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A municipality-based pressure index developed in the Campania Region as a geo-stratification tool for human and environmental monitoring studies

Antonio Pizzolante 1,*, Federico Nicodemo 1, Andrea Pierri 1, Amedeo Ferro 1, Biancamaria Pierri 1, Carlo Buonerba 1, Eleonora Beccaloni 2, Stefano Albanese 3, Bruno Basso 4 and Pellegrino Cerino 1

1 Centro di Referenza Nazionale per l'Analisi e Studio di Correlazione tra Ambiente, Animale e Uomo, Istituto Zooprofilattico Sperimentale del Mezzogiorno, Portici 80055, Italy.

2 Dipartimento di Ambiente e Connessa Prevenzione Primaria, Istituto Superiore di Sanità, Rome, Italy. eleonora.beccaloni@iss.it

3 Department of Earth Sciences, Environment and Resources, University of Naples Federico II, Naples, 80125, Italy; stefano.albanese@unina.it

4 Department of Earth and Environmental Sciences, Michigan State University, East Lansing, Michigan.; basso@msu.edu

*** Correspondence to: antonio.pizzolante@izsmportici.it**

Centro di Referenza Nazionale per l'Analisi e Studio di Correlazione tra Ambiente, Animale e Uomo, Istituto Zooprofilattico Sperimentale del Mezzogiorno, Portici 80055, Italy.

Abstract

In response to the complex social, environmental and economic situation caused by the "Terra dei Fuochi" phenomenon, the IZSM collaborated closely with the Terra dei Fuochi working group, carrying out additional monitoring surveys both on food (QR Code Campania project[30]), and on the environment (Campania Trasparente project[31]). This model was developed in the context of the experience accumulated in the field of environmental and food monitoring, and represents an innovative tool aimed at increasing knowledge of the environmental context of the Campania Region through an objective, integrated and organic synthesis of complex environmental phe-nomena and territorial dynamics. The model proposed here is useful for the global and synthetic assessment of environmental pressure on a municipal basis. As shown, it can also be applied to aggregations of municipalities. Furthermore, it can be used in the context of institutional actions for the planning and monitoring of improvements on a local or regional scale. Finally, the pro-posed municipality-based environmental pressure index represents the basis for geo-stratification of the sample in the context of population biomonitoring studies on a regional scale, as in the described biomonitoring study design applicable to the Campania Region.

Keywords: Terra dei Fuochi, Land of Fires, biomonitoring, environmental monitoring

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1. Introduction

Since the 1980s, the organized crime has been responsible for the continued illegal trafficking of industrial waste and toxic materials in the so-called “Terra dei Fuochi” (Land of Fire), a territory mostly located in the provinces of Naples and Caserta of the Campania region in Southern Italy. The term "Terra dei Fuochi" was introduced by the Italian environmental association Legambiente and refers to the fact that waste was abandoned and illicitly disposed through uncontrolled combustion [1].

In the early 1990s, the Campania region suffered from a prolonged "waste crisis", which lasted roughly 15 years, caused by the inability of the Institutions to provide for the proper mangament of urban solid waste. Waste that accumulated in municipal areas was often set on fire by citizens exasperated by the nauseating smell [2], which generated fears of being exposed to dioxins among indewelling citizens[3].

Public concern about the threats posed to human health by environmental contamination grew in 2004, when Mazza and Senior [4] used the expression “Triangle of Death” to indicate a geographical area comprised within the municipalities of Acerra, Nola and Marigliano of the province of Naples. The authors concluded that the area was characterised by an unexpected high incidence of some forms of malignant neoplasms, which they assumed was the result of exposure to toxic waste. While the report was extensively covered by the media, its methodological limits highlighted by other researchers [5] were largely ignored [3].

While a growing body of scientific evidence suggested that citizens indwelling in the provinces of Naples and Caserta could be affected by an increased risk of death, cancer-related mortality, cancer incidence and congenital abnormalities [6] [7] [8], the “bad reputation” of the Land of Fires severely harmed the local economy over the years and especially in 2013 and 2014, among widespread fears of consumers that the food produced in the Campania region was contaminated. As an example, in 2014 revenues of one typical product of the Campania Region, such as the water-buffalo mozzarella cheese, dropped by approximately 57 million Euros [9]. In order to tackle the social, economic and environmental emergency situation, a "Terra dei Fuochi Working Group" was established by the law 6 / 2014 [10]. In an area of 92 hectares assessed in the Region, 21 were identified as unsuitable for agri-food production by the Working Group, although none of the agricultural products analysed were found to be non-compliant with regulatory limits for toxic subsatnces [11]. The activities carried out by the Working Group sure had merits, but also suffered from several weaknesses, such as: 1) soil was the only environmental matrix analyzed (no air or water samples were assessed); 2) not all municipalities were included in the environmental monitoring plan; and 3) no human biomonitoring survey was conducted.

Although human biomonitoring studies play a key role in assessing the threats posed by environmental pollution, only few biomonitoring studies have been conducted in the Campania Region [12][13]. In a territory as vast and densely populated as that of the Campania region, which presents a surface of 13,590 km² and has over 5.5 million inhabitants residing in 550 municipalities divided in five provinces[14][15], a systematic biomonitoring survey can be effectively carried out at a regional level if the recrutiment plan is wisely designed.

In this original work, we constructed a mathematical model that computes a synthetic index of enviromental pressure at a municipality level (Municipality Environmental Pressure Index – MEPI). We computed the MEPI for all municipalities of the Campania Region and we used it as a geo-stratification tool for the recruitment plan of a human biomonitoring survey at a regional level[16].

2. Materials and methods

2.1 Development of the environmental pressure index applicable on a municipal basis

The Municipal Environmental Pressure Index (MEPI) is defined based on a pairwise comparison process between variables (Table 1) to which scores of relative significance are assigned through a multi-criteria approach based on the Analytic Hierarchy Process (AHP) method [14,15]. With this approach it was possible to move from a qualitative to a quantitative assessment of environmental sensitivity and to locally (at the municipal scale) establish the value of each variable in terms of its contribution to MEPI, according to the semantic classification proposed by Saaty[16] (Table 2).

Figure 1 shows the block diagram of the algorithm for calculating MEPI. In the process, A_i is the single source of contamination considered and a_{ij} is the numerical value resulting from the comparison between criteria i and j, which can vary from 1 to 9, where each value of the scale is assigned according to criterias proposed in table 2. In addition, intermediate values (e.g. 2, 4, 6, 8), not present in Table 2, were considered. The result of all the comparisons is reported in matrix A (Table 3). The latter was, subsequently, used to create the vector of the percentage weights (priority vector) of each single source taken into consideration (Table 1).

Matrix A is an 8 x 8 square matrix in which the values resulting from pairwise comparisons are reported above the main diagonal, while the reciprocals of these values appear in the lower part. The a_{ij} values of matrix A have the following properties:

1) *if $a_{ij} = a$, then $a_{ji} = 1/a$, with $a > 0$;*

2) *if the variable A_i is judged to be of equal intensity relative to A_j, then $a_{ij} = a_{ji} = 1$.*

The last row in matrix A shows the sum of the individual elements that make up each column.

Matrix A was normalised, dividing each element a_{ij} by the sum relative to the j-th column. Subsequently, the average value of each i-th row of the matrix was calculated, defining the "*priority vector*" as shown in Table 4.

For each source of contamination A_i, the model gave its percentage weight and in table 5 sources are sorted in descending order.

To evaluate whether matrix A was consistent, or that the requirements of consistency and significance in the judgments expressed by the "preference indices" were met, all the cells belonging to the i-th row of the non-normalised matrix were added together and multiplied vectorially by the sum of the *priority vector* and divided by the weight of the criterion relating to that row. In this way it was possible to quantify the consistency of each priority as shown in Table 6.

The consistency index (CI) of the entire matrix A was calculated using the following relation, where *λ* represents the maximum eigenvalue of matrix A and *n* the dimension of the matrix itself (Eq. 1):

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad \textbf{(Eq. 1)}$$

In equation 1, if the value of CI is equal to 0 then the matrix is consistent; if it deviates from *n*, then the matrix is not perfectly consistent, although the methodology used accepts a low degree of inconsistency because this does not affect the validity of the result obtained. As a first approximation, the maximum eigenvalue of matrix A can be evaluated by referring to the average of the consistencies relating to the individual variables; the result is a maximum eigenvalue equal to 8.70 which is close to the dimension n of matrix A.

