Farms at risk from environmental pollution: a proposal for a risk ranking procedure

Aziende zootecniche a rischio di contaminazione ambientale: una proposta metodologica di classificazione del rischio

Sabrina Battisti, Marcello Sala, Bruno Neri, Carlo Boselli, Carlo Corradini, Ziad Mezher, Paola Scaramozzino
Experimental Zooprophylactic Institute of Lazio and Tuscany 'M. Aleandri', Rome (Italy)
Corresponding author: Sabrina Battisti; sabrina.battisti@izslt.it

ABSTRACT

OBJECTIVES: to produce a methodology for the risk ranking of farms located around proven or potential sources of contamination to prioritize the monitoring procedures in food production.
DESIGN: environmental factors that can favour the risk of contamination of products of animal origin (POAO) around a pollutant source were identified. A scale of standardized scores was produced for each risk factor (RF) in order to obtain a risk-based classification. Subsequently, an algorithm was developed to obtain a relative risk assessment (RRA).
SETTING AND PARTICIPANTS: in order to validate the proposed methodology, data of 80 livestock farms in a polluted area, enrolled in a previous study, were subjected to the RRA. Results of RRA were compared with contamination data.
MAIN OUTCOME MEASURES: seven RFs were included in a mathematical formula used to classify each farm.
RESULTS: a scoring system was produced for each RFs and an algorithm was developed to obtain RRA which is an estimate of the farm probability of having POAO contamination in comparison to other farms located in the same area potentially affected by chemical pollution based exclusively on site-specific environmental characteristics. In the case study used for validation, a significant relationship between RRA and contamination data was found.
CONCLUSIONS: the proposed methodology is a useful tool to support the authorities responsible for the food safety in carrying out the monitoring of POAO in areas subject to environmental risks. It helps to rationalize resources and make controls more effective.

Keywords: contaminated site, risk assessment, ranking, farms

RIASSUNTO

OBIETTIVI: produrre una metodologia per la classificazione del rischio in aziende zootecniche che risiedono intorno a fonti di contaminazione comprovate o potenziali allo scopo di definire priorità nel monitoraggio della produzione alimentare.
DISEGNO: sono stati individuati fattori ambientali che favoriscono il rischio di contaminazione dei prodotti di origine animale (*products of animal origin*, POAO) in aziende situate intorno a sorgenti inquinanti. Al fine di ottenere una classificazione del rischio, è stata prodotta una scala di punteggi standardizzati per ciascun fattore di rischio (*risk factor*, RF). Successivamente, è stato sviluppato un algoritmo per ottenere una valutazione del rischio relativo (*relative risk assessment*, RRA).
SETTING E PARTECIPANTI: per validare la metodologia, sono stati sottoposti a RRA 80 allevamenti provenienti da un'area inquinata estrapolati da un precedente studio. I dati di RRA sono stati confrontati con i dati di contaminazione.
PRINCIPALI MISURE DI OUTCOME: è stata usata una formula matematica per classificare il rischio in ogni azienda. Sette RF sono stati inclusi nella formula.
RISULTATI: è stato sviluppato un algoritmo per ottenere RRA che è una stima della probabilità, basata esclusivamente su variabili ambientali, di contaminazione dei POAO in ciascuna azienda zootecnica rispetto alle aziende limitrofe esposte alla stessa sorgente. È stata prodotta una scala di punteggi per ciascun RF. Il test di validazione ha mostrato un'associazione significativa tra RRA e dati reali di contaminazione.
CONCLUSIONI: la metodologia proposta è uno strumento utile a supportare le autorità nello svolgimento del monitoraggio dei POAO in aree soggette a rischi ambientali. Aiuta a razionalizzare le risorse e a rendere i controlli più efficaci.

Parole chiave: siti contaminati, valutazione del rischio, classificazione, aziende zootecniche

WHAT IS ALREADY KNOWN

- **In case of release of pollutants, the soil represents the primary natural receptor and one of the most important source of exposure for living beings.**
- **The interaction between chemicals and receptors follows preferential routes and the concentration of pollutants in the soil around a polluting source is not homogeneous; therefore. farms are not all equally exposed.**
- **The exposure assessment allows a proper allocation of resources.**
- **Risk ranking is a well-known procedure useful to set priorities.**

WHAT THIS PAPER ADDS

- **This study offers a methodology for hierarchizing farms around a source of pollution based on the analysis of environmental risk factors.**
- **This analysis is useful for the planning of preliminary controls in the absence of more detailed data about the contamination event.**
- **The application of this methodology allows both the rationalization of resources and a more effective biomonitoring.**

