

Assessment of a Precaution Index for Environmental Evaluation: An Example of Application to the Cow's Milk Production

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Abstract

The paper presents a Precaution Index (P) developed to create an instrument to assess the potential risk related to the presence of pollution sources next to milk production farms. The methodology starts from the inventory and geo-referencing of all pollution sources in an area, with the help of the multi-criteria decision analysis. Results are represented in a map of P, which highlights which areas are most at risk and need monitoring, and which pollutants may be involved. This may help in the early identification of emerging hazards to food safety. P was calculated for the milk production in an Italian region. Results show that 97% of the area is in a condition of minimum precaution that would be needed in controlling the safety of dairy products.

Keywords

Environmental Pollution, Precaution Index, GIS, Multi-Criteria Analysis, Cow's Milk, Emilia-Romagna Region

1. Introduction

In recent times, the amount of Italian territory occupied by urban and industrial settlements, not to talk about roads and highways, has been increasing [1]. As a result, agricultural land adjacent to urban areas, the so-called “peri-urban” agriculture, is exposed increasingly to air pollutants of urban or industrial origins. Agricultural products are grown closer and closer to potential sources of pollutants, such as incinerators, power plants, highways, industrial factories, and so on, with the potential risk for their safety. Some of these pollutants can be considered a threat to crop production and cattle [2] for the significative yield losses and reduction safety of the

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products [3] [4]. Indeed peri-urban agriculture, and the potential risks to which it is subject, is a growing problem not only in Italy, but especially in countries with high population growth, such as in India, as reported by [5] [6].

Data about monitoring of single sources and their effects on environment or human health are widely available both in the scientific literature [7] [8] and at institutional web sites (e.g. European Pollutant and Release and Transfer Register, <http://prtr.ec.europa.eu>), but what is lacking and what we propose with this paper is a method to assess and treat all such information and data. A complete overview of the environmental situation of a territory highlights its critical points, hotspots, which means areas where there is a high concentration of sources of pollution, with negative consequences on environment matrixes (water, air, soil, etc.), agricultural products, livestock and, finally, the human health.

A map of the potential pollution risks provides very useful information both to the national and local authorities, and to farmers and companies. From the producers point of view this aspect is not negligible: on one hand, on the basis of potential risk, food products from large farms may be subjected to differentiated analysis of the quality. Given the high costs of analysis, this may bring to significant money savings and better results. On the other hand, when the products come from areas with certificated low risk of pollution, the company can use this information for advertising purposes. The benefits are numerous also for authorities: known the potential pollution risks, they can easily identify the hotspots and operate with specific monitoring on environmental matrixes. Therefore, the main aim of this work is not to provide a detailed description of the areas from the point of view of the risk of pollution, but orient the user (private companies, authorities, etc.), indicating the most critical situations. The user will evaluate whether or not to investigate further with due monitoring campaigns.

This approach is innovative, as demonstrated by the lack of specific scientific publications. Many publications discuss how agriculture can be a source of diffuse pollution [9]-[12], but it is not well stressed that the environment can cause adverse effects on agricultural and dairy products. This aspect of the food safety is rather neglected also in the European Union's (EU) food legislation. The declared aim of this legislation is the consumers protection against food dangerous for health and/or unfit for consumption, but in the determination of the hazard of food the potential effects of the pollution sources on the safety of the product are not taken into account.

The methodology of the process involves the use of the multicriteria analysis. This analysis, in association with GIS, is widely used as decision-making tool, in the field of environmental quality and land management [13]. Several examples can be cited, in various contexts, such as perimeters for the creation of protected areas [14], touristic areas [15] [16], flooding risk areas [17] [18], landfill site selection [19] and so on.

Aim of this work was to define a procedure for the calculation of an environmental Precaution Index. The index, considering all the main potential pollution sources, general or specific for a particular food (e.g., dairy products), has the aim to summarize in a single value the environmental situation of the territory where it is calculated, and to map it. The final result is the creation of a digital database on pollution sources in a given area, which can be used as a whole or for the part that affects a specific aspect. Thus this protocol of existing data elaboration may be used for other applications in the same field.

