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Health Risks Assessment in Three Urban Farms of Paris Region for Different Scenarios of Urban Agricultural Users: A Case of Soil Trace Metals Contamination

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Abstract

Within the context of a worldwide emergence of various forms of urban agriculture, there is a growing awareness concerning the health risks associated to the presence of different pollutants influencing the urban products safety. Among the most common pollutants found in soils and vegetables grown in the city, Trace Metals (TM's) are of major concern. This paper deals with risks assessment associated with the presence of TM's in soil, via two main exposure path ways: soil and vegetables ingestions. Risks assessments were conducted for various types of real scenarios encountered in three forms of urban farms near Paris (Ile-de-France Region). The farms have soil TM's levels in abnormally high concentrations (Pb (Lead), Cd (Cadmium), Hg (Mercury), Cu (Copper) and Zn (Zinc) contents higher than geochemical backgrounds and threshold values for sludge spreading, often used as reference values in France). The results of the Hazard Quotient (HQ)-based risk assessment approach (HQ defined as the ratio of estimated daily intake/tolerable daily intake) show that the most risky scenarios concern urban farmers (HQ_{tot} = 1.02, because of the on-site working on a daily basis all year round), children gardeners (HQ_{tot} = 1.29) and regular children consumers (HQ_{tot} = 1.6 in maximalist scenario, where the consumer would exclusively consume the vegetables of the farm). Next would be the adult gardener scenario (HQ_{tot}= 0.9), while the least risky are adult consumer scenarios (HQ_{tot} = 0.62) and the farm workers (HQ_{tot} = 0.45). For the highest risk scenarios (urban farmers and children), specific and drastic measures may be considered, such as reducing the site frequentation by sensitive populations (child and pregnant women) or proceeding to control analysis of TM's levels in blood for the most exposed peoples. The choice of parameters used in HQ-based method must be appropriated to the specificities of urban agricultural activities. The uncertainties in the choice of some parameters such as soil ingestion, vegetable intake and exposure frequency could result in an over- or under-estimation of the risk.

Keywords

Urban Agriculture, Pollutants

1. Introduction

Urban agriculture is currently on the rise again all over the world, particularly in North America and Europe [1]. In France, it comes in different forms: interstitial productive spaces, community gardens (allotment and shared gardens), urban micro-farms, urban greenhouse farms, or indoor and peri-urban market farms in short supply chains [2]. The projects are mostly set up on agricultural land near cities, on former urban wastelands, in urban parks, along railroad lines, on rooftops, or on lands found at the foot of buildings. Because of the proximity of urban centers, urban agriculture can be exposed to sources of pollution coming from human activity, industries and automobiles, and spread throughout the environment through the matrices of water, air and soil. As a result, in societies, there is a growing awareness of the health risks of growing vegetables in the city [3] [4] [5] [6] [7].

Trace Metals (TM's) are among the most common pollutants found in the soils and vegetables grown in the city [8] [9]. They can affect human health especially through the ingestion of soil, dust and vegetables. Numerous studies have shown that the risks associated with the presence of TM's in urban cultivated soils can, in some cases, be non-negligible [10] [11] [12] [13] [14].

In the vicinity of Paris, in the historically industrial region of the Ile-de-France, some agricultural soils were polluted with TM's following the disposal of Parisian sludge, and its use as a soil enrichment, a practice that reached its peak in the 19th century [15] [16]. Some of these soils are still cultivated today, through different forms of urban agriculture.

The purpose of this work is to assess the risks associated with the ingestion of TM's, via soil and vegetables, concerning various types of participants of urban agriculture. In order to do this, a testing ground was chosen near Paris that had already received Parisian sludge in the past, and where TM's levels were detected in abnormally high concentrations above the current soil guideline applied in France, *i.e.* geochemical background concentrations and threshold values of a national decree (No. 97-1133, 08/01/1998)[1] applied to soils before sludge spreading. This testing ground was comprised of 4 entities corresponding to 3 different

[1]https://aida.ineris.fr/consultation_document/5659

types of urban agriculture: allotment gardens, 2 productive micro-farms, and an association using market gardening as a social-insertion tool.

An experimental work is conducted to characterize the soil quality and to assess the risks related to the presence of TMs in these urban gardens for the exposed populations. Different users' scenarios are defined, vegetable and soil analyzes are made, and Hazard Quotients (HQ) estimations are carried out for each scenario using the HQ-based risk assessment approach. This latter is employed in the French national policy for managing contaminated land [17]. In this paper, its application to the specific case of urban agriculture is considered for a series of real on-site scenarios.

2. Materials and Methods

2.1. Characterization of the Different Activities Encountered in the Field and the Implementation of the Experimentation

The terrain study represents a 5.3 hectare common ground plot, one of the last historical market gardening sites in the small suburbs of the Île-de-France region, in an area strongly affected by its industrial past [18]. Three types of urban agriculture activities are represented (**Table 1**).

Two of these entities had been in operation for more than 10 years (the allotment gardens and the insertion project). The two micro-farms are recent additions. They have drawn the attention of the local town authorities, the landowner, as well as other project developers who are interested in finding out more about the soil quality.