Epidemiol Prev 2020; 44 (5-6):394-401. doi: 10.19191/EP20.5-6.P394.015

INTRODUCTION

Owing to the high costs of managing pollution-related problems, environmental pollution is a matter of great concern at international level for the negative effects on the ecosystems, health, and economy. In many countries, dealing with this issue is difficult mainly due to the lack of adequate resources and technologies. A worldwide interest for rapid methodologies that allow, through a preliminary risk assessment, an early detection of the sites that need urgent and in depth monitoring is rising.[1,2] The hierarchization of risk is considered a useful method that provides the basis for comparing, classifying and assigning priorities.[3-6]
Several risk-ranking methods have been already applied in many sectors of veterinary surveillance (e.g., for the assessment of transmissible diseases or for the evaluation of risks deriving from veterinary drugs).[7-12] However, just a few of these methods were used to assess the risk due to environmental pollutants.[13-16]
Regulation EC/178/2002 of the European Parliament, laying down the general principles and requirements of food law, specifies that controls on food and feed should be based upon a priori assessment of public health risks, and consequently a risk assessment is essential to optimize the controls on products of animal origin (POAO), such as eggs, milk, cheese, meat, and other food, even in case of environmental pollution.[17-19]
The present study aims to develop a methodology for the classification of livestock farms around a pollutant source based on the risk of contamination of POAO due to the potential or effective presence of chemicals in soil. It is widely recognized that, in case of chemical release, the soil is the primary receptor and the most important means of exposure for plants, animals, and humans.[20-25] In some regulatory acts, the term 'soil' indicates the entire set of surface soils, subsoil, crops, and human activities on it, highlighting the close interaction of soil with the ecosystem.[26] When chemicals enter the soil, they pass to water, plants, and animals through the food chain or by direct ingestion of a considerable amount of soil as happens with grazing ruminants.[27,28] Animals bred on contaminated soils have a greater risk of being contaminated.[29-31]
This assumption is valid and widely demonstrated as animals are more closely related to residential soils than humans due to the fact that they are often fed with local forages or through neighbouring pasture.[24,25,32,33]
Farms are not all exposed in equal measure around a pollutant source as the spatial distribution of pollutants in the environment is not homogeneous.
A procedure for the relative risk assessment (RRA) based on environmental parameters is proposed in this study. A second phase procedure is proposed to select the most susceptible farms among those previously ranked by RRA based on animal and farm management aspects.[33]
Specific objectives are: to allow a better allocation of resources for food safety controls in the nearness of a polluting source, through a preliminary assessment of the risk at the farm site based on environmental parameters (RRA), and to perform a more effective biomonitoring.

STUDY DESIGN

In the first phase, various risk factor (RFs) related to the environmental characteristics of the polluting site and surrounding area were considered in order to identify the criteria to perform an environmental risk-based classification of livestock farms. A risk-scoring system was implemented by creating a scale of scores for each RF.[5,34] The aim was a first ranking of farms based on the RRA.
In the second phase, zootechnical, biological, and sanitary criteria for animal biomonitoring were indicated; they are fundamental to successfully detect environmental contamination. The goal was to make the biomonitoring as effective as possible through POAO. Such criteria must be adopted on farms previously subject to RRA.
Moreover, the reliability and accuracy of the procedure was validated in an area affected by severe pollution in central Italy that was object of continuous monitoring in the past years: Sacco river Valley, located in Lazio Region (Central Italy).[15,35]

CONCEPTUAL FRAMEWORK

The conceptual framework underlying this study (figure 1) is the one normally used in environmental risk assessment models: 'Source-Diffusion Pathways-Receptors'.[1,5]
Knowledge of the source is important to estimate the spread of pollutants (relevance and magnitude) and to establish the size of the area (buffer) to be investigated. All farms falling within this buffer must be subject to RRA. Information on the type of chemicals is important to select the target animal for subsequent monitoring, as indicated in phase two.
The rationale of this study is that some natural characteristics of the territory make some farms more exposed. The spread of pollutants around the source is not homogeneous and some pathways are preferred.
Some RFs are the same as those already used in most of the preliminary risk assessment models in areas affected by soil contamination.[1,2,5,36]
Data on selected RFs can be easily found in environmental layers of official cartography: hydrography, hydrogeology, Digital Elevation Model (DEM), geology, land use map.[36-41] Since all RFs have a spatial component, Geographical Information Systems (GIS) are fundamental to study and measure the spatial relationships among sources, pathways, and receptors.
The overlapping in GIS of the aforementioned informative layers allows to extrapolate the data of RFs at level of

