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RESEARCH ARTICLE

Collective conceptualization and management of risk for arsenic pollution in urban community gardens

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Abstract At the global scale, an increase in urban gardening activities is being observed and the question of produce quality is therefore regularly investigated in relation to pollutant transfer in the environment. The scientific question investigated in the present study was in what way is the presence of arsenic pollution detected in community gardens a public problem and how would each party take ownership of this issue? An interdisciplinary and participative research study "JASSUR" based on both agronomy and risk assessments was conducted in a French collective garden impacted by arsenic pollution in the well water used for irrigation. Gardener surveys and public meetings examined the gardeners' representations of risk and research solutions for sustainable site management. The theoretical framework of Gilbert which applies a social construction of risk was used. Without an official arsenic limit concentration for vegetables produced in the gardens, a collective risk construction and management process took place. Arsenic total and human bioaccessible concentrations were measured in both vegetables and soil and compared to reference data from a national database to assess the level of health risk. Vegetable quantities produced were obtained in the field from

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gardeners using harvest booklets. On the basis of a quantitative assessment of the health risk due to produced vegetable consumption, it was concluded that gardening activities could safely continue. However, the regional health authorities forbid the use of the arsenic polluted water, and the wells were permanently closed. By favoring the exchanges between the gardeners and the other stakeholders (researchers and politicians), the arsenic pollution led to structuration in the community of gardeners and permitted a collective construction of risk management.

Keywords Urban community gardens · Arsenic pollution · Social construction · Risk assessment · Human exposure

Introduction

For many reasons such as economic crises or uncertainty about the quality and origin of purchased fruits and vegetables, a renewed interest in gardening activities is being observed across the planet (Chenot et al. 2013; Ghose and Pettygrove 2014; Pourias et al. 2015). The main objective of gardeners is to produce quality plants (Gojard and Weber 1995; Pourias and Duchemin 2013). According to Menozzi (2014), community gardens are a real tool for city planning. Hale et al. (2011) consider that community gardens are a potential urban resource for active and passive learning about ecological processes, and Dumat et al. (2016, 2018) suggested that these community gardens can act as laboratories for transdisciplinary pedagogical innovation and pragmatic ecological transition experiments. As demonstrated by Ghosh (2014), the development of gardening activities could contribute to preserve the environment. However, ecosystem pollution is often observed in urban areas mainly due to the proximity to roads, agricultural and present-day or centuries-old industrial activities (Douay et al. 2008; Mitchell et al. 2014). Indeed, many chemicals can flow or accumulate in the atmosphere, water, and soil of urban gardens (Schwartz 2013), and finally consumed vegetables (Uzu et al. 2014; Clinard et al. 2015).

Currently, there are no French regulatory threshold values for total concentrations of pollutants in garden soils (Foucault et al. 2012; Mombo et al. 2016), and only marketed plants are regulated in Europe, for some targeted inorganic pollutants such as lead, cadmium, mercury, and tin (European Commission 2006a). Arsenic (As) is a persistent metalloid, which is highly (eco)toxic and widely observed in the environment (WHO 2010; Bilal et al. 2015; Shahid et al. 2017; Tabassum et al. 2018). Accordingly to Jennings (2013), chronic oral arsenic exposure can result in gastrointestinal distress, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, and liver or kidney damage. Thus, for non-regulated inorganic pollutants such as this, a specific quantitative assessment of the health risks must then be carried out in order to scientifically assess human exposure from consumption of polluted vegetables (Badreddine et al. 2018).

Gardeners certainly join community gardens to mind off and produce "healthy" vegetables. When informed about pollution in their gardens, legitimate concerns arise (Austruy et al. 2013). As suggested by Boutaric (2013), when performed collectively, risk assessment and management can sometimes lead to a new norm or regulation. Indeed, health risk assessment is one of the instruments that scientists have developed at the frontiers of science and politics. However, due to the complexity of the biophysicochemical mechanisms involved in the transfer of chemical substances in heterogeneous and highly dynamic terrestrial ecosystems, scientists can rarely spontaneously respond to questions concerning pollution (Dumat and Sochaki 2016; Goix et al. 2015). The answer of one scientist will generally be “it depends” on soil characteristics (Wu et al. 2016), crop variety, and practices (Dumat et al. 2013).

Promoting operational collaboration between researchers and gardeners is therefore a crucial environmental health issue, as millions of citizens cultivate and consume vegetables in the world (Dumat et al. 2015), and according to Zask (2016), relationships between farmers and cultivated land favor democratic values and the citizenship. This is certainly the main goal of the French national scientific research project “JASSUR” (community urban gardens in France and sustainable cities: practices, functions and risks, http://www6.inra.fr/jassur) in which our present study falls. The interdisciplinary JASSUR project proposes to clarify the functions, uses, means of operation, and benefits or potential hazards from community gardens within emerging sustainable cities. The project aims to identify the necessary means of action for maintaining or even restoring, developing, or evolving these community gardens in urban areas faced with the challenges of sustainability. To do this, it relies on a consortium of 12 research partners and associations in seven French cities (Lille, Lyon, Marseille, Nancy, Nantes, Paris, and Toulouse). JASSUR is based on a central question: What services do urban gardening associations provide in the sustainable development of cities? These ecosystem services rendered to the city, in the completeness of the meaning of this term proposed by the Millennium Ecosystem Assessment (provisioning, regulating, supporting, and cultural services), are still very poorly understood. We are in a context of “citizen science” as described by Callon et al. (2009): Gardeners are directly involved in the research program and participate in risk construction and management.

In the context of the JASSUR project, an interdisciplinary and participatory research study based both on soil fertility, risk assessment, and management was conducted in a French community garden affected by arsenic pollution in the well water used for vegetable irrigation. The following sociological research question guided the present work: in what way will the presence of arsenic prove to be a public problem or not and how will each affected party take ownership of this issue? In particular, the gardeners’ representations of risk and their motivation to build collective solutions for a sustainable management of the gardening site were studied using the theory of Gilbert (2003) in his publication “the manufacture of risks.” The author suggests that the designation of risks as public problems as well as the selection and grading of these risks are often explained in three great principles, either as the result of (1) arbitration by the public authorities, (2) confrontations between “civil society”, and public authorities, and (3) the way in which multiple actors define and build the problems. This theoretical framework was applied in this study to categorize gardeners in terms of their position with respect to the risk. Actually, Gilbert (2003) brings an interesting perspective to this field: Regardless of the scientific analysis, risk is a social construct. It will become a public problem if the various stakeholders will be appropriated as an issue to deal with. It is this process which is followed in this paper concerning arsenic pollution in community urban gardens, by observing interactions between gardeners, researchers, and public authorities. Our interdisciplinary and participative approach is therefore useful to further improve pollution management in community or private urban gardens.

In this review, we first describe the overall and interdisciplinary methods used in the study. The chronology of the arsenic pollution "story" in the urban gardens and the interactions between the different actors involved are then described. Next, the collective construction of the health risk induced by arsenic pollution in the gardens is described. Finally, we explain how the arsenic pollution led to several organizational changes both in the "Environment-Health" dynamics and interactions between the various stakeholders involved in the polluted gardens.

Interdisciplinary methodology performed

Overall design of the research project

In the context of the national research project JASSUR ("ANR Sustainable Towns"), an interdisciplinary and participatory research study based both on agronomy, risk assessments, and social science was conducted in a French community garden localized in Castanet-Tolosan (Chemin du canal au pont de Tuile, 31,300, France). The garden was affected by arsenic pollution in the well water used for vegetable irrigation. This chapter aims to highlight the complementary (both quantitative and qualitative) and interdisciplinary scientific methods used as illustrated in Fig. 1. Indeed, in addition to the presentation and discussion of the acquired research results, we also describe the mixed and interdisciplinary research methodology which was developed in a systemic way. Field research work thus dealing in an integrated way with the topic of pollution is actually still relatively rare (Mombo et al. 2016, 2017).

