartphones applications or SMS?*
5. *Do people understand what is expected from a siren alert? Do people adopt appropriate behaviors after a siren alert?*

The data and methods used to answer these questions are described in section 2.

2. Data and methods

The results presented in this article are original, but draw upon prior researches conducted over the last 5 years. To answer the main research question, we applied methods that combine quantitative data produced with a Geographical Information Systems (GIS), with quantitative and qualitative data obtained from a few questionnaires and surveys. Figure 1 summarizes all the methods used to answer the research questions. First we created a GIS to provide an overview of the NAN coverage at national scale, and the SAIP coverage in the PACA region. We assessed factors explaining the location of the new siren network, identified non-covered areas, and quantified the future covered population. We have developed an in-person questionnaire to evaluate the functionality and usability of the alarms for the authorities in charge of "turning them on" (the prefects and the mayors), as well as questionnaires and surveys for the public to evaluate the effectiveness of the alarms in relation to perception and behavioral aspects. Finally, we consider these results obtained in light of how alert systems in the USA and Belgium have evolved, and conclude with recommendations to improve the effectiveness of sirens for risk management in France.

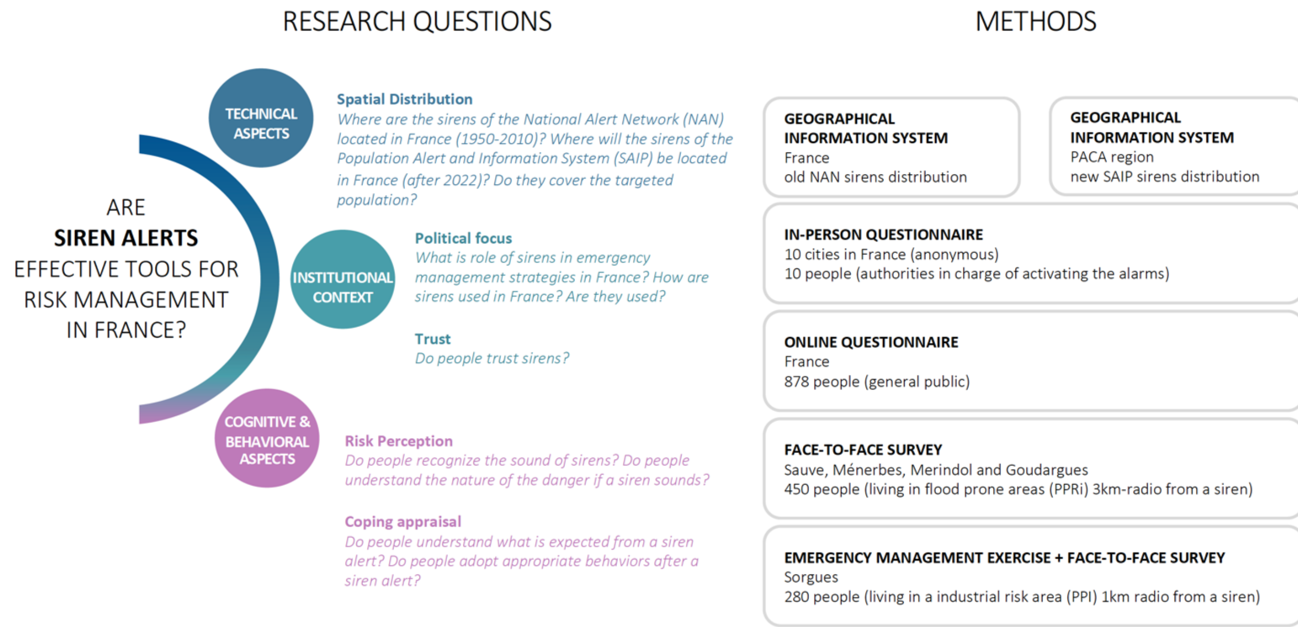

Figure 1. Research Questions and Methods

2.1. Analysis of the spatial distribution of the sirens in France

2.1.1. Analysis of the distribution of the NAN sirens

As of 2010, the NAN network encompassed a total of 4,189 sirens spread over 2,666 municipalities in continental France in 2010, intended to alert the population to all risks from eight natural and five industrial hazards identified by the French Ministry of Environment. Of these, 1,071 sirens (26 %) were mounted on top of town halls, 573 (14 %), on the roofs of churches and 28 % on other structures. Another 32% were mounted on poles placed along streets or buildings. The NAN network used different modulator-style sirens that broadcast the same sounds but with different intensities (ranging from 114 dB to a maximum of 126 dB), and with various power (from 1 up to 7kW). According to suppliers, the sirens have the ability to resonate sound in all directions at a maximum distance of 3 km with a power of 7 kW. To estimate areal coverage of the siren alert, we assumed a 3 km radius of coverage. Due to the confidential nature of data, especially in military areas, only siren location data were available, without information on power or installation date. Thus, our assumed 3-km radius for each siren would be an overestimate in many cases. To estimate the population within the areas where sirens were audible, we used the municipal population census of 2014 and the urban typology (provided by INSEE, 2010) for first estimates. Municipalities are not an ideal choice as neither the patterns of location of people at finer scale, nor the influence of environmental factors in the sound propagation (Mathews et al., 2017), nor mobility of people throughout the day are considered. But for this initial assessment, we could identify which municipalities were equipped and which were not, and we propose a rough ratio to discriminate over- and under-endowed municipalities. This is the first time that the theoretical population covered by the NAN siren network has been quantified at the national scale.

2.1.2. Analysis of the distribution of the NAN & SAIP sirens in the PACA region

The distribution of the future SAIP network (completion scheduled for 2022) is based on the concept of "risk area", taking into account no only population density, but also the speed of the process-creating hazards, the nature of the risk, as well as the location of sirens depending on specific circumstances (concentration of chemical industries for example). Delineations of risky areas were validated by the Ministry of the Interior, dividing the distribution of sirens into two priority levels. 640 high-priority areas are covered in 2020 by 2,832 sirens (45 % of which are inherited from the older NAN). 1,103 lower-priority areas will be covered by 2,699 sirens by 2022 (table 1). Once again, due to the confidential nature of databases, we cannot present the map expected for the future SAIP network over all of France. However, we have the agreement to address such an analysis in the PACA region of southern France, covering 31,400 km^2, with an estimated population of 5,029,214 inhabitants (INSEE, 2018). The population has doubled since the 1960s (2,414,958 inhabitants in 1954) thanks to tourism, immigrants from elsewhere in France drawn to the pleasant climate, and foreign immigration. 2/3 of residents live in major urban cities (Marseille, Nice, Toulon, and Avignon). 80 % of the population is located in coastal areas, while mountainous and rural areas in the Alpine interior regions are sparsely populated.

Table 1. Number of sirens in the SAIP project planned for 2022 (data from Vogel, 2017)

Priority level	Number of risk areas	Number of sirens in the SAIP project				
		NAN sirens	New sirens	Municipalities' sirens	Chemical risk areas sirens	Total number
Level 1 (2017-2020)	640	1,286	932	614	0	2,832
Level 2 (2020-2022)	1,103	191	854	533	1,121	2,699
Total (after 2022)	**1,743**	1,477	1,786	1,147	1,121	**5,531**

We obtained the SAIP siren location points from by DGSCGC, in a shapefile format. We opted to use the square mesh population density (with an aggregation at 200m) in this model (INSEE, 2014) to improve the previous estimates, and we calculated covered population using different (1, 2 and 3km) buffers around individual sirens. If a square mesh is partially included in the radius of a siren, the population of the mesh is proportional to the area of the related circle. These second estimates permitted comparisons between SAIP and RNA at regional scale, although at fine scales the differences could not be specified precisely (Mathews et al., 2016; Goto and Murray, 2020). The use of buffers requires mastering the sound propagation, but this depends on various factors like the strength and direction of winds, temperature, air density, nature of materials used for construction or the ambient sound in urban areas (Zunkel et al., 2015; Mathews et al., 2017). While the audibility distance for a siren with a power of 7 kw is considered to be up to 3 km, sirens may inaudible beyond a distance of 800m from the source point even under ideal conditions, and much less for weaker (1 kw) sirens. Energies between 2 sirens can be disturbed if they are not far enough apart: for example, for a 4-kw siren the spatial distance needed to be respected is 2.1 km in a calm urban environment, while 0.57 km in a densely urban area (Deloitte, 2014).

2.2. Analysis of the institutional context

2.2.1. Assessing use of sirens by authorities

We administered in 2020 a questionnaire (S1) to prefects and to several actors representing mayors of 10 authorities in France to better understand the place of sirens in their emergency alert strategies. Four of participants were recruited via the Ministry of Interior, the other via scientific and operational relations. All the participants gave their consent prior to taking part in the study, on a basis on anonymity, and we followed requirements of the French RGPD law (2016). The questionnaire focused on 4 topics: the organizational objectives (what were the objectives of sirens and which steps must be undertaken for their use?), the alerting structure (how does the approval process work and who triggers the siren?), the tools actually used (for which hazards sirens are used, and did the authorities use them?) and the operational culture (how efficient are the sirens and what factors lead to the activation?). We analyzed here responses coming from authorities with a view towards interactions between each topic, and identified gaps and benefits related to the future SAIP network.