After a study of relevant documentation and testimonials, allowing identifying the history and activities that affected the quality of the soil in the fields, a strategy for experimental crops, soil and vegetable sampling, was developed. It was then set up on the plots for one season, from March to September (**Figure 1**). The varieties of seeds and seedlings targeted for the study were purchased for experimentation. On the site of the micro-farm producers, three experimental plots of vegetable crops were planted (randomly located) and cultivated by the research team, in collaboration with the farmers (giving particular attention to the preparation of the seedbeds and their watering throughout the season). On the social insertion association site, specific experimental varieties were added to the cultivation plan and tended by the association. The team only came to collect and analyze the targeted vegetables. Finally, on the allotment garden plot site, two gardeners agreed to cultivate the vegetables for the experiment, provided that the scientists helped them maintain the experimental plots.

2.2. Sampling and Preparation of the Soils and Vegetables

Soil samples were collected at different spots (**Figure 1**) in a perimeter including each experimental plot, except for the site of the social insertion association where there were no experimental plots (the vegetables having been inserted into the culture plan put in place by the association). The samples were taken at three

Table 1. Description of the three types of activities in the field study.

Activity Reference	Activity Description	Number of Employees	Cultivated Area	Set Up Date
1	Two micro-farms producing market gardening foods	Two full-time urban farmers and seasonal workers	3.25 ha	2017
2	A social insertion association which works in organic market gardening	30 social insertion employees dedicating themselves to agricultural activities three days a week	0.7 ha	1999
3	34 allotment garden plots (200 m^2 each)	34 families of town residents growing various vegetables	0.7 ha	2000

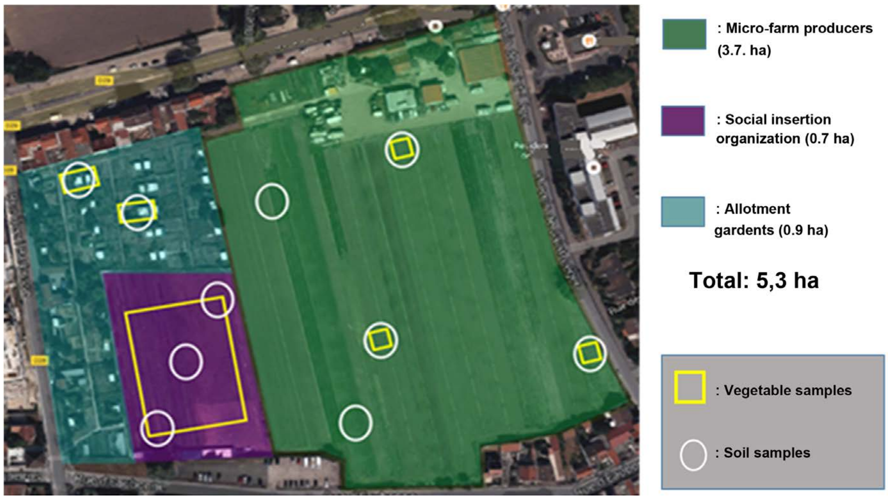

Figure 1. Site plan, soil and vegetable sampling strategy.

points on a diagonal of the plot. Each soil sample (10 in all) is a composite sample of 8 to 9 elemental samples (randomly taken from an area of 200 m^2) from the cultivated horizon (0 to 30 cm deep) taken by a hand auger.

Four vegetable species (lettuce, carrot, tomato and potato), representative of the four main types of vegetables found in urban agriculture (leaf, root, fruit and tuber), were grown. "Batavia Blonde de Paris" (*Lactuca Sativa*) and "Carottes de Colmar" (*Daucus Carota*) were sown in April and harvested in June and August, respectively. "Coeur de boeuf" (*Solanum Lycopersicum*) seedlings were planted in April/May and harvested in August/September. Finally, potatoes were planted in April and harvested in July of the same year. The consumable parts of each vegetable were washed, and peeled for carrots and potatoes, according to "traditional" food consumption practices. In all, 3 lettuce samples, 5 carrot samples, 5 tomato samples and 1 potato sample could be analyzed.

2.3. Soil and Vegetable Laboratory Analyzes

The washed or peeled vegetables were sent to the PHYTOCONTROL Cofrac certified laboratory for TM's analysis. Fresh samples were then crushed and mineralized by wet digestion using a high pressure closed system microwave or an open system digibloc.

The TM's were then quantified by inductively coupled plasma mass spectroscopy (ICP/MS) adapted from the standard EN NF 15763.

The physicochemical characteristics (pH, contents of the TM's (Lead (Pb), Cadmium (Cd), Mercury (Hg), Copper (Cu) and Zinc (Zn), $CaCO_3$, silt, clay, Organic Matter (OM)) of the soils were determined by the Paris Agronomic Laboratory[2]. The TM's were extracted with the *aqua regia* method using a Lab-Tech-type ED36 heating block, according to the NF ISO 11466 standard for low organic materials. For organic materials, the extraction was made with an *aqua regia* Millestone microwave - model Ethos one, according to standard NF EN 133346. The analysis of the soil TM's was done by high frequency induced plasma optical emission spectrometry (ICP-OES) according to the NF ISO 22036 standard. The measuring equipment used is a Thermo ICAP 7000 series.