Once the CI was known, it was possible to define the *Random Consistency Index* (RCI); for matrix A (with a n value equal to 8) the RCI value is equal to 1.41 (Table 7).

At this point it was possible to evaluate the *Consistency Ratio* (CR) of matrix A, defined by the following equation (Eq. 2):

$$CR = \frac{CI}{RCI} \qquad \textbf{Eq. 2}$$

For matrix A to be consistent, the value of CR must be less than 0.1. In the specific case, Eq. 2 gave a result of 0.07 stating the consistency of the matrix.

Once the "$\boldsymbol{P_i}$" weights to be assigned to each pressure variable were determined, the MEPI values were determined. Specifically, for each municipality, MEPI was calculated by a linear combination of the set of pressure variables considered, multiplied, in turn, by specific amplification coefficients as function of the number, type, extent, hazard, environmental status, and impact of the variable itself. These coefficients were introduced in such a way as to be able to define the model on the environmental and territorial characteristics of each municipality in Campania region. MEPI relating to the i-th municipality of Campania region is expressed by the following relationship:

$$Ipc_i = I_{PC,(siti\ contaminati)} + I_{PC,(aree\ di\ int.)} + I_{P,(uso\ suolo)} + I_{P,(corpo\ idrico)} + I_{P,(potential\ hazard)} + I_{PC(sversamenti)} + I_{PC,(imp.\ gestione\ rif.)} + I_{P,(part.\ TdF)}$$

In order to make a comparison between the environmental pressure indices determined, the variable was normalised in such a way as to have values between 0 and 100. The normalisation operation was carried out through application of the following relationship:

$$IP_i(n) = \frac{IP_i - P_{min}}{P_{max} - P_{min}} \times 100$$

2.2 Definition of model variables

2.2.1 "Contaminated sites" variable

The Contaminated Sites variable includes contaminated landfills as defined by Legislative Decree 152/2006 and class 3, 4 and 5 plots of land indicated in Decree No. 56 of 09/03/2015 and No. 191 of 19/08/2015 relating to Terra dei Fuochi. Following investigations by the Campania Regional Environmental Protection Agency (ARPAC), the plots of land defined by decree were further classified as reported in Table 8.

In determining the environmental pressure index, only types B, NC and D of class 3, 4 and 5 plots of land were considered. Table 9 shows the p' scores assigned: the criterion adopted in this case was to attribute a significant significance, in terms of hazard, to contaminated landfills.

A further p'' score was attributed according to the specific spatial extension of these sites, assuming that the degree of pressure is directly proportional to the extent of the site as reported in Table 10.

The pressure index relating to the variable in question is expressed by the following mathematical relationship, where the sum is extended to all the contaminated sites present in a municipality:

$$I_{PC,(siti\ contaminati)} = \sum_{i=1}^{n} p'_i \cdot p''_i$$

2.2.2 "Areas of particular interest" variable

This variable includes sites of national (SNI) and regional (SRI) interest present in the area, illegal landfills awaiting investigation, as well as potentially contaminated sites investigated. For each area of interest considered, a preliminary score p' is assigned on the basis of the different degree of presumed pressure. In the specific case, sites of national interest are assigned the highest score, followed by illegal landfills, areas awaiting characterisation and, finally, potentially contaminated sites. The potential risk index relating to the "Areas of particular interest" variable was evaluated by assigning the score to the single element of the variable as shown in Table 11. From an analytical point of view, the environmental pressure index for the considered variable is expressed by the following relationship*:*

$$I_{PC,(aree\ part.inter.)} = \sum_{i=1}^{n} p_i'$$

2.2.3 "Zoning" variable

The ***Zoning*** variable considers the different impacts, both direct and indirect, exerted by different land uses (urban, agricultural and commercial/industrial areas). To define the environmental pressure index relating to the *"zoning"* variable, scores (p') were assigned to the different land use destinations present in the 2012 edition of the "Corine Land Cover" map, based on qualitative assessments of pressures exerted in each of them. Based on the available data, the criterion followed consisted in attributing a greater weight, in terms of environmental hazard, to residential areas, followed by industrial areas and then agricultural and wooded areas (Table 12).

To represent the relative extension of each intended use over the entire municipal area, a specific p" indicator was introduced, divided into the following parameters:

1) Residential area/Municipal area
2) Industrial area/Municipal area
3) Wooded area/Municipal area

4) Agricultural area/Municipal area

Tables 13 and 14 show the bands considered and the relative scores assigned.

The environmental pressure index associated with the zoning variable is expressed analytically by the following expression:

$$I_{PC,(zoning)} = \sum_{i=1}^{n} p_i' \cdot p_i''$$

where the sum is extended to the n land uses present in a municipality.

2.2.4 "Illegal waste spills and fires" variable

The"Illegal waste spills and fires" variable indicates the presence of abandoned waste and uncontrolled fires. To determine the pressure index relating to this variable, the number of waste spills detected in the municipalities by the monitoring activity carried out by SMACampania was taken into consideration. The environmental pressure index relating to the "illegal waste spills and fires" variable coincides with the number n of spills detected on a municipal basis. It can be mathematically formalised by the following formula:

$$I_{PC,(svers.e\ roghi)} = \sum_{i=1}^{n} i$$

2.2.5 "Waste management plants" variable

This variable includes incineration, storage, composting, selection, purification, recovery, scrapping plants and controlled landfills. A p' score is assigned to the specific type of plant. Table 15 shows the types of plants considered and the relative scores assigned.

In assigning the weights, it was decided to attribute the same significance to the types of plants which, on the basis of the waste treated, present the same level of environmental hazard. The environmental pressure index relating to the variable was mathematically formalised by the following relationship:

$$I_{PC,(imp.gestione\ rif.)} = \sum_{i=1}^{n} p'_i$$

2.2.6 "Terra dei Fuochi plots of land decree" variable

As regards the Plots of land of the TdF Decree, defined in the Directive of 23/12/2013, all the plots for which a site-specific investigation has not yet been carried out (2.a and 2.b) and those of class 5, 4 and 3 which, following investigations, are not contaminated (Table 16) were taken into consideration.

The environmental pressure index relating to the variable "TdF decree plots" was assessed by assigning the score p' to the single element of the variable according to the formula presented below.

$$I_{P,(part.TdF)} = \sum_{i=1}^{n} p'_i$$

2.2.7 "Potential hazard – soil analysis" variable

The potential hazard variable was created starting from analysis of the spatial distribution of the concentration values of contaminants using spatial statistics models, which made it possible to reconstruct continuous concentration areas on the entire regional territory and to estimate the probability of exceeding the legal limits or reference values in areas not covered by sampling[17–19]. The *Potential Hazard* map is very useful insofar as, in addition to enabling the identification of areas potentially at risk, it serves to define the *background/baseline* values of the various geochemical elements investigated, according to the various types present in the substrate. On the basis of this cartography, the following indicator was taken into consideration for each municipality:

- *Potential Hazard* area/Municipal area.

The values of this ratio were divided into five classes defined on the basis of a classification of a *natural breaks* [20] type. A p' score was applied to each of the intervals thus defined in Table 17.

The environmental pressure index relating to this variable is determined through the relationship shown below, where a represents the number of analytes the concentrations of which have exceeded regulatory limits and the sum present is extended to the n areas potentially at risk, with reference to the municipal territory:

$$I_{P(potential\ hazard)} = a\sum_{i=1}^{n} p_i^{'}$$

2.2.8 "Water bodies status – water analysis" variable

This variable takes into account the quality status of groundwater bodies. To fully define the environmental pressure index relating to this variable, a series of attributes were introduced that indicate the qualitative status (Chemical Status of Groundwater - CSG) and a series of indicators that take into account the percentage municipal coverage of the underground aquifer. In fact, the CSG is an index that summarises the qualitative state of groundwater based on the comparison of the average annual concentrations of the chemical parameters analysed with the relative quality standards and threshold values defined at national level by Legislative Decree 30/09[21], also taking into account natural background values. Based on this, a p' score was assigned to the qualitative status of the groundwater body. The highest score was assigned to the "poor" status, insofar as this condition presupposes exceeding of the reference values (standard and threshold), even for a single parameter. The assigned score took into consideration the anthropogenic or natural origin of the aforementioned exceedances. Table 18 shows the scores assigned.

