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A SIMPLE METHODOLOGY FOR ASSESSING GROUNDWATER RELATED ENVIRONMENTAL RISK IN SALLIQUELÓ TOWN, ARGENTINA

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This paper presents an environmental risk-analysis methodology, as applied to water resources, for Salliqueló City (10,000 inhabitants), Buenos Aires Province, Argentina. The analysis proposes the existence of a potentially dangerous source (groundwater used for direct consumption), and its uncertain effects on some component of the environmental system (the people, in this case). The methodology was based on results of a polynomial expression, which was evaluated for each unit area (block). Such an equation considers complex forms for the source, the exposure, and the targets. The resulting values were then transformed into a chromatic scale of ten levels of severity, from low risk (cold colors) to high-risk scores (hot colors). The source was characterized from hydrochemical and bacteriological data, and the number of cesspools per unit area. The exposure took into account the access to safe water supply, as well as socio-economic variables (awareness to exposure, educational level, quality of household, special risky groups). The targets were simply computed as the quantity of people per unit area. It should be pointed out that the evaluation was done for the actual situation, and the scenario 15 years from now due to population growth. The methodology presented is a trade-off between scientifically-sound techniques and simplicity/low cost/data requirements, the latter being the current needs of water resources managers in the Salliqueló City.

INTRODUCTION

According to Sutter II (1990) risk is the probability that a dangerous effect occurs, or the relationship between the magnitude of such effect and its probability of occurrence. Risk analysis is necessary where a potential dangerous source exists and there is some degree of uncertainty about its effect. The increasing importance of environmental regulations has led to the development of methodologies for risk analysis, although the subject is still in its infancy and full of uncertainties (Cranor, 1995). In the field of water resources there are examples that cover individual to community risk (Sushella, 1995), from exposure scenarios given by a point source to spatially distributed risk analysis (Barcellos, 2000), creating or adapting mathematical models (Eisenberg et al., 1995), digital models, or software (such as the SADA model, Tennessee University, 1999).

Environmental management should take into account both environmental regulations as well as risk analysis. It is obvious that the decision-making process is based on the proper knowledge of the system status and processes and, in that regard, risk analysis is a tool for reducing uncertainties (Wilson, 1990).

Keeping in mind an audience of water managers, this paper proposes an environmental risk analysis focused on water resources that makes use of chemical, bacteriological, and socio-economic variables to model the target exposure and to reduce uncertainties. This approach stems from the need for tools that are technically sound and have practical management value (MMA, 1996). In view of the socio-economic reality of most small cities in Argentina, the requirements are simple calculations, rapid analysis, clear visualization and interpretation of results, and low cost.

Subject to the elements above, the objective of this paper is to develop a simple and easily applied methodology for assessing the risk of using water resources. The methodology is applied to obtain an environmental risk zoning for Salliqueló City (western Buenos Aires Province, population: 10000).

METHODOLOGY

The applied methodology consists of solving a polynomial equation, whose terms are previously calculated at each area unit. The final results are converted into a colored scale of degree of severity (cold to hot colors). The area unit is the block and for Salliqueló the total is 174.

The basic hypothesis is that the risk (R) for each block is related to three factors: the source S, the target T (block dwellers), and the exposure E (that is, the link between source and targets). Thus,

$$R = S\,T\,E \qquad (1)$$

Source Characterization

The source is taken to be a rather complex system, the local aquifer, whose chemical and bacteriological deterioration constitutes a potential damage to the targets. Such water quality deterioration is evaluated either by the concentration of chemical species or bacteriological loads that are above the maximum allowed standards for drinking water.

In evaluating the source, the estimation took into account the current as well as the future situation. The current status of the system was determined by collecting chemical and bacteriological water quality data from domestic wells, and considering a degradation factor related to socio-economic