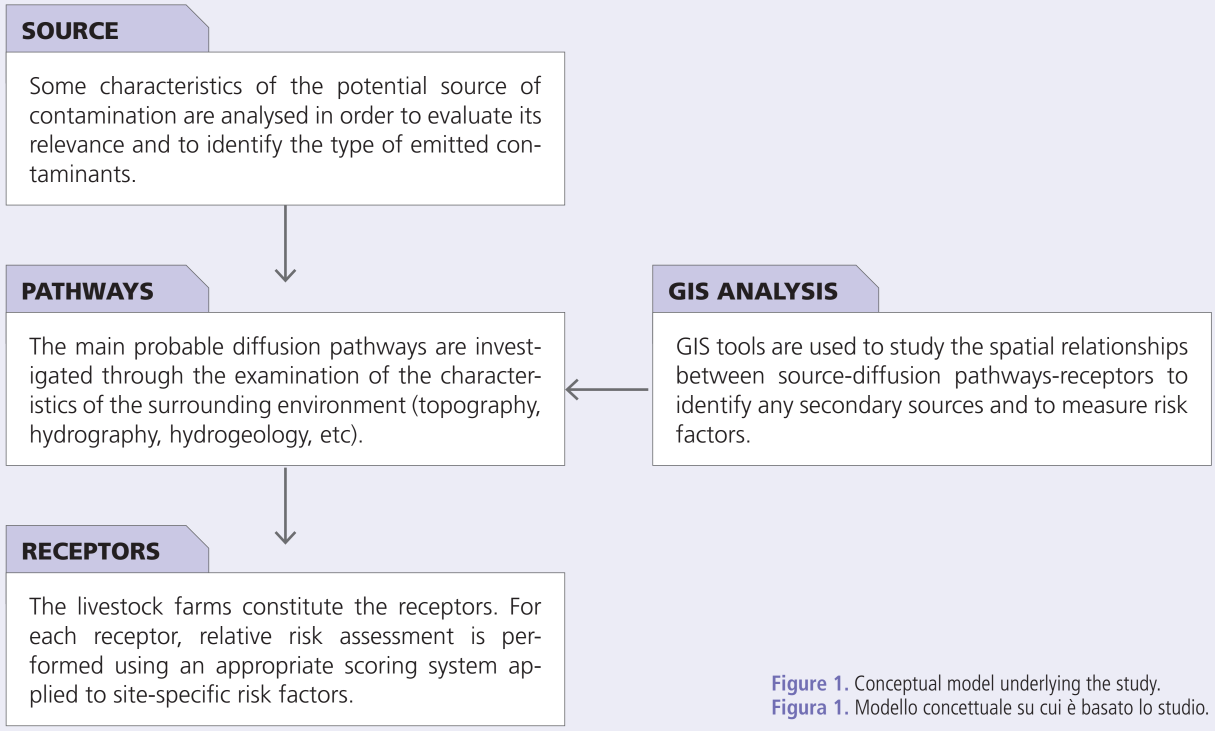

Figure 1. Conceptual model underlying the study.
Figura 1. Modello concettuale su cui è basato lo studio.

the geographical site of the farms by means of geographical coordinates.
The scoring process is generally used to standardize, compare, and aggregate risk factors in risk assessment.[5,42-44]
A mathematical equation that measures the RRA was produced.
In the model generally used in the areas affected by environmental contamination the risk (R) is a function of: probability of occurrence of a hazard/contamination (P), vulnerability of the receptors (V), extent of the damage to the receptors (D): $R = f(P;V;D)$.[3,5]
In the proposed model, the extent of D is not estimated, since it would require an economic evaluation of the farm production process as well as an evaluation of the consequential health impact, that are beyond the scope of this study. Moreover, the estimation of the dangerousness of the source (polluting flow rate and toxicity) was not introduced in the present model, since farms are assumed to be exposed to the same source; therefore, it is a constant not affecting the RRA.
In this study, the RRA is exclusively a function of the vulnerability of the receptors: $R = f(V)$, which is an expression of the farm probability of being involved in a contamination event due solely to site-specific environmental characteristics that facilitate the exposure.[3,36]
To ensure the reproducibility of the results, the methodology has been designed only for sources where pollutants are released into the soil. For the same reason, it can be applied around a single source or a circumscribed one, such as an industrial area or district. In addition, since the radius normally studied around a pollutant source rarely exceeds 30 kilometres, the proposed methodology does not provide a scoring system nor a classification beyond this distance.[15,16,35]
For the purposes of this study, the polluting sources are classified into two types:
- **primary:** sites from which the contamination originates and is introduced into the environment (e.g., industrial activities, landfills);
- **secondary:** environmental compartments (e.g., water streams, lakes), located near the primary source which act as natural collectors of pollutants and contribute to spread them thus becoming passive sources.

ENVIRONMENTAL RF

The environmental characteristics that affect the farm probability of being contaminated by a source were selected as risk factors and their measurement determines the final result of RRA. The reasons behind the choice of each RF and related assumptions underlying the association with risk are illustrated below. Most of the subsequent assumptions come from the previous experience of the Authors or evidences drawn from other studies.[1,5,6,15,20,21,24,29,31,35]

■ **Distance from the primary or secondary sources (D1, D2):** the probability of having a contamination inside a farm is inversely proportional to the distance between the farm site and the polluting sources, because the degradation and dilution of pollutants in soils increase with distance; in particular, the closer the receptor is to the source, the greater the probability of being contaminated.

■ **Position respect to the propagation direction (i.e., angular distance):** pollutants follow preferential routes in the environment; consequently, the farms located on these routes are more exposed. These routes of propagation normally coincide with the direction of surface and underground water main flow. Farms placed on the opposite side have a much lower risk. The position respect to the propagation direction is measured considering the angle of the 'primary source-receptor' vector with respect to the 'primary source-outflow main direction' vector (e.g., water course). Two different scoring systems are indicated for farms that are below and above 90° respect to the propagation axis, taking into account the greater reduction of risk above 90° (table 1).

■ **Elevation (Q):** the elevation respect to the source (measured as altitude difference) inversely influences the probability of animal exposure since the natural transport occurs according to gravimetric lines (from top to bottom).

■ **Groundwater depth (F):** when the depth of the groundwater decreases, the risk of contamination increases, since a shallow groundwater is more likely to be contaminated due to the reduced thickness of the overlying soils and the lower filtering effect. The maximum score was attributed to shallow aquifer (0-10 m) where the contaminants that reached the underground waters can move up again into the soils by using water wells or by means of seasonal oscillations of the phreatic surface or capillarity.