Subsequently, for each municipality, the following indicator was introduced to take into account the extension of the groundwater body in relation to the municipal area:

- Groundwater body area/Municipal area

The values of these indicators were divided into a series of intervals (bands), established according to a classification of the "*natural breaks*"type. A second p'' score was then assigned to each interval thus defined. Tables 13 and 14 show the bands considered and the relative scores assigned. The environmental pressure index related to the variable was evaluated through the following relationship:

$$I_{P(corpo\ idrico)} = \sum_{i=1}^{n} p_i^{'} \cdot p_i^{''}$$

where the sum is extended to all groundwater bodies within a municipality.

2.3 Design of a regional-scale human biomonitoring study

Impact areas are made up of an aggregation of municipalities, chosen in an arbitrary manner according to criteria of spatial contiguity and technical-logistical needs. The Impact Area Pressure Index is calculated as the average of the municipalities that make it up, weighted with respect to the resident municipal population (ISTAT, 15th population census, 2011[22]). Relative to the Impact Area Pressure Index, Impact Areas are classified as high, medium and low impact for values > = 50, less than 50 but greater than 25, and less than 25, respectively. Within the Areas, clusters are identified consisting of sub-aggregations of Municipalities grouped according [20] to the MPI following the Jenks Natural Breaks Classification. Municipalities that fall into particular geographical contexts in which there is a limited source of pollution can nevertheless be aggregated into specific clusters. The Impact Area Pressure Index is calculated as the average of the municipalities that make it up, weighted with respect to the resident municipal population (ISTAT, 15th population census, 2011)[22].

3. Results

3.1 Calculation of the environmental pressure index on a municipal basis

Following the application of multicriteria analysis, the contaminated sites variable assumes greater significance than the others considered as health risk has been ascertained (exceeding Risk Threshold Concentrations - RTC) for the potentially exposed population. With a difference of about 9 percentage points, it follows the Areas of particular interest variable, which includes all those territorial circumstances in which there has been an exceeding of contamination threshold concentrations (CTC) in one or more environmental compartments investigated through sampling and analytical tests, thus denoting phenomena of potential contamination in progress. This is followed on a par by the Zoning variable, which directly considers the different land uses (residential areas, industrial areas, agricultural areas, etc.), with particular reference to the set of activities present and potential pressures exercised on environmental sectors. Status of water bodies and Potential Hazard come next, with a difference of about 8 percentage points; the two variables indicate the degree of pressure determined by the quality status of the underground/surface water bodies that pass through and by the presence of soil contamination phenomena, also attributable to natural factors. The Illegal waste spills and fires variable was considered more important than the last two variables - Waste management plants and Plots of land of the TdF Decree - since the former considers mainly authorised plants with controlled management, while the latter considers the TdF Plots for which a site-specific survey has not yet been carried out (classes 2.a and 2.b) and for those which, following the investigations, are not polluted. Figure 2 shows a bar graph with the attribution of percentage scores for each single variable entered.

For each municipality in the Campania Region, the model gave an environmental pressure index (MPI) value ranging from 0 to 100 (Table 20) (figure 3).

Upon analysing the results, it is observed that the municipalities with the highest PI are concentrated mainly in the Province of Naples and Caserta, areas known for the massive presence of specific and/or widespread sources of pressure and, at the same time, subject to frequent monitoring and environmental investigation which allow a more meaningful analysis to be developed. In particular, high values of the index are found in all the municipalities that are part of Litorale Agro-Domitio, the metropolitan area of the Municipality of Naples, the Vesuvian hinterland and Ager Nolanus. Other sensitive areas coincide with Agro-Nocerino Sarnese, Valle del Sabato and some municipalities of Piana del Sele, although to a lesser extent.

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3.2 Design of a human biomonitoring study in the Campania Region

For the design of a human biomonitoring study to be conducted at a regional level, a total of 174 Municipalities of the Campania Region, representing 80% of the regional population, were chosen on the basis of geographical contiguity and logistical constraints. First, the Municipalities were grouped into 3 areas, as described in Tables 21 and 22, based on geographical contiguity and classified at high, medium and low environmental pressure based on the average MEPI weighted per municipality residents. We then grouped municipalities within the same area into "clusters", which represents the actual tool for geo-stratification to be used for the biomonitoring study, following the "Natural Breaks" approach[20], wit hthe expetion of municipalities of the Sabato and Irno Valleys, which were included into 3 separate clusters (Valle dell'Irno 1, Valle del Sabato 1 and Valle dell'Irno 2), because of peculiar local sources of contamination, the effect of which our model was not designed to capture [23] [24].

4. Discussion

Existing literature provides several examples of synthetic environmental pressure/risk indexes, sometimes for purposes that differ substantially from those pursued by our research group. Vacca et al. [25] applied a model of contamination risk analysis in the industrial district of Ottana (Nuoro, Italy), an area characterised by the massive presence of chemical and textile industries, which have strongly modified the entire territorial and social structure since the early 1970s. In this study, carried out within a programme agreement between the Provincial Administration of Nuoro and the Department of Botany at the University of Sassari, the authors evaluated micro-discharges in the floodplain area of the Tirso river within the industrial district of Ottana, with the aid of GIS applications, in order to correlate the shapes, dimensions, typology and toxicity of the materials contained therein) with the characteristics and quality of the earth. A total of 28 sites were identified and subjected to a relative risk assessment; these sites were contaminated by materials of various origins and nature (drums containing support materials for chemical production, furnishings, tanning and meat processing residues, abandoned automobiles, animal carcasses, plastics and tyres, and non-inert and often highly fragmented asbestos). The Relative Risk Analysis Model applied by Vacca et al. is based on a score and weight system which takes into account 24 analysis factors, grouped into 3 main categories: characteristics of the waste, migration routes of contaminants, and typology of receptors. Each factor is measured by an index-score with a range of variability from 0 to 10 proportional to the incidence of the factor itself on the risk analysis. The score obtained is then multiplied by a weight (Pesoi), which varies from 1 to 3 depending on the significance of the factor's contribution to overall risk conditions. In accordance with the risk indices obtained, three priority areas were identified (low, medium and high), in a manner similar to the methodology we used.

In the study by Chrysochoou et al. [26], the authors present a risk assessment model applied to a large number of brownfield sites in large areas (municipalities, counties, states or other types of districts), which is useful for planning reclamation and redevelopment actions. The model uses socioeconomic aspects and sustainable growth and the environment for each of which the authors propose a synthetic index calculated on the basis of territorial variables. Socioeconomic variables include population density, property values and unemployment rates, which collectively indicate how brownfield regeneration can contribute to economic growth. The environmental index incorporates variables that represent the potential source of contamination, routes of exposure, and the presence of targets. The application of this model to the town of New Haven, Connecticut, led the authors to identify fourareas for intervention out of the 47 analysed.

In the study by Martuzzi et al. [27], which evaluated the impact on public health of the waste emergency in the provinces of Naples and Caserta, the authors developed a municipal index of environmental pressure from waste disposal, which was used in the analysis of geographical correlation with epidemiological data. Starting with a census of waste treatment plants and their characteristics in the study area, the authors assigned a hazard to each site and to the impact areawithin a 1km radius of the identified site. The impact areas and the corresponding hazard levels were re-aggregated at the municipal level to derive a municipal hazard index as well as a municipal index of pressure from waste disposal, which considers the surface area and the population in each impact area. In the geographic correlation study, a discretised index was used in five increasing risk classes; disaggregation of distribution of the risk index was carried out following two different methodologies, including "adjusted" quintiles and that of Natural Breaks, as was ours. Natural Breakswas used in Martuzzi's work[27] to divide the environmental pressure index into five homogeneous classes: the groups of municipalities obtained are not of the same number, but remain internally homogeneous and non-homogeneous. The group with the greatest environmental pressure from waste disposal covers eight municipalities including Acerra, Aversa, Bacoli, Caivano, Villa Literno, Castel Volturno, Giugliano in Campania and Marcianise. The authors believe that use of the results of this methodology in the analysis of geographic correlation with health data makes it possible to evaluate whether there is a relationship between the risk of mortality or congenital malformations and classes of municipalities at different levels of environmental pressure.