2.2.2. Assessing public trust in sirens

Another sample (S2) involved 878 persons (441 women and 434 men), aged 18-80 years old (M=39.90, SD=14.81), who completed an online questionnaire in 2019. All the participants gave their consent prior to taking part in this research, respecting the RGPD protocol (European Directive). Participants rated from 1 to 10 how much they trusted difference forms of alerts, including sirens. Given the online and blind dissemination of the questionnaire, representativeness was not sought. The profile of the 878 collected answers indicates there is an over-representation of higher-grade professional occupation (+29.5% compared to the number of higher-grade professional people overall France) and students (+11.0%). There is an under-representation of retired people (-18.6%), lower-grade professional occupation (-10.6%) and people with no professional activities (-9.2%). More interestingly, the participants present different ages (138 18-24 years old, 321 are 25-39 years old, 247 are 40-54 years old, 122 are 55-64 years old, and 50 > 65 years) and such a repartition approaches the global repartition of ages in France (INSEE, 2014). On the other hand, 508 persons (61%) belong to a large urban area, and the number of persons is homogeneously divided according to other urban areas (128 in small urban areas, 118 in rural areas and 124 in medium urban areas).

2.3. Analysis of behavioural aspects

2.3.1. Assessing public understanding of sirens

Another sample involved 450 persons surveyed face-to-face (219 women and 231 men), aged 19-88 years old (M=52.57, SD=13.85). All respondents lived in recognized flood-prone areas (namely the "blue zones" in the PPRI, *Plan de Prévention du Risque Inondation* perimeter in French) within a 1km-radius around a siren. We conducted surveys in Sauve, Ménerbes, Merindol and Goudargues, four small cities presenting similar characteristics in terms of population and flooded areas (Gisclard, 2017). We asked respondents to identify the sound of an alert siren played from a recording, and if recognized, asked them what actions were indicated. We analyzed these responses with statistical tools, for each sample separately. The face-to-face survey showed an over-representation of aged population (+19.5% compared to the average population for these municipalities in 2014) and retired people (+ 14.1%), whereas an under-representation for higher-grade professional people (-21.3%) and young people (-8.4%). Thus, we did not aggregate the data as they referred to different spatial, social and temporal contexts.

2.3.2. Documenting public response to sirens

We took advantage of a siren test during a civil security exercise carried out with the Vaucluse Prefecture in December 2016, in Sorgues (a small city located near Avignon). We administered a questionnaire to assess the perception and understanding of the alert to 280 persons (147 women and 133 men), aged 19-81 years old (M=55.67, SD=12.25), who were present in this risky area (so-called the Plan Particulier d'Intervention perimeter in French). All the participants gave the written informed consent prior to taking part in these studies. Observers (12) were located in areas (10) around the site, in less than 1km from the sirens, which were activated at 8:45 and 9:15am. We analyzed responses quantitatively and analyzed correlations between signal detection and reaction variables. This sample was not conducted to assess a representative survey as the context and the situation is of paramount importance to generate reactions in case of an activation siren. However, it enabled us to assess residents' knowledge of appropriate behaviors during an alert and to compare this to the actual behaviors they reported during the alerts (Douvinet et al., 2017).

3. Results

3.1. Estimate of the population covered by sirens in France

3.1.1. Estimate of the population covered by the old network of the National Alert Network in France

The 4,291 NAN sirens (Fig. 2) were located over 2,647 municipalities (which represent only 7.6% of the total number of municipalities in France). Among these, urban areas (48.3%) were most represented (Table 2), divided among "large urban areas" (44.1%), "small urban areas" (16.1%) and "medium urban areas" (12.9%). Overlaying siren coverage over population distribution, the NAN theoretically covers a maximum of 52.2% of the population (34.9 million out of 69 metropolitan residents) in 2014. A maximum of 76.7.3%, 52.4% and 41.8% of the residents respectively living in “large”, “medium” and “small urban areas” are covered, whereas this ratio decreases to 4.4% in rural areas, whereas the latter represent 49.6% of the French administrative levels. The location of the sirens is largely a function of urban classification, giving a priority to larger urban areas, except for “peri-urban crowns of large urban area” (only 4.2% of the municipalities and 14.6% of the resident living municipality are covered).

Table 2. General overview on the maximum rate of municipalities and population covered by the National Alert Network in France in 2010, in relation to different urban density areas.

Urban classification (INSEE)	Municipalities			The NAN coverage		Theoretically covered population		
	Number of municipalities in France	Number of covered municipalities	% of equipped Municipalities	Number of NAN sirens	Average number of siren per municipality	Number of people in France (in millions)	People covered (in millions)	% of people covered
Large and densely urban areas *	3,218	1,424	44.3%	2,718	1.90	39.09	30.00	76.7%
Periurban crowns of densely areas **	15,552	651	4,2%	717	1.10	1.97	2.37	14.6%
Medium urban area + periurban parts ***	1,188	153	12.9%	227	1.48	2.29	1.20	52.4%
Small urban areas****	1,411	227	16.1%	303	1.33	2.63	1.10	41.8%
Rural areas*****	13,599	211	1.6%	224	1.06	6.41	0.28	4.4%
Total	**34,970**	**2,666**	**7.6%**	**4,189**	**1.57**	**66.99**	**34.95**	**52.17%**

** A group of municipalities, in a single block and without an enclave, consisting of an urban unit center with more than 10,000 jobs.*
*** Periurban municipalities in which at least 40% of the employed resident population works in the large and densely urban area yo which it is attracted.*
**** An urban unit with 5,000 to 10,000 jobs, and rural municipalities or urban units in which at least 40% of the resident population with a job works in the center or in municipalities attracted by it.*
***** A group of municipalities, in a single block and without an enclave, consisting of a cluster (urban unit) with 1,500 to 5,000 jobs, and of rural municipalities or urban units where at least 40% of the resident population with work in municipalities attracted by it.*
****** Municipalities outside urban areas.*

Numerous sirens exist in the region of Ile-de-France (Paris), equipped with 82 sirens, and in several major urban cities: Strasbourg (60 sirens), Marseille (57), Lyon (28), Toulouse (27), and Nice (26). 15 cities out of 22 with more than 100,000 inhabitants (out of 22) are equipped with more than 10 NAN sirens (68 %). Aside from population density, several factors influence siren density, including proximity to military sites (explaining the high number of sirens near Brest and Toulon, Fig. 1), the proximity to political frontiers (near Germany and Belgium), and the concentration of industrial sites in several areas (along the Rhine and the Rhone River valleys).