■ **Hydrogeological vulnerability (Vu):** it is a qualitative index of the propensity/aptitude of soils to protect the underlying aquifer from pollution and it is related to the soil ability to retain contaminants. The soils that are hydrogeologically less vulnerable prevent chemicals from passing to the underlying aquifer, but, for the same reason, represent a greater risk to crops grown on the same soil due to their ability to retain pollutants. The risk of having forage/pasture contamination and scoring is considered inversely proportional to the vulnerability.[15]

■ **Alluvial soils (A):** the location of a receptor on land subject to high risk of floods by watercourses that act as secondary sources increases the risk, because the contaminants transported in the liquid or solid phase are deposited in high concentrations on the neighbouring soils during the floods.

■ **Natural barriers (B):** the presence of natural barriers (e.g., topographic prominences, hydrographic basins, tectonic barriers) between source and receptor that obstruct the diffusion of pollutants reduces the risk of contamination.

RESULTS

A scoring system for seven RFs (table 1) and a specific mathematical formula was developed to compute RRA. A step-by-step procedure describes the assessment. In the second phase (step 7 to 10), some supplementary criteria are illustrated for the choice of the most susceptible farms, among those previously classified by RRA, suitable for biomonitoring purposes.

The procedure to obtain RRA consists of the following steps:

1. acquisition of information on: position of the source, neighbouring livestock farms (after extrapolation from the National Animal Registry), and related characteristics (livestock management, type of reared animal species, and POAO), magnitude, and type of pollution release;[45]

2. spatial analysis by GIS of the source and receptors; measurement of spatial relationship among source and receptors, delimitation of the geographical area within which to apply the procedure: a variable buffer is adopted around both the sources, primary and secondary (if present), that is conditioned by the evaluation of the size/extent of the polluting load performed during step 1. Commonly, the buffers range between 1 and 6 kilometres around the primary source and between 0,5 and 3 kilometres around the secondary source;[35]

3. overlapping by GIS of different informative layers (hydrography, hydrogeology, geology, DEM) in order to acquire all the information related to RF;

4. normalization of the values of RF through the scoring system in table 1;

5. aggregation of the normalized values in the RRA model equation;

6. classification of the farms, their listing (according to the acquired RRA) and representation on map. The maps show ranked risk on the territory.

In the second phase, in the ranked farms the following activities should be carried out to identify priorities for monitoring purposes:

1. identification of the animal species (cattle, sheep, poultry) more susceptible to the specific- emitted substances/pollutants: the animal management and physiology of each species should be considered;

2. identification of the most susceptible matrices, i.e., the POAO (e.g., milk, eggs, meat) that have a greater aptitude to bioconcentrate the specific chemicals;

3. selection of the most susceptible farms under the live-

RISK FACTOR	UNIT	SCALE	SCORE
Angular distance of the "primary source-receptor" vector towards the "primary source-direction of propagation" vector ≤90°			
Distance from the primary polluting source (D1)	Meters	0-1,500	1
		1,501-3,000	0.8
		3,001-5,000	0.6
		5,001-10,000	0.4
		10,001-30,000	0.1
		≥ 30,001	0
Distance from secondary source (D2)	Meters	0-700	1
		701-1,500	0.5
		≥ 1,501	0.1
Elevation/altitude in relation to the primary or secondary source (considering the nearest one) (Q)	Meters	<10	1
		11-30	0.7
		31-70	0.3
		≥ 71	0
Piezometric level of the aquifer (depth of the aquifer level with respect to the topographic surface) (F)	Meters	0 - 10	1
		11-20	0.8
		21-50	0.5
		51-200	0.1
		≥ 201	0
Hydrogeological vulnerability of surfacing lithotypes (Vu)	Qualitative	Low or very low	1
		Very high, high, and medium	0
Alluvial/floodable soils (A)	Qualitative	Yes	1
		No	0
Presence of natural barriers between source and receptor (river basin limits, tectonic discontinuities, poorly permeable lithotypes) (B)	Boolean	No	1
		Yes	0
Angular distance of the "primary source-receptor" vector towards the vector "primary source-direction of propagation" >90°			
Distance from the primary polluting source (D1)	Meters	0-1,500	0.9
		1,501-3,000	0.6
		3,001-5,000	0.3
		≥ 5,001	0
Distance from secondary source (D2)	Meters	0-700	0.5
		701-1,500	0.3
		≥ 1,501	0.1
Elevation/altitude in relation to the primary or secondary source (considering the nearest one) (Q)	Meters	<10	0.5
		11-30	0.4
		31-70	0.2
		≥ 71	0
Piezometric level of the aquifer (depth of the aquifer level with respect to the topographic surface) (F)	Meters	0-20	0.8
		21-50	0.6
		51-200	0.3
		≥ 201	0
Hydrogeological vulnerability of surfacing lithotypes (Vu)	Qualitative	Low or very low	0.5
		Very high, high, or medium	0
Alluvial/floodable soils (A)	Qualitative	Yes	0.5
		No	0
Presence of natural barriers between source and receptor (river basin limits, tectonic discontinuities, poorly permeable lithotypes) (B)	Boolean	No	0.5
		Yes	0