The Experimental Zooprophylactic Institute of Southern Italy (IZSM), with headquarters in Portici (NA), to which a part of the authors of this research belong, is one of the ten Zooprophylactic Institutes in Italy operating within the National Health Service on Hygiene and Veterinary Public Health as a technical-scientific tool for the State and of the Campania and Calabria Regions. In response to the complex social, environmental and economic situation caused by the "Terra dei Fuochi" phenomenon, the IZSM collaborated closely with the Terra dei Fuochi working group, carrying out additional monitoring surveys both on food (QR Code Campania project[28]), and on the environment (Campania Trasparente project[29]). This model was developed in the context of the experience accumulated in the field of environmental and food monitoring, and represents an innovative tool aimed at increasing knowledge of the environmental context of the Campania Region through an objective, integrated and organic synthesis of complex environmental phenomena and territorial dynamics. The particular context we are studing is characterised by the presence of specific and/or widespread sources of pressure, of different types and sizes, variously distributed over the territory and capable of generating highly heterogeneous impacts. The analysis assumes the municipal limits as a territorial reference since many of the environmental data taken into consideration, produced by different bodies (Municipalities, Provinces, ARPAC, Campania Region, Universities, etc.), were very often aggregated on this basis. In this way, an attempt was made to safeguard the spatial detail of the data. Within the limits of this analysis, it is necessary to bear in mind the approximate and, in part subjective, component inherent in the attribution of scores of significance relative to the variables considered and linked to qualitative assessments on the potential impacts generated, on any transport mechanisms of active contaminants, and on potentially exposed targets (food, humans, etc.). The strengths of this approach lie in the wide set of variables considered which, to varying degrees, contribute to determining the "environmental balance" of the municipality assessed. The proposed model enables simultaneous evaluation of a large number of variables, objective expression of the environmental pressure relating to the municipal territory, and summarises it in a single index. When applied as part of the design of a monitoring study on a large number of municipalities, this index allows them to be grouped on the basis of similar environmental pressures, making it possible to identify a geo-stratification unit on which to perform population sampling, with significant resource savings and faster recruitment[13].

In conclusion, the model proposed here is useful for the global and synthetic assessment of environmental pressure on a municipal basis. As shown, it can also be applied to aggregations of municipalities. Furthermore, it can be used in the context of institutional actions for the planning and monitoring of improvements on a local or regional scale. Finally, the proposed municipality-based environmental pressure index represents the basis for geo-stratification of the sample in the context of population biomonitoring studies on a regional scale, as in the described biomonitoring study design applicable to the Campania Region.

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6. FIGURES

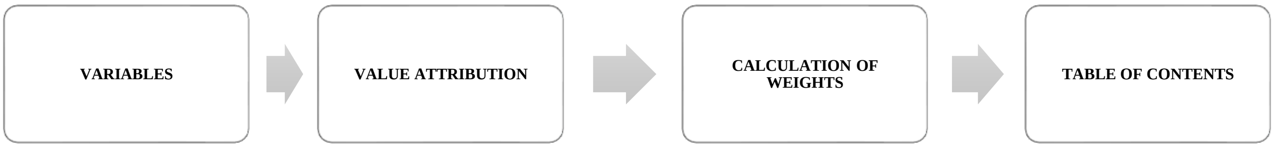

Figure 1 - Block diagram of the algorithm for calculating the index.

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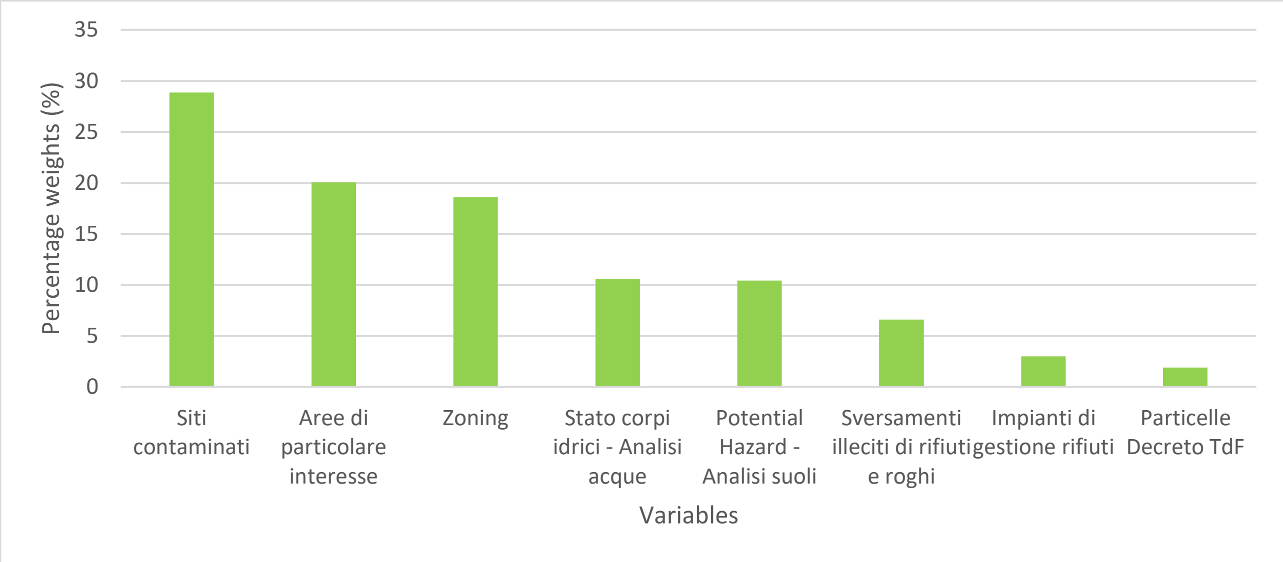

Figure 2 - Graph of the percentage weights of variables.

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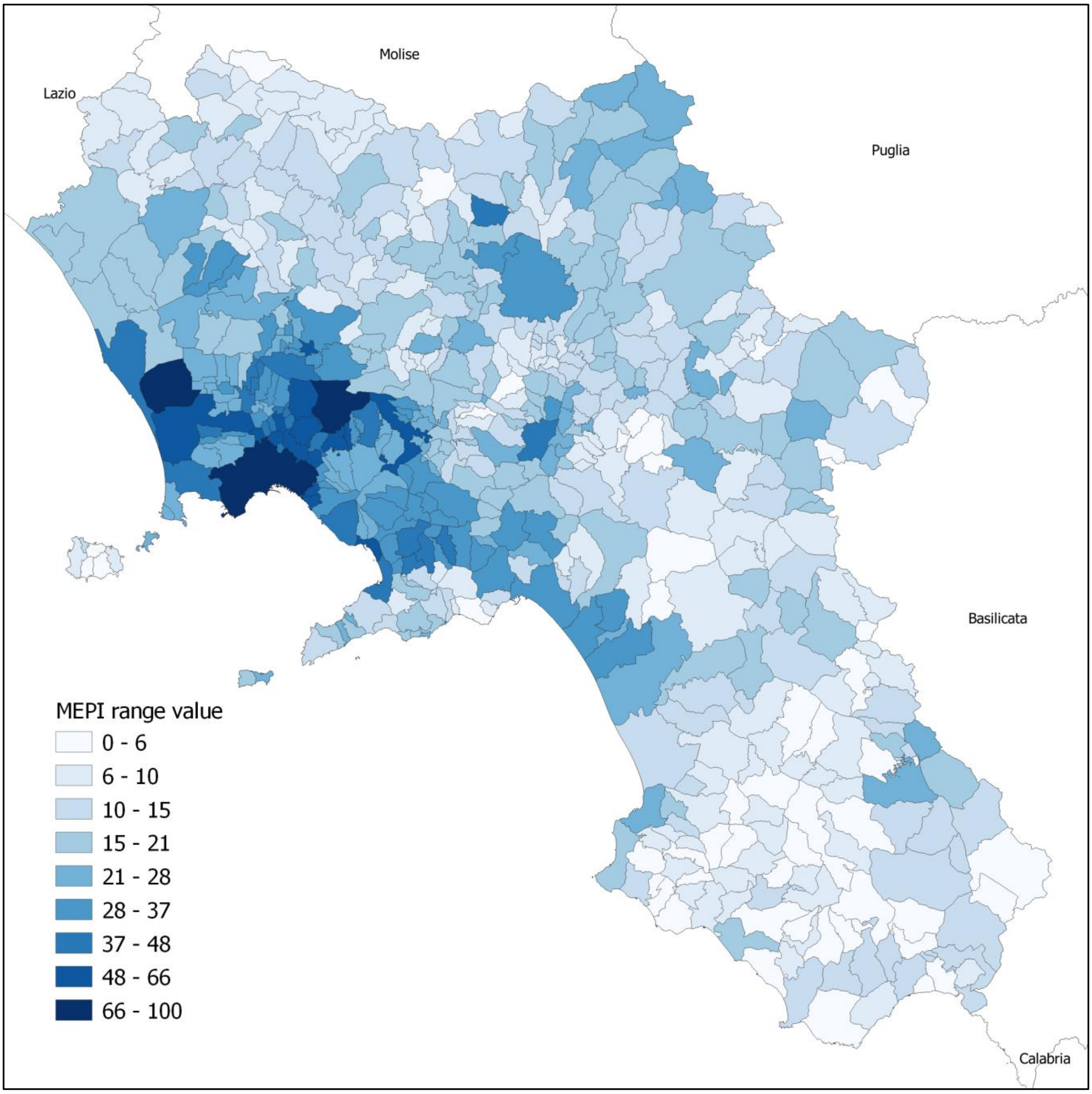