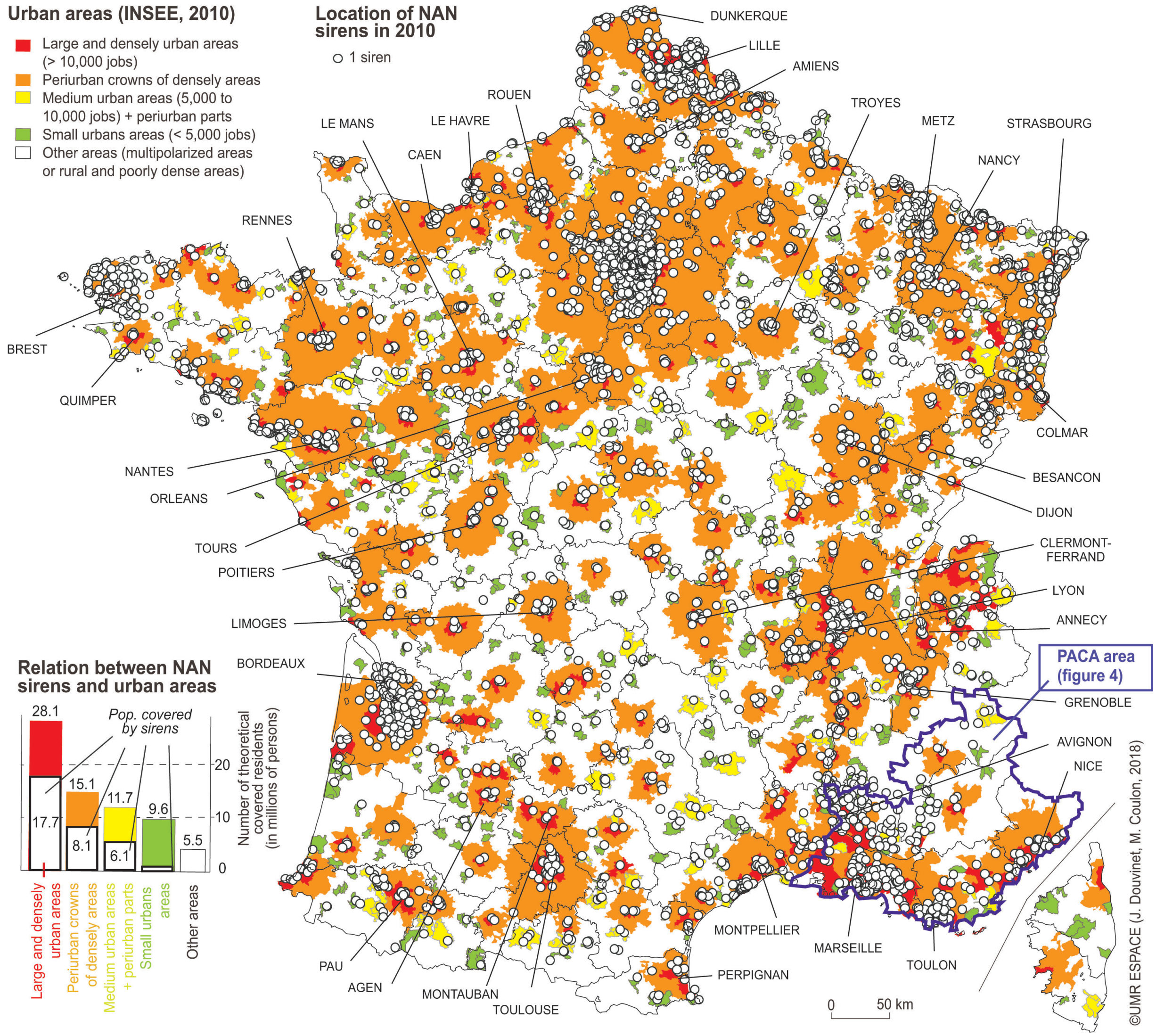

Figure 2. Distribution of the 4,291 sirens of the National Alert Network (NAN) in France related to the urban areas.

Several cities appear over-endowed (27 sirens in Mulhouse, 20 in Colmar, for example), and a few small rural areas also seem over-endowed (Fig. 2). 12 municipalities have one siren for fewer than 100 inhabitants; 3 sirens had been installed at Broye-Aubigney (Haute-Saône), which had 477 inhabitants in 2014, or at Bricy (Loiret), with 557 inhabitants in 2014. In these areas, the urban classification is not an explaining factor, as well as the severity of risks, so there are likely other factors involved. In contrast, the "large urban areas" of Lyon (2 sirens for 515,685 inhabitants in 2014), Bordeaux (1 siren for a city of 252,040 inhabitants in 2014), or Argenteuil (1 siren for 110,468 residents in 2014) present a relatively lighter coverage by sirens, and they are well identified in figure 3, with less than one siren for over 100,000 inhabitants. For these cities, other sirens could exist, but they were not integrated in the NAN network.

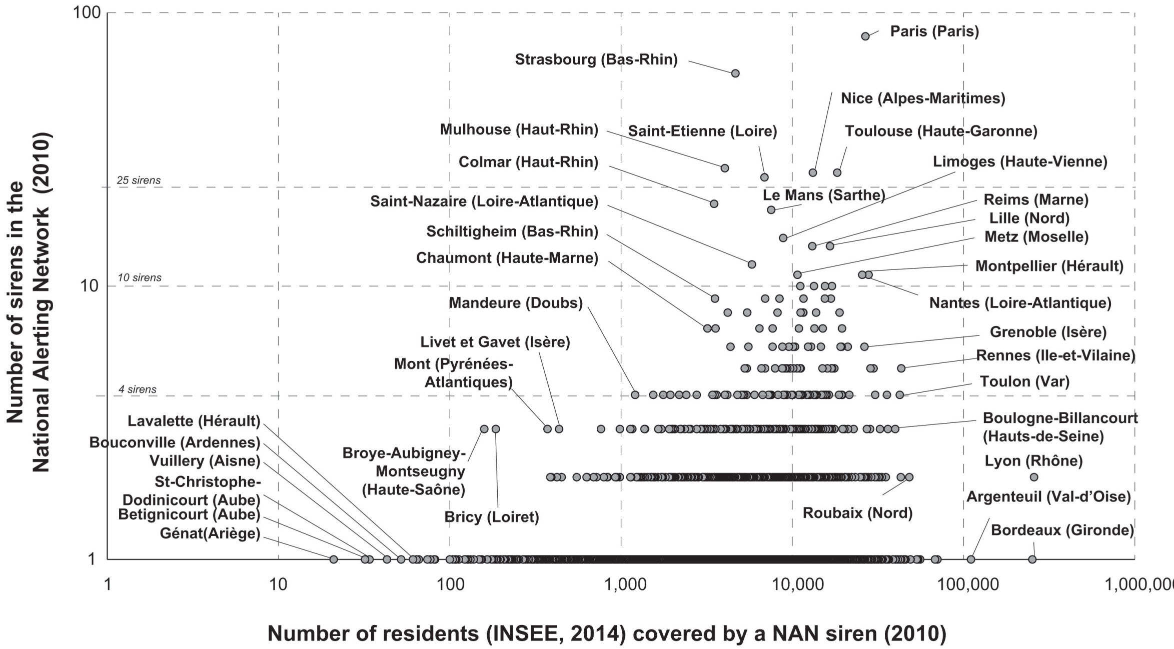

Figure 3. Number of NAN sirens by municipalities and average number of inhabitants served by each siren (Source: Douvinet 2018, based on DGSCGC 2018 database)

3.1.2. Population covered by the future Population Alert and Information System in the PACA region

In the PACA area, the number of risks plays a key role in the spatial distribution of SAIP sirens: 30% of communes with more than 6 risks (49 communes out of 150) are equipped with at least one siren, whereas only 9% of communes with 5 risks (31 communes out of 328) are equipped with one. This threshold between 5 and 6 risks is also identified within the RNA network. But comparing the SAIP and NAN networks supports new results (Fig. 4 and 5):

1) the number of SAIP sirens will be slightly less numerous (254, with 105 new sirens) in comparison with the 301 NAN sirens. Building up the population at the municipal level, the SAIP seem to spread over 58.54% of the population, against 59.54% with the NAN. So the decreasing number of sirens does not induce a decrease of the theoretical rates.

2) the number of SAIP will increase in "large urban areas" (Fig. 4), in Marseille (+12 sirens), around the Etang-de-Berre lagoon, where chemical risk are numerous (+13 sirens), in Toulon (+ 6 sirens), Saint-Tropez (+ 5 sirens), or in downstream parts of rivers, like along the Argens River (+ 11 sirens) or along the Durance River (+ 7 sirens);