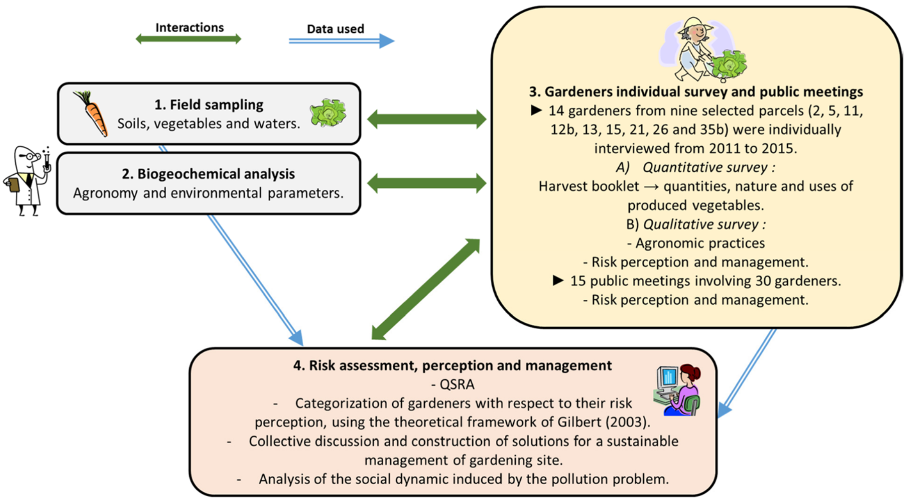

Fig. 1 General design of the research project in the polluted gardens: complementary of the mixed (both quantitative and qualitative) and interdisciplinary scientific methods used. For the step 4, the data from the steps 1, 2 (analysis), and 3 (survey and meetings) are needed. Interactions exist between several steps, for instance the sampling of vegetables in the gardens is also the opportunity to discuss with the gardeners

Data collection from the garden survey

The set of data we worked with included quantitative data on harvests in the gardens or arsenic concentrations measured in water, soil, and vegetables, as well as qualitative data from questionnaires and interviews with gardeners and from our observations of the plots. Comprehensive interviews with gardeners were carried out in order to (i) characterize the nature, quantities, and uses of the vegetables produced in the gardens using harvest booklets as described by Pourias et al. (2015); and (ii) discuss their agronomic practices and arsenic pollution risk perception and management.

The harvest booklet (see Fig. 2) includes tables with the following headings: (a) type of crop, (b) date of harvest, (c) quantity harvested (in grams or units), (d) use of the crop (eaten raw or cooked, preserved or immediate consumption), and (e) destination of the crop (own consumption or gifts outside the close family). The harvest booklet may also be considered as a "listing": an instrument that transforms the material into writing, essential traces to the production of scientific facts. The instruments of the "laboratory" produce a reality that Latour and Woolgar (1986) call "technical phenomena" which is the starting point for the production of facts.

Gardeners from nine different selected allotments were followed with the harvest booklets in order to characterize their production, practices, and risk perception. Gardeners from these nine selected plots (14 individual gardeners) were individually interviewed from 2011 to 2015, and each gardener was interviewed twice during the growing season. At the beginning of the growing season, a semi-structured individual interview was held regarding his or her point of view on the importance of the food function of his or her plot (importance of the garden in the gardener's overall food supply, use, and destination of the produce, etc.). At the end of the growing season, a second interview was held to assess the gardening practices (nature of the soil amendments and treatments such as copper foliar addition) and their level of concern about arsenic pollution. For that point, the following questions were asked: (1) Do you know the situation with water quality in the gardens? (2) Are you interested to read the study performed by the students from the University on that subject? (3) Do you have questions on that subject? (4) What is your opinion on the management of the arsenic pollution? And (5) do you want to discuss a particular point concerning your gardening activity? In addition, several meetings of the association and with the city hall helped to complete the individual analysis of how the association became more organized to deal

Fig. 2 Harvest Booklet: Front and Back Covers and Inside Pages (Pourias et al. 2015)

with arsenic pollution. From 2010 to 2015, the arsenic pollution was discussed by 30 gardeners and the researchers at 15 meetings (each meeting went for around 3 h).

The gardener surveys and public meetings allowed the gardeners' representations of risk to be studied according to the theory of Gilbert (2003) in his publication the manufacture of risks and build collective solutions for sustainable management of the gardening site.

Biogeochemical analysis performed in the gardens with the gardeners

Another aim of our research study was also to promote sustainable gardening practices, especially based on improved knowledge among the gardeners of both nutrient and pollutant transfer in the soil-plant-water system in relation with their practices and with the main objective of vegetable quality. Indeed, it is important for them to know the agronomic characteristics of their soil in order to reasonably choose which plants to cultivate and which amendments to make. These soil parameters also influence soil-plant transfer of both nutrients and pollutants (Elouaer et al. 2014). Moreover, the agronomic study was a "friendly handshake" with the gardeners. This is why open access pedagogical resources are such as those created by Dumat and Dupouy (2016).

Soil, water, and vegetable samples from the gardens were analyzed with normalized procedures. The main soil agronomic parameters useful for assessing soil fertility were measured (pH, soil organic matter levels, carbon/nitrogen ratio, soil texture, carbonates, cationic exchange capacity, exchangeable phosphorus, potassium, and copper) and then compared to reference values in order to give advice to the gardeners. Water quality was studied in the wells used for garden irrigation, and also outside the site in order to investigate the origin of arsenic pollution. Numerous discussions were performed with the gardeners and local politicians to identify the origin of the arsenic pollution: Could it be a natural geochemical phenomenon or is it due to anthropogenic activities? Both lettuce (leafy vegetable) and carrots (root vegetable) were sampled in the gardens in order to take into account the different potentials of plants to accumulate the arsenic (Ademe 2014a). After peeling for carrots, vegetable samples were washed to remove potential surface contamination (Uzu et al. 2010) and analyzed using the same procedure as in Schreck et al. (2011). Currently, in Europe, the arsenic concentration in consumed plants is not regulated. To interpret the measured arsenic values in the gardens, it was therefore necessary to compare measurements with values from plants grown under different arsenic conditions available in databases such as the "BAPPET," free open access tool (Ademe 2014b). An extract from the BAPPET tool shows measured arsenic soil concentrations between 17 and 322 mgAs kg^{-1} (dry weight of soil) and arsenic concentrations measured in various vegetables (lettuce, carrot, leek, green bean, pea, and radish) between 0.001 and 11 mgAs kg^{-1} (dry weight of plant). In addition, Mench and Baize (2004) reported values of 0.1 mgAs kg^{-1} for spinach and 0.3 for organically grown carrots.

Human arsenic bioaccessibility tests were performed according to Xiong et al. (2014) using the in vitro Unified Barge Method that simulates the processes occurring in the mouth, stomach, and intestine compartments with synthetic digestive solutions. Using the bioaccessibility measurements for arsenic in vegetables, it is possible to determine more precisely the fraction of arsenic that is effectively absorbed by humans after ingestion of polluted vegetables and that can induce a toxic effect. Actually, in vitro bioaccessibility measurements allow for an educated discussion of the environment-health relationship (Dumat et al. 2017) and follow the advice of the European REACH regulation on chemicals (European Commission 2006b), which aims to reduce animal testing both for scientific and ethical concerns. Arsenic bioaccessibility was expressed as the ratio between the extracted arsenic concentration in the saliva-gastric phase and the total concentration. The data obtained were analyzed for differences between treatments using an analysis of variance (one-way ANOVA). Statistical analysis was carried out using the software Statistica, Edition'98. A Fisher's LSD test was used to determine the level of significance (p value < 0.05) compared to the control.