2.4. Definition of the Scenarios According to the Specificities of Different Sites

In order to define the scenarios met on the urban agriculture sites, semi-structured interviews were conducted on each plot with urban farmers. Concerning the allotment gardens, questionnaires were distributed, and the results were treated with 10 families of gardeners.

Along with the interviews, there were site visits and field observations in order to define the scenarios consistent with on-site reality.

2.5. Hazard Quotient (HQ)-Based Risk Assessment

HQ-based risk assessment approach, defined in 1983 in the United States by the National Research Council (NRC), is employed in the French national policy for managing contaminated land [17].

In this study, the HQ approach was applied for 5 TM's (Cd, Pb, Zn, Cu and Hg). HQ values associated to each TM were calculated for the main exposure pathways of urban agriculture (soil ingestion and vegetables intake). Inhalation and skin contact pathways were not dealt with in accordance with other publications [12] [13] [14].

HQ results from the comparison of the Estimated Daily Intake (EDI) with the Tolerable Daily Intake (TDI, cf. **Table 2**) according to the following Equation (1):

$$HQ = \frac{EDI}{TDI} \tag{1}$$

The TDIs were selected in accordance with current regulations in France (**Table 2**).

The Estimated Daily Intakes through soil particle ingestion (EDI_{soil}) and vegetable consumption (EDI_{veg}) were calculated, for each TM according to the following Equations (2) and (3):

$$EDI_{soil} = \frac{Cs \times TASDR \times ED \times EF_{soil}}{TABW \times AT} \tag{2}$$

[2]Laboratoire d' agronomie de la Ville de Paris.

Table 2. Choice of TDI values (mg/kg/j).

Substance	Effect	TDI	Reference
Pb	Threshold effect	6.3×10^{-4} (mg/kg/j)	[22]
	Non-threshold effect	8.5×10^{-3} (mg/kg/j)$^{-1}$	[23]
Cd	Threshold effect	3.6×10^{-4} (mg/kg/j)	[24]
Hg	Threshold effect	$1 \cdot 10^{-4}$ (mg/kg/j)	[25]
Cu	Threshold effect	1.4×10^{-1} (mg/kg/j)	[25]
Zn	Threshold effect	$3 \cdot 10^{-1}$ (mg/kg/j)	[26]

$$EDI_{veg} = \frac{\left[\sum \left(C_{veg} \times TAVCR \times SF\right)\right] \times ED \times EF_{veg}}{TABW \times AT} \quad (3)$$

With C the concentration of TM in soils (Cs) and in vegetables (C_{leaves}, C_{roots}, C_{fruits} and $C_{potatoes}$) in mg/kg of dry matter (soil) and fresh produce (vegetables), TASDR, the time-averaged soil and dust ingestion rate (kg/day), TAVCR, the time-averaged vegetable consumption rate (kg of fresh weight vegetables/day), SF the percentage of vegetables consumed (unitless), ED the exposure duration, set at 30 years for adults and 6 years for children, EF_{soil} the exposure frequency, *i.e.* the number of days of site use for each scenario, EF_{veg} the number of annually days of vegetables consumption (set at 365 days assuming that people eat vegetables every day), TABW the time-averaged body weight (adult 69.5 kg and child 14.6 kg [19]), AT the averaged time, the period of time on which is averaged the exposure (days) (for a threshold effect substance AT = ED × 365, for a non-threshold effect substance, AT = 70 × 365).

For each TM, the HQ by exposure pathway (HQ_{soil} and aHQ_{veg}) was then summed to give aHQ_{tot} according to the following Equation (4):

$$HQ_{tot} = HQ_{soil} + HQ_{veg} \quad (4)$$

HQ_{tot} represents, for a given scenario, the risk related to the urban agricultural activity. When HQ_{tot} is less than 1, the exposed population is unlikely to experience obvious adverse effects. When HQ_{tot} is greater than 1, it is considered that the risk is not negligible because the appearance of a toxic effect cannot be excluded [20]. Pb could have a non-threshold carcinogenic effect [9] [21]. To evaluate the carcinogenic risk specific to Pb, a second risk indicator, the Excess of Individual Risk (EIR), was calculated according to the Equations (5) and (6):

$$EIR_{soil/veg} = EDI_{soil/lvg} \times TDI \quad (5)$$

$$EIR_{tot} = EIR_{soil} + EIR_{veg} \quad (6)$$

When the EIR_{tot} is greater than 10^{-5}, the risk for human health is considered as non-negligible (probability of an occurrence of an additional cancer case out of a population of 100,000 people exposed) [20].

3. Results and Discussion

Soil physicochemical characteristics and TM's contents found in soils and vegetables are firstly presented. The "typical" scenarios specific to each garden and the associated parameters are defined, detailed and justified in order to express the results of the HQ-Based risk assessments for each scenario.

3.1. Soil Properties and TM's Soil Levels

Due to the strictly agricultural use of the study area for more than a century, it is considered that the agronomic characteristics and TM's levels are homogeneous over the entire area, without distinguishing the soils of the three types of activity.

Soils are relatively basic (pH = 7.9) and rich in organic matter (OM = 8.9% about 4 times more than conventional agricultural soil). The total limestone level is moderately high and the texture is rather clay-silty (**Table 3**).