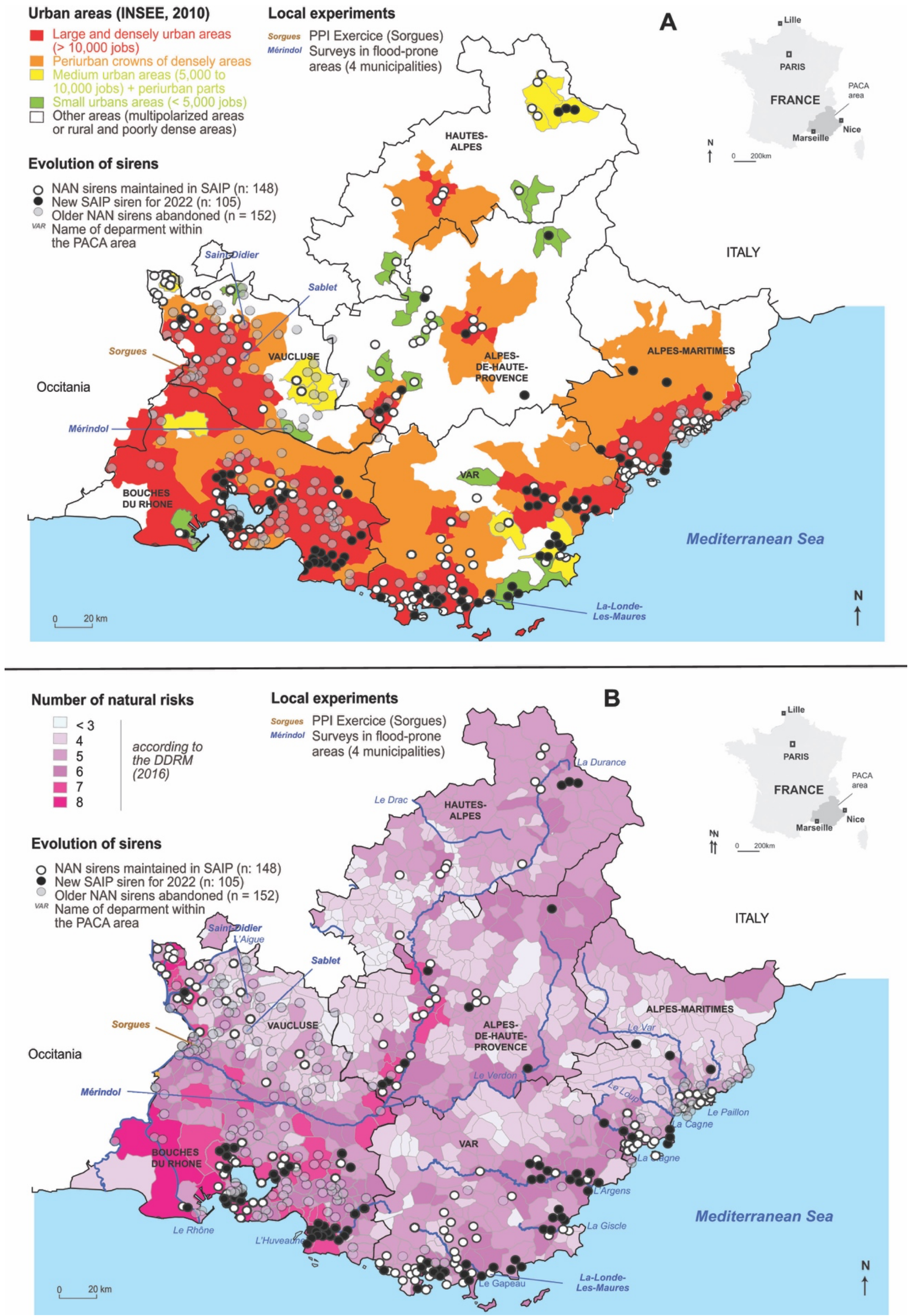

Figure 4. Distribution of the sirens of the new People's Alert and Information Systems (SAIP) in the PACA (Provence-Alpes-Côte d'Azur) region in relation to the National Alert Network (NAN), and to **A)** the urban classification; **B)** the number of natural risks identified by the French Ministry of Environment.

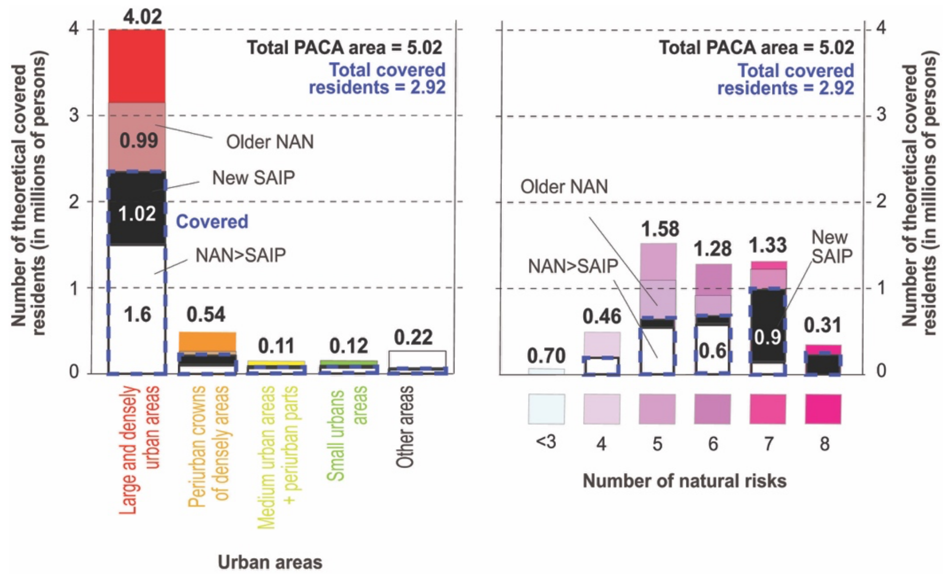

Figure 5. Number of covered residents by the older NAN and the future SAIP systems in PACA region

Table 3. General overview on the municipalities and population covered by the new siren system (People's Alert and Information Systems) in the PACA (Provence-Alpes-Côte d'Azur) region.

Urban classification (INSEE)	Municipalities			The SAIP coverage		Theoretically covered population		
	Number of municipalities in PACA area	Number of covered municipalities	% of equipped municipalities	Number of SAIP sirens	Average number of SAIP siren per municipality	Number of people in PACA area (in millions)	People covered in PACA area (in millions)	% of people covered
Large and densely urban areas *	220	71	32.3%	174	2.45	4.028	2.641	65.6%
Periurban crowns of densely areas **	296	22	7.4%	24	1.09	0.541	0.109	20.2%
Medium urban area + periurban parts ***	31	8	25.8%	17	2.13	0.109	0.067	61.7%
Small urban areas****	38	12	31.6%	20	1.67	0.122	0.075	62.2%
Rural areas*****	361	16	4.4%	19	1.19	0.220	0.033	15.2%
Total	**946**	**129**	**13.6%**	**254**	**1.97**	**5.021**	**2.927**	**58.3%**

** A group of municipalities, in a single block and without an enclave, consisting of an urban unit center with more than 10,000 jobs.*
*** Periurban municipalities in which at least 40% of the employed resident population works in the large and densely urban area yo which it is attracted.*
**** An urban unit with 5,000 to 10,000 jobs, and rural municipalities or urban units in which at least 40% of the resident population with a job works in the center or in municipalities attracted by it.*
***** A group of municipalities, in a single block and without an enclave, consisting of a cluster (urban unit) with 1,500 to 5,000 jobs, and of rural municipalities or urban units where at least 40% of the resident population with work in municipalities attracted by it.*
****** Municipalities outside urban areas.*

3) the newly covered areas have been affected by one severe event in the last decade (in 2010 along the Argens River due to sudden flash floods, in 2014 near La-Londe-les-Maures, in 2015 at Cannes...). These disasters influence the selection of sirens (but on the contrary, disasters occurred before the 2000s seem not to be taking into account).

4) the number of SAIP sirens will decrease in several areas. As an example, in the department of Vaucluse the NAN network, composed of 85 sirens (which cover about 386,100 residents within a radius of 3 km), will be replaced in the SAIP project by only 33 sirens covering 315,000 residents in a radius of 4.5 km. The yellow dots in figure 4 indicate NAN sirens that will not be incorporated in the SAIP network, but these sirens could be retained and managed independently by the municipalities or communities of municipalities.

We also made estimates of population covered by sirens using the mesh population density (with an aggregation at 200m) and varying siren buffers (1,2 or 3km). In the PACA region, the SAIP project will cover 24.6% of residents with a 1km buffer, 40.5% with a 2km buffer, and 48.5% with a 3km buffer. Using a 1.4km, chosen since as the best radius given siren power and sound propagation (Bopp and Douvinet, 2020), SAIP will cover 38.9% of residents. There is also a very strong spatial inequality of siren warning: the Gini index of the rates of individuals covered (ranging from 0, perfect equality, to 1, very strong inequality) is 0.87. Moreover, the global Moran's autocorrelation index is 0.22, which means that the number of individuals covered by sirens tends to be close between neighboring municipalities.

3.2. The alerting governance in France and its impacts

3.2.1. Authorities inherit solutions steeped in tradition, …

Despite changes in the distribution of the siren network, mayors, prefects and/or the Ministry of Interior remain the only ones who can authorize the activation of sirens in emergencies in France (Fig. 6). Mayors consider the siren activation as a priority in the case of sudden events. In addition, they have to inform parents, heads of schools, or the guardians responsible, etc. As Directors of the rescue operations and coordination, mayors ensure that the alert will be distributed to all the people, without any social or cultural distinction. The prefect can activate sirens alone in three situations: 1) if the mayor fails to issue the alert, 2) if the event covers several municipalities located within the area, he is responsible for, or 3) when the technical, logistic, or financial capacities of the mayor are exceeded. According to Article L.1322-2 of the Defense Code, the prefect will be in charge of the civil Defense management, with the help of the mayors, except in all areas where military operations are taking place. In this case, the government confers to a military commander the responsibility for the activation, if necessary, of sirens. The siren alarm follows a specific pattern in France (a sound ascending and descending over 101 seconds, separated by a silence of 5 seconds and repeated three times). This signal is intended to interrupt social activities (Creton-Cazanave, 2010). While warnings may inform people a few hours before the occurrence of a hazardous event (Douvinet and Janet, 2017), the activation of an alert announces the beginning of a significant threat to human lives, and is intended to generate prompt reactions, from people and rescue services (DGSCGC, 2013). In France, given the responsibilities entailed, the alert is a state competence, related to civil security issues and regulated by the Security Code (Articles L.112-1, L.711-1 and -2, L.732-7).