Quantitative assessment of health risks due to polluted vegetable consumption

Human exposure to arsenic due to the consumption of polluted vegetables is a function of the arsenic concentration measured in vegetables and also the quantity of plants ingested (Swartjes 2011; Okorie et al. 2012). Since the arsenic concentration is not regulated in foodstuffs marketed in Europe, quantitative assessment of the health risks was performed in order to present scientific findings to the authorities in charge of the studied collective gardens and to inform the gardeners. The objective of the quantitative assessment of the health risks was to assess the arsenic quantity ingested by gardeners in the case of consumption of polluted vegetables and compare it with toxic reference values (Boutaric 2013; Dumat and Autruy 2014; Pascaud et al. 2014). The daily quantity of arsenic ingested via polluted vegetable consumption is then compared to the tolerable daily intake (TDI), without a health impact: 80 μg arsenic per day for a 60 kg human (Okorie et al. 2012). For this calculation, it is therefore necessary to know both the quantity of vegetables produced in the gardens and their use (consumption, donations...), information which was obtained from the gardener surveys, and the arsenic concentration in the vegetables (Xiong et al. 2014). Daily vegetable consumption data was previously obtained from field studies such as those carried out by Sharma et al. (2009): Formal interviews conducted in the urban areas of Varanasi showed that the average daily consumption of fresh vegetables per person (average body weight of an adult = 60 kg) was 77 g of fresh weight (or 13 g dry weight). Interviews with gardeners from Castanet-Tolosan indicated a daily vegetable consumption (fresh weight) between 30 and 300 g.

Study site and "arsenic pollution story"

Characteristics of the studied site

The community garden site is located in Castanet-Tolosan near the "Canal du Midi" in the Midi-Pyrénées Region. Forty allotments are cultivated in a total surface of 1200 m^2. Knowledge of the history of a site is an essential step for determining the environmental quality of soil, surface and ground waters, and the air quality. In particular, this information leads to (i) reasoned assumptions about the origin of the pollutants observed on the site or (ii) a list of chemicals that could a priori be present in the soil at the site, due to previous anthropogenic activities at the site and their persistence in the soil. This historical investigation step is included in the national policy for the management of contaminated sites and soils (ICPE 2017). This policy assigns a crucial role to the use of the site in order to discuss possible health risks and specify sensitive uses such as crop production or the presence of a school. Moreover, the agronomic characteristics of the soil influence the quantities and the quality of the plants produced, and they interest both curious gardeners and researchers who wish to discuss and interpret the measurements.

In this case, in 2005, a previous agricultural plot was converted into the 40 different individual subplots that are rented out to the 50 amateur gardeners involved in the association, who pay 50 euros per year. Originally, the soil characteristics were therefore approximately the same for all 40 allotments. However, progressively as a function of their agricultural practices, each gardener has significantly changed the soil characteristics.

Table 1 highlights the variations in the main agronomic parameters measured with standardized methods on dried and sieved (under 2 mm) soils. In comparison with reference values (natural background), medium copper pollution was observed: Copper is mildly toxic for humans (except at strong doses), but it can reduce biological activity in soils. The gardener survey highlighted that Bordeaux mixture (enriched with copper), liquid manure (nettle and comfrey), and biological anti-slug compounds were widely used. Comparing the measured values of exchangeable elements (P and K) with the current agriculture reference values which are shown in Table 1 in parentheses in the order (1) reinforcement reference value (Tr, below which the soil is considered depleted in nutrients) and (2) impasse reference value (Ti, above which the soil is considered enriched in element), over-fertilization of garden soils was concluded in all plots.

However, garden soils are different from agricultural soils: They present higher soil organic matter content and often contain higher amounts of coarse particles; it could therefore be pertinent to determine specific reference values for garden fertilization.

Story of the arsenic pollution in the gardens

Arsenic pollution of the well water used for watering vegetables in the associative gardens was discovered accidentally in 2010 by students as part of a teaching project to characterize the agronomic and environmental quality of the site. Following the detection of arsenic pollution, the research team contacted the regional health agency (ARS). Further water analyses were conducted, and finally, a prefectural notification prohibited the use of the water. The wells were then condemned to avoid the acute health risks associated with the ingestion of contaminated water or its use for hand or vegetable washing. However, because arsenic is highly toxic, the gardeners remained skeptical on the quality of their cultivated plants and the future use of their gardens. This is why the participative research project on plant quantity and quality was organized. Thus, regular measurements of arsenic in different samples were organized with the gardeners in order to respond to their legitimate concerns about the potential human health risk in that context of scientific and regulatory uncertainties induced by arsenic environmental pollution. Well water, soil, and plant products were analyzed at the site between 2010 and 2014 with regular exchanges with gardeners about the results.

Moreover, once the wells were condemned, and therefore the health risk controlled, the gardeners wished to continue gardening and therefore expected quick answers from ARS, the mayor, and researchers on the quality of plants. To respond to that social problem, the researchers first conducted a series of analyses without being part of a precise research program, but then the JASSUR project (2013–2016) was funded by the

Table 1 Agronomic parameters. The values in parentheses just after the measured values for exchangeable P_2O_5 and K_2O, correspond to the reference values (Tr, reinforcement value - Ti, impasse value)

Parcel number	Surface (m^2)	pH-H_2O and pH-KCl	OM (%)	C/N	Clay (%)	Loam (%)	Sand (%)	Carbonates (%)	CEC (me kg^{-1})
2	105	8–7.5	2.6	10	32	36	32	0.25	207
5	142	7.6–7.2	2	9	30	35	25	0.3	208
11	142	8.1–7.6	2.45	8.9	35.8	36.2	25.5	0.2	265
12b	71	8–7.6	3	11	35	37	28	0.3	211
13	163	8.2–7.4	2.85	9.7	31	38.7	27.8	1	209
15	150	7.6–6.8	2	10.6	35.3	37.1	25.7	0.1	237
21	124	7.8–7	2.8		24.4			0.7	146
26	124	8.2–7.4	4.05	12.4	33.5	37.2	25.4	0.8	242
35b	50	8.1–7.5	2.6	10.5	31	37	32	0.3	206
Parcel number	Exchangeable P_2O_5 JH (mg kg^{-1})			Exchangeable K_2O (mg kg^{-1})			Exchangeable Cu (mg kg^{-1}) (Ti = 0.75)		
2	185 (50–125)			575 (180–260)			1.8		
5	260 (170–240)			203 (180–260)			2.1		
11	71 (50–125)			239 (200–285)			3.6		
12b	53 (50–130)			260 (200–280)			2.8		
13	80 (50–125)			225 (175–250)			2.3		
15	79 (50–125)			346 (200–280)			6.6		
21	383 (170–240)			294 (200–280)			2.2		
26	107 (50–125)			280 (185–270)			5.5		

"sustainable cities" program from the French Agency for Research (ANR). Previously, the ADEME funded an initial research program (without analyzes) dedicated to the state of knowledge of the gardens in France (SOJA project, 2009–2011). Following this project, ADEME was aiming to analyze the pollution in the gardens but, ultimately, ADEME did not wish to engage in this garden characterization project for economic and strategic reasons. However, thanks to the results of this project, a book about French gardens was written entitled: "Jardins potagers: terres inconnues?" (Chenot et al. 2013). Actually, the complexity of these ecosystems makes them difficult and expensive to characterize and generate numerous uncertainties. Faced with the pollution and how to manage the uncertainties, the aims and perceptions of the various actors involved were different: (i) Gardeners wanted above all else to continue their gardening activities; (ii) the mayor and the ARS wanted to manage the health risks; and (iii) researchers wanted to obtain robust data, to quantify the production and measure the pollutants. Finally, these different stakeholders interacted throughout the project to co-build a common representation of the risk and then plan for its sustainable co-management.