Table 1. Risk factors and proposed scoring for relative risk assessment.
Tabella 1. Fattori di rischio e punteggio proposto per la valutazione di rischio relativo.

stock management point of view among those with the same RRA value: use of pasture, feeding with local fodder, use of water from local wells, and other factors that make the farms more sensitive;

4. exclusion from the biomonitoring plan of all farms that do not have any of the above sensitive factors (i.e., all farms with animal species that are unable to bioconcentrate the target contaminants in their organs or POAO or that have a management – use of non-local feeding – that does not allow to absorb environmental contamination). This step is critical for the confirmation of presence/absence of pollution in the environment and for the validation of the RRA as well as the choice of the most sensitive species, POAO, and livestock management.[33]

To estimate the RRA the overall risk (OR) is measured for each farm by the following formula:

$$OR = D1 \times D2 \times (Q+F+Vu+A+B)$$

A multiplicative operator is used for factors considered most influential, such as the distances, and summation for the less influential ones.[46]

The RRA equation is:

$$RRA = OR \setminus OR_{max}$$

The OR for each farm is divided by the highest OR (OR_{max}) in the investigated area. RRA values are in the range between 0 and 1.

A value of RRA equal to one indicates maximum relative risk while a value equal to or close to zero highlights a negligible risk of contamination.

After the application of RRA, results of performed biomonitoring could reveal different situations:

- absence of contamination in the farms with the highest RRA and in those with lowest RRA (sampled to a lesser number as control): contamination can be excluded in all the farms of the area with significant cost savings in the management of controls;
- presence of contamination in farms with the highest RRA and to a lesser extent in those with lower RRA: in this case, biomonitoring confirms RRA and a contamination has been ascertained that degrades in the environment;
- presence of contamination at the same intensity both in farms with the highest and lowest RRA: it could be a massive contamination that requires more specific studies;
- presence of contamination in farms with lowest RRA, but not in those with highest RRA: in this case, the methodology is not adequate, probably because the real pollution framework in the environment is not explained by the model.

VALIDATION OF METHODOLOGY THROUGH A CASE STUDY

The procedure has been tested for validation in a polluted area in Central Italy: the Sacco river Valley. Data of 80 livestock farms belonging to such area were abstracted from a previous study and subjected to the RRA.[15]

RRA data was compared to values of beta isomer of hexachlorocyclohexane (β-HCH) measured in 2005 on bulk milk samples of dairy cattle raised in the 80 farms. Figure 2 shows a graphical agreement between RRA results (graduated circular symbols) and β-HCH measurements previously interpolated by Indicator Kriging (IK), as reported by the aforementioned study (IK shows the probability of having milk concentration of β-HCH above 0.0005 mg/kg in 4% of fat).[15]

The primary source of β-HCH is an illicit storage site of toxic waste that caused soil contamination with β-HCH and subsequent involvement of different vegetable and animal matrices.

The secondary source is the Sacco river, which contributed to spread the pollution.

All 80 livestock farms are within the buffers of 5 and 3 km, respectively, around the primary and secondary sources which extended up to 30 kilometres from the primary source (red line of figure 2).

RFs values extracted from the informative layers through GIS are: hydrography, hydrogeology, digital elevation model (DEM).[39-41] Analysed RFs were: D1, D2, Q, Vu, F, and angular distance between 'source-receptor' vector and 'source-propagation' vector. Information on other RFs was lacking.

A Spearman's Rank Correlation showed a significant relationship between RRA and β-HCH measurements ($p<0.001$), with a rank correlation coefficient equal to 0.44. This result shows that the RRA process can be a useful tool. The moderate magnitude of the correlation is probably due to the non-execution of the second phase of procedure. β-HCH measurements refer to farms that did not use fodder and water at greatest risk, as indicated by the aforementioned study.[15] Greater correlation is expected with RRA if biomonitoring is applied to the highest risk farms also under the veterinary and management point of view as outlined in the second phase of procedure.

CONCLUSIONS

In this study, a new methodological approach was proposed to establish priorities in veterinary controls in areas exposed to environmental risk. The methodology is based on a preliminary assessment of the risks, as advocated by the EU legislation. A one-health approach was adopted by combining geological, geographical, toxicological, and veterinary skills.