The paper is divided in two parts: the first describes the procedure to realize the map, in the second there is an application of the methodology in a region of Northern Italy on milk production, as a case study.

2. Methodology

A procedure to calculate the *Precaution Index* was elaborated, analyzing the environmental pollution sources and their influences on agricultural and livestock's products in the geographical area of interest. The flowchart of **Figure 1** summarizes the logical process to build the index, calculate and map it. The protocol is developed following several steps, as listed below.

2.1. Collection and Managing of Data

Many different types of potential anthropogenic pollution sources are identified and geo-referenced, creating a geo-database managed in a GIS environment (ArcGis 9.1). All the collected data comes from EU and Italian public services. Each category of pollution source is an information layer for the GIS software.

2.2. Elaboration of the Informative Layers through the Multicriteria Analysis

Data elaboration is conducted using the Analytic Hierarchy Process (AHP) method [20] [21], which is a multi-

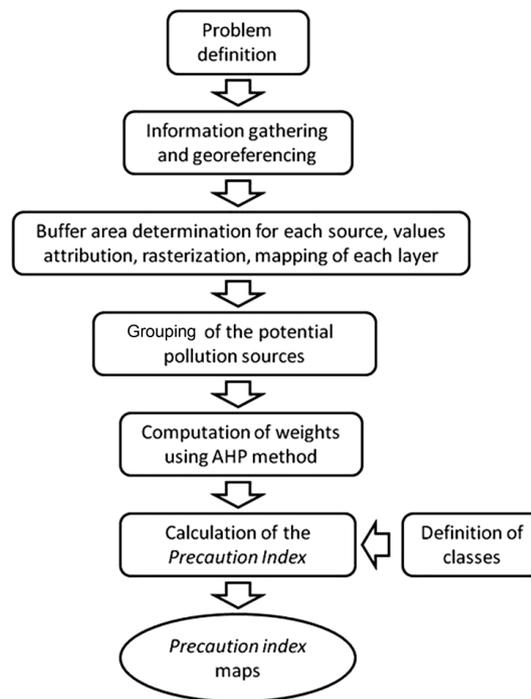


Figure 1. Flowchart for the preparation of a Precaution Index map.

criteria analysis (MCA).

The method allows the treating of different criteria (the pollution sources in this specific case), functional for the same purpose, creating a hierarchy of importance. This is quantified through a system of pairwise comparisons, and gives as a result the weight to assign to each criterion (called also element). The attribution of the values relies on a specific scale of importance later described in details. Pairwise comparisons are based on the best information available, and on the decision maker knowledge and experience. The “AHP” method is performed thanks to a specific module (extension) through the ArcGis 9.1 software [22].

2.3. Realization of the Maps of the Precaution Index

Once the weights are assigned to the various layers of information (criteria), *i.e.* to the types of pollution sources, it is possible to complete the process described previously. The layers of information are added together, thus generating the final information layer that represents the Precaution Index (P):

$$P = \sum x_i \cdot w_i, i = 1, \dots, n$$

where,

x_i = value of this i -th criterion.

w_i = weight of this i -th criterion.

n = number of the considered criteria.

P takes into account both the potential hazard of the source (weight) and its presence (the sum of the layers). The P value mapped at the end of this procedure is encoded on the basis of increasing intensity of precaution. Finally, P values are clustered in intervals of precaution intensity, so to define areas with negligible precaution till areas that needs maximum precaution.