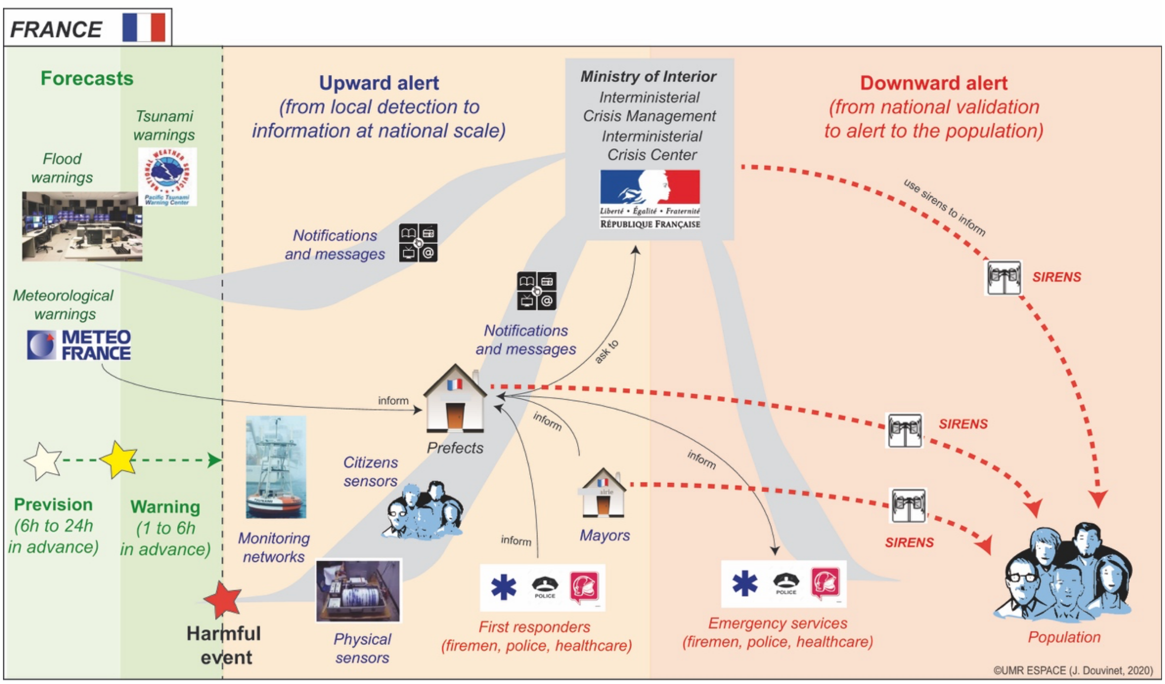

Figure 6. Current warning and alerting process in France.

For 7 of 10 authorities responding to our questionnaire, the main objective of the siren is to inform the greatest number of people in an area threatened by danger, so that the population can take appropriate action. Thus, it would be desirable to specify the nature of the danger and to include instructions for the public in the alert signal. Other objectives cited by respondents include that the warning must be adapted to the context (5/10); sirens should provoke residents to seek information (3/10); the alarm should provoke a reaction from the authorities who issue it (2/10); warning should minimize human and economic losses (2/10). An alert is a signal that calls for further signals that may clarify the nature of danger and recommended steps. Time stands out as a crucial notion, as do uncertainties about effects that are not predictable for the community. In France, the alerting process is then "top-down", and people are at the end of this chain (Fig. 6)

Responding authorities also noted that the alarm is best considered as only the first step in crisis communication. 6 of 10 respondents also highlighted the importance of feedback, to identify corrective measures to be implemented, and to check coordination between the actors involved, even if this means establishing new synergies (by creating "gateways" for example). Some respondents observed that lessons learned from past events have not been sufficiently shared. Some respondents said that tools should not be differentiated according to hazards (3/10), only the warning message should vary, while others (4/10) held that tools should be adapted to the territorial and contextual situation less (urban/rural). The complementary nature of the tools was also highlighted (the siren is better understood than the RSN for elderly individuals). Discussions with these actors who had actually sounded sirens in recent years highlight two contradictions in the current procedure: 1) "we sound the alarm to comply with the regulatory framework, knowing that the sirens will have a limited range". In other words, this strategy is comfortable for prefects or mayors, who "cover up" to avoid problems later on (during post-event investigations in particular); 2) "The difficulty is that it is necessary to warn locally, with the means available, while benefiting from a robust architecture at the national level". In this respect, the SAIP network is a solution perceived as positive (yet sirens do not exist everywhere! cf. 3.1.1).

3.2.2. …, and people have blind trust in tradition

Our website questionnaire regarding the population's trust in sirens and other alerts showed the sirens were the most trusted alert method (Fig. 7). Surprisingly, the siren scored the highest average (8.00) ahead of a CBC/LB-SMS solution (7.80), the automatic telephone call system (7.78), door-to-door (7.17) and the smartphone application (6.69). There is also homogeneity in the scores given to the siren: the Gini index is IG=0.15 (knowing that an IG of 0 corresponds to a perfect homogeneity between results and 1 to an extreme heterogeneity between results). Thus, social-territorial factors of individuals are ultimately not very decisive in the notes given to the siren. There is no significant difference according to the age of participants (P=0.077), the urban area to which their municipality of residence belongs (P=0.794), or the individual's experience facing to disasters (P=0.921). However, the siren is rated better by individuals belonging to a lower socio-professional category (SPC) than individuals belonging to a higher socio-professional category (P=0.031). Above all, it should be retained that compared to several means of alerting, the siren remains one of the significantly better accepted means (along with the SMS and the telephone call system) for each social and territorial factor.

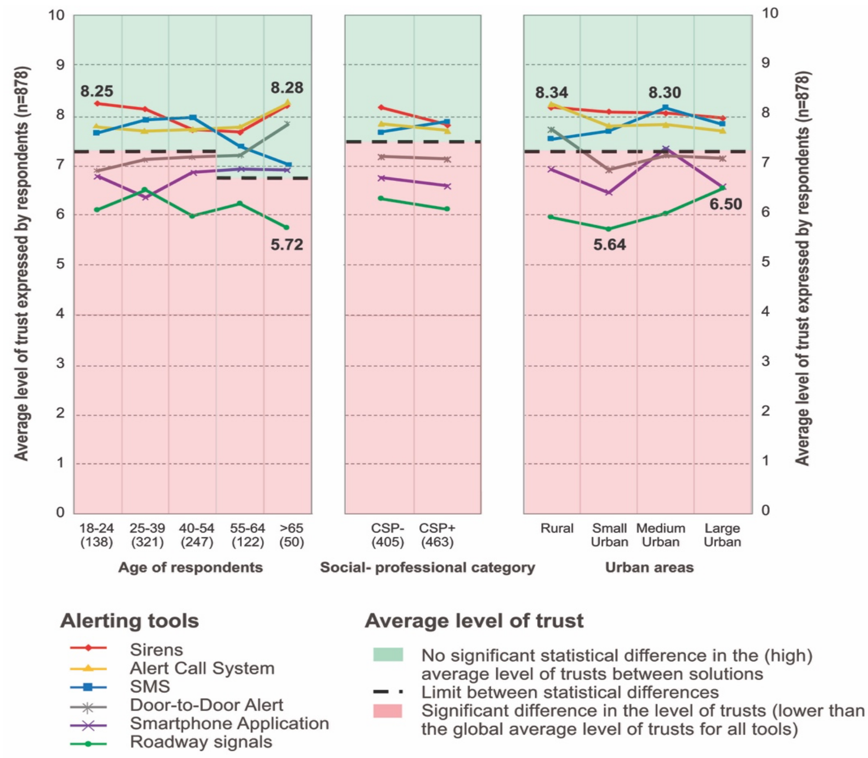

Figure 7. Average level of trust expressed by respondents for different means of communicating alerts.

3.3. A lack of public understanding and response

3.3.1. Most people don't understand sirens

From 450 interviews with residents of flood-prone areas, we found 34 (<8%) recognized the sound for what it was, and half (274/450) indicated that they would not identify the nature of danger if siren sounds. The alert sound, although intended to be unambiguous, is difficult to interpret in real conditions. It is "one sound in addition to another" (Dedieu, 2009), heard over ambient noise (especially in urban areas), and is not accompanied by any additional information. The interpretation of this signal depends on the knowledge and experience of each actor, but also on the training and information work carried out upstream (Créton-Cazenave, 2010; CEPRI, 2011), and all these elements will play a role in decision-making and adaptation, as well as in the analysis of the situation (Colbeau-Justin, 2002; Daupras et al., 2015). Moreover, the interpretation of the signal is considered to be an obstacle to the rationalisation of alert signals, while it is futile to conceive of alerting as a technical process. For some respondents (145), the alarm had an unreal quality, similar to findings by Mileti and Sorensen (1990), and some assumed that the alarm would be differentiated in case of flooding.