Figure 3 – Rapresentation of municipality environmental pressure index (MEPI) value ranging from 0 to 100.

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7. TABLES

	Sources of contamination A_i	*Data source*
A	**Contaminated sites** A1) Contaminated landfills pursuant to Leg. Decree 152/06 A2) Plots TdF 5, 4, 3 respectively pursuant to Leg Decree No. 56 of 09/03/15 and Leg. Decree No. 191 of 19/08/15	*ARPAC - Regional remediation plan [30]*
B	**Areas of particular interest** E1) Sites of national interest E2) Sites of regional interest E3) Illegal landfills E4) Landfills awaiting investigation	*ARPAC - Regional remediation plan [30]*
C	***Zoning*** C1) Land use (Residential, Industrial, Agricultural) C2) Population density	*Corine Land Cover 2012[31]*
D	**Status of water bodies – Water analysis** C1) Surface water bodies C2) Groundwater bodies	*ARPAC- qualitative monitoring of water bodies[32]*
E	***Potential hazard* – Soil analysis**	*[33]*
F	**Illegal spills and fires**	*SMA Campania[34]*
G	**Waste management plants**	*ARPAC - Plants authorised for waste*

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		management[35]
H	**Plots TdF Decree class 2a, 2b and 3, 4 and 5 of class a**	*ARPAC - Regional remediation plan[30]*

Table 1 – Variables used as sources of contamination.

Values a_{ij}	***Interpretation***
1	i and j are equally important
3	i is slightly more important than j
5	i is much more important than j
7	i is very much more important than j
9	i is extremely more important than j

Table 2 - Saaty semantic scale for the attribution of weights.

	A	B	C	D	E	F	G	H
A	1.00	3.00	2.00	3.00	3.00	5.00	7.00	9.00
B	0.33	1.00	3.00	2.00	2.00	4.00	6.00	8.00
C	0.50	0.33	1.00	3.00	4.00	4.00	6.00	6.00
D	0.33	0.50	0.33	1.00	1.00	3.00	5.00	6.00
E	0.33	0.50	0.25	1.00	1.00	3.00	5.00	6.00
F	0.20	0.25	0.25	0.33	0.33	1.00	5.00	6.00
G	0.14	0.17	0.17	0.20	0.20	0.20	1.00	3.00
H	0.11	0.13	0.17	0.17	0.17	0.17	0.33	1.00
SUM	**2.95**	**5.88**	**4.17**	**10.70**	**11.70**	**20.37**	**35.33**	**45.00**

Table 3 – Matrix of pairwise comparison between sources of contamination.

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	A	B	C	D	E	F	G	H	**Priority Vector**
A	0.34	0.51	0.28	0.28	0.26	0.25	0.20	0.20	**0.29**
B	0.11	0.17	0.42	0.19	0.17	0.20	0.17	0.18	**0.20**
C	0.17	0.06	0.14	0.28	0.34	0.20	0.17	0.13	**0.19**
D	0.11	0.09	0.05	0.09	0.09	0.15	0.14	0.13	**0.11**
E	0.11	0.09	0.03	0.09	0.09	0.15	0.14	0.13	**0.10**
F	0.07	0.04	0.03	0.03	0.03	0.05	0.14	0.13	**0.07**
G	0.05	0.03	0.02	0.02	0.02	0.01	0.03	0.07	**0.03**
H	0.04	0.02	0.02	0.02	0.01	0.01	0.01	0.02	**0.02**

Table 4 – Matrix for construction of "priority vector".

Variables		***Weights (%)***
A	Contaminated sites	28.9
B	Areas of particular interest	20.0
C	Zoning	18.6
D	Status of water bodies – Water analysis	10.6
E	*Potential Hazard* – Soil analysis	10.4
F	Illegal waste spills and fires	6.6
G	Waste management plants	3.0
H	Plots of land of the TdF Decree	1.9

Table 5 – Variables with their respective weights as a percentage.

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	A	B	C	D	E	F	G	H	Priority Vector	**Substance**
A	0.34	0.51	0.28	0.28	0.26	0.25	0.20	0.20	**0.29**	**9.02**
B	0.11	0.17	0.42	0.19	0.17	0.20	0.17	0.18	**0.20**	**9.33**
C	0.17	0.06	0.14	0.28	0.34	0.20	0.17	0.13	**0.19**	**9.09**
D	0.11	0.09	0.05	0.09	0.09	0.15	0.14	0.13	**0.11**	**8.81**
E	0.11	0.09	0.03	0.09	0.09	0.15	0.14	0.13	**0.10**	**8.78**
F	0.07	0.04	0.03	0.03	0.03	0.05	0.14	0.13	**0.07**	**8.39**
G	0.05	0.03	0.02	0.02	0.02	0.01	0.03	0.07	**0.03**	**8.24**
H	0.04	0.02	0.02	0.02	0.01	0.01	0.01	0.02	**0.02**	**8.60**

Table 6 – Substance matrix of variables used.

MATRIX ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 7 – Values of Random Consistency Index (RCI) as a function of matrix order.

Agricultural use class	**Definition**
A	*Land suitable for agri-food production*
A1	*Land suitable for agri-food production after removal of waste and analysis of sedimentation areas*
B	*Land with limitation for certain agri-food productions under certain conditions*
NC	*Non-classifiable land*
D	*Land where agri-food production is prohibited*

Table 8 – Class of agricultural use for plots of land of the Terra dei Fuochi decree.

Contaminated sites	p' score
TdF 3, 4, 5 Class B plots	3
TdF 3, 4, 5 Class NC plots	5
TdF 3, 4, 5 Class D plots	7
Contaminated landfills	9

Table 9 – p' score by type of contaminated sites.

Contaminated sites surface area (sqm)	p' score
0-2500	2
2500-5000	3
5000-10000	4
10000-20000	5
20000-50000	7
> 50000	9

Table 10 – p'' score referred to extent of contaminated sites.

Areas of particular interest	Score
Sites of national interest	9
Illegal landfills	7
Areas awaiting characterisation	5
Potentially contaminated sites	3

Table 11 – p' score for "areas of particular interest" variable.

Type of residential use	Score
Wooded	0
Residential 1	1
Residential 2	2
Agriculture	3
Residential 3	4
Residential 4	5
Industrial	7
Residential 5	8
Residential 6	9

Table 12 – Score attributed to types of land use.

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Industrial Area/Municipal Area (%)	**Score**		**Residential Area/Municipal Area (%)**	**Score**
0-1%	1		*0-7%*	1
1-4%	3		*7-12%*	3
4-10%	5		*12-33%*	5
10-21%	7		*33-56%*	7
21-100%	9		*56-100%*	9

Table 13 – Score attributed to p'' indicator for industrial and residential areas

Agricultural Area/Municipal Area (%)	**Score**		**Wooded Area/Municipal Area (%)**	**Score**
0-24%	1		*0-10%*	1
24-43%	3		*10-25%*	3
43-60%	5		*25-47%*	5
60-75%	7		*47-78%*	7
75-100%	9		*78-100%*	9

Table 14 – Score attributed to p'' indicator for agricultural and wooded areas.

