Management Initiatives in Support of the Soil Quality of Urban Allotment Gardens: Examples from Nantes (France)

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MANAGEMENT INITIATIVES IN SUPPORT OF THE SOIL QUALITY OF URBAN ALLOTMENT GARDENS: EXAMPLES FROM NANTES (FRANCE)

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Abstract

Urban allotment gardens (UAG) are important for: the provision of foodstuffs, social cohesion, residents' well-being, and prevention of the formation of local heat islands during summer. The soils of these gardens however may be adversely affected by pollution threats and thus create health risks. In such cases, appropriate management becomes necessary.

For several gardens exhibiting soil contamination (e.g. Pb at 100-400 mg kg^{-1}) in the city of Nantes, local actors collaborated, including: scientists, the municipality's Parks and Open Space Department, elected officials, sanitary administration, and each site's gardeners' association. The soil characterization step was performed along with a sanitary risk evaluation and discussion of management options, based on both the pollution characteristics and local context.

The most frequent option consisted of replacing the polluted soils with clean soils. Managing the excavated polluted soils on-site (e.g. for ornamental purposes) limited the economic and environmental impacts associated with this solution. Alternative solutions, including a combined system of non-accumulative cropping vegetables at the time of phytoextraction, were also employed to maintain gardening uses. In some cases, land use (gardening) was changed into, for example, an orchard, open space or ornamental space. A combination of solutions was introduced in several gardens.

The various options available for managing polluted soils, as implemented in Nantes' UAGs and based mainly on NBS, can be applied more generally in order to improve soil quality. In addition to enhancing the quality of both residents' lives and biodiversity, several solutions

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allow preserving or even restoring soil functions.

1. Introduction

Sustainable and attractive green cities include urban allotment gardens (UAG) in their development programs. Such UAG have become widespread across the world, especially in industrialized countries (Draper & Freedman, 2010; Guitart *et al.*, 2012). These gardens provide many benefits to the community, namely: assets for social cohesion, health and gardeners' well-being (Genter *et al.*, 2015); foodstuffs, especially important in times of economic crisis; contribution to water regulation and prevention of local heat islands through evapotranspiration; sources of biodiversity development (Haase *et al.*, 2014; Breuste & Artmann, 2015; Bell *et al.*, 2016). The soils in these gardens however may be adversely affected by pollution due to their location on former urban industrial sites or near roads with intense traffic (Hough *et al.*, 2004; Hursthouse *et al.*, 2016). Individual gardening behavior can also introduce contaminants. These soils might thus be contaminated by anthropogenic sources, but also they could sometimes be affected by geogenic anomalies and present health risks (Jean-Soro *et al.*, 2014). In such cases, finding appropriate management solutions is crucial for sanitary and economic reasons.

Several feasible options exist to manage soil pollution:

i) Excavating the contaminated soil and replacing it by uncontaminated (top)soil (called *ex situ* management). Urban developers and city councils most often rely on such an option in order to reopen the gardens as quickly as possible. Removing the source of danger solves the problem immediately and definitively, thus avoiding any liability issue in the event of insufficient soil cleanup (precautionary principle). Nonetheless, when taking soil sustainability into consideration, landfilling low contaminated soils as the main management option is a questionable practice. Once excavated and removed from the site, soil indeed becomes a waste and cannot be reused except for very specific uses (e.g. road base course). The availability and quality of the marketed (top)soil used to replace the polluted soil also raises questions;

ii) Excavating the contaminated soil and keeping it on site (called "on-site management"). In this case, the excavated soil retains its status as soil. Depending on the pollutants involved as well as on the deadline for land use conversion and available on-site space, the soil may be put under cover or treated on-site. After a (successful) depollution process, this soil could be reused on the same site for various purposes, as long as the specific reuse is deemed compatible with soil quality;

iii) Managing the contaminants *in situ* (i.e. "*in situ* management"). More common for biodegradable or volatile organic pollutants, with as an example the (bio)venting method, such an *in situ* strategy is not widely used for inorganic pollutants (trace elements). Moreover, only phytoextraction, i.e. the use of plants capable of extracting trace metals from the soil, followed by transfer from roots to aerial parts can be applied in such cases. Yet this process is time-consuming and slows the urban development process since it often results in a large discrepancy between the time needed for soil cleanup (several years to decades) and the time constraints imposed by city planning processes. However, in terms of soil sustainability, this option is undoubtedly the most appropriate, when considering the increased global need for soils as a resource to feed the world's population.

Nature-Based Solutions (or NBS) are defined as actions to protect, sustainably manage and restore natural or modified ecosystems in a way that effectively and adaptively addresses societal challenges, while simultaneously providing for human well-being and biodiversity benefits (Cohen-Shacham *et al.*, 2016). Most researchers agree that the NBS concept is a rational strategy for promoting the ecological restoration (Maes et al., 2017; Kabisch et al., 2016). In their chapter, Bouzouidja et al. (2018) reviewed the used of NBS for developing safe urban cropping for the case of metal contamination. The objectives of this paper are to discuss the range of potential solutions, with a particular emphasis on NBS, to ensure the compatibility of land use as regards soil quality in the context of low to moderate soil pollution, based on the example of Nantes' UAGs. A description of the options for three representative UAGs will be complemented by a discussion of the options selected for all contaminated UAGs.

2. Materials and methods

2.1 Study area

Nantes is located 40 km east of the Atlantic coast and enjoys an oceanic climate (820 mm rainfall/year); this large city in northwestern France has a high population density (4,100 inhabitants/km^2). The city possesses over 1,000 plots in more than 25 gardens located throughout the city (Fig. 1), with soil contamination being reported for 8 of them (Fig. 1). Among these 8 UAGs, Crapaudine, Oblates and Eglantiers appear to be representative since they display various contamination origins and applied management solutions. The characteristics and past land use of the Crapaudine and Eglantiers UAGs are detailed in

Béchet *et al.* (2016). The Eglantiers garden (95 plots) is located north of Nantes in an urban-rural transition zone near the ring-road. Eglantiers was formerly a crop farm that included a small vineyard. The Crapaudine garden is a public green space containing 90 plots. Until the 1970's, the area supported market gardening. The Oblates park is situated near industrial sites. Until recently, Oblates belonged to a religious congregation that used it as a private park, with some zones being used for cropping or an orchard. The city council bought this parcel for transformation into a public park, in the aim of setting up a 30-plot UAG and a collective cropping garden.