Crops diversity, yield, and quality

The quantities of the various vegetables produced in the gardens in 2013 and 2014, obtained from the interviews with the gardeners in the harvest booklet, highlighted that although there was some high plant biodiversity in the gardens (artichokes, eggplants, beets, broccoli, carrots, cabbages, cauliflowers, cucumbers, zucchinis, shallots, broad beans, strawberries, raspberries, green beans, yellow beans, melons, onions, peas, leeks, peppers, potatoes, pumpkins, radishes, salads, tomatoes…), approximately 10 principal species were widely cultivated in the plots. Clinard et al. (2015) previously made the same type of observation. In the studied gardens, the following sequence was observed in terms of annual quantities for the 10 main vegetables produced: potatoes (around 100 kg maximum for one plot in one year) > tomatoes (maximum 50 kg year^{-1}) > green beans > salads > zucchinis > leeks > pumpkin > cabbages > cucumbers, broad beans, eggplants, and carrots. For the studied cropped plots with average surfaces of around 110 m^2, there were significant differences in the total quantities of vegetables produced between the nine studied allotments: for 2013, between 56 and 226 kg year^{-1} and the same trend for 2014 between 48 and 238 kg year^{-1}. From 1 year to the other (2013 and 2014), the quantities of vegetables were stable; however, the cultivated species varied: For example, due to heavy rains in 2013, tomato production was relatively low, and the gardeners had adapted their practices to climate and favored potato cultivation.

In order to verify the vegetable quality before human consumption, the arsenic concentration was regularly measured in various vegetables (carrots, lettuce, green beans, and leeks) and the corresponding soils, in 2010, 2013, and 2014. Measured arsenic concentrations in all the vegetables were generally lower than 0.05 mgAs kg^{-1} dry weight (DW), with only one maximum value at 0.06; this is a low arsenic concentration, close to the value considered for vegetables cultivated on unpolluted soils. According to Dumat and Autruy (2014), ordinary arsenic values in unpolluted French soils are between 1 and 25 mg kg^{-1} DW; the arsenic concentration measured in soils for the various plots reached a maximum of 14 mg kg^{-1}, with only a 2% phyto-available fraction (assessed by chemical extraction with $CaCl_2$).

Scientific expertise on the risk and gardeners' interest in the pollution problem

The assessed daily arsenic quantities ingested by gardeners (via consumption of their cultivated vegetables) were therefore between 0.32 μg arsenic and maximum 3.2 μg. These values can be compared with the tolerable daily intake (TDI): 80 μg arsenic per day (for a 60 kg human taken as an average adult weight). Using the measured arsenic concentration in lettuce, the maximum daily quantity of vegetables cultivated in the gardens that can be consumed without exceeding the TDI was therefore calculated. It ranged between 2.8 kg DW and 16.8 kgFW day^{-1}. These quantities are very high, and it was finally concluded that the gardeners were not significantly exposed to the arsenic through the consumption of vegetables from their gardens. In addition, the bioaccessibility measurements for arsenic in vegetables indicate that only a fraction (and not 100%) of the total ingested arsenic is effectively bioavailable: between 21% and a maximum of 75%. Taking into account arsenic bioaccessibility in vegetables allowed a definitive conclusion that the cultivated vegetables in the collective gardens from Castanet-Tolosan can be consumed without any significant health risks. Furthermore, the source of the arsenic pollution was under control: The wells were closed and the soil was not polluted.

Here were therefore the findings of the risk assessment by the "experts". However, the interviews with the gardeners of the nine plots studied in detail, and also the general discussions during the meetings with a total of 30 gardeners, identified three levels of interest in the arsenic pollution problem: (group-I) the "confidents," (group-II) the "dynamics," and (group-III) the "oppositionals."

1. Some gardeners (20% of the total studied population) and the Mayor were reassured: This group is referred to as "the confidents," these gardeners were not very concerned about pollution. Since the wells were condemned, at meetings, they were heedless and listened distractedly to the information provided on the arsenic analyses. They had full confidence in the management of the gardens, the Mayor, and scientists. They came to the gardens to cultivate vegetables and apply the good practice guidelines but did not ask questions and were not dynamic agents of change. Better knowledge of factors influencing transfer of pollutants in soils or human exposure to pollutants was not a priority for them.
2. The "dynamic gardeners involved in environment-health aims" (70%). The majority of gardeners were very interested in information on arsenic pollution. They promptly wanted the results of measurements and asked many questions. They are dynamic actors to develop pro-health-environment practices. For example, providing quality compost or using green manure plants. They were also very active in the search for a lasting solution for watering their gardens. Since the wells were closed and based on the arsenic analysis results, they were not worried, because their opinions were based on scientific findings. Moreover, these gardeners were also strongly involved in the life of the association, very dynamic and motivated to take part in sustainable development projects such as the creation of a pond to encourage biodiversity in the gardens (2013) or the creation of a plot garden accessible for disabled gardeners (2015). They worked in harmony with the Mayor and therefore were in a position of seeking solutions to sustainably manage the pollution and reduce arsenic exposure while remaining in the gardens.

3. Other gardeners were suspicious of the results as they would have expected a larger-scale research program to be funded by the city, and also due to the uncertain origin of the pollution, multiple theories and further contamination were still possible. These "oppositional gardeners" (10%) were quite vehement during the meetings. They wanted to communicate their disagreement with the Mayor who provided these gardens or the scientists who cannot convince them that the health risk is controlled if human exposure is low. Furthermore, they do not understand why the origin of the arsenic cannot be determined with certainty. They would like that the mayor writes regularly that the arsenic water pollution is totally under control and has no impact on their health. Rather worried, they did not propose any solutions. Only some of them are interested in knowing the results and gaining a better understanding of pollutant transfer. On the other hand, this gardener group is less involved in gardening activities and much more anxious with respect to pollution. They would like clear evidence that arsenic cannot contaminate them. A gardener in this group preferred to leave the garden, explaining that he was not reassured by the analysis, the Mayor's attitude, and researcher's findings.

Collective construction of the health risk

Water pollution: what consequences and management?

The origin of the arsenic contamination remains unclear. Table 2 shows the arsenic concentrations measured in the water of the various wells (P_1–P_4) between 2010 and 2014. Compared to the regulated value for drinking water in France (10 μg arsenic l^{-1}), we can conclude that the water was strongly polluted. That was why the water could not be used anymore for even hand washing and watering and even less ingested until further analysis was performed and a reduction in arsenic concentration demonstrated. Meetings were organized with political and technical services in the town in order to manage the situation. The regional agency for health was contacted by the researchers and supplementary analyses of the waters were performed. Finally, a prefectural attestation banned the use of the polluted water in 2011. Several hypotheses were proposed by the different people involved to explain the arsenic pollution of the well water:

1. A former landfill is located just near the main entrance to the gardens. As the gardens were moved to this location in 2005, gardeners who supported this hypothesis were highly critical because they thought that the Mayor made a bad decision when changing the location of the gardens.