2.4. Evaluation of the Judgment Consistency

The AHP also provides measures to evaluate the consistency of judgments, using an algorithm. Based on the properties of reciprocal matrices, a Consistency Ratio (CR) can be calculated. This process is automatically performed by the ArcGis 9.1 plus AHP software. This passage is necessary for the recognized human limitations in

establishing, simultaneously, many relationships between objects or concepts in a logical manner [21]. Consequently, this method is used to identify what is the degree of inconsistency of the process performed, and accept or refuse it. A CR of the order of 0.10 or less is a reasonable level of consistency [20], while a consistency ratio above 0.10 requires revisions of judgments in the matrix because of some inconsistent treatment in the rating of at least one of the factors involved.

3. Application to a Case Study: The Emilia-Romagna Region

3.1. Studied Area

The *Precaution Index* was calculated for the Emilia-Romagna region (Figure 2), an area of about 22,450 km², located in the North Italy, a highly industrialized territory. From the geographical point of view the area is constituted by the Apennines in the southern side, the Po valley in the central and northern part and borders with the Adriatic sea to the East. The Po valley is characterized by flatlands and superficial watertable, and is very suitable for agriculture, livestock and dairy industry. In fact, this is the production area of the Parmigiano Reggiano cheese, the Parma ham (Parma and Reggio Emilia provinces) and the balsamic vinegar (Modena province), food products famous and popular all over the world.

Other than agricultural activity, Emilia-Romagna is one of the most developed and productive area of the country. A high specialization of the industrial areas is quite common, like in the provinces of Ravenna and Ferrara, where there are many chemicals companies in a few square kilometres (Figure 3).

3.2. Application to Cow's Milk Production and Results

As an example of the described methodology, the Precaution Index was calculated for cow's milk production, strategic product for the Emilia-Romagna economy.

The trace element and mineral concentrations in milk may be influenced by two kind of factors, some related to the secretion from the mammary gland (lactation state, health status, animal species) and others not depending on cow but to external such as season, nutritional status of the cow, and environment [23] [24]. International literature reports that the environment (e.g. soil type, location of the farm, etc.) interferes with the quality of milk [25]-[30], and there are studies that have examined correlations of elements contained in milk and cows' feed [31]-[33].

In the study area, as affirmed by farmers, cows are mostly fed with forage, cultivated from fields adjacent to the stables. It is therefore realistic that, in presence of pollution sources near the cultivated fields, the forage for the cows can be contaminated by harmful substances, which can then reach the milk, affecting its safety.

The map of Precaution Index individuates which areas are most at risk of potential pollution for milk. For this purpose the sources of pollutants that could be deposited on forage, the beginning of the milk chain, have been identified. This choice has been carried out through consultation with technical experts in the sector of milk quality and taking into account recent papers on the relations between pollutants and cow's milk [24] [32]-[36].

In Emilia-Romagna thirteen sources of environmental pollution were identified as potentially harmful for milk safety: incinerators, landfills, nuclear sites, sites of national interest—SIN (contaminated area), cement factories, roads of major communication, urban areas (later merged with the main roads in a single layer), foundries, chemical plants, treatment and coating of metals industries, waste treatment sites, petrochemical plants (including refineries), industrial and commercial areas, as called in CORINE land use map, and natural gas power plants (in the region this is the only type of power plant). Table 1 shows the list of the data sources.

Precaution Index P was calculated as following:

- 1) Georeferencing of pollution sources;
- 2) Creation of areas of influence of pollution sources;
- 3) Assignment of consistent values to the various categories of pollution sources;
- 4) Grouping of pollution sources in macro-categories;
- 5) Pairwise comparison of sources to calculate weight of each macro-category;
- 6) Calculation and mapping of the Precaution Index.

In details the steps are:

- 1) The identified potential pollution sources were geo-referenced, using the digital cartographic base (topographic maps at the scale 1:250,000, Table 2), each category in a single layer. Figure 3 shows an example of



Figure 2. The study area: the Emilia-Romagna region.