The geological and geochemical contexts could be determined thanks to: a local geological map (Béchennec, 2007, Fig. 1), borehole descriptions available in the national geological database, and a departmental soil geochemical study (Le Guern *et al.*, 2013). Crapaudine and Eglantiers lie on micaschist formations known to present locally mineralized veins that may contain arsenic and/or lead (in association or not) (Le Guern *et al.*, 2013; Jean-Soro *et al.*, 2014). Oblates lies on granite that might also present natural anomalies in arsenic (Le Guern *et al.*, 2013), but to a lesser extent than the micaschist.

2.2 From soil characterization to site management

A multi-actor cooperative approach has been carried out for this study. The overall methodology is summarized in Figure 2 and described hereafter, providing more details on the tasks carried out by scientists. The first step consisted of a preliminary soil characterization commissioned by the city. Should soil contamination be discovered, scientists conducted a more in-depth characterization. This scientific approach included: a synthesis of land use history, determination of a sampling strategy, the sampling itself with a core, and the precise georeferencing of sampling locations using a Differential Global Positioning System (DGPS). On-site measurement using a field portable X-Ray fluorescence analyzer (PXRF; NITON XL3t GOLDD), after sample preparation, was completed by additional ICP-MS analyses in the laboratory for calibration purposes. PXRF allows carrying out a screening of several trace elements on site, leading to adapting the on-site sampling strategy by taking the geochemical and lithological heterogeneity observed *in situ* into account. Within this framework, the number of sampling points was proportional to the level of heterogeneity. These steps are described in Béchet *et al.* (2016) and Jean-Soro *et al.* (2014). Not all plots could be sampled in each UAG (Crapaudine and Eglantiers). Some sampling was also carried out in uncropped zones. The sampling in Oblates was performed over a large area of the park before renewal.

Contaminant mapping relied on Mapinfo 8.5. All results were interpreted in light of historical land-use changes.

The second step focused on the verification of health issues, as required in the case of a questionable geochemical anomaly; soil ingestion, dust inhalation and vegetable ingestion were considered as scenarios of human exposure to contaminants. Direct contact was not considered given that medium-to-low soil contamination was typically observed in the case studies. As scientists, we sampled and analyzed the typical vegetables cropped in the contaminated plots according to the French guide on vegetation sampling (Marot *et al.*, 2014). Such sampling was impossible in Oblates UAG because the plots were not implemented yet. Trace element concentrations in the edible parts of vegetables were measured by ICP-MS (Varian 820-MS) after careful washing, with preparation similar to cooking practice and *aqua regia* digestion. The contents obtained were compared with the EC regulation that defines the maximum authorized concentration of 4 trace elements (Pb, Cd, Hg, Sn) in vegetables intended for human consumption (Commission Regulation (EC) No. 1881/2006, European Commission, 2006). For Pb, the threshold value ranges from 0.1 to 0.3 mg kg^{-1} of fresh matter according to vegetables. The health risk calculation for ingestion scenarios involved a consulting firm or the local health administration, which was also assigned to validate the calculations carried out by consulting firms. For As and Pb, the local health administration established the threshold values to be used in the case of lead or arsenic anomalies (i.e. 100 mg kg^{-1} and 50 mg kg^{-1} for Pb and As, respectively), by taking into account national recommendations for lead and the local background for arsenic (Le Guern *et al.*, 2013).

In the event of health risks, a third step was launched, consisting of the joint development of a management plan with the various actors (city, administration, residents/gardeners, and scientists) through technical, public and field meetings. During these rounds of meetings, various scenarios were discussed and a cost-benefit assessment was performed by the city.

Depending on the specificity of each site (i.e. spatial distribution of soil contaminants, heterogeneities, origin, transfer to vegetables) as well as the level of sensitivity expressed by the gardeners, city and administration, either a single option or a set of management options was implemented for each garden. These options included soil replacement, preservation or restoration using conventional or alternative techniques.

3. Results and discussion

3.1 Site specificities

Trace elements (As, Cu, Pb, and Zn) are the main contaminants observed in Nantes' eight UAGs, with Pb being the principal contaminant. Tables 1 and 2 show the concentrations for As and Pb in the topsoil of the Eglantiers and Crapaudine gardens and in the Oblates park. In most cases, Pb (for the three sites) and/or As (only for Eglantiers) contents were above acceptable sanitary levels or above the local baseline level (i.e. 100 mg kg^{-1} and 50 mg kg^{-1} for Pb and As, respectively).

Table 1: As concentrations (mg kg^{-1}) in topsoil samples collected at Eglantiers garden (PXRF measurement) (Nantes, France)

Table 2: Pb concentrations (mg kg^{-1}) in topsoil samples collected at a selection of representative sites (PXRF measurement) (Nantes, France)

A comparison of the percentiles shows that Pb concentrations vary significantly: from 28 to 371 mg kg^{-1}. The spatial distribution (Figs. 3a and 3b) confirms this strong heterogeneity of Pb concentrations in the topsoil of the Eglantiers and Crapaudine gardens. For Oblates, lead shows moderate to high levels of anomaly over the entire park (Fig. 3c), as compared to usual contents in French agricultural soils (maximum at 25 mg kg^{-1} for As and 60 mg kg^{-1} for Pb, Baize *et al.*, 2008).

For Eglantiers (Fig. 3a), the geological context better explained the anomalies than land use history. Indeed, the central plots exhibit high Pb concentrations (100-500 mg kg^{-1}) in topsoil, increasing with depth (until 1,000 to 5,780 mg kg^{-1} at 60 to 100 cm of depth), associated with high arsenic concentrations (up to 384 mg kg^{-1}); these are of a geogenic origin due to a mineralized vein in the micaschist substratum (Jean-Soro *et al.*, 2014).

As for Crapaudine (Fig. 3b), high concentrations (100-200 mg kg^{-1}) are observed in the southeastern part of the garden, on topsoils only. The study of past land uses of this garden zone, from historical data and aerial photographs, suggests that these high concentrations are due to the use of plant protection products or materials in relation to more intensive market gardening activities. For the Oblates site, the presence of lead at the surface (Fig. 3c) is attributed to the impact of a former lead smelter located close to the park under prevailing winds.

3.2 Soil pollution management options to maintain (or allow) gardening

Presented herein are the options selected to maintain (or allow) gardening activity.

The primary conventional option introduced was soil input. Such was the case at the Eglantiers garden: given that Pb content was increasing with depth, fresh soil was imported onto the central part of this site (on a thickness of 80 cm). This new soil originated from a nearby site, where soil excavation was necessary for development purposes. Prior to application, the soil quality (geochemistry) was verified for the absence of geogenic or anthropogenic elements/contaminants (e.g. Pb < 60 mg $kg^{-1}$and As < 25 mg kg^{-1}). Marker tape was placed between the original and new soil. Even though the municipal Parks and Open Space Department carried out the work itself, this solution proved to be quite costly (approx. €200,000 to manage roughly 5,000 m², i.e. €40/m²).