Soil Pb, Cd, Hg, Cu and Zn contents are presented in **Table 4**. These exceed all the regional reference thresholds corresponding to pedogeochemical background levels [27] as well as the threshold values for soils receiving sludge (national decreen 97-1133, 08/01/1998) except for Cd, slightly above regional thresholds but not exceeding the national decree.

In France, there are no regulatory values defining the quality of agricultural soils [27]. The only French regulation that proposes thresholds, especially for TM's, is the decree n˚ 97-1133 and its technical prescriptions (decree of 08/01/98) which are the French transposition of the European directive governing agricultural soils intended to receive sludge for applications (Directive 86/278/CEE). These thresholds are often taken as references for urban soils cultivated, by default, however they are generally not intended to receive sludge (themselves contaminated).

Other countries propose TM's reference values that should not be exceeded in agricultural soils (**Figure 2**). There is considerable variability between the thresholds used in the different countries: the maximum Pb content not to be exceeded in soils is more than ten times higher in Germany (1000 ppm) than in China (80 ppm) [28].

There are vigilance thresholds issued by the health authorities concerning Pb in France for the soil of public spaces often frequented by vulnerable populations (children and pregnant women or those women planning a pregnancy). In France, a threshold of 100 mg/kg triggers the need for a risk assessment and a threshold of 300 mg/kg triggers the recommendation for screening of blood lead levels [29].

More generally, the approach recommended by the Ile-de-France health authorities is to carry out a health risks assessment since the contents of the regional reference standards [27] of TM's in soils are outdated.

3.2. The TM Content of Vegetables

It is to be noticed that among the five TM's, only Cd and Pb contents are regulated in different types of fruit and vegetables according to the European Directive No. 1881/2006 and its recent updates[3]. The results of TM's concentrations

[3]https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006R1881-20180319

Table 3. Main agronomic characteristics of soils in the study area.

Site (n = 10)	Clay (%)	Silt (%)	$CaCO_3$ (%)	OM (%)	pH ($CaCl_2$)
Mean ± Standard Deviation	16.9 +/−0.9	31.8 +/−1.7	8.1 +/−3.7	8.9 +/−1.4	7.9 +/− 0.1

Table 4. TM's content in soil compared to reference values.

		Pb	Cd	Hg	Cu	Zn
Testing ground (n = 10)	Mean ± SD	320 ± 76	0.68 ± 0.14	1.57 ± 0.70	102 ± 25	316 ± 47
	(min-max)	(229 - 436)	(0.55 - 0.99)	(0.97 - 3.3)	(81 - 156)	(231 - 367)
IDF Regional Thresholds [27]		53.7	0.51	0.32	28	88
Soil threshold values receiving sludge (decree n° 97-1133)		100	2	1	100	300
Chinese regulatory values [28]		80	0.3 - 0.6	0.3 - 1	50 - 200	200 - 300
Dutch regulatory values [28]		530	13	36	190	720
German regulatory values [28]		1000	5	5	200	600

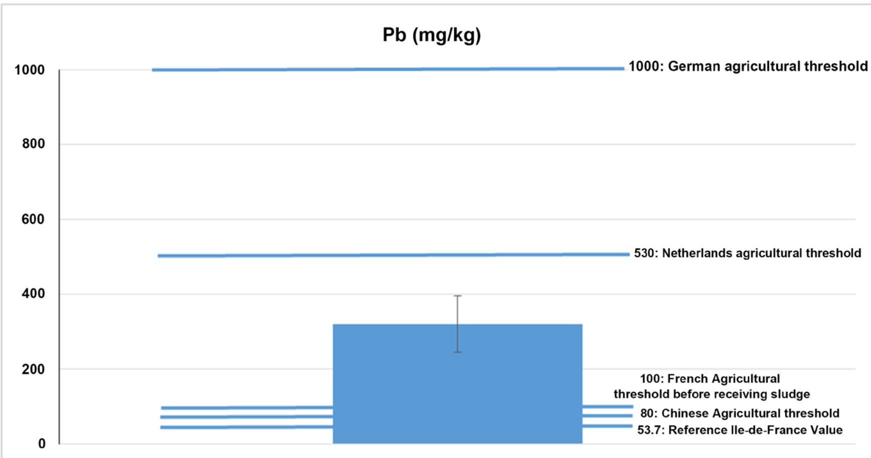

Figure 2. Average lead contents in soils comparing to different reference threshold values.

in vegetables are summarized in **Table 5**. Except of Pb in carrot samples, Pb and Cd contents are below the European values for all vegetables.

TM's contents were also compared to the average values found in French commercial vegetables [30]. For Cd, Cu and Zn, the contents found in vegetables are close to the average values found in French commercial vegetables. Pb levels found in tomatoes and potatoes do not exceed commercial values. However, Lettuce (0.12 ppm) and carrots (0.11 ppm) have concentrations ten times higher in Pb than commercial vegetables. Hg contents are below the Maximal Concentration Recommended by the French Council of Public Hygiene [31].