Treatment plants	Score
Controlled landfills	3
Scrapping plants	3
Other	3
Recovery	3
Purification	6
Selection/Sorting	6
Composting	6
Storage	7
Incineration	9

Table 15 – p' score for each waste treatment plant identified.

Decree plots of land	Score
Class 2 A	9
Class 2 B	7

Class 3, 4, 5 A	5

Table 16 – Score attributed to plots of the TdF decree.

Surface area exceedances CTC/Municipal area	**Score**
0-9%	0
9-30%	3
30-55%	5
55-80%	7
80-100%	9

Table 17 – p' score for relationships identified between CTC and municipal area.

Qualitative status of groundwater bodies*	**Score**
Good	0
Particularly good	1
Not monitored	3
Poor	9

Table 18 – p' score attributed to qualitative status of groundwater bodies.

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Groundwater surface area/Municipal surface area	**Score**
0-15%	1
15-37%	3
37-60%	5
60-85%	7
85-100%	9

Table 19 – p'' score attributed to ratio of areas.

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Municipality	MPI
Acerno	5
Acerra	81
Afragola	53
Agerola	17
Agropoli	26
Aiello del Sabato	22
Ailano	16
Airola	25
Albanella	12
Alfano	5
Alife	13
Altavilla Irpina	17
Altavilla Silentina	12
Alvignano	14
Amalfi	16
Amorosi	12
Anacapri	19

Municipality	MPI
Andretta	26
Angri	44
Apice	16
Apollosa	15
Aquara	9
Aquilonia	6
Ariano Irpino	17
Arienzo	9
Arpaia	7
Arpaise	9
Arzano	63
Ascea	17
Athena Lucana	24
Atrani	33
Atripalda	28
Auletta	6
Avella	20

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Municipality	MPI
Avellino	40
Aversa	38
Bacoli	27
Bagnoli Irpino	7
Baia e Latina	12
Baiano	11
Barano d'Ischia	4
Baronissi	23
Baselice	20
Battipaglia	32
Bellizzi	26
Bellona	14
Bellosguardo	9
Benevento	32
Bisaccia	17
Bonea	18
Bonito	12
Boscoreale	36
Boscotrecase	24
Bracigliano	20
Brusciano	31
Bucciano	10
Buccino	18

Municipality	MPI
Buonabitacolo	15
Buonalbergo	12
Caggiano	9
Caianello	13
Caiazzo	13
Cairano	6
Caivano	65
Calabritto	9
Calitri	15
Calvanico	16
Calvi	21
Calvi Risorta	16
Calvizzano	26
Camerota	6
Camigliano	9
Campagna	9
Campolattaro	19
Campoli del Monte Taburno	17
Campora	3
Camposano	32
Cancello e Arnone	19
Candida	15
Cannalonga	9

Municipality	MPI
Capaccio	14
Capodrise	35
Caposele	13
Capri	28
Capriati a Volturno	8
Capriglia Irpina	19
Capua	26
Carbonara di Nola	22
Cardito	41
Carife	12
Carinaro	39
Carinola	18
Casagiove	23
Casal di Principe	24
Casalbore	12
Casalbuono	2
Casalduni	42
Casaletto Spartano	13
Casalnuovo di Napoli	47
Casaluce	20
Casalvelino	10
Casamarciano	25
Casamicciola Terme	6

Municipality	MPI
Casandrino	43
Casapesenna	22
Casapulla	29
Casavatore	43
Caselle in Pittari	5
Caserta	29
Casola di Napoli	16
Casoria	58
Cassano Irpino	3
Castel Baronia	10
Castel Campagnano	10
Castel di Sasso	9
Castel Morrone	7
Castel San Giorgio	19
Castel San Lorenzo	9
Castelcivita	8
Castelfranci	8
Castelfranco in Miscano	24
Castellabate	17
Castellammare di Stabia	45
Castello di Cisterna	50
Castello Matese	9
Castelnuovo Cilento	7

Municipality	MPI
Castelnuovo di Conza	19
Castelpagano	15
Castelpoto	18
Castelvenere	10
Castelvetere in Valfortore	24
Castelvetere sul Calore	5
Castelvolturno	44
Castiglione del Genovesi	7
Cautano	16
Cava dei Tirreni	35
Celle di Bulgheria	12
Cellole	20
Centola	11
Ceppaloni	7
Ceraso	4
Cercola	34
Cerreto Sannita	6
Cervinara	18
Cervino	16
Cesa	26
Cesinali	23
Cetara	7
Chianche	8

Municipality	MPI
Chiusano San Domenico	9
Cicciano	30
Cicerale	10
Cimitile	35
Ciorlano	13
Circello	17
Colle Sannita	17
Colliano	11
Comiziano	26
Conca dei Marini	22
Conca della Campania	7
Contrada	16
Controne	11
Contursi Terme	15
Conza della Campania	17
Corbara	10
Corleto Monforte	9
Crispano	47
Cuccaro Vetere	1
Curti	24
Cusano Mutri	14
Domicella	19
Dragoni	13

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Municipality	MPI
Dugenta	12
Durazzano	16
Eboli	24
Ercolano	34
Faicchio	11
Falciano del Massico	16
Felitto	5
Fisciano	30
Flumeri	21
Foglianise	11
Foiano di Val Fortore	23
Fontanarosa	14
Fontegreca	7
Forchia	10
Forino	17
Forio	9
Formicola	7
Fragneto l'Abate	9
Fragneto Monforte	13
Francolise	19
Frasso Telesino	9
Frattamaggiore	56
Frattaminore	40

Municipality	MPI
Frigento	26
Frignano	22
Furore	19
Futani	8
Gallo Matese	0
Galluccio	12
Gesualdo	12
Giano Vetusto	7
Giffoni Sei Casali	9
Giffoni Valle Piana	21
Ginestra degli Schiavoni	23
Gioi	7
Gioia Sannitica	18
Giugliano in Campania	65
Giungano	14
Gragnano	17
Grazzanise	27
Greci	12
Gricignano d'Aversa	36
Grottaminarda	11
Grottolella	18
Grumo Nevano	44
Guardia Lombardi	9

Municipality	MPI
Guardia Sanframondi	11
Ischia	10
Ispani	5
Lacco Ameno	12
Lacedonia	17
Lapio	11
Laureana Cilento	9
Laurino	6
Laurito	0
Lauro	13
Laviano	7
Letino	9
Lettere	11
Liberi	17
Limatola	12
Lioni	10
Liveri	24
Luogosano	28
Lusciano	27
Lustra	4
Macerata Campania	23
Maddaloni	37
Magliano Vetere	7

Municipality	MPI
Maiori	2
Manocalzati	27
Marano di Napoli	26
Marcianise	48
Mariglianella	30
Marigliano	38
Marzano Appio	10
Marzano di Nola	21
Massa di Somma	22
Massa Lubrense	14
Melito di Napoli	51
Melito Irpino	10
Melizzano	14
Mercato Sanseverino	33
Mercogliano	15
Meta di Sorrento	22
Mignano Monte Lungo	8
Minori	8
Mirabella Eclano	13
Moiano	10
Moio della Civitella	4
Molinara	17
Mondragone	21

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Municipality	MPI
Montaguto	8
Montano Antilia	3
Monte di Procida	26
Monte San Giacomo	14
Montecalvo Irpino	11
Montecorice	15
Montecorvino Pugliano	35
Montecorvino Rovella	7
Montefalcione	12
Montefalcone di Val Fortore	20
Monteforte Cilento	5
Monteforte Irpino	23
Montefredane	32
Montefusco	11
Montella	12
Montemarano	6
Montemiletto	15
Montesano sulla Maricani	6
Montesarchio	25
Monteverde	12
Montoro	20
Morcone	12
Morigerati	2

Municipality	MPI
Morra de Sanctis	17
Moschiano	13
Mugnano del Cardinale	10
Mugnano di Napoli	36
Naples	100
Nocera Inferiore	31
Nocera Superiore	30
Nola	51
Novi Velia	8
Nusco	25
Ogliastro Cilento	18
Olevano sul Tusciano	6
Oliveto Citra	20
Omignano	3
Orria	1
Orta d'Atella	36
Ospedaletto d'Alpinolo	18
Ottati	2
Ottaviano	25
Padula	11
Paduli	18
Pagani	39
Pago del Vallo di Lauro	17