Table 2 Values of arsenic concentrations in wells water since between 2010 and 2014

Well number and date for sampling.	P_1 02–2011	P_1 05–2014	P_2 02–2011	P_2 05–2014	P_3 11–2010	P_3 01–2011	P_3 02–2012	P_4 05–2014
Arsenic (μg L^{-1})	5	28	9.9	28	120	372	220	90

2. Another hypothesis was the piling up of large quantities of pesticides enriched with arsenic in the soil after a pesticide factory closed in 1980. Several old gardeners who have been living in Castanet-Tolosan for a long time seemed to remember these practices.
3. According to another gardener, during the explosion of the "AZF factory" in Toulouse, polluted excavated soils were used at a regional scale; a third hypothesis is therefore that arsenic pollution was induced by the addition of these polluted soils. However, as the main chemical substance used on the AZF site was ammonium nitrate and according to the ARIA database (Analysis, Research, Information on Accidents) most of the polluted lands were cleared on the site, this hypothesis appears to be implausible.
4. A final hypothesis is the natural origin of arsenic in the mother rock from which the soil has developed; well water could therefore become enriched especially as the wells were used often and dug deep (Shahid et al. 2017). Actually, high arsenic values in waters due to the natural alteration of rock enriched with arsenic have been observed in the Midi-Pyrénées Region.

In addition to the wells in the collective gardens, supplementary analyses were performed in different wells from surrounding areas upstream and downstream of the collective gardens, and no water pollution was observed. Consequently, the hypothesis of arsenic transfer from an anthropogenic source such as waste storage (landfill for instance) was ruled out. The local geological origin of the arsenic was finally concluded to be the most likely after a newly dug well also became enriched with arsenic. Nevertheless, it was complex to explain to certain gardeners why the origin of the pollution was difficult to determine with absolute certainty.

Many gardeners who have plots on municipal land were shocked to learn that the well water was polluted with arsenic. Since a municipal ordinance quickly prohibited watering, discussions started between the gardeners both about the solutions for irrigation of their plants without the wells and about the potential for arsenic pollution in the soil and vegetables. The gardeners were party-actors in the development of these solutions. Overwhelmingly, they wanted to keep their gardens and were very motivated to find solutions for watering the crops using different means other than the wells. Moreover, once the danger associated with the well water was removed, it was logical to shift the health risk assessment to soil and especially plant quality. However, the gardeners' exposure to the arsenic was influenced by both the arsenic concentrations in plants and also garden uses. In order to solve the problem of polluted water, different approaches were explored: (i) Use water from the nearby canal? (ii) Use drinking water? (iii) Establish a water decontamination system. Or finally (iv) should the Mayor organize access to safe drinking water for the gardeners? Actually, the Mayor has an administrative obligation to protect the gardeners' health in community gardens. That is why he needs to take care with health risk management. In the case of water pollution, it was quite easy to make decisions, as a maximum limit value is available for water quality. But, in the case of vegetable quality, as mentioned above, it was more difficult to make a decision as no threshold value is available and thus a quantitative health risk assessment was needed. Thus, questions were quickly raised about the quality of plants: what risks? Should the gardens be condemned or is it possible to continue gardening and under which conditions?

Dynamics of the actors and collective risk construction

With regard to arsenic pollution, the level of implication of the gardener's groups varies. Once the risk of pollution was identified, the ARS and the Mayor had a strong position: The main source of risk (wells) was confined. As previously explained in Sects. 3–4, the gardeners adopted three different attitudes on the basis of tangible scientific results on which to build. A collective risk assessment process took place and involved three main different categories of stakeholders: gardeners, public managers, and researchers. Some gardeners were very involved in the acquisition of useful data for researchers, "we really appreciate the work done by researchers to accompany us in the management of pollution and in addition it costs nothing!" (verbatims collected in 2012 at a public meeting concerning the collective gardens). Other gardeners did not believe that the mayor was taking measure of the situation and doubted that the seriousness of the risk management carried out the ARS, the Mayor, and experts: "would have the mayor agree in writing that the gardens are safe for our health" (verbatim collected in 2014, while both the ARS and the mayor gave the green light to continue gardening activities after closing the wells). In order to explain to that category of gardeners why only certain analysis was performed in the gardens and not all the available scientific analysis, a parallel between "human health" and "environmental health" can be used: A doctor first performs simple, quick, cheap, and standard tests and an interview of a patient before making a diagnosis, and then he may eventually send him to consult a specialist for further analysis. An expert in soil science will proceed using the same steps and by taking into account the economic aspects of the soil quality study.

Researchers from the JASSUR program were involved in the management of the pollution and worked at the interface between the gardeners and the authorities. They organized research and participated as experts and also as observers (in risk management by gardeners and the Mayor). This scenario therefore was in the context of risk manufacture of type 3 according to the theory developed by Gilbert (2003). The author uses the concept of risk manufacture to underline here the constructed nature of risk due to arsenic pollution. Therefore, the public authorities, responsible for our collective security, are forced to make adjustments and even trade-offs to integrate this dimension into risk management strategies. Shifts can therefore occur constantly between these different modes of explanation. One of the challenges for human and social scientists is probably to better understand the multiple uses of these different modes of explanation of "manufactured risks." With this "risk setting," the uncertainties associated with hazards are reduced, facilitating their objectification. Overall, therefore, the idea of a possible risk control is required due to the link between expertise and decision. Chevassus-au-Louis (2000) describes in detail the thinking on uncertainties in areas that affect food. However, in the case of collective gardens, except if the health risks are very high, the gardeners generally want to stay in their gardens: They therefore researched solutions to manage the pollution and were very interested in collaborating with the other stakeholders.

At the national level, as a sharing experience, the case study of the Castanet-Tolosan's gardens participated in the collective development of the sustainable management of the risks associated with pollution in areas used to cultivate plants for human consumption. Gardeners hoped to stay at their gardening site where they had already invested time, energy, expertise, and built emotional bonds. They expected unambiguous explanations from the Mayor's team and researchers. Measuring the arsenic concentration directly in the cultivated plants was ultimately the most effective way to convince them of the absence of pollutant in their plants. The Mayor and his team wished to reconcile the social dynamics brought about by the collective gardens while controlling the population's exposure to pollutants in these gardens, of which he is the legal manager. The implementation of new, easier to apply, operational standards was therefore one of the high expectations for these actors. Association leaders adopted an intermediate position between the gardeners and the Mayor. That is, they are primarily gardeners but also very involved in the negotiations for the management of the arsenic pollution in close collaboration with the Mayor. The researchers structured, organized, conceptualized measured data, information, and interviews obtained from the different stakeholders, and they also have knowledge of the mechanisms involved in the transfer of pollutants throughout the plants. These actors are aware of the potential risks related to urban gardens and are highly motivated to promote sustainable gardening practices, but they are also unwilling to excessively oversimplify the methods used to measure and evaluate the health risks. However, that step is often needed for environmental regulation. In practice, the management of the pollution involves interdisciplinary, collective, and multi-player work in order to build a sustainable solution in the absence of national legislation. That national legislation appears increasingly necessary as the number of identified pollution cases increases in France.

Social dynamics which resulted from the arsenic pollution in the gardens

Influence of the quantitative assessment of risk due to polluted vegetable consumption

Improving the scientific understanding of how quantitative risk assessments are performed among the different actors involved in this case of potential arsenic exposure (induced by ingestion of vegetables cultivated in the collective gardens of Castanet-Tolosan) was an important challenge (Dumat et al. 2015). Both the pollution on a scientific base, as well as the gardener's perception of the pollution, needed to be managed. The exchanges with gardeners about agronomy highlighted their relatively poor understanding of mechanisms involved in nutrient and pollutant transfer to plants. Actually, the Castanet-Tolosan collective gardens are productive, even if the gardeners pay special attention to the esthetics of the gardens (flowers and decorations are widely present in the plots), between 80 and 100% of the available surface area is used to grow vegetables. "Bordeaux mixture" treatment is currently used in the gardens; however, copper is persistent in the environment, so it would be wise to reduce inputs. Moreover, to obtain good yields, the gardeners frequently add composts and water on their plots. The issue of water quality was therefore crucial for them. Thus, since the arsenic discovery in well water, meetings between the different actors were organized regularly (2011–2015) at which both the arsenic pollution and also sustainable practices that can be develop in the gardens were discussed.