Soil input was also chosen for both the Crapaudine and Oblates sites. Only a small number of plots (about 10) in the Crapaudine garden exhibited lead concentrations above 100 mg kg^{-1} MS. Since a stockpile of excavated soil was available on-site, the local authority decided to replace the top layer of the cultivated soil in the plots by this stockpiled soil. Before application, the added soil was tested for its trace elements content (low level, e.g. 59 ± 6 mg kg^{-1} of Pb); moreover, its origin was known and assessed to be suitable as a fertile soil. This soil management solution was implemented before the growing season without causing any break in the cultivation calendar. The topsoil layer was stripped at a 40-cm thickness covering the entire plot surface. Marker tape was placed over the surface, and the new soil was spread out. The weakly contaminated soil was stored close to the garden prior to a risk-free future use. The work was completed in 4 days by 2 employees with the City's Open Space Department. This soil management solution therefore proved to be a "low-cost" option (less than 10 €/m²) since uncontaminated soil was available on-site. At Oblates' park, soil was only replaced in the future gardening zone. The excavated topsoil (30 cm), featuring a medium Pb content (103-125 mg kg^{-1}MS), was stored in a single location for flower growing. Another option pursued in other gardens not detailed here consisted of transitioning to raised bed culture.

At the Eglantiers garden, a secured cropping system with vegetables unable to accumulate Pb and associated with Indian Mustard (*Brassica juncea*) (Bouquet *et al.*, submitted), previously used in studies devoted to phytoextraction, was tested as an alternative and innovative solution in order to avoid plot closure and soil replacement, in light of the high agronomic quality. Carried out on 4 plots, this particular solution also involved the gardeners. This *in* *situ* and participatory 2-year experiment was launched in July 2015. Vegetables and Indian mustard (*Brassica juncea* cv. Vitamine), used for phytoextraction, were cultivated in inter-cropping or as crop co-cultures and then compared to a control (without phytoextraction). Most vegetables showed that Pb concentrations in the edible parts of tomatoes, winter cabbage, leeks and potatoes were below the EC regulatory threshold, which was set at 0.1 and 0.3 mg kg^{-1} (for cabbage and leeks) of fresh matter, respectively (Fig. 4). Pb concentrations in green bean pods were also below the threshold (0.2 mg kg^{-1}), except for the two sub-plots 6JL and 3CD with the lowest biomass production (7.25 times lower compared to the others, Fig. 4). Detailed results of these experiments are presented in Bouquet *et al.* (submitted).

Regarding phytoextraction efficiency, Pb concentrations in shoots of *B. juncea* are very low (approx. 2 mg kg^{-1} dw in above-ground parts). Geogenic Pb availability (as evaluated by BCR sequential extraction), which is about half of that measured in a similar soil with the same Pb concentration yet of anthropogenic origin, partially explains this low phytoextraction efficiency (Bouquet *et al.*, 2017). These same authors showed that by enhancing Pb mobility in the soil with EDTA, the Pb concentration increased in *B. juncea* shoots by up to 26 times compared to the control sample. Phytoextraction efficiency by *B. juncea* remains low on moderately Pb-contaminated soils and might not be the best candidate in such a context. With a maximum of 45 mg Pb kg^{-1} dw in shoots, 604 years are needed to remove the non-residual Pb, but much less if just the bioavailable fraction of Pb is considered (DTPA extraction). Since EDTA used to enhance the phytoextraction rate is toxic for plants at millimolar concentrations and even reduces growth at micromolar concentrations (Shahid *et al.*, 2012), bioaugmentation-assisted phytoextraction might be a relevant alternative (Lebeau *et al.*, 2008).

3.3 Options leading to land use evolution

The management solutions presented in Section 3.2 are aimed at maintaining the land use (gardening) of the various sites. In several cases however, gardening was abandoned within specific parts (most heavily contaminated). Within this framework, NBS were proposed as much as possible to replace previous gardening activities. For example, for some plots, the land use (gardening) was modified to an orchard, open space or ornamental space. Figure 5 summarizes the various options identified and tested in the 8 contaminated gardens indicated in Figure 1. In several gardens, a number of management options were actually implemented, as depicted in Figure 6 for the Eglantiers and Oblates gardens. Although the number of experiments remains low, this case study has provided an overview of several possible options.

3.4 Role of NBS in managing low-to-moderate soil contamination in UAGs

Table 3 summarizes the various management options applied at Nantes' 8 contaminated UAGs plus an additional UAG within the urban zone (not presented in this paper). This table compares the duration, impacts of solutions (economic, social and environmental), the potential for integrating the principles of circular economy, and the city's or owner's responsibilities.

The decision to frequently change soil may be explained by the fact that this choice limits the site owner's responsibility in terms of health impacts, in addition to allowing for fast implementation. However, two issues emerge: i) the availability and quality of the marketed topsoil used for soil replacement; and ii) the low-contaminated soils that, once excavated and removed from the site, become waste and cannot be reused as soil except in very specific uses (e.g. road base course). In addition, environmental impacts are pronounced (e.g. CO_2 emissions due to soil transportation, soil consumption), and such solutions appear to be costly. This cost may nevertheless be reduced by applying the principles of a circular economy (soil reuse).

Table 3: Various management options applied at Nantes' 8 contaminated UAGs plus an additional UAG within the urban zone

NBS appear as options to be considered in the case of low-to-moderate contamination. In particular, phytoextraction is the only method available for the *in situ* remediation of soils contaminated by trace metals. Considered as an environmentally-friendly solution, this approach unfortunately requires many years to achieve a state of soil cleanup. For this reason, phytoextraction has yet to gain widespread popularity. When taking this constraint into consideration, the association of non-accumulating vegetables and metal-accumulating crops appears to offer a promising solution as a means of securing cropping on contaminated soils. An alternative option consists of soil excavation followed by building up temporary vegetated stockpiles that contribute to urban landscape quality (Todd *et al.*, 2016; Wilschut *et al.*, 2013). Once cleaned up, the soil could be reused in various ways. Phytostabilization can also be practiced in order to avoid the dissemination of contamination, but in this case the contaminants are not removed. Raised beds with imported soil constitutes another technique for urban gardens to avoid or reduce exposure to contaminants (ingestion of soil or after plant uptake). The raised beds solution requires less capital investment than remediating or importing soil (Clark *et al.*, 2008; Witzling *et al.*, 2011; Pfeiffer *et al.*, 2014; Kessler, 2013).