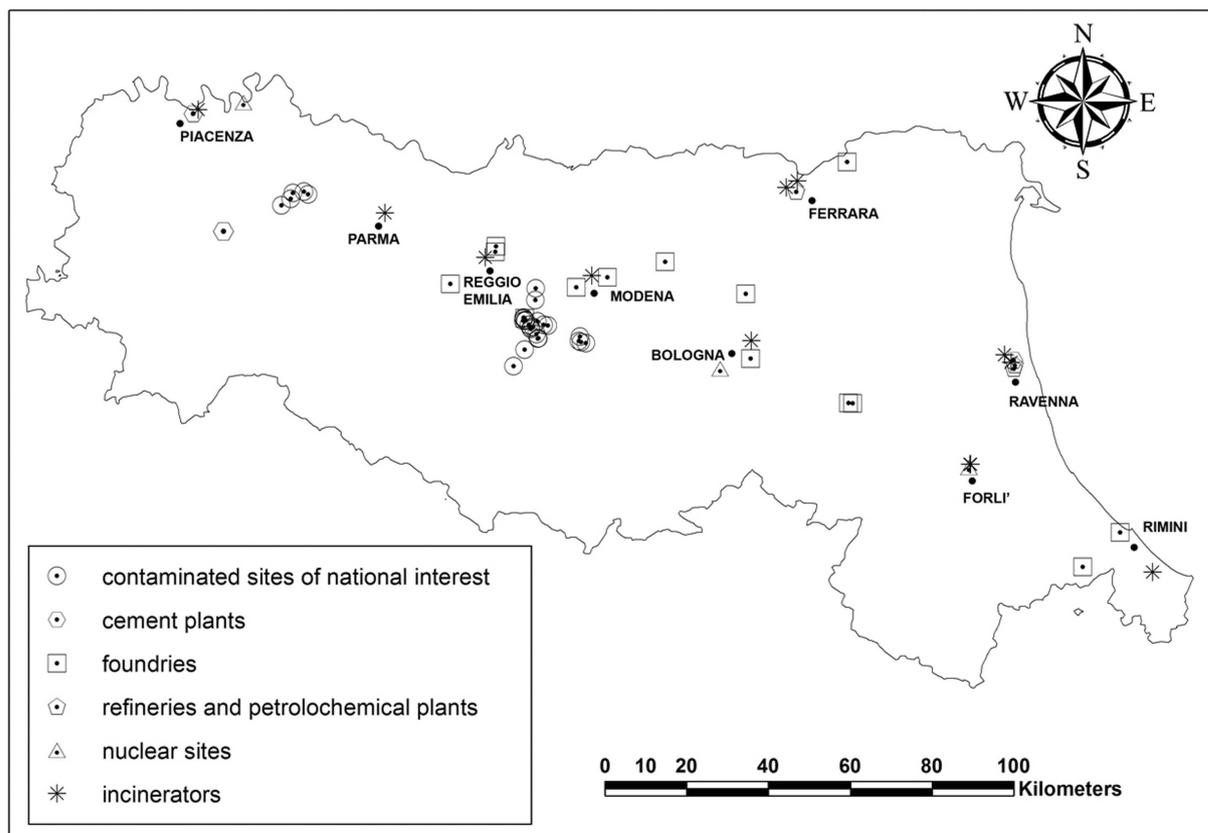


Figure 3. Thematic map representing the distribution of sites of national interest (SIN), cement plants, foundries, incinerators, petrochemical plants and refineries and nuclear sites in Emilia-Romagna region.

Table 1. List of data sources used to gather information and produce thematic maps of the possible sources of pollutants, generated specifically for this study case.