A risk ranking procedure around a pollutant source must

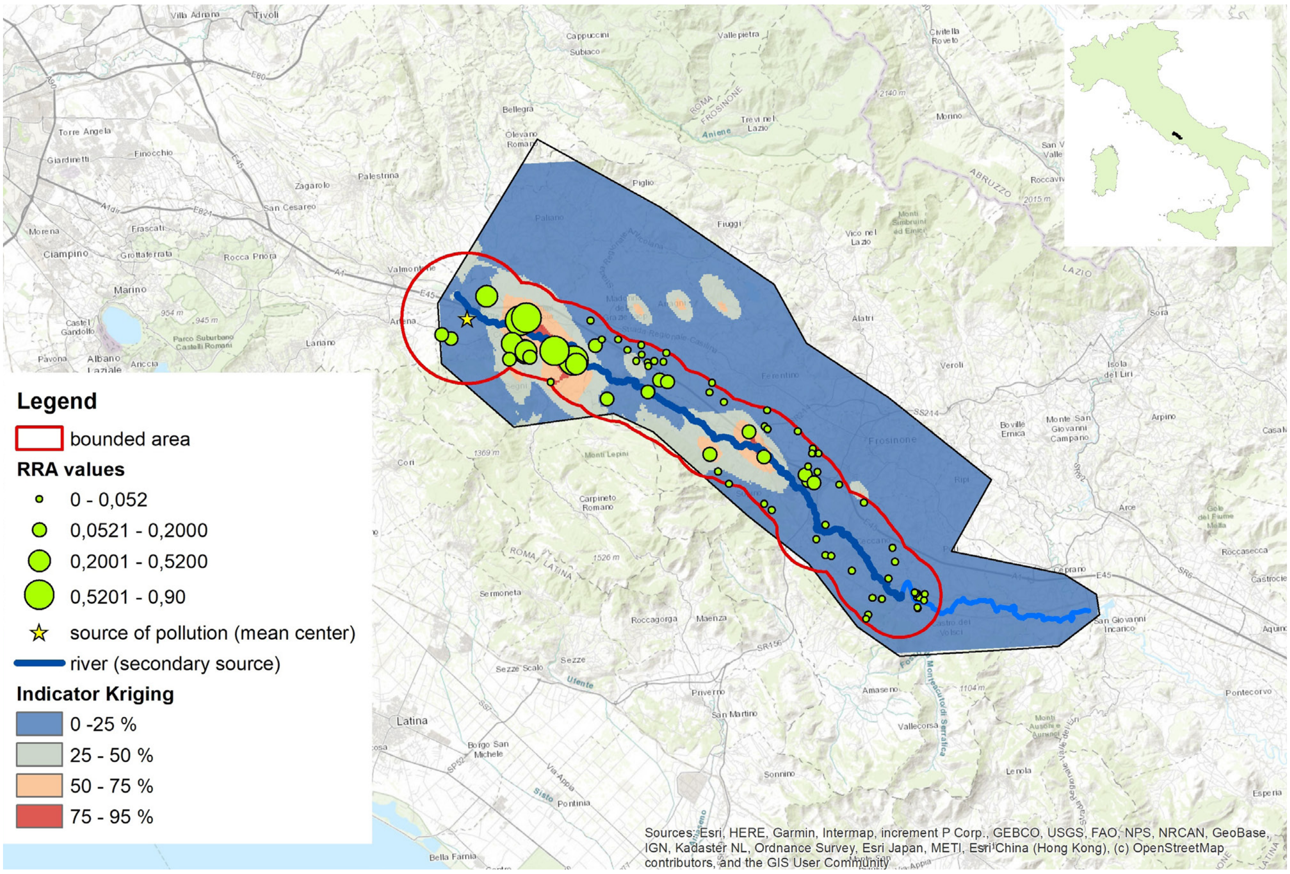

Figure 2. Relative risk assessment values in the Sacco river Valley (Lazio Region, Central Italy) (graduated points) superimposed over the representation of the probability of having beta-HCH concentration in milk above 0.0005 (mg/kg in 4% of fat) obtained through Indicator Kriging as in Battisti et al.[15]

Figura 2. Valutazione di rischio relativo nella valle del fiume Sacco (Lazio) (pallini graduati) sovrapposta alla rappresentazione della probabilità di avere una concentrazione di beta-HCG nel latte superiore a 0,0005 mg/kg sul 4% di grasso ottenuta con l'indicatore Kriging, come in Battisti et al.[15]

be kept in great consideration for land management, since chemicals can persist for decades in the soil before being naturally degraded and the most exposed farms need to be often monitored. Risk ranking allows to identify sentinel farms for early warning of pollution and monitoring the effectiveness of corrective or safety measures.[47] The proposed RRA algorithm proved to be effective in predicting risk in a case study in Central Italy (Sacco river Valley). It is known that, in the construction of most models, it happens that the greater the field of application the greater the difficulty of making the results reproducible in different contexts. A limitation of this model is that it is not applicable to aerogenic sources, but only around sources that release pollutants into the soil, because the effect of winds that have a great influence on the areal dispersion of pollutants was not considered in the model. The model may be more appropriate in certain situations than in others, as the different chemicals released into the environment have different behaviours that cannot be perfectly represented in the same model. Any bias in the prediction of RRA can be highlighted by the results of the subsequent biomonitoring (phase two) that can reveal different situations and distortions of RRA compared to reality (see paragraph "results"). It proved to be simple to apply and suitable even when knowledge of some RFs is lacking, because the measurement of RRA is still possible if done under equal conditions for all receptors. This means that the RRA equation could be applied using only variables for which information is available. For example, when information on hydrogeological and geological conditions is lacking, but distances from primary and/or secondary sources are available for all farms, the RRA calculation is still possible through the equation using only variables D1 and D2 and removing all the others. This aspect makes the procedure suitable even for quick evaluations as in a time of emergency.