According to the concentrations found in soils (**Table 3**), the TM's are not very phytoavailable, for vegetables grown in these experimentations, compared to previous studies [13] [21]. This can be explained by the specific characteristics

Table 5. TM's contents in vegetables compared to reference values.

C(3)* in mg/kg FP(1)	Pb	EAT	EC	Cd	EAT	EC	Hg	MCREC	Cu	EAT	Zn	EAT
Lettuce (n(2) = 3)	0.12 ± 0.02	0.008	0.3	0.015 ± 0.002	0.0122	0.2	0.0025*	0.03	0.51 ± 0.10	0.66	2.9 ± 0.3	2.34
Carrots (n = 5)	**0.11 ± 0.02**	0.008	0.1	0.013 ± 0.002	0.0122	0.1	0.0025*	0.03	0.63 ± 0.13	0.66	3.7 ± 0.4	2.34
Tomatoes (n = 5)	0.005*	0.008	0.05	0.0055 ± 0.001	0.0122	0,05	0.0025*	0.03	0.57 ± 0.12	0.66	1.6 ± 0.2	2.34
Potatoes (n = 1)	0.005*	0.005	0.1	-	-	-	0.0025*	0.03	-	-	-	-

(1): mg/kg of fresh product; (2): Number of samples; (3): Mean ± Standard Deviation; EAT: Values from the French total diet study [30] representing mean levels found in vegetables from French marketplaces; EC: Threshold values from European Directive No. 466/2001 (and recent updates); MCREC: Maximal Concentration Recommended [31]; *In cases where concentrations were below the limit of quantification (LQ), the concentration was chosen at LQ/2.

of the soil (relatively basic pH and high organic matter content: 8.9%) which could inhibit the TMs remobilization [32].

3.3. Definition of User Scenarios Encountered in Studied Farms

3.3.1. Scenarios Encountered Depending on the Activity

Thanks to the surveys carried out on the 4 urban agriculture entities, different user scenarios have been defined and are presented in **Table 6**. These can be seen as "typical" scenarios that can be encountered on different urban agriculture sites.

In our knowledge, some scenarios have never been taken into account in current literature dealing with the health risk assessment in urban agriculture with the scenarios of people with private gardens [13] or scenarios of community gardens [9]. Scenarios of professional urban farmers, which are similar to those of a traditional market gardening environment, are not considered.

Given the multi-functionality of the different forms of urban gardens, the chosen approach aims to cover all the exposure possibilities in order to estimate the risk in line with the reality and specificity of each site. Some scenarios might correspond to a minority of the population and seem to be maximalist (consumers consuming 100% of vegetables from site). However, it is important that possible situations should be taken into account.

3.3.2. The Time-Averaged Soil and Dust Ingestion Rate for Each Particular Scenario

The amount of soil ingested as defined in an urban agriculture scenario is the estimation of the amount of unintentionally ingested soil during gardening and/or agricultural activity, by soil contact, hand-to-mouth, or swallowed as dust. There is few data on soil ingestion [33]. Where it exists, it mainly quantifies soil amounts ingested in adult scenarios [34] [35] or those of children [34] [36] spending time in green spaces, without specifically taking into account gardening and/or agricultural uses. The latter implies *a priori*, a higher level of soil ingestion.

The soil ingestion values concerning urban agriculture scenarios noted in scientific literature are highly variable. Classically, values range between 50 [12]

Table 6. Definition of the user scenarios encountered on the study site.

Scenario	Activity reference	Scenario descriptions of what took place
Urban farmer	1	Adult market gardener working daily on the site and consuming most of his vegetables from the site.
Social insertion farmer	2	Adult social insertion farmer not working daily on site and consuming few vegetables coming from the site.
Adult gardener	3	Adult gardener coming to cultivate several days a week on his plot at his leisure and consuming some of the vegetables from the site.
Child gardener	3	Child gardener coming to garden occasionally and consuming some of the vegetables from the site.
Adult consumer	1 - 2	Adult consuming 100% of the vegetables from the site but not visiting the site.
Child consumer	1- 2	Child consuming 100% vegetables from the site but not visiting the site.

and 100 mg/day [9] for adults and between 91 mg/day [13] and 200 mg/day [12] for children. However, some minor or major values are sometimes cited. For example, one study [14] fixed 10 mg/day for adult and another [4] quoted 480 mg/day.

The high variability of reference values in the literature indicates a lack of scientific precision related to the estimation of this parameter, which is nevertheless a key criterion for risk assessment. In fact, the use of the minor or major values in the same situation, could make the HQ related to soil ingestion vary by a factor of 40.

In this paper are chosen not maximal, but high reference values, considering that the activity of urban agriculture implies a higher rate of soil ingestion, compared to those coming from green spaces or walkways (**Table 7**).

The reference value of 200 mg/day (French national policy for managing contaminated land [17]) is chosen for gardening or urban agricultural activity involving digging. It is attributed to the scenarios of social insertion and adult gardeners, supposing that their activities on the site are entirely devoted to the production work (*i.e.* tillage, sowing, planting, weeding, maintenance, health monitoring etc.).