Potential pollution sources	Data sources
Cement plants	AITEC associazione italiana tecnico economica cemento, www.aitecweb.com - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Chemical industries	- European pollutant release transfer register, www.prtr.ec.europa.eu - Ministero dell' Ambiente, inventario nazionale degli impianti a rischio rilevante di incidente, - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Contaminated sites of national interest (SIN)	ISPRA (Istituto Superiore Protezione e Ricerca Ambientale) www.isprambiente.gov
Foundries	- European pollutant release transfer register, www.prtr.ec.europa.eu - Ministero dell' Ambiente, inventario nazionale degli impianti a rischio rilevante di incidente, - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Incinerators, Waste to Energy Plants	- Hera spa, www.gruppohera.it - ARPA Emilia-Romagna, www.arpa.emr.it - European pollutant release transfer register, www.prtr.ec.europa.eu - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Landfill sites	- Arpa Emilia-Romagna direzione tecnica, gestione integrata rifiuti, - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Nuclear sites	- ENEA, Ente per le Nuove tecnologie, l'Energia e l' Ambiente, www.enea.it , revisione critica dell' inventario nazionale dei rifiuti radioattivi ai fini dello smaltimento.
Petrochemical plants (including refineries)	- European pollutant release transfer register, www.prtr.ec.europa.eu - Ministero dell' Ambiente, inventario nazionale degli impianti a rischio rilevante di incidente, - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Roads of major communication	Digitalization of the 1:250,000 road maps
Thermal power plants (both natural gas and oil/coal)	European pollutant release transfer register, www.prtr.ec.europa.eu - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Treatment and coating of metals industries	- European pollutant release transfer register, www.prtr.ec.europa.eu - Ministero dell' Ambiente, inventario nazionale degli impianti a rischio rilevante di incidente - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it
Urban, commercial craft areas	CORINE land use map
Waste treatment plants	- European pollutant release transfer register, www.prtr.ec.europa.eu - Hera spa, www.gruppohera.it - AIA Autorizzazione <i>integrata ambientale</i> , www.aia.minambiente.it

Table 2. Cartographic themes acquired.

Acquired Cartography	Format	Reference system	Data sources
Topographic Maps 1:250,000	Raster: TIF	Gauss-Boaga	Regional mapping service
Administrative boundaries	Vectorial: Shapefile.shp	UTM ED 50	ISTAT (Italian National Institute of Statistics) http://www3.istat.it/ambiente/cartografia/
CORINE land use map and derived thematic areas, mainly industrial/commercial areas	Vectorial: Shapefile.shp	UTM ED 50	http://www.centrointerregionale-gis.it/script/corinedownload.asp

thematic map, reporting the distribution of some potential pollution source (SIN, cement plants, foundries, incinerators, petrochemical plants and refineries and nuclear sites).

2) For each single source-point georeferenced in each category, an area of potential influence, called buffer area, is created. The radius of influence of each type of pollutant source is evaluated using information found in

the scientific literature. The buffer area and the main pollutants of each source were listed in **Table 3**. Lacking direct measurements of impact of each specific source in the studied area, data come mainly from literature [7] [37]-[54]. In case there was literature discrepancy in the influence radius of a particular potential pollutant source, a caution criterion was chosen selecting the largest among those cited. The area of influence was approximated to a circle, (with the exception of roads where it was linear), not being able to go into characteristic details of every single location (winds, geomorphology, etc.).

3) For each buffer area consistent values (x) are assigned:

$x = 1$ within the buffer (1 = presence of pollutant source),

$x = 0$ outside the buffer (0 = absence of pollutant source).

In case of overlapping of buffers within the same category (e.g., the buffers of two chemical industries close one to the other) a common value is attributed to the union of the two buffer areas, with a value averaged using the area of the union (similarly to a density of population). Each buffer is then converted from vector to raster format (matrix of cells with 250 m size) for application in the AHP module of ArcGis. During this procedure the x values, attributed to the buffer in the previous step, are transformed to the closest integer.

4) After all the single sources were mapped, they were grouped by the relevance on the potential risks in milk safety. Considering that for the pair comparison Saaty [20] suggested that the number of elements compared must be small than nine, sources were clustered into four macro-categories (called criteria for the AHP analysis). **Table 4** summarizes the grouping. This part of the process was carried out with the help of staff with specific knowledge in dairy industry and milk safety. Based on these indications, the following pollutants were taken into account: dioxins (PCDD and PCDF), PCBs, dioxin-like PCBs, PAHs, heavy metals, pesticides, radionuclides, and organic solvents. Sources considered as similar potential impact on milk have the same ranking. A caution attitude was chosen at this decision level.