Consequently, the arsenic pollution led to an improvement in the structuration of the community due to the development of exchanges with each other. This case study also led to great exchanges about the management of health risks resulting in a collective process of risk manufacture. The aim was to organize information (open access databases and educational resources on sustainable gardening practices) and develop communication tools. Moreover, it was important to clearly describe this experience of arsenic pollution to further diffuse it to the French gardening community. As concluded from our study, if citizens are interested in sustainable environmental management, they especially feel concerned about their health. The health risk occurring with arsenic found in the water and potentially in the vegetables that they cultivate with care was a driving force for gardeners to understand the transfer of chemicals in the environment. They understood that the characteristics of the soil or the crop species can influence the amount of arsenic found in the crops. In this favorable environment for trading information, it was also an opportunity for researchers to engage with gardeners on the different advantages of developing sustainable gardening practices. For example, to determine their soil texture, be vigilant about the Bordeaux mixture doses made or compost quality.

The health risks were assessed efficiently using daily intake measurements. In the studied gardens, the water was significantly polluted with arsenic with regard to French regulations, so restrictions forbidding its usage were made by the authorities. However, assessing the potential health risk due to soil and plant pollution is complex and requires field measurements. Indeed, prior to root uptake, a transfer step from the soil to the soil solution occurs and represents the fraction of pollutant which is eventually considered as phytoavailable (Austruy et al. 2014). This phytoavailable fraction is strongly influenced by soil parameters such as pH, soil texture, organic matter content, and the type of plant (Leveque et al. 2014). Measuring the pollutant concentration in the edible parts of plants allows the phytoavailable fraction to be determined. Using and completing existing databases on soil quality should be promoted. Finally, the origin of the pollution remains unanswered as the priority of the ARS, and the Mayor of Castanet-Tolosan was certainly to protect populations (and not to perform scientific investigations in order to highlight the mechanisms involved). This objective was achieved with shut-in wells and verifying the quality of cultivated plants. Looking beyond the pollution source is also an approach that is advocated through sustainable management of soil resources. That is why the potentially most polluting anthropogenic activities are classified in France for the protection of the environment (ICPE). In particular, ICPE regulations impose participation in databases (BASIAS and BASOL) that record the history of anthropogenic activities and widely inform all interested parties. This approach is pragmatic and allows rational pollution management based on knowledge of the various chemical substances used on each site.

Pollution breathed new life into the debate on health and environment issues

For most of the gardeners, the numerous interactions with researchers ultimately strengthened their skills in the health and environment fields. They were very active in researching for new irrigation solutions, which they discussed with researchers and the Mayor. They also diversified their activities: creating a pond to encourage biodiversity in the gardens (2013) and a garden space open to people with disabilities (2015). It can also be noted that only one plot was abandoned by a couple of gardeners due to the arsenic pollution: The collective construction and ownership of risk management have therefore worked on this site. Researchers for their part have also evolved during the project from a highly scientific attitude towards an engaging attitude for the citizens' benefit: Keeping both scientific expertise with an open mind to societal concerns allows Science and Society projects to be effectively developed. The researchers strengthened the network of stakeholders by offering meetings where managers and gardeners from several community gardens were invited. The Mayor now wants to develop an eco-district for which he has requested meetings with the researchers prior to the project.

Thus, in order to develop a complete risk management system for the gardens, it was particularly interesting to rely on gardeners from Group II to organize the research and disseminate information because they were particularly receptive and dynamic. However, it was also very important to discuss everything with the gardeners from Group III because they had another rationality (that the only rational scientist approach) to assess the risks. Exchange with the gardeners of this group has allowed researchers to gain a better understanding of the knowledge of these gardeners on the link between environment and health. Responding to numerous questions from these gardeners on vegetable quality and also soil quality has reasserted the robustness of the analysis. Farges (2014) examined the conditions in which allotment gardeners integrate practices and norms on sustainability and demonstrated that while they adopt new cultivation techniques for their plots, the meanings of their gardening practices differ, as do their relationships with the environment. Three "ideal types of gardeners" were identified, and Farges (2014) showed that the diffusion of pro-environmental practices is not systematically related to share concerns and that the meaning of practices can be interpreted differently by policymakers and lay individuals.

However, one gardener in conflict with the management team chose to leave their garden due to the feeling that "the mayor has already made a strong mistake by proposing that polluted site for installation of the gardens." In addition, we observed the problem of timing, from gardeners on one side who wanted instant answers and the council and researchers on the other side, who needed time for measurements, surveys, and analyses. The council also had to take into account economic criteria to choose one kind of solution, while gardeners directly concerned by the site sometimes had other expectations.

Conclusions and perspectives

Arsenic is a non-regulated pollutant for vegetables cultivated in gardens and more widely for commercialized vegetables in Europe. By favoring exchanges between gardeners, the arsenic pollution led to structuration of the community and permitted discussions with the other actors, and progressively a collective construction and management of risk. Currently in France and more broadly around the world, the question arises of how to safely live in polluted environments (air, soil, and/or water). In particular, strategies for growing safe edible plants in urban areas, with the aim of lower human exposure to pollutants, are crucial. Indeed, the majority of the population resides in urban areas, and anthropogenic activities in recent decades have led to pollution of the environment. Now, several important objectives must be reconciled for credible public action and to effectively promote the development of sustainable urban agriculture projects increasing food justice: Develop sustainable food systems;

preserve human health, in relation to environmental quality and safe food production; encourage the housing of populations close to places of professional activities; and establish safe channels for fertilizers and amendments qualities (straw, compost ...).

Assessing the potential health risks of arsenic pollution required that both the production level in the gardens was quantified and that the arsenic concentrations in consumed vegetables were measured in order to precisely determine the potential human exposure and finally to compare it with reference values. This multi-step procedure can potentially lead to uncertainties. To improve the precision of the potential for human exposure to pollutants in the gardens, we needed to know the proportion of produced plants truly consumed by the gardeners themselves: As for instance, some produce could be given to friends or the number of people in the family can change. Further studies are therefore needed to think about arsenic regulation for consumed vegetables, as this pollutant is widely observed at the global scale.

In urban areas with high population density, numerous cases of pollution exist, but citizens generally have only low knowledge about mechanisms involved in the fate of pollutants in the environment leading to wrong conclusions on the environmental or health risks. For example, even very small amounts of arsenic in water can induce toxicity if ingested, but a higher arsenic quantity in soil will not be a health risk due to adsorption on soil components. This explains why drinking water was prohibited in the studied gardens, whereas vegetable consumption could continue. Discussions about metal concentrations in vegetables require some precautions, for instance (i) to specify the units and if the result is expressed as a function of fresh or dry plant matter, and (ii) to define the sampling and analytical procedures used. Misinterpretation of data must be absolutely avoided, because decisions such as the prohibition of cultivating edible plants could then be made. It is indeed important to keep in mind all the known positive effects for both mental and physical health of gardening activities. Regarding the search for alternative solutions for watering the gardens, in 2016, the administration agreed that water from the nearby Canal du Midi could be used.