Green space and ornamental space are other options, although they lead to a change in use. Urban orchards are defined as tree-based food production systems that can be owned and run either privately or by the community to provide wildlife habitat (Lin *et al.*, 2015). They can also increase vegetative cover, which is helpful in combating soil erosion (phytostabilization solution). Ornamental plants expand in UAG (Lin *et al.*, 2015) depending on the cultural habits of gardeners (Bell *et al.*, 2016). This new habit can then be practiced to manage polluted plots. Well located and well equipped (with urban furnitures such as seating, play areas), green common areas in UAGs exert a strong impact on the relations between gardeners (Bell *et al.*, 2016). Ornamental, open space and shipyards also appear to be feasible solutions; they prove to be quite attractive from a quality-of-life perspective. While they do not alter soil functions, they still require the implementation of precautions by the city/owner in order to limit their liability as regards sanitary risks (e.g. exposure to dust from soils).

These solutions may also be applied in other contexts than UAGs. For instance, phytoextraction may be used to restore geochemical quality and increase the multifunctionality of soils; it could contribute to managing low-level contaminated excavated soils through ornamental spaces in the public or private space. More specifically, it could be introduced when creating new districts or within the scope of redeveloping existing districts, such as in a polluted area of Amsterdam's harbor (Wilschut *et al.*, 2013) and in the case of polluted vacant lands in Canadian municipalities (Todd *et al.*, 2016). Developers and urban planners would thus need to anticipate such *ex situ* treatment in the planning and development process, and regulations would need to evolve to allow for such an option.

It is also interesting to note that the city now systematically inspects the environmental quality of the soil of planned UAGs early enough in the planning process to adapt the initial plan according to the soil geochemical quality.

NBS thus appears to be attractive in managing low-to-moderate levels of soil contamination. However, UAGs or land owners / the city needs to be aware of their legal responsibilities. They must ensure limiting the exposure to soil (in particular ingestion of soil or dust, Denys *et al.*, 2007; Pascaud *et al.*, 2014, Kessler, 2013) as a means of mitigating health risks.

Grassing is one solution to avoid soil sealing, and phytostabilization is another appealing option to minimize soil erosion and trace element transfer. In addition to controlling health risks, communication outreach to the public constitutes another challenge. Along these lines, a socio-scientific approach is useful in helping managers face such challenges (Mombo *et al.*, 2016). Success story examples point to the political transparency of the stakeholders and partnerships closely involving the city of Nantes, scientists, gardeners and other actors.

4. Conclusion

Environmental investigation within UAGs may reveal soil contamination, Pb being the primary contaminant detected in French (Joimel *et al.*, 2016) and in Nantes' UAGs. For three representative gardens in Nantes, detailed management scenarios have been proposed. The various options available for managing polluted soils, including several NBS (as carried out in 8 of Nantes' UAGs), can be applied more generally to cope with soils containing low-to-medium contaminant levels. Within this framework, a key challenge consists of controlling health risks. In addition to improving the quality of residents' life and biodiversity, several solutions make it possible to preserve or even restore soil functions.

Moreover, anticipating soil quality allows adapting the planning process to ensure compatibility with land uses while limiting soil management expenses.

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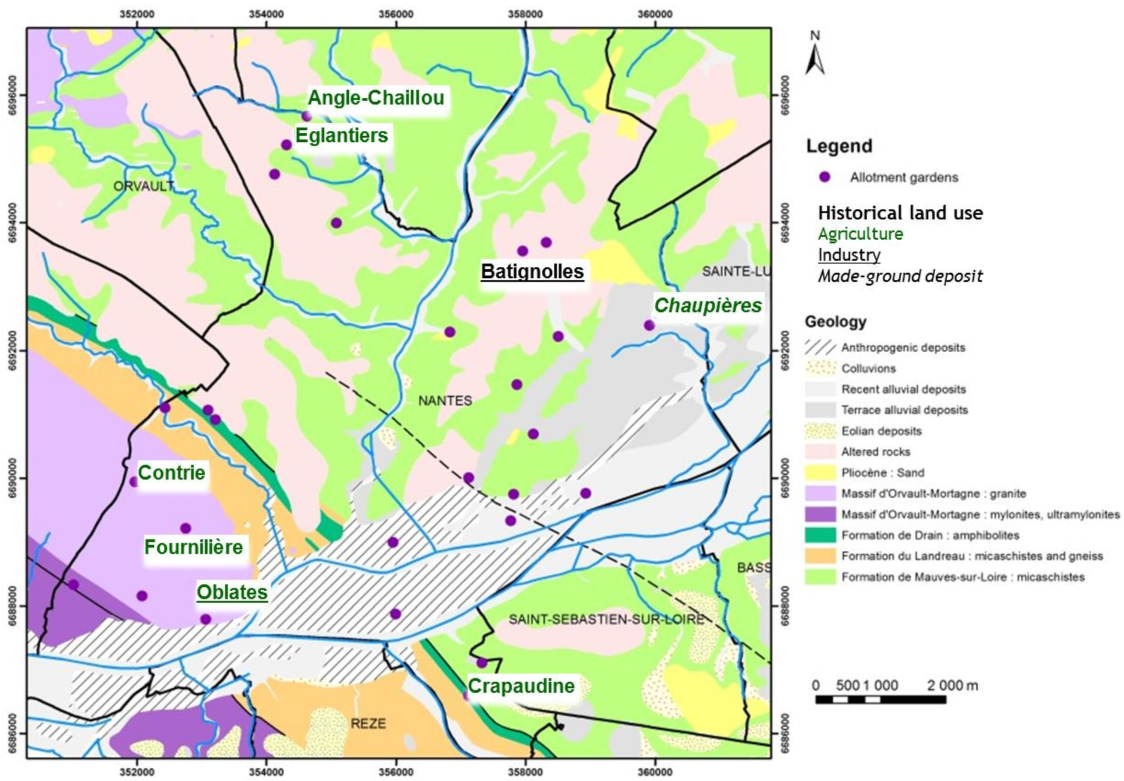


Fig. 1: Location of the studied gardens within the city of Nantes, with emphasis on geological and historical contexts - allotment gardens requiring specifications on contamination issues are indicated along with historical land use (adapted from Béchet et al., 2016) (geological map 1/50 000, Béchennec, 2007)