It is meaningful to note that, if the biomonitoring confirms the RRA prediction, the RRA can also be applied to sites not yet affected by animal husbandry for the sole purpose of preliminary assessing the area suitability for animal husbandry or agriculture. This is possible as the RRA is based solely on site-specific environmental parameters. RRA mapping facilitates the identification of the areas at greatest risk.

Conflicts of interest: none declared.

REFERENCES

1. Altieri A, Falconi M, Quercia F, Vecchio A. Towards an EEA Europe-wide assessment of areas under risk for soil contamination. Volume II. Review and analysis of existing methodologies for preliminary risk assessment. Final version. European Environment Agency 2004. Available from: https://www.yumpu.com/en/document/view/33392080/review-of-available-methods-eionet
2. World Health Organization. Contaminated sites and health. Geneva: WHO; 2013. Available from: https://www.euro.who.int/__data/assets/pdf_file/0003/186240/e96843e.pdf?ua=1
3. Environment Protection Agency. Guidelines for Ecological Risk Assessment. Federal Register 63(93):26846-924. EPA 1998. Available from: https://www.epa.gov/sites/production/files/2014-11/documents/eco_risk_assessment1998.pdf
4. Van-Camp L, Bujarrabal B, Gentile AR, et al. Reports of the technical working groups established under the thematic strategy for soil protection. EUR 21319 EN/4. Luxembourg: Office for Official Publications of the European Communities; 2004. Available from: https://ec.europa.eu/environment/archives/soil/pdf/vol5.pdf
5. Pizzol L, Critto A, Agostini P, Marcomini A. Regional risk assessment for contaminated sites part 2: ranking of potentially contaminated sites. Environ Int 2011;37(8):1307-20.
6. Falconi M, Quercia F, Schamann M, Tarvainen T, Vecchio A, Wepner M. Towards an EEA Europe-wide assessment of areas under risk for soil contamination. Volume III. PRA.MS: scoring model and algorithm. Final version. Copenhagen: European Environment Agency; 2005.
7. Cito F, Rijks J, Rantsios AT, et al. Prioritization of Companion Animal Transmissible Diseases for Policy Intervention in Europe. J Comp Path 2015;155(1) Suppl 1:S18-26.
8. World Health Organization. Methodology for Prioritizing Severe Emerging Diseases for Research and Development. Geneva: WHO; 2017. Available from: https://www.who.int/blueprint/priority-diseases/RDBlueprint-PrioritizationTool.pdf?ua=1
9. Cardoen S, Van Huffel X, Berkvens D, et al. Evidence-based semiquantitative methodology for prioritization of foodborne zoonoses. Foodborne Pathog Dis 2009;6(9):1083-96.
10. EFSA Panel on Biological Hazards. Scientific opinion on the development of a risk ranking toolbox for the EFSA BIOHAZ Panel. EFSA J 2015;13(1):3939. Available from: https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2015.3939
11. Kools SAE, Boxall ABA, Moltmann JF, Bryning G, Koschorreck J, Knacker T. A ranking of European veterinary medicines based on environmental risks. Int Environ Assess Manag 2008;4(4):399-408.
12. Di Nica V, Menaballi L, Azimonti G et al. Rankvet: A new ranking method for comparing and prioritizing the environmental risk of veterinary pharmaceuticals. Ecol Ind 2015;52:270-76.
13. Broadhurst JL, Petrie JG. Ranking and scoring potential environmental risks from solid mineral wastes. Mineral Eng 2010;23(3):182-91.
14. Umeh AC, Duan L, Naidu R, Semple KT. Residual hydrophobic organic contaminants in soil: Are they a barrier to risk-based approaches for managing contaminated land? Environ Int 2017;98:18-34.
15. Battisti S, Caminiti A, Ciotoli G, et al. A spatial, statistical approach to map the risk of milk contamination by -exachlorocyclohexane in dairy farms. Geospatial Health 2013;8(1):77-86
16. Desiato R, Bertolini S, Baioni E, et al. Data on milk dioxin contamination linked with the location of fodder croplands allow to hypothesize the origin of the pollution source in an Italian valley. Sci Total Environ 2014;499:248-56.
17. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety.
18. Scaramozzino P, Rombolà P, Battisti S, et al. Surveillance model for environmental contaminants through their monitoring in animal production. It J Public Health 2010;7(1):3-11
19. Rombolà P, Battisti S, Scaramozzino P. Animal biomonitoring and micropollutants in public health – review. Epidemiol Prev 2012;36(5) Suppl 4:5-14.
20. Lake IR, Foxall CD, Lovett AA, et al. Effects of river flooding on PCDD/F and PCB levels in cows' milk, soil, and grass. Environ Sci Technol 2005;39(23):9033-38.
21. Kirkham MB. Cadmium in plants on polluted soils: Effects of soil factors, hyperaccumulation, and amendments. Geoderma 2006;137(1-2):19-32.
22. Gummow B, Kisten WFA, Gummow RJ, Heesternbeek JAP. A stochastic exposure assessment model to estimate vanadium intake by beef cattle used as sentinels for the South African vanadium mining industry. Prev Vet Med 2006;76(3-4):167-84