The grouping in macro-categories is the following:

a) the first macro-category (C1) comprised the sites of national interest—SIN, recognized as actually polluted areas by ministerial decrees. They were considered at the top of the ranking, compared to other sources that are “only” potentially polluting;

b) the second macro-category (C2) comprised the nuclear sites, because of the potential hazard of radionuclides, and cement plants, foundries, incinerators, petrochemical plants and refineries, grouped for the similarity of their pollutants (dioxin, PCBs, PAHs and heavy metals, radionuclides) and their typical large size;

c) the third macro-category (C3) included landfills, treatment and coating of metals industries and waste treatment sites. From the milk safety point of view, they emit heavy metals and organic solvents, that may be released in soil and superficial water-bodies. This group includes chemicals industries too, that means a wide range of products (e.g. fertilizers, detergents, paints, etc.), with different environmental impact (site-specific) and facilities production capacity. Not being able to going into too much detail and given the variety of emissions, chemical industries have been attributed to C3, thus mediating their potential dangers;

d) the fourth macro-category (C4) included thermal power plants (natural gas), urban and commercial-industrial areas and roads. All these sources emit heavy metals at low concentration (traces) than the previous sources into the atmosphere.

5) Pairwise comparison of the sources and calculation of their weights, or multiplying factors, account for the dangerousness of potential pollution sources. The weights assignment is done through the AHP module, which, as mentioned above, requires the compilation of a table of pairwise comparisons, where each category is compared with all the others. For this phase the “fundamental scale of Saaty” [21] (**Table 5**) is used, which help to indicate how many times more important or dominant one element is over another. This scale consists of nine values, the numerousness was selected because psychologists suggest that nine is the maximum quantity of objects that an individual can simultaneously compare and consistently rank [20]. The whole process is summarized in **Figure 4**.

As seen above, in parallel with the calculation of the weights, the AHP method provides the calculation of data necessary for checking the internal consistency of the matrix, *i.e.* of its reliability, by means of the consistency ratio CR. The statistical results showed that the hierarchical tree was consistent ($CR < 0.10$), guaranteeing the use of the values generated for the P calculation.

6) When calculated, P assumes continuous values, ranging from zero to a maximum. These values identify the areas with the highest potential pollution, corresponding to the highest precaution needs. All P values were then reclassified on the basis of increasing intensity of precaution in a scale from 0 to 4, with 0 = negligible precau-

Table 3. Potential sources of pollution, their estimated buffer areas (fall-out or ground infiltration), and their main pollutants for milk production.

Pollution sources	Radius (km)	Main pollutant
Sites of national interest (SIN)	2	Site-specific pollutant, typically industrial waste
Cement plants	5	
Foundries	5	
Incinerators, waste-to-energy plants	5	Dioxin, PCBs, PAHs, heavy metals, radionuclides
Petrochemical plants including refineries	5	
Nuclear sites	2	
Treatment and coating of metals industries	3	
Landfills sites	2	Heavy metal, organic solvents
Waste treatment sites	3	
Chemical industries	3	
Thermal power plants (natural gas)	5	
Roads of major communication and urban areas	0.25	Heavy metal and other non-individually specifiable
Commercial-industrial areas	0.25	

Table 4. Grouping of pollution sources in to macro-categories (criteria), taking into account the type of emissions and the impact on milk, and weights calculated through the Analytic Hierarchy Process.