For the urban farmer scenario, the value of 125 mg/day is chosen, which corresponds to the estimated average soil intake, assuming that his working time on site corresponds to:

- 50% allocated to production (200 mg/day [17]).
- 50% to other agricultural work for activities such as marketing, administrative management, harvesting, washing and packaging work where the value of 50 mg/day [37] was chosen corresponding to visiting the site without working the soil [38].

For the child gardener scenario, the US EPA [38] high value of 200 mg/day is assigned, considering that it is difficult to control the risk of soil ingestion for this type of population, especially because hand-to-mouth use is common in small children.

Finally, for consumer, the soil ingested is considered zero because it is assumed they don't visit the site.

Table 7. Daily Ingested soil quantities (TASDR, mg/day) defined for each scenario encountered on the site.

Scenario	Urban farmer	Social insertion farmer	Adult gardener	Child gardener	Adult consumer	Child consumer
TASDR (mg/day)	125	200	200	200	0	0

3.3.3. Exposure Frequency for Each Scenario

In scientific literature, visits to the site are generally majored considering, that the people represented in the scenarios are exposed on a daily basis year-round [12] [13]. In this paper the exposure frequency (theoretical number of annually days of exposure) is close to the real attendance of the participants for each scenario. This was made possible thanks to the data of site-specific practices and uses, acquired during interviews and site visits. When these data were not available, bibliographic references as close as possible to the on-site situations were consulted.

The days of attendance depend on the scenarios and are specific to each activity carried out on the study site. Specific studies on site attendance may vary in other contexts. The surveys have shown that the urban farmer works 5 days a week, 47 weeks a year, or 235 days. The social insertion farmer spends a third of his working time on agricultural production work (78 days). The rest of the time, he works outside the site, so is not in contact with the contaminated soil. Finally, the surveys showed that gardeners came, on average, once a week from March to October. As regards the adult gardener scenario, the scenarios on the site being varied, a reference value of 150 days per year was chosen as a median scenario [21]. The exposure frequencies are summarized in **Table 8**.

3.3.4. Time-Averaged Vegetable Consumption Rate

It is considered that all the scenario players consume vegetables (coming from the site or not) every day of the year.

As with the soil ingestion parameter, the choice of the reference value of vegetable intake can vary the risk significantly. In France, it is customary to refer to national databases resulting from surveys such as the Individual and National Food Consumption Survey [39].

However, according to the sources, the values can vary significantly. For example, for a child scenario of an age group of 0 to 6 years, the daily consumption of leaf vegetables can vary from 12 g/day [33] to 37.5 g/day [40].

In this work, vegetables are grouped by type, assuming that the concentrations of TM's in lettuce would be concentrations of TM's in leafy vegetables, carrots would be root vegetables, and tomatoes would be fruit vegetables and potatoes on their own. This approach could bring another source of uncertainty (linked to the inter-type variations of TM's in vegetables). Nevertheless, this choice appeared to be the most feasible and safe stone.

For adults, consumption data correspond to those of French families with a vegetable garden, consuming significantly more fruits and vegetables than the French average (**Table 9**) [41]. In urban agriculture, consumer profiles are considered to be those of people consuming more vegetables than the average

Table 8. Theoretical Exposure Frequency (EF, day/year) defined for each particular on-site scenario.

	Urban farmer	Social insertion farmer	Adult gardener	Child gardener	Adult consumer	Child consumer
EF_{soil} (d/year)	235	78	150	32	0	0
EF_{veg} (d/year)	365	365	365	365	365	365

Table 9. Definition of vegetable quantities consumed (TAVCR, g/day) and percentages of self-consumption (SF) for each on-site scenario.

	Urban farmer	Social insertion farmer	Adult gardener	Child gardener	Adult consumer	Child consumer
$TAVCR_{leaf}$ (g/day)	84.7*	84.7*	84.7*	37.5*	84.7*	37.5*
$TAVCR_{fruit}$ (g/day)	140*	140*	140*	110.9*	140*	110.9*
$TAVCR_{root}$ (g/day)	34.8*	34.8*	34.8*	20.3*	34.8*	20.3*
$TAVCR_{potatoe}$ (g/day)	106.9*	106.9*	106.9*	49.1*	106.9*	49.1*
SF_{leaf} (%)	65**	20	53.2*	53.2*	100	100
SF_{fruit} (%)	65**	20	21.6*	21.6*	100	100
SF_{root} (%)	65**	20	41*	41*	100	100
$SF_{potatoe}$ (%)	75**	20	40*	40*	100	100

*[41] [21]; **[33].

person. For children, the consumption data correspond to the average values of the French child population [21].

Regarding the percentage of self-consumption, it is estimated that farmers consume the majority of their vegetables from their plots, 65% for leafy vegetables, fruits, roots and 75% for potatoes [33]. Social insertion farm workers do not consume more than 20% of vegetables from the site since they do not buy a basketful of vegetables (personal consumption data for gardeners [41]). Finally, it was considered that some consumers eat 100% of the vegetables coming from the site assuming that they buy vegetables every week from the same producer (which could be probably an overestimated assumption).

The quantities of vegetables ingested, and the percentages of self-consumption, are summarized in **Table 9** for the main types of vegetables found in the diet.