Municipality	MPI
Pago Veiano	14
Palma Campania	30
Palomonte	21
Pannarano	19
Paolisi	9
Parete	26
Parolise	23
Pastorano	34
Paternopoli	13
Paupisi	16
Pellezzano	13
Perdifumo	6
Perito	5
Pertosa	9
Pesco Sannita	10
Petina	8
Petruro Irpino	9
Piaggine	5
Piana di Monte Verna	18
Piano di Sorrento	18
Piedimonte Matese	8
Pietradefusi	13
Pietramelara	12

Municipality	MPI
Pietraroja	13
Pietrastornina	6
Pietravairano	11
Pietrelcina	21
Pignataro Maggiore	29
Pimonte	8
Pisciotta	4
Poggiomarino	33
Polla	14
Pollena Trocchia	27
Pollica	5
Pomigliano d'Arco	53
Pompei	33
Ponte	19
Pontecagnano Faiano	36
Pontelandolfo	13
Pontelatone	13
Portici	51
Portico di Caserta	30
Positano	11
Postiglione	20
Pozzuoli	39
Praiano	16

Municipality	MPI
Prata di Principato Ultra	21
Prata Sannita	7
Pratella	9
Pratola Serra	27
Presenzano	17
Prignano Cilento	12
Procida	23
Puglianello	20
Quadrelle	6
Qualiano	39
Quarto	25
Quindici	18
Ravello	11
Raviscanina	7
Recale	33
Reino	14
Riardo	21
Ricigliano	8
Rocca d'Evandro	10
Rocca San Felice	14
Roccabascerana	10
Roccadaspide	10
Roccagloriosa	15

Municipality	MPI
Roccamonfina	7
Roccapiemonte	23
Roccarainola	17
Roccaromana	9
Rocchetta e Croce	8
Rofrano	1
Romagnano al Monte	5
Roscigno	10
Rotondi	12
Rutino	10
Ruviano	13
Sacco	8
Sala Consilina	16
Salento	7
Salerno	33
Salvitelle	7
Salza Irpina	7
San Bartolomeo in Galdo	23
San Cipriano d'Aversa	22
San Cipriano Picentino	14
San Felice a Cancello	21
San Gennaro Vesuviano	34
San Giorgio a Cremano	51

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Municipality	MPI
San Giorgio del Sannio	21
San Giorgio la Molara	18
San Giovanni a Piro	7
San Giuseppe Vesuviano	35
San Gregorio Magno	9
San Gregorio Matese	8
San Leucio del Sannio	11
San Lorenzello	10
San Lorenzo Maggiore	17
San Lupo	10
San Mango Piemonte	13
San Mango sul Calore	11
San Marcellino	30
San Marco dei Cavoti	26
San Marco Evangelista	36
San Martino Sannita	7
San Martino Valle Caudina	14
San Marzano sul Sarno	30
San Mauro Cilento	5
San Mauro la Bruca	7
San Michele di Serino	17
San Nazzaro	12
San Nicola Baronia	7

Municipality	MPI
San Nicola la Strada	50
San Nicola Manfredi	11
San Paolo Bel Sito	24
San Pietro al Tanagro	18
San Pietro Infine	10
San Potito Sannitico	8
San Potito Ultra	18
San Prisco	19
San Rufo	6
San Salvatore Telesino	10
San Sebastiano al Vesuvio	34
San Sossio Baronia	10
San Tammaro	20
San Valentino Torio	34
San Vitaliano	28
Santa Croce del Sannio	10
Santa Lucia di Serino	9
Santa Maria a Vico	18
Santa Maria Capua Vetere	35
Santa Maria La Carità	30
Santa Maria la Fossa	18
Santa Marina	11
Santa Paolina	11

Municipality	MPI
Sant'Agata dei Goti	20
Sant'Agnello	25
Sant'Anastasia	23
Sant'Andrea di Conza	16
Sant'Angelo a Cupolo	11
Sant'Angelo a Fasanella	5
Sant'Angelo a Scala	9
Sant'Angelo all'Esca	20
Sant'Angelo d'Alife	11
Sant'Angelo dei Lombardi	16
Sant'Antimo	33
Sant'Antonio Abate	39
Sant'Arcangelo Trimonte	16
Sant'Arpino	25
Sant'Arsenio	12
Sant'Egidio del Monte Albino	36
Santo Stefano del Sole	10
Santomenna	20
Sanza	15
Sapri	13
Sarno	37
Sassano	12
Sassinoro	9

Municipality	MPI
Saviano	27
Savignano Irpino	21
Scafati	42
Scala	12
Scampitella	9
Scisciano	25
Senerchia	10
Serino	12
Serramezzana	4
Serrara Fontana	4
Serre	19
Sessa Aurunca	18
Sessa Cilento	9
Siano	16
Sicignano degli Alburni	15
Sirignano	8
Solofra	15
Solopaca	18
Somma Vesuviana	26
Sorbo Serpico	10
Sorrento	21
Sparanise	29
Sperone	23

Municipality	MPI
Stella Cilento	8
Stio	9
Striano	29
Sturno	9
Succivo	33
Summonte	13
Taurano	14
Taurasi	18
Teano	25
Teggiano	24
Telese Terme	16
Teora	13
Terzigno	33
Teverola	43
Tocco Caudio	11
Tora e Piccilli	13
Torchiara	8
Torella dei Lombardi	20
Torraca	9
Torre Annunziata	66
Torre Del Greco	39
Torre le Nocelle	18
Torre Orsaia	12

Municipality	MPI
Torrecuso	30
Torrioni	7
Tortorella	13
Tramonti	7
Trecase	26
Trentinara	9
Trentola Ducenta	28
Trevico	6
Tufino	28
Tufo	11
Vairano Patenora	11
Vallata	12
Valle Agricola	8
Valle dell'Angelo	7
Valle di Maddaloni	10
Vallesaccarda	11
Vallo della Lucania	14
Valva	7
Venticano	19
Vibonati	2
Vico Equense	11
Vietri sul Mare	12
Villa di Briano	22

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Municipality	MPI
Villa Literno	91
Villamaina	18
Villanova del Battista	8
Villaricca	32
Visciano	21

Municipality	MPI
Vitulano	16
Vitulazio	28
Volla	58
Volturara Irpina	9
Zungoli	12

Table 20. Municipal pressure indices of all municipalities in the Campania Region

IMPACT AREA DESCRIPTION	NUMBER OF MUNICIPALITIES	RESIDENT POPULATION (2011 CENSUS)	PRESSURE INDEX WEIGHTED ON RESIDENT POPULATION
Most of the corresponding provinces of Naples and Caserta, located in the Voltuno-Regi Lagni plain, Campi Flegrei and Vesuvian municipalities	114	3,405,056	57.5
Area south of the province of Naples, north-west of the province of Salerno and west of the province of Avellino, located in the plain of the Sarno river and Solofra-Cavaiola, in Valle dell'Irno and in Valle del Sabato	32	765,513	35.8
Municipalities located in the south-west and north-east of the province of Salerno,	28	76,427	13.0

located along the Cilento coast and in the innermost part of Valle del Sele-Tanagro			

Table 21 Identification of Impact Areas applicable to the geo-stratified recruitment plans of a biomonitoring study of the Campania Region population

Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
HIGH IMPACT					
Naples	985,450	high 12	100	98.8	1,055,325
Villa Literno	11,323	high 12	91		
Acerra	58,552	high 12	81		
Caivano	38,315	high 11	65	64.6	185,372
Giugliano in Campania	110,858	high 11	65		
Arzano	36,199	high 11	63		
Casoria	80,425	high 10	58	55.5	240,476
Volla	23,276	high 10	58		
Frattamaggiore	30,758	high 10	56		
Afragola	65,907	high 10	53		
Pomigliano d'Arco	40,110	high 10	53		
Melito di Napoli	38,348	high 9	51	49.6	306,075
Nola	33,969	high 9	51		
Portici	56,856	high 9	51		
San Giorgio a Cremano	45,920	high 9	51		
Castello di Cisterna	7,480	high 9	50		
San Nicola la Strada	21,011	high 9	50		
Marcianise	40,071	high 9	48		
Casalnuovo di Napoli	50,055	high 9	47		