3.3.1. Most people don't know how to react when they hear a siren

In the survey conducted in Sorgues (Fig. 8), 103 persons (out of 280) said they inform themselves in the situation of an alert, 95 reported that they would enter a building, 59 said they would call their relatives. However, during the test activation of sirens, while they heard the sound, they confessed that they continued their activities at the time of the signal (133), and only 28 attempted to enquire about why the alert had sounded. Of the 27 who understood the meaning of the sirens, 21 continued their activities. These concerns confirm that actual behaviour is clearly out of step with behavioural statements. People face difficulties in making decisions in real time (e.g. picking up their children from school or not, or driving). The question could be asked whether it is useful to add an anxiety signal at a time when individuals are already stressed. Thus, assessing the utility of sirens in such cases requires a good knowledge of the nature and urgency of the danger, which is not always predictable (as with terrorist attacks or industrial accidents), and these limitations will persist with the future SAIP system (Douvinet, 2018).

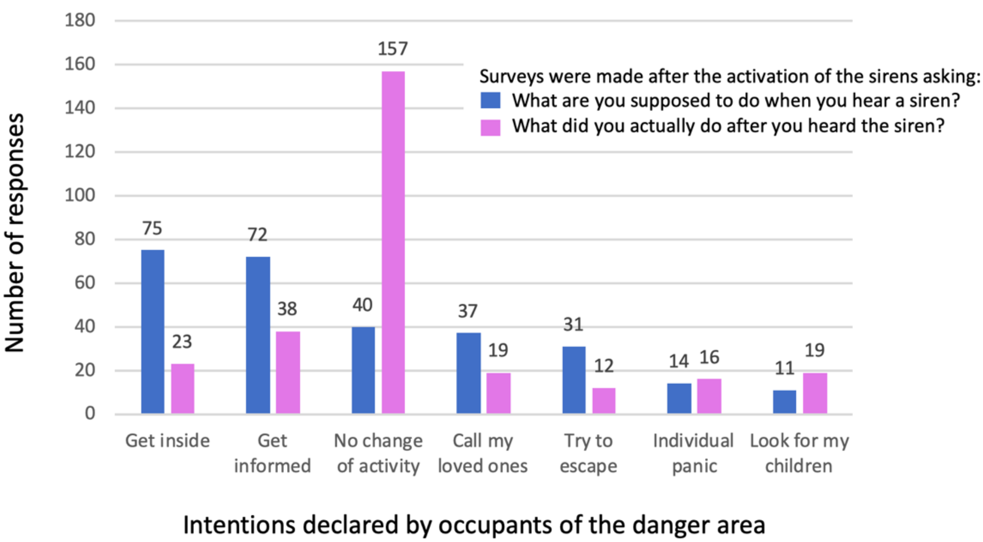

Figure 8. Results sample 4 (Survey + Emergency Management Exercise): Differences between the people's knowledge about the appropriate behavior (blue) and their real behavior (pink) after hearing sirens during a emergency management exercise in Sorgues (Vaucluse).

4 Discussions

Results of our mapping analysis, surveys, and interviews yield two major ideas: 1) siren coverage is lacking in many areas, 2) many inhabitants do not respond to siren alerts, but continue their activities (Lutoff et al., 2016) or do not perceive the risks (Weiss et al., 2011). Thus, even in areas covered by alert sirens, the desired-for response and implementation of emergency safety measures does not occur (Lagadec, 2016; Creton-Cazanave, 2010; Douvinet, 2018).

The French government allocated more than 83 million euros in 2010 to create the future SAIP siren network. But other opportunities to alert populations have never been developed. For example, the SAIP smartphone application failed due to coordination issues among state services and ultimately was not adapted to the emergency level of dangerous events (such as the terrorist act in Nice on July 14th 2016). When the application was launched in June 2016, the French Ministry of the Interior hoped to reach 5 % of the population (Vogel, 2017). But the usefulness of the SAIP® application was quickly criticized (Bopp et al., 2018). It was only used 4 times over the 2016-2018 period, during which time 85 events required the intervention of the national crisis centre, COGIC (Fig. 6). The SAIP smartphone application generated more problems than benefits and was abandoned in May 2018.

Learning from the experience of other countries, there are some options to be considered that could reduce the time for the activation of sirens. We propose three main changes in France. First, the Overall, the set of agencies authorized to send alerts should be increased, to improve responsiveness and to reduce activation and/or reaction time. For example, alerts could come from firefighters in the event of fire as envisaged by the SAIP project, or from flood forecasting services in the event of flash floods. In some cases, private providers now sell alerts to municipalities.

Second, the services in charge of the forecasting and the detection of hazards should work together, within a multi-hazard system. Their reactivity depends on the risks involved, and on the detection period for the hazards, but also on the availability of tools, and the time before the first impact. Schematically, earthquakes require automated systems since the alerting time is limited to a few seconds, or even a few hundredths of a second, whereas tornadoes or flash floods occur in a few hours. When the latter are forecast, various services can anticipate the event and it would be appropriate to activate the alert from the moment the triggering thresholds are exceeded. This solution should give time for protective measures to be implemented. Actually, the authorities prefer not to activate alerts, in part because they have misgivings about the likely behavior of the alerted population, whereas with better public education and training in response, the sirens could have a real utility. Third, it would be necessary to create a single platform to improve the coordination between different services with their unique competencies. However, for this to occur, France must stop multiplying the number of services, operating differently depending on the type of danger or threat. At present, CENALT (National Tsunami Warning Center) issues tsunami forecasts; the CSEM (Euro-Mediterranean Seismological Center) monitors earthquakes; the SCHAPI (Central Service of Hydrometeorology and Flood Forecasting) is responsible for flood warning and vigilance. As emergency call platforms are increasingly shared, like those centralizing the 15, 17, and 18 calls within Greater Paris, we must go much further in this inter-service logic and promulgate the single 112 call number at the European scale. In addition, guidelines (Table 4) are critical for the improvement of siren alerts in France. Some are already integrated in some international standards, in the Common Alerting Protocol (CAP) or in the Early Warning System Monitoring (EWSM), but not yet applied in France. Fourth, people need to know what we expect from them in the situation of danger. It requires communication tools, but also exercises to make individuals aware that their instincts may lead them to behave differently from what is expected of them by the authorities.

Table 4. Some guidelines for improving the efficiency of alerts for the population (Douvinet, 2018)

Major guidelines	Advantages and desired outcomes	References
Create an interoperable offer	Favour interactions between technologies and the targets	Landwehr *et al.,* 2016
Coordinate the offer	Compensate for inadequacies of each solution used in isolation	FEMA, 2019
Design a single platform piloted by a single manager	Avoid multiplying alert tools and centralize the entire offer	Sorensen et Sorensen, 2000
Send single messages	Avoid contradictory or different messages depending on the services, to reduce uncertainties and hesitations	IBZ, 2017
Satisfy a multi-phenomenon logic	Be adapted to the plurality of phenomena, and take into account interactions between different types of risk	Liu et al., 2015
Adapt the alert to space-time aspects	Target the alert in time and in space, so that information reaches the right people at the right time	Reghezza-Zitt *et al.,* 2015
Define a scale of alerts depending on the phenomena	Decline the systems at different levels of observation, depending on the hazards involved and the territories under consideration	Douvinet, 2018
Define the alert timing	Modulate the alert depending on the time before the first impacts	Péroche, 2016
Define a multi-channel system	Reach a maximum of people in a short time	FEMA, 2019 ; IBZ, 2017
Adapt the alert to the needs of the targets	Be able to respond to the evolving needs of populations, to the context, and to individuals' perception of the danger	Kouabénan, 2007 ; Weiss *et al.,* 2011

All these principles must be respected to create an effective alert system in France: (1) be coherent in the diffusion of messages, and to avoid gaps in coverage; (2) have competent services confirm weak signals, announcing the beginning of an emergency situation, and relay precise and complete information on a larger scale without making assumptions about public understanding; (3) use common references to communicate with a large public and to produce individual reactions (Matveeva 2006).

Finally, what alerting system would be best suited to the French context given that sirens will be maintained into the future? First, the activation system must be coordinated between services, with a single platform managed by a single service. Second, the alerting system must be adapted to "space-time", and be better adapted to the needs of an evolving population. Each tool (sirens, smartphone applications or phone calls) can contribute to a coordinated system. Third, the platform needs to be created by optimizing dissemination channels and to be adapted to contexts (in terms of mitigation, risks, regulations, etc.). It must integrate suitable reactions to be prompted by the majority of people. Finally, the platform must be developed in order to ensure diffusion using short-wave radio, to overcome network congestion and to avoid the impact of a power failure. All the guidelines will then enable a new alerting platform to be designed for France (Fig. 9).