More broadly, our results illustrate the complexity of the interactions involved in the fate of pollutants in high heterogeneity ecosystems such as gardens. An important issue is how to reconcile scientific research into the biogeochemical mechanisms involved and practical solutions to improve ecosystem services. This is an important challenge to increase initiatives to bring science and society in this direction. This was the case of the participatory research-formation network “Reseau-Agriville” (http://reseau-agriville.com/) (Jacquemoud 2015). It helps to shape a favorable interface between knowledge and practice in the context of ecological transition at the global scale. Gardeners are very independent and therefore a priori reluctant to meet the imposed rules. However, when the central issue is health, they are mostly ready to mobilize to act in cooperation with other stakeholders. This is why different levels of networking (at the regional, national and international scales) appear as an effective approach. It can also be pointed out that health and food are very good levers to mobilize citizens on the quality of the environment. Actually, the authorities in charge of public gardens now have a responsibility for the health of gardeners who exploit these plots, but no regulatory obligation on the quality of soil or plant products. In conclusion, in the case of pollution in garden ecosystems, the construction of risk faces the complexity of both scientific and social factors; the motivation of gardeners to stay in their site and continue the production of food induces, however, a strong social dynamic.

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References

Ademe. (2014a). *Guide d'échantillonnage des plantes potagères dans le cadre des diagnostics environnementaux.* Seconde édition. http://www.ademe.fr/guide-dechantillonnage-plantes-potageres-cadre-diagnostics-environnementaux.

Ademe. (2014b). Base de données des teneurs en éléments traces métalliques de plantes potagères (BAPPET). http://www.ademe.fr/base-donnees-teneurs-elements-traces-metalliques-plantes-potageres-bappet-presentation-notice-dutilisation.

Austruy, A., Xiong, T., Alletto, L., & Dumat, C. (2013). Health and environmental management in associative gardens: practices and risk perception. *Colloque International et Interdisciplinaire Dynamiques Environnementales, Politiques Publiques, pratiques locales : quelles interactions ?* Geode, Toulouse, 4–7 juin 2013.

Austruy, A., Shahid, M., Xiong, T., Castrec, M., Payre, V., Khan Niazi, N., Sabir, M., & Dumat, C. (2014). Mechanisms of metal-phosphates formation in the rhizosphere soils of pea and tomato: environmental and sanitary consequences. *Journal of Soils and Sediments, 14*(4), 666–678.

Badreddine, R., Dumat, C., Branchu, P., Velly, N. 2018. Méthodologie pour la mise en place d'un potager expérimental urbain dans un objectif d'évaluation des risques sanitaires. *Actes du Congrès international « Agricultures urbaines durables : Vecteur pour la transition écologique, 2017 ».* Ed. Nature Paris. Coord. Dumat C., Sochaki L., Bories O., Lagneau A.

Bilal, M., Niazi, N., Bibi, I., Rahman, M., Naidu, R., Dong, Z., Shahid, M., & Arshad, M. (2015). Unraveling health risk and speciation of arsenic from groundwater in rural areas of Punjab, Pakistan. *International Journal of Environmental Research and Public Health, 12*(10), 12371–12390.

Boutaric, F. (2013). La méthode de l'évaluation des risques sanitaires en France: représentations, évolutions et lectures plurielles. *Vertigo, 13*(1), 1–23.

Callon, M., Lascoumes, P., & Barthe, Y. (2009). *Acting in an uncertain world: An essay on technical democracy.* (Trans. Graham Burchell). Cambridge: MIT Press.

Chenot, E., Dumat, C., Douay, F., & Schwartz, C. (2013). *Jardins potagers: terres inconnues ?* EDP Sciences, 176 pages, ISBN: 978–2–7598-0723-9.

Chevassus-au-Louis, B. (2000). Retour de l'irrationnel ou conflit de rationalités. Que mangeons-nous ? *Revue Projet*. http://www.revue-projet.com/articles/retour-de-l-irrationnel-ou-conflit-de-rationalites/.

Clinard, F., Delefortrie, A., Bellec, S., Jacquot, G., Bonnelles, A., Tillier, C., & Richert, J. (2015). Enquête de pratiques agricoles et de consommation alimentaire dans les jardins ouvriers de l'agglomération de Belfort (Franche-Comté). *Environnement risques & santé, 14*(1), 56–71.

Douay, F., Roussel, H., Pruvot, C., Loriette, A., & Fourrier, H. (2008). Assessment of a remediation technique using the replacement of contaminated soils in kitchen gardens nearby a former lead smelter in northern France. *Science of the Total Environment, 401*(1–3), 29–38.

Dumat, C., & Autruy, A. (2014). Phytotechnologies. *Techniques de l'Ingénieur*, 20pp.

Dumat C., & Dupouy D. (2016). BioGéoChimie des jardins. *Réseau-Agriville*, copyright 2016, http://reseau-agriville.com/ressources.html.

Dumat, C., & Sochaki, L. (2016). Les projets de recherche participatifs dans les jardins collectifs urbains : des opportunités pour la transition écologique ! *4e Conférence sur l'entretien des Jardins, Espaces Végétalisés et Infrastructures*, 19 et 20 octobre 2016-ENSAT Toulouse.

Dumat, C., Leveque, T., Alletto, L., Barbaste, M., Sejalon, N., & Gaillard I. (2013). Environmental and sanitary risk assessment and management in associative gardens: vegetable quality in relation with practices and context. *International Conference Environmental Geochemistry and Health*, Toulouse.

Dumat, C., Pierart, A., Sochaki, L., Borries, O., Messina, M., Chevalarias, F., Cazenave, J. M., & Bertoni, G. (2015). Socio-scientific strategies for research and formation projects to favor sustainable urban agricultures at the global scale. *8th International Conference of the Urban Soils Working Group - SUITMA 8*, 20–25/09, Mexico. Session: Education strategies to promote awareness on urban soil ecological functioning.

Dumat, C., Xiong, T., & Shahid, M. (2016). *Agriculture urbaine durable : opportunité pour la transition écologique.* Presses Universitaires Européennes, Saarbrücken, DE. ISBN 978–3–639-69662-2.

Dumat, C., Leveque, T., Mombo, S., Austruy, A., Shins, R., & Foucault, Y. (2017). Measurement of human bioaccessibility for metals: relevant indicator of the link between environment and health! *Actes du Congrès international « Agricultures urbaines durables : Vecteur pour la transition écologique, 2017 ».* Ed. Nature Paris. Coord. Dumat C., Sochaki L., Bories O., Lagneau A.

Dumat, C., Sochaki, L., Messina, M., Dupouy, D., & Schreck, E. (2018). Les jardins collectifs urbains : de précieux terrains d'exploration de la transdisciplinarité recherche-formation sur les sujets Environnement-Santé. *Les systèmes complexes de la biologie aux territoires. Les dossiers d'Agropolis international*, n°23, mai 2018.

Elouaer, Z., Bouhamed, F., & Bouzid, J. (2014). Evaluation of different amendments to stabilize cadmium, zinc, and copper in a contaminated soil: influence on metal leaching and phytoavailability. *Soil and Sediment Contamination, 23*(6), 628–640.

European Commission. (2006a). Règlement (EC) N° 1881/2006 du 19 décembre 2006 portant fixation de teneurs maximales pour certains contaminants dans les denrées alimentaires modifié par les règlements (EC) 1126/2007–565/2008 et 629/2008 et les règlements (EU) 105/2010–165/2010–420/2011–835/2011–1258/2011–1259/2011 et 594/2012.

European Commission. (2006b). Regulation (EC) n°1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).

Farges, G. (2014). Convergence on sustainable lifestyles? Mechanisms of change and resistance in a French allotment. *Sociologia Ruralis*. https://doi.org/10.1111/soru.12052.