Pollution sources	Criteria	Weights (wi)
Sites of national interest (SIN)	C1	0.5831
Cement plants		
Foundries		
Incinerators, waste-to-energy plants	C2	0.2895
Petrochemical plants (including refineries)		
Nuclear sites		
Treatment and coating of metals industries		
Landfills sites		
Waste treatment sites	C3	0.0849
Chemical industries		
Thermal power plants (natural gas)		
Roads of major communication and urban areas	C4	0.0425
Commercial-industrial areas		

Table 5. Relative scale used in the construction of pair-wise comparison matrices (modified from Saaty, 2008). For populating the pair-wise comparison matrix, numbers are used to represent the relative importance of one criterion over another and derive the weights accorded to the different categories of sources.

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

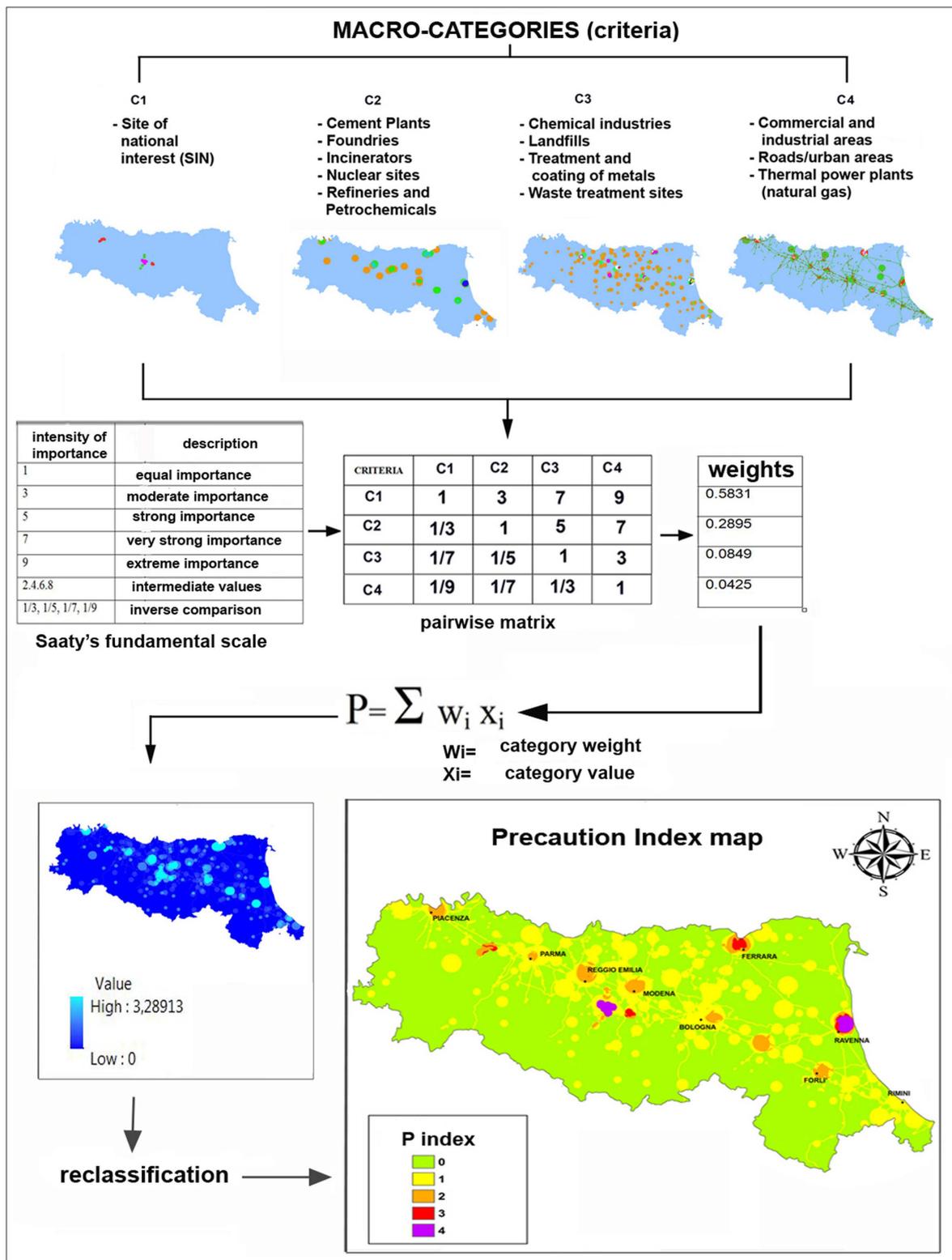


Figure 4. Summary of the whole process: first the maps for each criteria, comparison by means of the pairwise process of all the potential criteria and the resulting Precaution Index map, obtained after the calculation of weights and final processing. Please note that 0 = negligible precaution; 1 = minimum precaution; 2 = moderate precaution; 3 = high precaution and 4 = maximum precaution.

tion; 1 = minimum precaution; 2 = moderate precaution; 3 = high precaution and 4 = maximum precaution. Following that cluster precaution interval, in Emilia-Romagna region (**Figure 4**) the $P = 0$ in most part of the region, precisely in the 75% of the total area, indicating that in most of the territory there is no potential risk for milk safety, while $P = 1$ in the 22%, $P = 2$ in the 2%, $P = 3$ in the 0.5% and $P = 4$ in the last 0.5%. Most of the area with negligible precaution corresponds to the mountain (Apennines). The areas with maximum precaution ($P = 4$) are next to Modena and Ravenna towns: in fact as visible from **Figure 3**, these are areas with important pollutant sources. Specifically, the first is related to the SIN of Sassuolo (MO), while the second represents an area with high concentration of pollutant sources, in particular petrochemical and refinery plants, cement plant and clustered chemicals plants.

4. Discussion and Conclusions

Until recently the effect of the surrounding environment on food products, such as milk, has not been adequately taken into account. Some studies deal with the contamination on the milk by specific pollutants from specific sources [24] [33] [36], but none addresses the problem of environmental pollution as a whole, although it is an important topic, taking into account also the expansion of peri-urban agriculture.