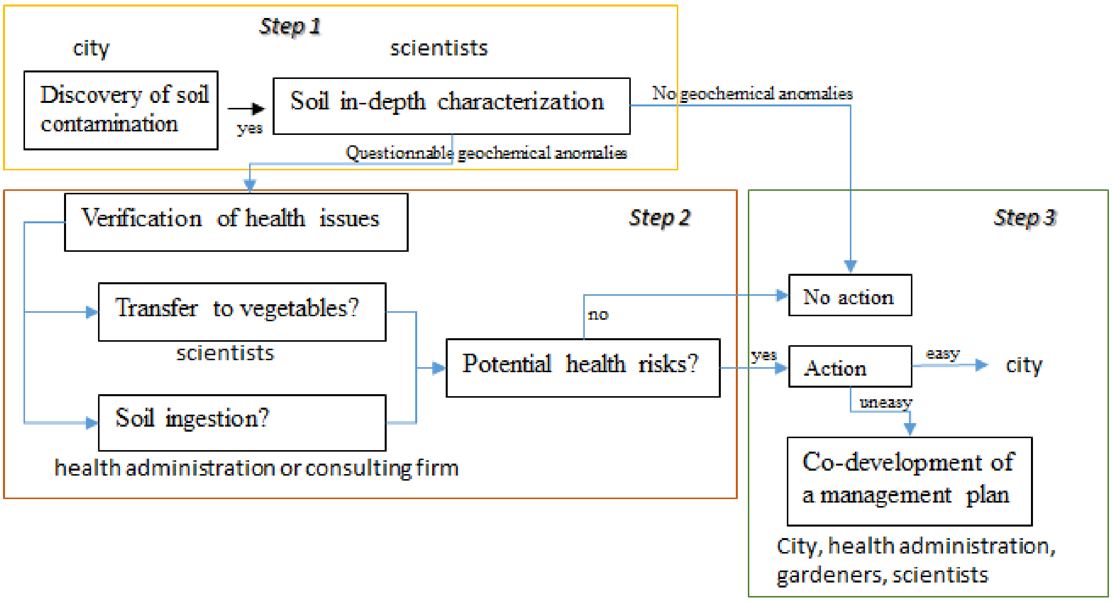
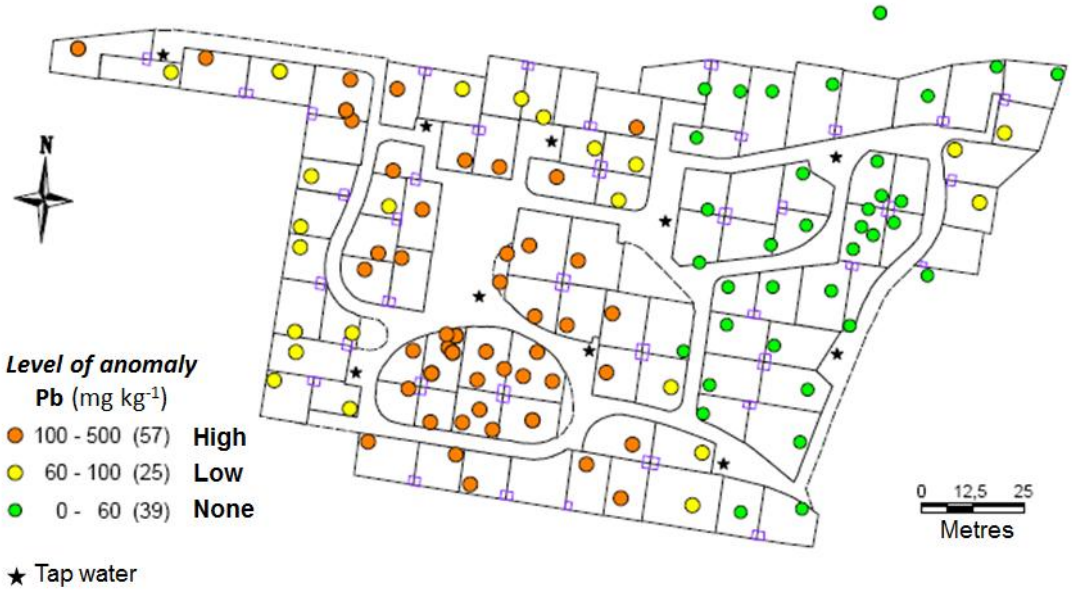
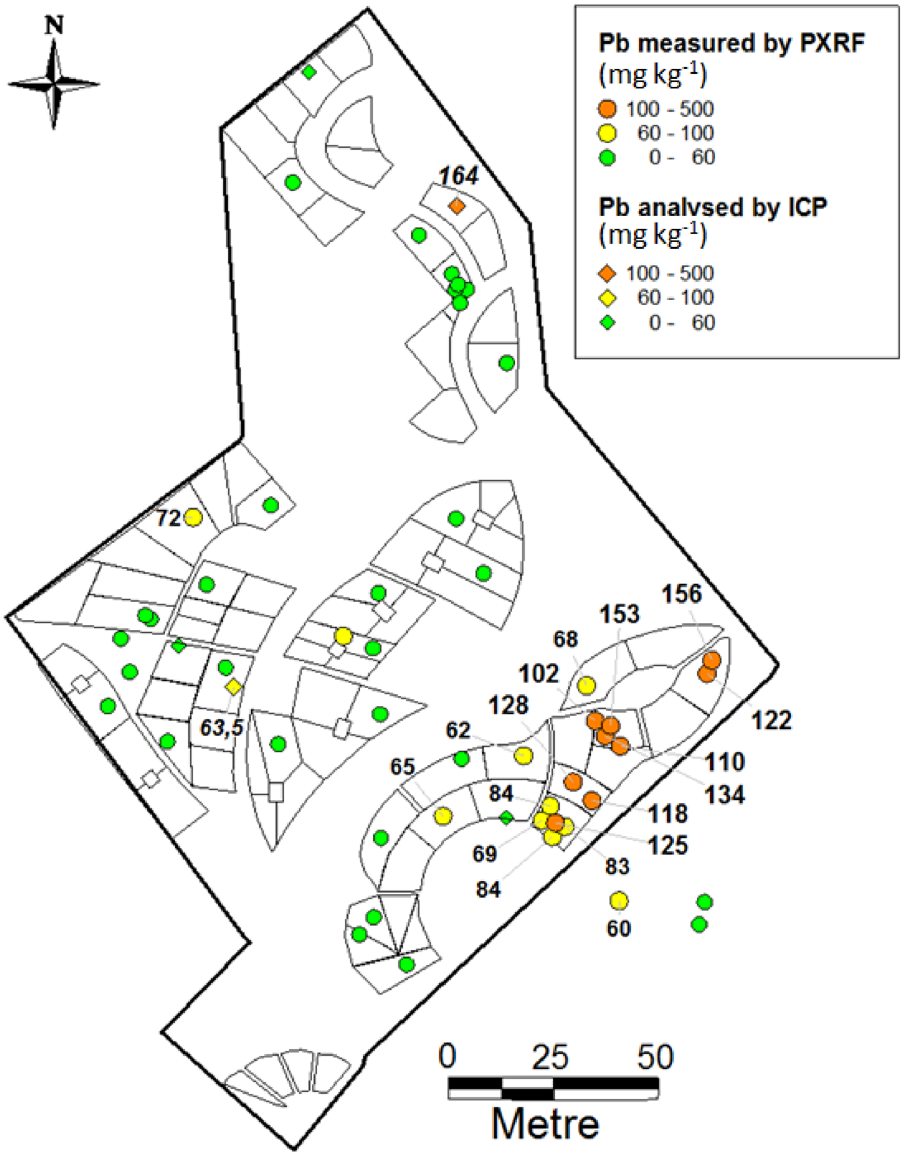