3.4. Hazard Quotient (HQ)-Based Risk Assessment for Each Scenario

The risk associated with each defined urban agriculture user scenario was evaluated by calculating, and then summing, the HQ corresponding to the five TM's (Pb, Cd, Hg, Cu and Zn), and for both exposure pathways: soil ingestion and vegetable intake. For the latter exposure pathway, vegetable types were distinguished: leaves, roots, fruit and potatoes. The $HQ_{soi\ ltot}$ and $HQ_{veg\ tot}$ were then summed to give a total hazard quotient (HQ_{tot}), representative of the overall risk related to each scenario (**Table 10**).

In addition, the Excess of Individual Risks (EIR), corresponding to the carcinogenic risk related to non-threshold effects of chemicals, have also been calculated for Pb. EIR values are found to be below 10^{-5} (**Table 10**) for all scenarios. The carcinogenic risk associated to Pbis not problematic for these scenarios.

For urban farmer scenario, HQ_{tot} is 1.02, so slightly higherthan 1, the risk is non negligible and requires attention. The risk comes mainly from soil ingestion (HQ_{soil} = 0.61) and from the intake of leafy vegetables (HQ_{veg} = 0.41), due to the important use of the site, the daily contact with soil and the high rate of vegetable self-consumption (65% to 75%).

In the scenario of the social insertion agricultural worker, HQ_{tot} is 0.45 dealing with no considerable risk. The risk comes more from soil ingestion (HQ_{soil} = 0.33) than from the vegetable intake (HQ_{veg} = 0.12), particularly because of low vegetable consumption (20%) and low attendance (2.5 days a week).

The adult gardener scenario has aHQ_{tot} of 0.90. It is therefore less than 1 but nevertheless non-negligible. As for the urban farmer, the risk comes more from soil ingestion (HQ_{soil} = 0.62) than from vegetable intake (HQ_{veg} = 0.27). This is due to the time spent exclusively on production activity maximizing the soil ingestion and to a lower self-consumption rate (around 25% on average).

With regard to the child gardener, a population that is particularly sensitive to risks, HQ_{tot} is 1.29. The risk comes from both soil ingestion (HQ_{soil} = 0.63) and vegetable intake (HQ_{veg} = 0.65).

The adult consumer scenario (which comes only from vegetable consumption) has aHQ_{tot} of less than 1 (0.62), with a half due to the ingestion of leafy vegetables.

The child-consumer scenario has aHQ_{tot} of 1.6, greater than 1, with an important influence of leafy vegetables consumption accounting for almost half of the risk (0.69). The sensitivity of children to vegetable intake is higher than adults. These results for adult and children consumers correspond in part to a maximalist scenario considering that all the vegetables consumed by the consumer population come from the site.

Generally, the risk is mainly due to the presence of Pb in the soil and vegetables of the studied sites. Indeed, only very recently, has the French scientific community come to the agreement that Pb has adverse effects on human health, even at doses below the values that were considered to be a threshold in the past. In particular, the TDI for Pb has been revised and implies an increase in the impact of Pb in HQ calculations [29].

The significant risk (greater than 1) in some of the scenarios, due to both soil ingestion and vegetable intake, requires management measures to be implemented. This orientation towards the implementation of management measures is currently a specific work in progress, by our research team in REFUGE[4]

[4]Risk in Urban Farms: Evaluation and Management, Innovation Statement made by Agro Paris Tech-INRA 2018 (http://www.inra.fr/en/Partners-and-Agribusiness/Results-Innovations-Transfer/All-the-news/REFUGE).

Table 10. Results of HQ-based risk assessment related for the five TM's in all scenarios.

Scenarios	Urban farmer	Social insertion farm worker	Adult gardener	Child gardener	Adult consumer	Child consumer
			Risk characterization—Soil ingestion			
HQ_{soil}	**0.61**	**0.33**	**0.62**	**0.63**	-	-
EIR_{soil}	1.3×10^{-6}	7.2×10^{-7}	1.4×10^{-6}	2.8×10^{-7}	-	-
			Risk characterization—Vegetable intake			
$HQ_{veg\ leaf}$	0.21	0.07	0.17	0.37	0.33	0.69
$HQ_{veg\ root}$	0.08	0.02	0.05	0.14	0.13	0.35
$HQ_{veg\ fruit}$	0.08	0.02	0.003	0.10	0.12	0.44
$HQ_{vegpotatoe}$	0.04	0.01	0.02	0.04	0.05	0.11
$HQ_{veg\ tot}$	**0.41**	**0.12**	**0.27**	**0.65**	**0.62**	**1.6**
$EIR_{veg\ leaf}$	3.5×10^{-7}	$1.1 \times \quad \times 10^{-7}$	$2.8 \times 10^{--7}$	1.2×10^{-7}	5.3×10^{-7}	2.2×10^{-7}
$EIR_{veg\ root}$	1.3×10^{-7}	4.0×10^{-8}	8.2×10^{-8}	4.8×10^{-8}	2.0×10^{-7}	1.1×10^{-7}
$EIR_{veg\ fruit}$	2.4×10^{-8}	7.3×10^{-9}	7.9×10^{-9}	6.0×10^{-9}	3.7×10^{-8}	2.7×10^{-8}
$EIR_{vegpotatoe}$	2.1×10^{-8}	5.6×10^{-9}	1.1×10^{-8}	4.9×10^{-9}	2.8×10^{-8}	1.23×10^{-8}
$EIR_{leg\ tot}$	5.2×10^{-7}	1.6×10^{-7}	3.8×10^{-7}	1.8×10^{-7}	7.98×10^{-7}	3.8×10^{-7}
			Risk characterization—Total of soil & vegetable ingestion			
HQ_{tot}	**1.02**	**0.45**	**0.90**	**1.29**	**0.62**	**1.6**
EIR_{tot}	**1.9×10^{-6}**	**8.8×10^{-7}**	**1.8×10^{-6}**	**4.6×10^{-7}**	**8.0×10^{-7}**	**3.8×10^{-7}**