Considering simultaneously all the involved variables is extremely complex: P computation derives from a simplification of the reality, which, however, have the advantage to make the methodology generalizable. One of these simplifications is the description of the area from a static point of view. Of course, the study could be refined with further research, such as introducing the study of prevailing winds and orography; and it would be useful to define in more details the buffer areas; and this may be done in the future. Overall, it is impossible to know the pollution sources in more detail, as this would require lengthy and costly monitoring campaigns for each one, but this would be possible in case of application in smaller areas and to respond to very precise queries. Hence, in general the map of Precaution Index aims to highlight which areas are most at risk (hotspots) and to direct the investigation: the knowledge of potential environmental risks, and of the pollutants that may be involved, is very useful to drive national and regional authorities in deciding if a monitoring is necessary, and which substances may be involved. This may help in the early identification of emerging hazards to food safety [54]-[56], with the aim of preventing them from becoming real risks and causing the reduction of food quality.

In addition, this procedure can be very useful for farmers and food companies: through this map they may know if their product could be potentially contaminated, and eventually address more efficiently the processes of quality control on their product. As an example, the showed case study of milk in Emilia-Romagna region highlights the presence of some hotspots, where the presence of pollution sources (for type or quantity) makes the surroundings potentially at risk of contamination. Therefore, this result suggests that these areas should be subject to intensified inspection and monitoring, and that milk coming from stables located within or near a hotspot should be liable to specific control to verify if contamination occurred on feed and therefore on milk.

The main aspect of the described process is its versatility: it can be applied in various fields and for very different purposes. It is possible to adapt the system, paying particular attention to two points, the choice of the potential pollution sources and the relative importance among the sources. In fact, the reciprocal importance of the selected sources (and sometimes the sources themselves) can vary for different applications, such as food safety in general, organic production, milk quality, DOP, DOC and other special titles that characterize Italian food products, and so on. These decisions must be made by specific experts and consulting the international and local literature.

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