Fig. 2: Methodology flowchart used to manage soil contamination issues in Nantes' UAGs


N
Level of anomaly
Pb (mg kg-1)
100 - 500 (57) High
60 - 100 (25) Low
0 - 60 (39) None
Tap water
0 12,5 25
Metres


N
Pb measured by PXRF
(mg kg-1)
100 - 500
60 - 100
0 - 60
Pb analysed by ICP
(mg kg-1)
100 - 500
60 - 100
0 - 60
164
72
63,5
156
153
68
102
128
122
62
110
65
134
84
118
125
69
83
84
60
0 25 50
Metre

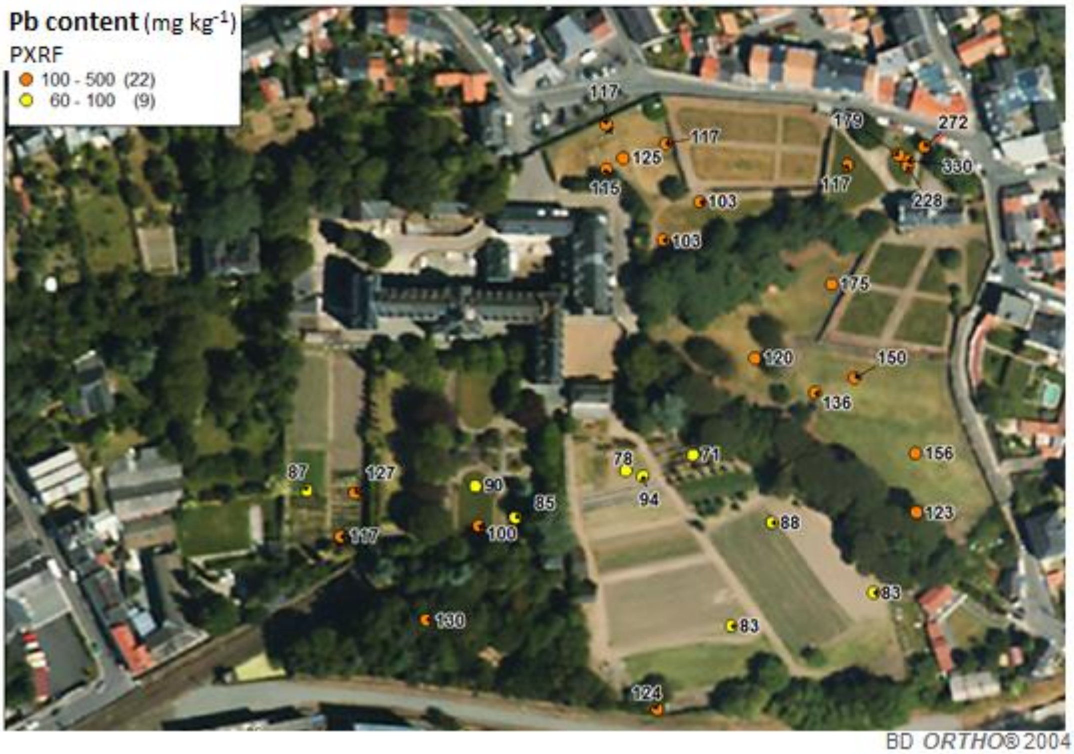


Fig. 3: Lead spatial distribution in topsoil at the a) Eglantiers site, b) Crapaudine site and c) Oblates park