HQ: Hazard Quotient (threshold effect); EIR: Excess of Individual Risks (Non-threshold effect without).

program, on these and other studied sites. Some of simple measures are cited here. To reduce the soil ingestion, especially due to hand-to-mouth contact, hygiene measures can be recommended such as wearing gloves, wearing activity-specific clothing, washing hands and brushing nails. Measures concerning agricultural practices can also be put forward to reduce the risk of creating, spreading and ingesting dust: avoid tilling the soil in dry weather, watering the soil before tilling it, and covering the soil as much as possible with mulch and sodding pathways. Other measures limiting the dangers pertaining to soil are under consideration, such as using healthy organic amendments and/or cultivating on reconstitute soils.

Concerning the risk related to vegetable intake, it is recommended to limit crops to low-accumulating vegetables that respect regulatory limits and to respect good consumption practices such as washing and peeling vegetables (when possible).

For the highest risk scenarios (urban farmers and children), more specific and drasticmeasures may be considered such as reducing the site frequentation by sensitive populations (child and pregnant women) or proceeding to control analysis of TM's levels in blood for the most exposed peoples (urban farmer and child gardener).

Finally, the management measures could be extended to setting up a safety control plan in order to identify all possible hazards during the production process (from the choice of the plot to the consumption) and propose the management measures for each of them. The development of this tool is currently under progress in REFUGE program.

4. Conclusions

This paper focused on the risk assessments associated to the presence of TM's in soils of a terrain hosting different forms of urban agriculture (micro-farms, social insertion association, and allotment gardens) and therefore different scenarios of users (urban farmers, social insertion workers, adult and child gardeners, and adult and child consumers). The study area shows higher Pb, Cd, Hg, Cu and Zn contents than geochemical backgrounds and sludge spreading thresholds, often used in France as a reference in urban agriculture.

Results show that, except for carrot samples, TM's contents in all vegetables remain under the European guidance values for Pb, Cd, close to the mean values in French commercial vegetables for Zn, Cu and below the maximal concentration recommended for Hg. This is probably due to soil properties such as relatively high pH and organic matter leading to a low phytoavailability. Nevertheless, the risk assessments show that, in certain scenarios, the risk is not negligible because the soil ingestion factor is considered as a second source of exposure.

Risk assessments show that the riskiest scenarios concern urban farmers (in particular because they are on-site working on a daily basis all year round), children gardeners (more sensitive than adults) and children regular consumers (maximalist scenario, where the consumer would exclusively eat the vegetables at the site and would therefore be significantly more exposed). Next would be the adult gardener scenario, while the least risky are the farm workers and adult consumer scenarios. These results deal with the necessity of the implementation of management measures, concerning the cultivation of vegetables specific to urban agriculture, and especially, concerning the protection of users who work on or play in the soil. More drastic measures must be considered for the highest risk scenarios (urban farmers and children), such as reducing the site frequentation or control analysis of TM's levels in blood.

The HQ-based risk assessment is a recognized approach in France, but it is based on parameters that are subject to numerous uncertainties, as shown in this paper. In fact, depending on the chosen parameters (soil ingestion, vegetable intake, exposure frequency, etc.), the Hazard Quotient can vary rapidly by a factor of 10. Therefore, it is advisable to consider this method as an indicator of the risk, rather than a precise and quantified description of the risk [4] [12].

On the other hand, HQ-based risk assessment could be a tool that overestimates the risk, particularly because daily exposure is compared with reference toxicological values (TDI) made up for lifetime exposures to pollutants, which is not the case in reality, especially in urban agriculture where there is a significant mixing of populations from year to year. In addition, when creating the scenarios, certain parameters are majored, such as the consumption rate of consumer scenarios, for which it is assumed that 100% of their annual consumption of vegetables comes from the site.

Finally, the HQ-based risk assessment, as applied, does not take into account the notion of bioaccessibility of TM. It is considered that 100% of the TM entering the body by ingestion is absorbed by the blood and found in the organs. Recent studies, however, show that some of the elements are not totally absorbed [13] [42] [43], which again represents an overestimation of risk.

Therefore, it is important when applying this method to field situations, to systematically discuss the uncertainties and make relevant management decisions pertaining to them after the discussion.

This work helped to contextualize the HQ-based risk assessment approach by highlighting its site-specific nature. It is the basis of the current reflection of the REFUGE program in order to produce an operational guide for the characterization of contaminated soils and the risk assessment in all possible scenarios of exposure to TM's in urban agriculture.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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