Foucault, Y., Schreck, E., Levêque, T., Pradère, P., & Dumat, C. (2012). Gestion et remédiation des sols contaminés au plomb. *Environnement, Risques et Santé, 11*, 61–66.

Ghose, R., & Pettygrove, M. (2014). Urban community gardens as spaces of citizenship. *Antipode, 46*(4), 1092–1112.

Ghosh, S. (2014). Measuring sustainability performance of local food production in home gardens. *Local Environment: The International Journal of Justice and Sustainability, 19*(1), 33–55.

Gilbert, C. (2003). La fabrique des risques. *Cahiers Internationaux de Sociologie, 1*(114), 55–72.

Goix, S., Mombo, S., Schreck, E., Pierart, A., & Lévêque, T. (2015). Field isotopic study of lead fate and compartmentalization in earthworm–soil–metal particle systems for highly polluted soil near Pb recycling factory. *Chemosphere, 138*, 10–17.

Gojard, S., & Weber, F. (1995). Jardins, jardinage et autoconsommation alimentaire. *INRA Sciences Sociales, 2*, 1–4.

Hale, J., Knapp, C., Bardwell, L., Buchenau, M., Marshall, J., Sancar, F., & Litt, J. S. (2011). Connecting food environments and health through the relational nature of aesthetics: gaining insight through the community gardening experience. *Social Science & Medicine, 72*, 1853–1863.

ICPE. (2017). Note du 19 avril relative aux sites et sols pollués - Mise à jour des textes méthodologiques de gestion des sites et sols pollués de 2007 - NOR : DEVP1708766N (via : installationsclassees.developpement-durable.gouv.fr).

Jacquemoud, F. (2015). Réseau-Agriville, la science au service de l'agriculture urbaine. *La France Agricole*, 3612.

Jennings, A. (2013). Analysis of worldwide regulatory guidance values for the most commonly regulated elemental surface soil contamination. *Journal of Environmental Management, 118*, 72–95.

Latour, B., & Woolgar, S. (1986). *Laboratory Life. The Construction of Scientific Facts*; Paperback ISBN 9780691028323, 296 pp.

Leveque, T., Capowiez, Y., Schreck, E., Xiong, T., Foucault, Y., & Dumat, C. (2014). Earthworm bioturbation influences the phytoavailability of metals released by particles in cultivated soils. *Environmental Pollution, 191*, 199–206.

Mench, M., & Baize, D. (2004). Contamination des sols et de nos aliments d'origine végétale par les éléments en traces. Mesures pour réduire l'exposition. *Le Courrier de l'Environnement de l'INRA, 52*, 31–56.

Menozzi, M. J. (2014). *Les jardins dans la ville entre nature et culture*, Rennes, Presses universitaires de Rennes, coll. « Espace et Territoires », 362 p., ISBN : 978–2–7535-3263-2.

Mitchell, R. G., Spliethoff, H. M., Ribaudo, L. N., Lopp, D. M., Shayler, H. A., Marquez-Bravo, L. G., Lambert, V. T., Stone, E. B., & McBride, M. B. (2014). Lead and other metals in New York City community garden soils: factors influencing contaminant distributions. *Environmental Pollution, 187*, 162–169.

Mombo, S., Foucault, Y., Deola, F., Gaillard, I., Goix, S., Shahid, M., & Dumat, C. (2016). Management of human health risk in the context of kitchen gardens polluted by lead and cadmium near a lead recycling company. *Journal of Soils and Sediments, 16*, 1214–1224.

Mombo, S., Dumat, C., Shahid, M., & Schreck, E. (2017). A socio-scientific analysis of the environmental and health benefits as well as potential risks of cassava production and consumption. *Environmental Science and Pollution Research, 24*(6), 5207–5221.

Okorie, A., Entwistle, J., & Dean, J. R. (2012). Estimation of daily intake of potentially toxic elements from urban street dust and role of oral bioaccessibility testing. *Chemosphere, 86*, 460–467.

Pascaud, G., Leveque, T., Soubrand, M., Boussen, S., Joussein, E., & Dumat, C. (2014). Environmental and health risk assessment of Pb, Zn, As and Sb in soccer field soils and sediments from mine tailings: solid speciation and bioaccessibility. *Environmental Science and Pollution Research, 21*(6), 4254–4264.

Pourias, J., & Duchemin, E. (2013). *Impacts nutritionnels des initiatives en agriculture urbaine : aménager et nourrir la ville.* Éditeur scientifique : Duchemin, E., Laboratoire sur l'agriculture urbaine ISBN : 9782923982953. p. 379.

Pourias, J., Duchemin, E., & Aubry, C. (2015). Products from urban collective gardens: food for thought or for consumption? Insights from Paris and Montreal. *Journal of Agriculture, Food Systems and Community Development, 5*(2), 175–199.

Schreck, E., Foucault, Y., Pradere, P., & Dumat, C. (2011). Influence of soil ageing on bioavailability and ecotoxicity of Pb carried by process waste metallic ultrafine particles. *Chemosphere, 85*, 1555–1562.

Schwartz, C. (2013). Les sols de jardins, supports d'une agriculture urbaine intensive. *VertigO*, Hors-série 15, Pollutions atmosphériques, transport et agriculture.

Shahid, M., Khalid, M., Dumat, C., Khalid, S., Niazi, N. K., Imran, M., Bibi, I., Ahmad, I., Hammad, H. M., & Tabassum, R. A. (2017). Arsenic level and risk assessment of groundwater in Vehari, Punjab Province, Pakistan. *Exposure and Health*, 1. https://doi.org/10.1007/s12403-017-0257-7.

Sharma, R. K., Agrawal, M., & Marshall, F. M. (2009). Heavy metals in vegetables from production and market sites of a tropical urban area of India. *Food and Chemical Toxicology, 47*(3), 583–591.

Swartjes, F. A. (2011). *Dealing with contaminated sites: From theory towards practical application* (1st ed.p. 264). Berlin: Springer Verlag.

Tabassum, R. A., Shahid, M., Dumat, C., Niazi, N. K., Khalid, S., Shah, N. S., Imran, M., & Khalid, S. (2018). Health risk assessment of drinking arsenic-containing groundwater in Hasilpur, Pakistan: effect of sampling area, depth, and source. *Environmental Science and Pollution Research*, 1–12.

Uzu, G., Sobanska, S., Sarret, G., Muñoz, M., & Dumat, C. (2010). Foliar lead uptake by lettuce exposed to atmospheric fallouts. *Environmental Science & Technology, 44*, 1036–1042.

Uzu, G., Schreck, E., Xiong, T., Macouin, M., Lévêque, T., Fayomi, B., & Dumat, C. (2014). Urban market gardening in Africa: metal(oid)s foliar uptake and their bioaccessibility in vegetables, implications in terms of health risks. *Water, Air & Soil Pollution, 225*, 2185.

World Health Organization. (2010). Preventing disease through healthy environments exposure to arsenic: a major public health concern.

Wu, J., Dumat, C., Lu, H., Li, Y., Li, H., Xiao, Y., Zhuang, P., & Li, Z. (2016). Synergistic improvement of crop physiological status by combination of cadmium immobilization and micronutrient fertilization. *Environmental Science and Pollution Research, 23*(7), 6661–6670.

Xiong, T., Leveque, T., Shahid, M., Foucault, Y., & Dumat, C. (2014). Lead and cadmium phytoavailability and human bioaccessibility for vegetables exposed to soil or atmosphere pollution by process ultrafine particles. *Journal of Environmental Quality, 43*, 1593–1600.

Zask, J. (2016). *La démocratie aux champs. Du jardin d'Eden aux jardins partagés, comment l'agriculture cultive les valeurs démocratiques.* Les Empêcheurs de penser en rond, 250 page.