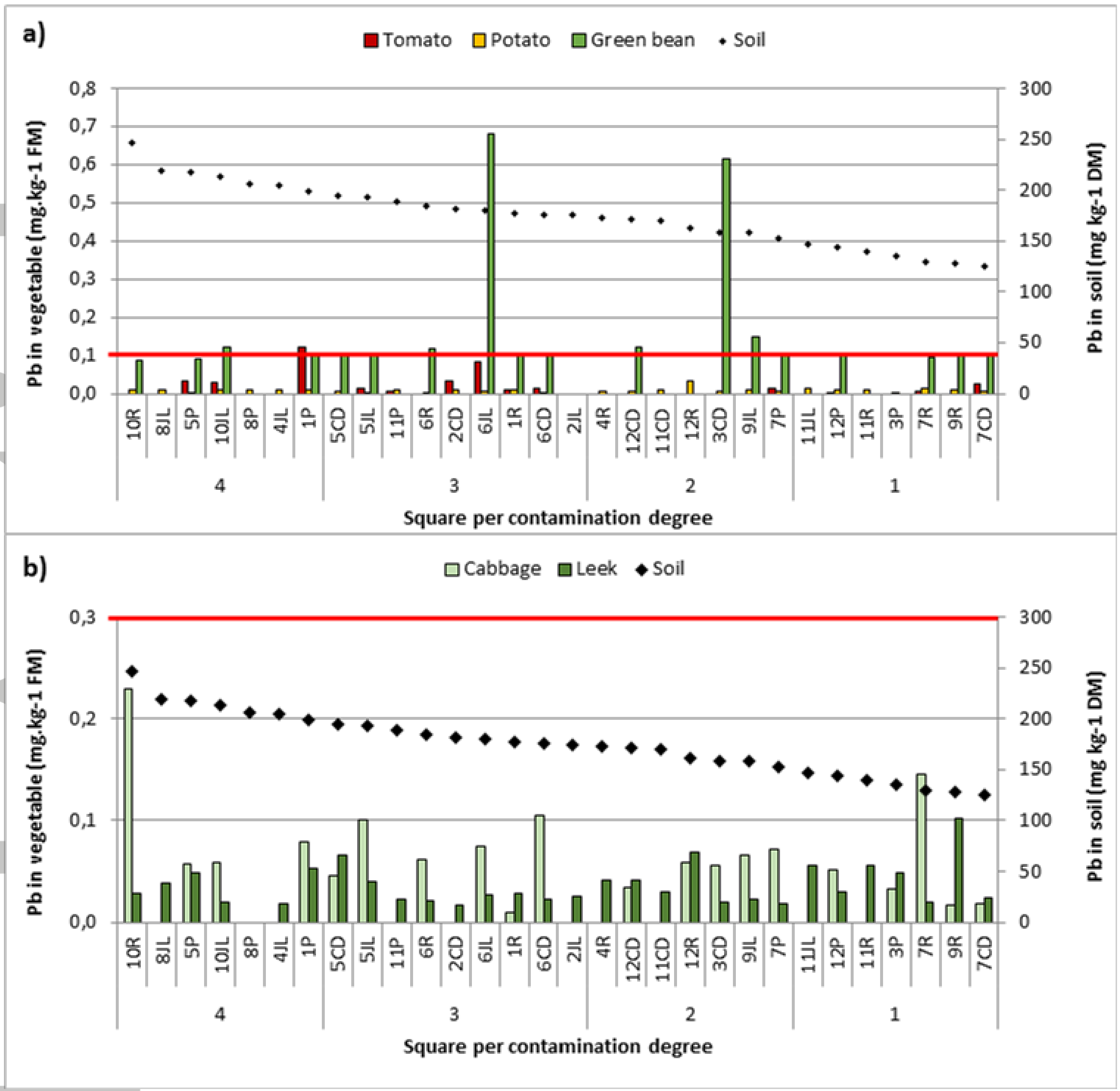


Fig. 4: Pb content measured in a) fresh vegetables, and b) leafy vegetables, compared to lead contents measured in soils before the cropping experiments, and regulatory thresholds for vegetables (solid red line, and dotted line for green beans), for the Eglantiers garden; the number and lettering refer to a sub-plot managed by a given gardener.

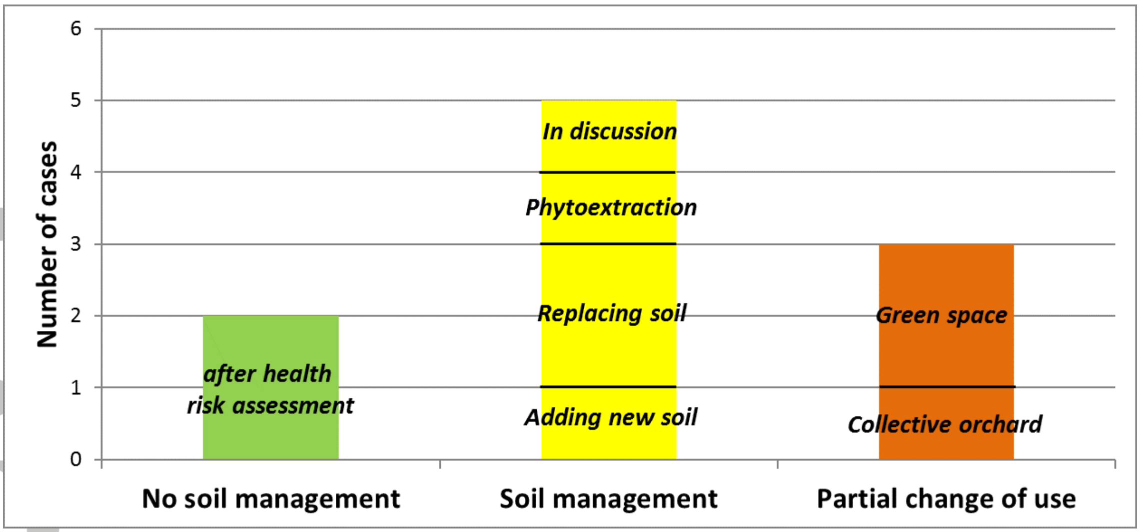


Fig. 5: Summary of the options adopted in 8 contaminated UAGs managed by the city of Nantes (France) in the objective of maintaining gardening as much as possible. A partial change of use was sometimes necessary: green space includes ornamental or open space.