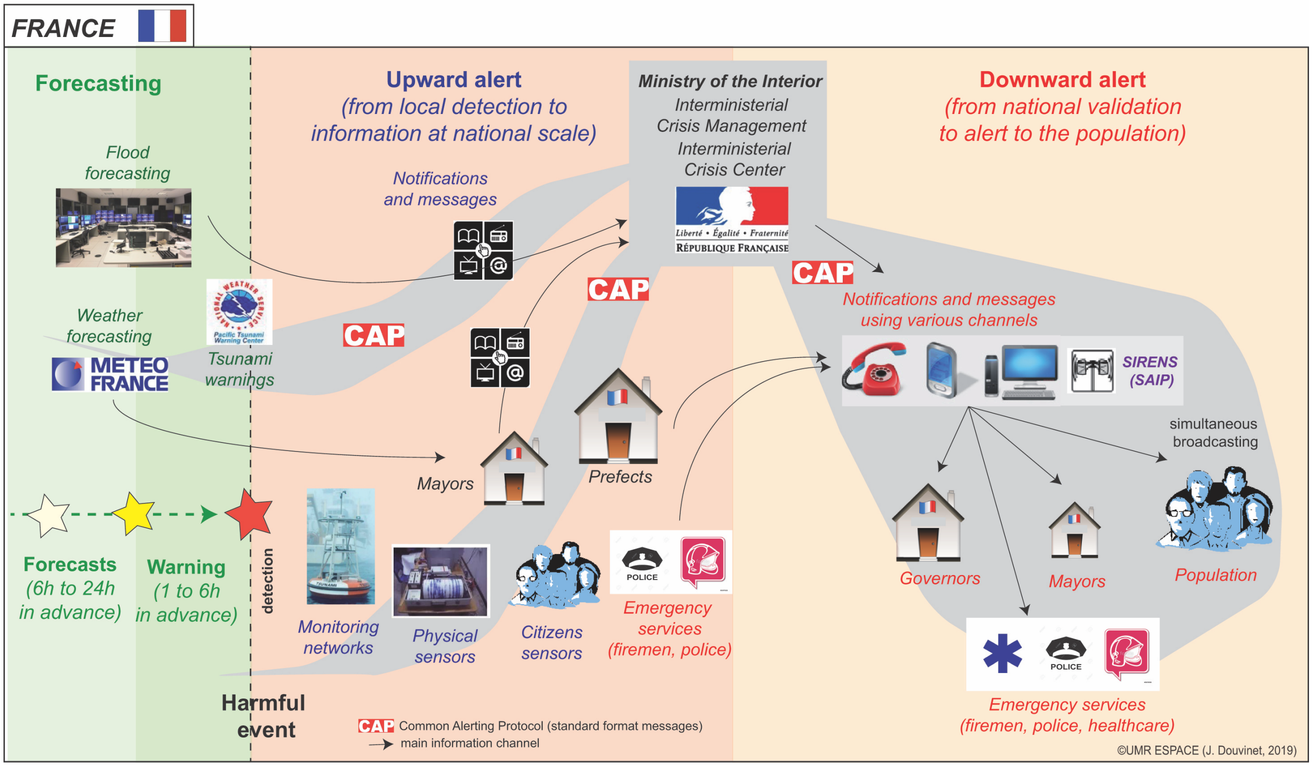

Figure 9. Recommended improvements for the alert system in France (compared to Figure 5)

In a more disruptive point of view, authorities may accept the abolishment of sirens, like in Belgium, where the 550 sirens were completely deleted in 2016 (Douvinet, 2018). In this direction, it is necessary to take the decision at the highest political level, to trust individuals who will have to face dangers alone, and to learn from past events. It is also necessary to define a long-term forward-looking strategy, which remains a utopia in France, as the regalian system and the trust in what we know how to do still prevails. Unless a major disaster (which we do not want) changes the situation.

5. Conclusions

This study aimed to understand the reasons why sirens are the only alerting tools available in France, and why successive governments have maintained their trust in these tools since the end of World War II, despite their well-known limitations. Such a choice represents a long political tradition. On the one hand, the mayors and prefects plebiscite sirens to justify their budgets, regardless of whether they reach the audiences targeted. But it is not because tools exist that they will be used in real situations. On the other hand, the real use of sirens depends on a political decision accepted by all the stakeholders involved in the institutional chain. But the slowness of the validation process, rigidity of the administrative mechanisms, and the high number of actors involved are all obstacles to the effectiveness of sirens.

To improve the future SAIP system expected in 2024, authorities and forecasters need to work together. Important changes are expected in the technical, organisational, and contextual dimension. Challenges need to be overcome to respect the *Common Alerting Protocol* (CAP) and in the next few years, France also has the responsibility of creating a national SMS alerting system, to respect the December 14th 2018 European Decree (asking all of the European members to create a national SMS alerting solution). Progress is also needed in the human and social dimension. In France, people do not know the diversity of alert channels, which increases the confusion and cacophony in an emergency situation. This reinforces a "polyphony of ignorance" (Cardon, 2015). But if the population does not understand what is expected from it, the people cannot adopt appropriate reactions. It is therefore also important to include more effective tools that can complement sirens with a clear unified message. Furthermore, we must consider the alert not as a constraint, but as an opportunity to put reflex reactions into practice in a spirit of solidarity. This requires a gentle change of posture, because in France the alert remains synonymous with a negative event and with major damage.

Code and data availability

The data are not publicly accessible because of the confidential nature of the data. The precise location of sirens is not to be disclosed for security reasons. The data were provided to us for processing at large scales (regional and national) and not to display results at fine scales. The RGDP (European Directive applied in France since 2016 Maty 28th) also explains a restricted access to data obtained during the crisis exercise (**Fig. 5**), because of individual and personal information.

Author contribution

The contributions of all co-authors are briefly described. J. Douvinet and E. Bopp designed the experiments and realized maps and spatial analysis treatments. J. Douvinet prepared the main part of the manuscript with contributions from all co-authors, and all co-authors contributed significantly to multiple rounds of revisions.

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgements

The co-authors would like to express their sincere thanks to several people who have contributed to improving the thinking of the “alert by sirens” in France: the members of BASEP (DGSCGC), the members of the University of Avignon (B. Gisclard, Q. Godoye, M. Coulon). They also thank the funders who supported this work, in particular the Research Federation Agor@ntic (FR CNRS 3621), the University of Avignon, and the ERDF fund through the WP4 of the CoRESTART meta-project (PA0004129), financed with the support of the European Union ("Europe is committed to the Alpine Massif with the European Regional Development Fund"), within the framework of the Interregional Operational Programme of the Alpine Massif (2017-2020). The co-authors also thank the Interministerial Service for Defence and

Civil Protection (SIDPC) of the Vaucluse Prefecture for geolocation data on sirens (RNA and SAIP). Finally, the coauthors thank the anonymous reviewers, whose comments greatly improved the manuscript.

References

Bean, H., Liu, B.F., Madden, S., Sutton, J., Wood M.M. and Mileti, D.S.: Disaster Warnings in Your Pocket: How Audiences Interpret Mobile Alerts for an Unfamiliar Hazard. *Journal of Contingencies and Crisis Management*, 24, 136–147, 2016.

Becerra, S., Peltier, A., Antoine, J.M., Labat, D., Chorda, J., Ribolzi, O., Daupras, F., and Dartus, D.: Comprendre les comportements face à un risque modéré d'inondation. Etude de cas dans le périurbain toulousain (Sud-Ouest de la France). *Hydrological Sciences Journal*, 58, 945–965, 2013

Becker, D. and Bendett, S.: Crowdsourcing solutions for disaster response: examples and lessons for the US Government. *Procedia Engineering*, 107, 27–33, 2015.

Bopp, E., Douvinet, J. and Serre, D.: Faire un tri dans le monde des applis. Expérimentation sur 50 applications smartphones proposant d'alerter la population face aux risques en France. *Netcom*, 32, doi:10.4000/netcom.3531, 2018

Bopp, E., Douvinet J.: Cell Broadcast vs Sirens: Which Solution is the Most Spatially Efficient? Early findings in the southern part of France. 10th Conference of the International Society for Integrated Disaster Risk Management (IDRIM), Nice, October 2019.

Cardon, D.: *À quoi rêvent les algorithmes ? Nos vies à l'ère des big data*. Éditions Seuil. Collection La république des idées, Paris, 145 p., 2005.

Centre Européen de Prévention du Risque d'Inondation : *Prévision et anticipation des crues et des inondations*. 72p., 2017

Colbeau-Justin, L. : *Stratégies de faire face dans le cas d'une inondation catastrophique: analyse des paramètres psychosociaux dans les procédures de gestion de crise*. Ministère de l'Écologie et du Développement Durable. Programme de recherche RIO2. 91p., 2002.

Coleman, T. A., Knupp, K. R., Spann, J., Elliott, J. B., & Peters, B. E. (2011). The History (and Future) of Tornado Warning Dissemination in the United States. Bulletin of the American Meteorological Society, 92(5), 567–582. doi:10.1175/2010bams3062.