Municipality	**Residents by municipality (2011 Census)**	**Cluster**	**MPI**	**Synthetic index weighted for resident population applied to cluster**	**Resident population in cluster (2011 Census)**
Crispano	12,365	high 9	47		
Castel Volturno	23,068	high 8	44	42.9	109,316
Grumo Nevano	18,029	high 8	44		
Casandrino	13,208	high 8	43		
Casavatore	18,590	high 8	43		
Teverola	13,549	high 8	43		
Cardito	22,872	high 8	41		
Frattaminore	16,452	high 7	40	38.5	340,131
Carinaro	6,817	high 7	39		
Pozzuoli	80,987	high 7	39		
Qualiano	24,695	high 7	39		
Torre del Greco	88,121	high 7	39		
Aversa	53,324	high 7	38		
Marigliano	30,162	high 7	38		
Maddaloni	39,573	high 7	37		
Boscoreale	28,730	high 6	36	34.5	370,977
Gricignano di Aversa	10,483	high 6	36		
Mugnano di Napoli	34,768	high 6	36		
Orta di Atella	24,880	high 6	36		
San Marco Evangelista	6,669	high 6	36		

Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
Capodrise	9,647	high 6	35		
Cimitile	7,037	high 6	35		
San Giuseppe Vesuviano	27,699	high 6	35		
Santa Maria Capua Vetere	32,934	high 6	35		
Cercola	18,141	high 6	34		
Ercolano	57,078	high 6	34		
Pastorano	2,898	high 6	34		
San Gennaro Vesuviano	10,983	high 6	34		
San Sebastiano al Vesuvio	9,145	high 6	34		
Poggiomarino	22,095	high 6	33		
Recale	7,623	high 6	33		
Sant'Antimo	34,736	high 6	33		
Succivo	8,061	high 6	33		
Terzigno	17,370	high 6	33		
Camposano	5,297	high 5	32	30.8	108,083
Villaricca	31,099	high 5	32		
Brusciano	16,202	high 5	31		
Cicciano	12,743	high 5	30		

Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
Mariglianella	7,505	high 5	30		
Palma Campania	14,906	high 5	30		
Portico di Caserta	7,650	high 5	30		
San Marcellino	12,681	high 5	30		
Casapulla	8,180	high 4	29		192,448
Caserta	76,819	high 4	29	28.2	
Pignataro Maggiore	6,193	high 4	29		
Sparanise	7,719	high 4	29		
Striano	8,405	high 4	29		
San Vitaliano	6,321	high 4	28		
Trentola Ducenta	17,656	high 4	28		
Tufino	3,758	high 4	28		
Vitulazio	6,919	high 4	28		
Grazzanise	7,082	high 4	27		
Lusciano	14,406	high 4	27		
Pollena Trocchia	13,388	high 4	27		
Saviano	15,602	high 4	27		
Calvizzano	12,703	high 3	26		287,442
Capua	20,468	high 3	26	25.3	
Cesa	8,460	high 3	26		

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Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
Comiziano	1,817	high 3	26		
Marano di Napoli	57,673	high 3	26		
Parete	10,956	high 3	26		
Somma Vesuviana	36,037	high 3	26		
Trecase	9,010	high 3	26		
Casamarciano	3,266	high 3	25		
Ottaviano	23,947	high 3	25		
Quarto	39,952	high 3	25		
Sant'Arpino	13,967	high 3	25		
Scisciano	5,757	high 3	25		
Boscotrecase	10,547	high 3	24		
Casal di Principe	20,844	high 3	24		
Curti	7,002	high 3	24		
Liveri	1,637	high 3	24		
San Paolo Bel Sito	3,399	high 3	24		
Casagiove	13,548	high 2	23	21.8	159,832
Macerata Campania	10,533	high 2	23		
Sant'Anastasia	28,105	high 2	23		
Carbonara di Nola	2,269	high 2	22		
Casapesenna	6,576	high 2	22		

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Municipality	**Residents by municipality (2011 Census)**	**Cluster**	**MPI**	**Synthetic index weighted for resident population applied to cluster**	**Resident population in cluster (2011 Census)**
Frignano	9,219	high 2	22		
Massa di Somma	5,559	high 2	22		
San Cipriano d'Aversa	13,398	high 2	22		
Villa di Briano	6,008	high 2	22		
Mondragone	27,935	high 2	21		
San Felice a Cancello	17,189	high 2	21		
Visciano	4,523	high 2	21		
Casaluce	9,985	high 2	20		
San Tammaro	4,985	high 2	20		
Cancello e Arnone	5,418	high 1	19	17.9	49,579
Francolise	4,847	high 1	19		
San Prisco	11,976	high 1	19		
Carinola	8,011	high 1	18		
Santa Maria la Fossa	2,677	high 1	18		
Roccarainola	7,098	high 1	17		
Calvi Risorta	5,685	high 1	16		
Falciano del Massico	3,867	high 1	16		
MEDIUM IMPACT					
Torre Annunziata	44,780	medium 3	66	45.3	291,239
Castellammare di Stabia	67,186		45		

Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
Angri	33,477		44		
Scafati	50,096		42		
Pagani	34,992		39		
Sant'Antonio Abate	19,367		39		
Sarno	32,732		37		
Sant'Egidio del Monte Albino	8,609		36		
San Valentino Torio	10,359	medium 2	34	31.3	166,004
Mercato San Severino	21,817		33		
Pompei	26,190		33		
Nocera Inferiore	46,626		31		
Fisciano	14,014		30		
Nocera Superiore	24,826		30		
San Marzano sul Sarno	10,110		30		
Santa Maria la Carità	12,062		30		
Roccapiemonte	9,002	medium 1	23	18.5	65,647
Montoro	19,357		20		
Castel San Giorgio	13,270		19		
Calvanico	1,671		16		
Siano	9,927		16		

Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
Solofra	12,420		15		
Avellino	54,366	Valle del Sabato	40	35.5	81,205
Montefredane	2,273		32		
Atripalda	10,888		28		
Manocalzati	3,184		27		
Pratola Serra	3,620		27		
Aiello del Sabato	3,928		22		
Prata di Principato Ultra	2,946		21		
Salerno	133,811	Valle dell'Irno Cluster 2	33	33	133,811
Baronissi	16,565	Valle dell'Irno Cluster 2	23	19.0	27,607
Pellezzano	11,042		13		
LOW IMPACT					
Palomonte	3,904	low 3	21	17.5	34,885
Oliveto Citra	3,702	low 3	20		
Santomenna	414	low 3	20		
Castelnuovo di Conza	602	low 3	19		

Municipality	Residents by municipality (2011 Census)	Cluster	MPI	Synthetic index weighted for resident population applied to cluster	Resident population in cluster (2011 Census)
Buccino	4,778	low 3	18		
Ascea	5,949	low 3	17		
Castellabate	8,956	low 3	17		
Contursi Terme	3,312	low 3	15		
Sicignano degli Alburni	3,268	low 3	15		
Montecorice	2,631	low 2	15	11.1	24,352
Caposele	3,370	low 2	13		
Centola	5,087	low 2	11		
Colliano	3,521	low 2	11		
Casalvelino	5,468	low 2	10		
Senerchia	770	low 2	10		
Calabritto	2,314	low 2	9		
Laureana Cilento	1,191	low 2	9		
San Gregorio Magno	4,089	low 1	9	6.6	17,190
Ricigliano	1,102	low 1	8		
Stella Cilento	689	low 1	8		
Laviano	1,378	low 1	7		
San Mauro la Bruca	549	low 1	7		
Valva	1,617	low 1	7		
Perdifumo	1,767	low 1	6		

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Municipality	**Residents by municipality (2011 Census)**	**Cluster**	**MPI**	**Synthetic index weighted for resident population applied to cluster**	**Resident population in cluster (2011 Census)**
Pollica	2,284	low 1	5		
San Mauro Cilento	868	low 1	5		
Pisciotta	2,555	low 1	4		
Serramezzana	292	low 1	4		

Table 22. Identification of Clusters within the Impact Areas applicable to the geo-stratified recruitment plan as part of a monitoring study in the Campania Region