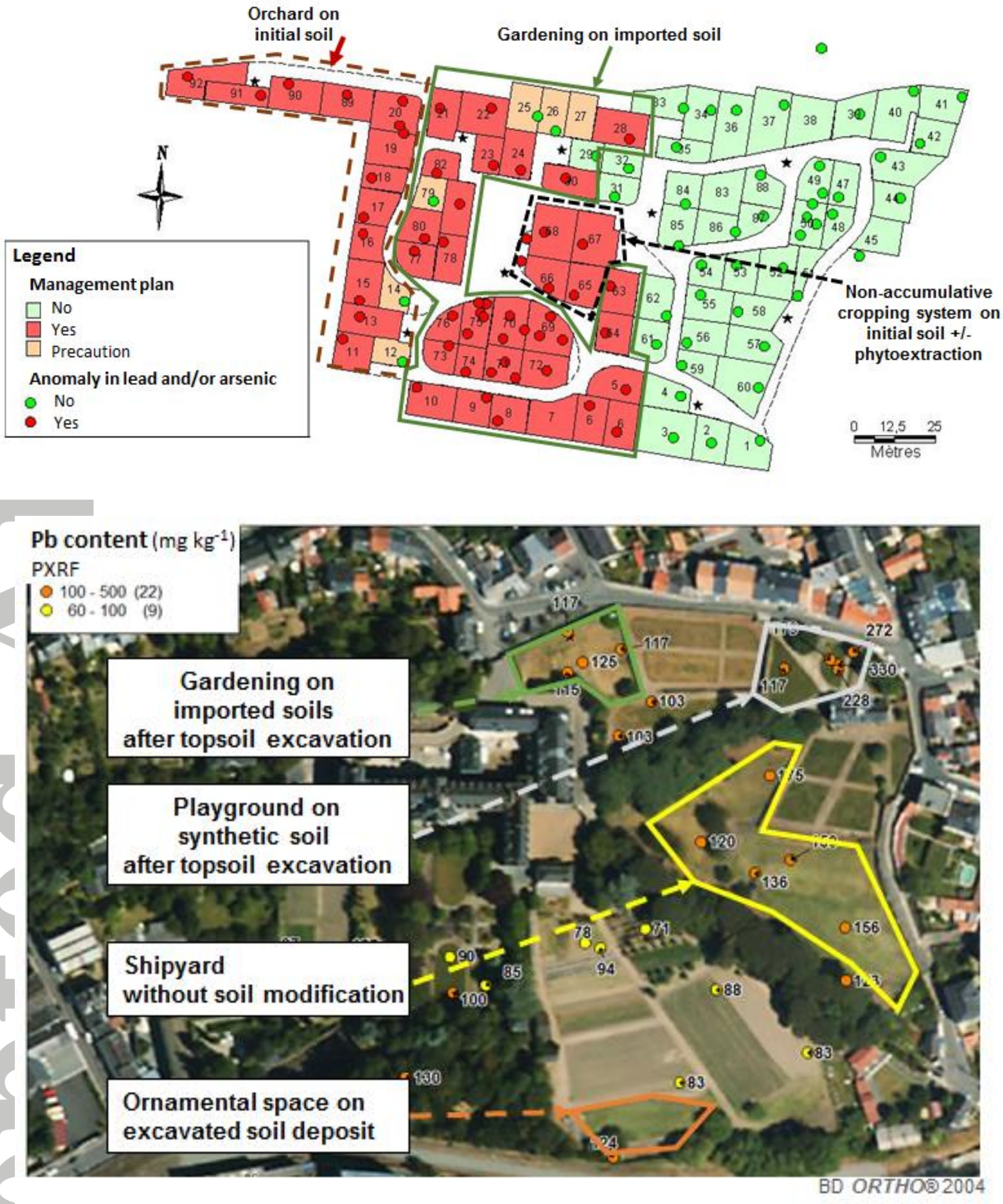


Fig. 6: Example of multiple contaminated soil management options, including NBS for Eglantiers (a) and Oblates (b) UAGs

Table 1: As concentrations (mg kg^{-1}) in topsoil samples collected at Eglantiers garden (PXRF measurement) (Nantes, France)

Site	Number of measurement points	Min	25%	Median	75%	Max	Mean
Eglantiers	95	19	25	29	39	92	36

Table 2: Pb concentrations (mg kg^{-1}) in topsoil samples collected at a selection of representative sites (PXRF measurement) (Nantes, France)

Site	Number of measurement points	Min	25%	Median	75%	Max	Mean
Eglantiers	95	28	50	84	126	371	98
Crapaudine	82	34	44	53	69	134	61
Oblates	31	71	87	117	127	272	119

Table 3: *Various management options applied at Nantes' 8 contaminated UAGs plus an additional UAG within the urban zone*

Management option	Land use change (gardening)	Duration	Economic impacts	Social impacts	Environmental impacts	Principles of circular economy	City / owner responsibility
Soil change	No	Short	Expansive Less expansive if local soil reused and/or excavated soil locally reuse (e.g. for ornamental space)	-: Need to stop gardening, to find new soil, Necessity to make the soil arable (cultivable) again. Possible sanitary impact linked to change of habits, closure of some plots.	-: Transportation of soil (CO_2 emissions) Soil landfilling Soil function modified: some function may be lost, depending on the quality of the added soil	Possible if soil reuse (imported and excavated)	Limited: Verify quality of imported soil (at least sanitary aspects, agronomic properties, biodiversity)
Raised bed	No	No treatment	Limited	Limited to positive -: Change of habits Loss of growing space +: Possible to have plots adapted for disabled people +: Possible to involve gardeners / inhabitants / pupils to build the raised beds.	Limited -: Transportation of soil (limited amount of imported soil) +: No soil landfilling Little change of soil functions (under the raised beds	Possible if reuse of wood waste/residues to build the raised beds	Verify quality of imported soil (filling the raised beds) Avoid naked ground to avoid sanitary risk linked to dust (of contaminated soil) inhalation: e.g. by putting grass (Kessler, 2013) (avoid sealing except if sanitary risks too high, heavy pollution => parking places, cabins, building may be a solution)
Non-cumulative cropping	No	No treatment	None	Limited No change of habits	No change Optimized rotation to maintain or improve soil function	Pay attention to: i) the potential accumulation of contaminants in non edible parts of the plants before composting. If no accumulation, composting can continue; ii) potential differences in the accumulation level of Pb in vegetables according to the variety.	Verify quality of crops to make sure there is no accumulation. Edit rules of gardening (authorized, non authorized crops, hands and vegetable washing, limit naked soils, no children or sensitive people in the garden) Verify responsibility if no respect of rules.
Phytoextraction	No	Applicability of *in situ* phytoextraction to be verified (sometimes	Less expansive if gardeners are involved	Possible participation of gardeners Can be used for educational purpose	+: Soil function Maintained/Restored/Improved (including biodiversity) - Management of green	Plant used at the same time for soil cleanup, contribution to the urban landscape and reuse of green waste (e.g. energy)	Manage the green waste Avoid naked soil to mitigate sanitary risk linked to dust (of contaminated soil) inhalation: e.g. by planting grass*

		many years)**			waste	(Todd *et al.*, 2016; Wilschut *et al.*, 2013)	Control soil quality
Orchard	Yes	No treatment	Inexpensive	Landscape and quality-of-life improvement Food provided Common harvest New place of exchange	Little change in soil functions Biodiversity	Composting green waste. Pay attention to the potential accumulation of contaminants	Verify quality of crops Avoid naked ground to mitigate sanitary risk linked to dust (of contaminated soil) inhalation: e.g. by planting grass*
Ornamental space	Yes	No treatment	Inexpensive	Landscape and quality-of-life improvement May be associated with collective area to improve social relations	Little change in soil functions Biodiversity Remark: Possible to apply on soils excavated and shifted on site (may change depending on country legislation)	Receiving compost	Avoid naked ground to mitigate sanitary risk linked to dust (of contaminated soil) inhalation: e.g. by planting grass*
Open space such as green communal areas	Yes	No treatment	Inexpensive	Landscape and quality-of-life improvement	Little change in soil functions	Reusing waste materials (like wood) to build tables, chairs, etc.	Avoid naked ground to mitigate sanitary risk linked to dust (of contaminated soil) inhalation: e.g. by planting grass*
Shipyard	Yes	No treatment	Rather inexpensive	Landscape and quality-of-life improvement	Little change in soil functions	Limited	Avoid naked ground to mitigate sanitary risk linked to dust (of contaminated soil) inhalation: e.g. by planting grass* Ensure soil/grass quality compatible with ship environment. Ship supervision

* Avoid sealing except if sanitary risks deemed too great due to localized heavy pollution => parking spaces, cabins, buildings may offer solutions.

** Soil excavation and its local use in redevelopment projects as an alternative, with the prospect of reusing the soil for cropping in allotment gardens.