Courteau, R. : La prévention et l'alerte du risque de tsunami sur les côtes françaises, Rapport du député pour le Sénat, 64 p., https://www.senat.fr/rap/r18-399/r18-3991.pdf, 2019

Créton-Cazanave, L.: *Penser l'alerte par les distances. Entre planification et émancipation, l'exemple du processus d'alerte aux crues rapides sur le bassin versant du Vidourle*. UJF, Grenoble I. http://www.sudoc.fr/153530588, 2010.

Daupras, F., Antoine, J.M., Becerra, S. and Peltier, A.: Analysis of the robustness of the French flood warning system: a study based on the 2009 flood of the Garonne River. *Natural Hazards,* 75, 215–241, 2015.

Dedieu, F.: Alerte et catastrophe : le cas de la tempête de 1999, un risque scélérat. *Sociologie du Travail,* 51, 379–401, 2009.

Deloitte: *Système d'alerte et d'information des populations (SAIP).* Note de capitalisation du projet (2009-2014). 33p., 2014.

Direction Générale de la Sécurité Civile et la Gestion de Crise: *Guide Orsec. Alerte et information des populations*. Ministère de l'Intérieur, 90p., 2013.

Douvinet, J.: *Alerter la population face aux crues rapides en France : compréhension et évaluation d'un processus en mutation.* Université d'Avignon, 220 p., 2018.

Douvinet J.: Smartphone applications, a means to promote for emergency management in France? In Sedes F. (Eds), Information system for Alarm Diffusion, ISTE Publications, 3, 45-55, doi: DOI:10.1016/B978-1-78548-302-8.50003-4, 2018

Douvinet J. and Janet B.: Effectiveness of Institutional Alert Tools in Flood Forecasting in France. In VINET F. (Ed), Floods, Volume 2, Risk Management, ISTE Publications, 179-193, 2017.

Fajardo, J.T.B. and Oppus, C.M.: A mobile disaster management system using Android technology. *International Journal of Communications* 3, 77–86, 2009.

FEMA. *Integrated Public Alert and Warning System (IPAWS). 2018 Performance Report*. Federal Emergency Management Agency. 2019

Garcia, C. and Fearnley, C.J.: Evaluating critical links in early warning systems for natural hazards. *Environmental Hazards,* 11, 123–137, 2012.

Gisclard, B. *L'innovation sociale territorialisée : un levier de réappropriation du risque inondation par les habitants. L'exemple des crues rapides dans les territoires ruraux du Gard et du Vaucluse (France) 7 décembre 2017*. PhD, Université d'Avignon et des Pays de Vaucluse, Avignon, 2017.

Goto H., Murray A.T. Acoustical properties in emergency warning siren coverage coverage planning. *Computers, Environment and Urban Systems*, 81, 2020.

Huang, C.-M., Chan, E. and Hyder, A.A.: Web 2.0 and Internet Social Networking: A New tool for Disaster Management? - Lessons from Taiwan. *BMC Medical Informatics and Decision Making* 10, 2010.

Jagtman, H.M.: Cell broadcast trials in The Netherlands: Using mobile phone technology for citizens' alarming. *Reliability Engineering & System Safety* 95, 18–28, 2010.

IBZ (Service public federal Intérieur): *Principes de fonctionnement de Be-Alert,* 42 p., 2017

Kouabénan, D.R. *Des croyances aux comportements de protection*. In Psychologie du Risque, 155-171, 2007.

Kouadio, J. : *Les technologies smartphone comme outils d'aide à l'alerte face aux crues rapides en France : Expérimentation dans le Vaucluse et le Var*. Université d'Avignon et des Pays du Vaucluse, 254 p., 2016.

Kuligowski, E. D., Lombardo F.L., Phan L.T., Levitan M.L. and Jorgensen, D. P.: Final Report, National Institute of Standards and Technology (NIST) Technical Investigation of the May 22, 2011, Tornado in Joplin, Missouri, NIST, National Institute of Standards and Technology: Gaithersburg, MD, 2014.

Landewr, P.M., Wei, W., Kowalchuck, M. and Carley, K.M. Using tweets to support disaster planning warning and response. Safety Science, 90, 33-47, 2016.

Landry, S., Jeon, M., Lautala, P., and Nelson, D. (2019). Design and assessment of in-vehicle auditory alerts for highway-rail grade crossings. Transportation Research Part F: Traffic Psychology and Behaviour *62*, 228–245.

Leo, Y., Sarraute, C., Busson, A. and Fleury, E.: Taking Benefit from the User Density in Large Cities for Delivering SMS. In Proceedings of the 12th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks - PE-WASUN '15, (Cancun, Mexico), 55–61, 2015.

Lindsay, B.R.: Social Media and Disasters: current uses, future options, policy considerations (Congressional Research Service), 7-5700, 2011.

Liu, Z., Nadim, F., Garcia-Aristizabal, A., Mignan, A., Fleming K and Bryon Q.L. A three-level framework for multi-risk assessment. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 11:1, 59-74, 2015.

Lutoff, C., Creutin, J. D., Ruin, I., and Borga, M.: Anticipating flash-floods : multi-scale aspects of the social response. *Journal of Hydrology*, 541, 626-535, 2016.

Maillard M. : Justices seigneuriales et police des communautés rurales en Anjou au xviiie siècle. Annales de Bretagne et des Pays de l'ouest, 111, 143-165, 2011.

Mathews, A.J., Haffner, M. and Ellis, E.A. : GIS-based modeling of tornado siren sound propagation: Refining spatial extent and coverage estimations. *International Journal of Disaster Risk Reduction* 23, 36–44, 2017.

Matveeva, A.: Early Warning and Early Response: Conceptual and Empirical Dilemmas. *European Centre for the Conflict Reduction*, 1, 66 p., 2016.

Mileti D.S. and Sorensen J.H.: Communication of Emergency Public Warnings, in Landslides, Colorado State University: *Centre for International Research on Education Systems website*, 52–70, 1990.

Pappenberger, F., Cloke, H.L., Parker, D.J., Wetterhall, F., Richardson, D.S. and Thielen, J.: The monetary benefit of early flood warnings in Europe. Environmental Science & Policy, 51, 278–291, 2015.

Péroche, M. La gestion de crise tsunami dans la Caraïbe : contribution géographique aux dispositifs d'alerte et d'évacuation des populations. PhD, Université Paul Valéry, Montpellier, 2016.

Pritnat (Pôle des RIsques NATurels en montagne de la Cotrao), Actes de l'atelier transfrontalier sur les risques naturels « Gestion du risque torrentiel partage transfrontalier d'expériences », 31 mai et 1er juin 2006 au Cemagref de Grenoble. Pôle Grenoblois des risques Naturels, 100 p., 2006.

Reed S.A, Boggs J.L. and Mann J.P.: A GIS tool for modeling anthropogenic noise propagation in natural ecosystems, *Environmental Modelling & Software,* 37, 1-5, 2010.

Reghezza-Zitt, M. Territorialiser ou ne pas territorialiser le risque et l'incertitude. La gestion territorialisée à l'épreuve du risque d'inondation en Ile-de-France. *L'Espace Politique*, 26, 2015.

Roux, J. *Être vigilant. L'opérativité discrète de la société du risque.* Saint-Étienne, Presses Universitaires de Saint-Étienne, France, 145 p., 2006.

Sättele, M., Bründl M. and Staub D.: Quantifying the effectiveness of early warning systems for natural hazards. Natural Hazards and Earth System Science, 16, 149-166, 2016.

Sorensen J.H.: Hazard Warning Systems: a review of 20 years of progress, *Natural Hazards Review*, 1, 119–125, 2000.

Stokoe, M. R.: Putting People at the Centre of Tornado Warnings: How perception analysis can cut fatalities. *International Journal of Disaster Risk Reduction*, 17, 137-153, 2016.

Vinet F., Lumbroso D., Defossez S. and Boissier L.: A comparative analysis of the loss of life during two recent floods in France: the sea surge caused by the storm Xynthia and the flash flood in Var. *Natural Hazards*, 2011.

Vogel, J.-P. : *Rapport sur le système d'alerte et d'information des populations* (SAIP). 48., 2017.

Weiss, K., Girandola, F. and Colbeau-Justin, L. Les comportements de protection face au risque naturel : de la résistance à l'engagement. Pratiques Psychologiques, 17:3, 251-262, 2011.

Whitmore, A., Agarwal, A. and Da Xu, L. The Internet of Things—A survey of topics and trends. Information Systems Frontiers 17, 261–274, 2015.

Zhang, Y., Prater, C.S. and Lindell, M.K.: Risk Area Accuracy and Evacuation from Hurricane Bret. Natural Hazards Review, 5, 115–120, 2004.

Zunkel, P.: The spatial extent and coverage of tornado sirens in San Marcos, Texas. Applied Geography, 60, 308–312, 2015.