23. Calvelo Pereira R, Camps-Arbestain M, Rodríguez Garrido B, Macías F, Monterroso C. Behaviour of alpha-, beta-, gamma-, and delta-hexachlorocyclohexane in the soil-plant system of a contaminated site. Environ Pollut 2006;144(1):210-17.
24. Turrio-Baldassarri L, Alivernini S, Carasi S, et al. PCB, PCDD and PCDF contamination of food of animal origin as the effect of soil pollution and cause of human exposure in Brescia. Chemosphere 2009;76(2):278-85.
25. Waegeneers N, De Steur H, De Temmerman L, Van Steenwinkel S, Gellynck Y, Viaene J. Transfer of soil contaminants to home-produced eggs and preventive measures to reduce contamination. Sci Total Environ 2009;407(15):4438-46.
26. Decreto legislativo n.152, 03.04.2006. Norme in materia ambientale. Gazzetta ufficiale n. 88; 14.04.2006. Available from: https://www.gazzettaufficiale.it/dettaglio/codici/materiaAmbientale
27. Thornton I, Abrahams P. Soil ingestion – a major pathway of heavy metals into livestock grazing contaminated land. Sci Total Environ 1983;28:287 94.
28. Abrahams PW, Steigmajer J. Soil ingestion by sheep grazing the metal enriched floodplain soils of mid-Wales. Environ Geochem Health 2003;25(1):17 24.
29. Raj GB, Patnaik MC, Babu PS, Kalakumar B, Singh MV, Shylaja J. Heavy metal contaminants in water-soil-plant-animal continuum due to pollution of Musi river around Hyderabad in India. Indian J Anim Sci 2006;76(2):131-33.
30. Mamontova EA, Tarasova EN, Mamontova AA, Kuzmin MI, McLachlan MS, Khomutova MIu. The influence of soil contamination on the concentrations of PCBs in milk in Siberia. Chemosphere 2007;67(9):71-78.
31. Hang X, Wang H, Zhou J, Ma C, Du C, Chen X. Risk assessment of potential toxic element pollution in soils and rice (Oryza sativa) in a typical area of the Yangtze River Delta. Environ Pollut 2009;157(8-9):2542-49.
32. Juan Y, Thomas GO, Sweetman AJ, Jones KC. An input-output balance study for PCBs in humans. Environ Int 2002;28(3):303-14.
33. Scaramozzino P, Battisti S, Desiato R, et al. Application of a risk-based standardized animal biomonitoring approach to contaminated sites. Environ Monit Assess 2019;191(8):526.
34. Zabeo A, Pizzol L, Agostini P, Critto A, Giove S, Marcomini A. Regional risk assessment for contaminated sites part 1: vulnerability assessment by multicriteria decision analysis. Environ Int 2011;37(8):1295-306.
35. Sala M, Caminiti A, Rombolà P, et al. Beta-hexachlorocyclohexane contamination in dairy farms of the Sacco River Valley, Latium, Italy, 2005. A Retrospective cohort study. Epidemiol Prev 2012;36(5) Suppl 4:34-43.
36. Corine Land Cover. Roma: Istituto Superiore per la Protezione e per la Ricerca Ambientale; 2012. Available from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover/corine-land-cover-2012/view
37. ENG_OneGeology-Europe_1:1M_AGE. Servizio Geologico d'Italia. Roma: Istituto Superiore per la Protezione e per la Ricerca Ambientale; 2010. Available from: http://portal.onegeology.org/OnegeologyGlobal/
38. ITA_CARG_Geomorfologia_1:25K. Servizio Geologico d'Italia. Roma: Istituto Superiore per la Protezione e per la Ricerca Ambientale; 2010.
39. Complessi idrogeologici – Dataset. Roma: Istituto Superiore per la Protezione e per la Ricerca Ambientale; 2013. Available from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/complessi-idrogeologici/view
40. DEM 75 – dataset. ISPRA – Roma: Istituto Superiore per la Protezione e per la Ricerca Ambientale; 2013. Available from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/dem75/view
41. Reticolo Idrografico Nazionale – Dataset. ISPRA - Istituto Superiore per la Protezione e per la Ricerca Ambientale (2004). Available from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/reticolo-idrografico/view
42. Carlon C, Pizzol L, Critto A, Marcomini A. A spatial risk assessment methodology to support the remediation of contaminated land. Environ Int 2008;34(3):397-411.
43. Giubilato E, Zabeo A, Critto A, et al. A risk-based methodology for ranking environmental chemical stressors at the regional scale. Environ Int 2014;65:41-53.
44. Agostini P, Pizzol L, CrittoA, D'Alessandro M, Zabeo A, Marcomini A. Regional risk assessment for contaminated sites part 3: spatial decision support system. Environ Int 2012;48:121-32.
45. Sistema Informativo Veterinario. Available from: https://www.vetinfo.it/
46. U.S. Fish and Wildlife Service. Ecological Services Manual - Standards for the Development of Habitat Suitability Index Models. Department of the Interior Washington, Division of Ecological Services, transmittal sheet release number 1-81, 1981. Available from: https://fwslibrary.on.worldcat.org/oclc/823270478
47. Smith PN, Cobb GP, Godard-Codding C, et al. Contaminant exposure in terrestrial vertebrates. Environ Pollut 2007;150(1):41-64.