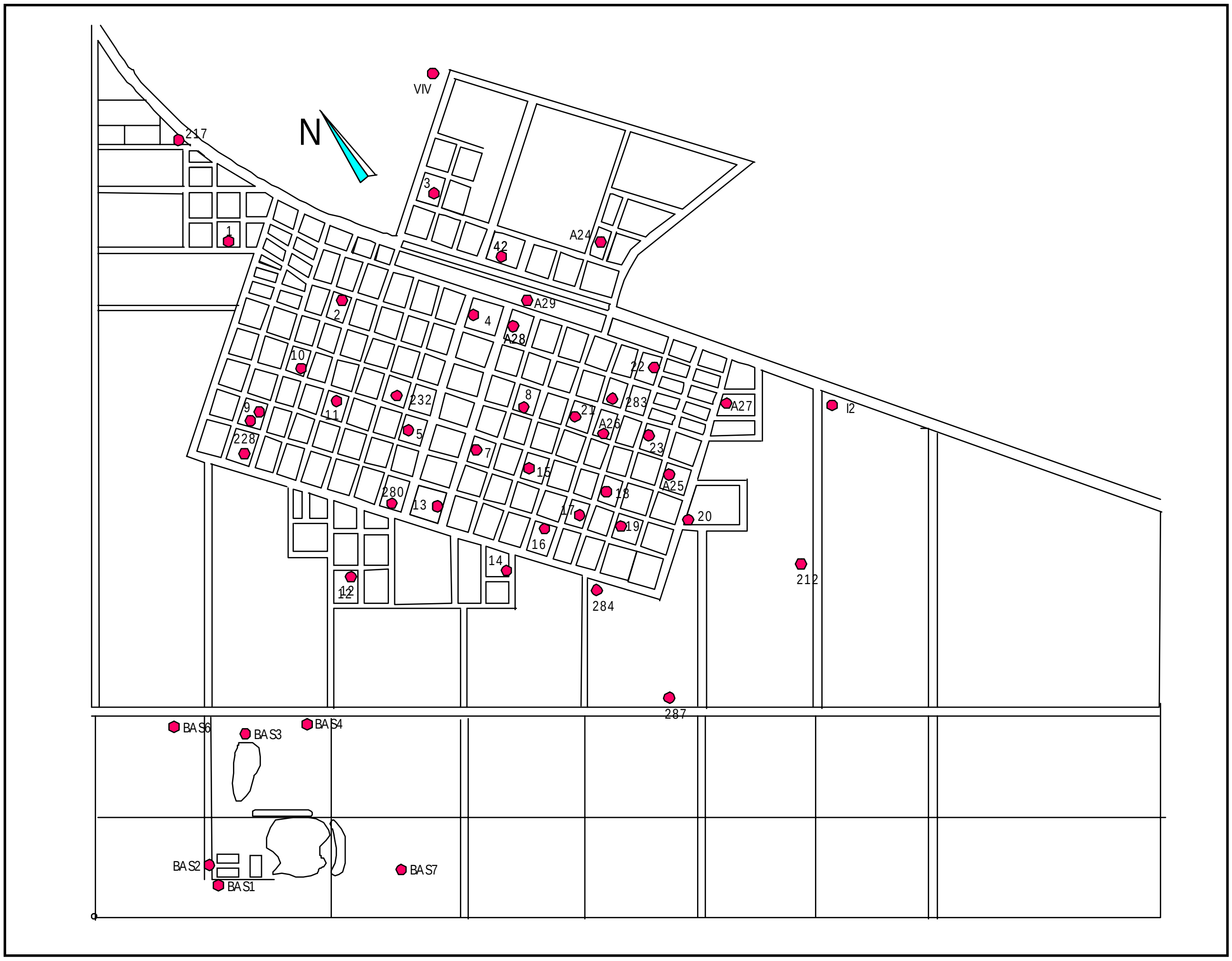

Figure 1. Sampling locations (bacteriological and chemical analyses) in Salliqueló City, Buenos Aires Province, Argentina.

features. The future perspective is inferred from the population growth index (INDEC, 1998).

The hydrochemical source (*HS*) was defined in terms of the concentration of the following variables measured with standard techniques: nitrate, carbonate and bicarbonate (as total alkalinity), hardness (i.e., calcium and magnesium), chloride, fluoride, pH, sulfate, arsenic, dry residue (representative of total dissolved solids), nitrite, and ammonium. Three sampling surveys were carried out in 25 wells distributed on the urban domain (Figure 1). Kriging interpolation using SURFER 5.0 (Golden Software Inc., 1994) gave representative values for each block. The *HS* was defined as the sum of the proportion in which each chemical variable is above the maximum allowable value set by the national regulation (ADLA, 1971, De La Canal y Asociados, 1994):

$$HS = \Sigma\,[(CP/MAV)-1] \qquad (2)$$

CP = measured chemical parameter

MAV = maximum allowable value

Range of *HS* = 0-∞

The biological source (*BS*) was based on the results of the bacteriological sampling (same wells and frequency as for the *HS*) and the national standards for drinking water (ADLA, 1971, De La

Canal y Asociados, 1994). Then, a scale of severity was proposed:

0: safe water

1: excess of aerobic bacteria

2: excess of coliform bacteria or pseudomonas

3: excess of colifecal or other pathogenic bacteria

The official statistical agency (INDEC) divides the urban domain in census sectors (Figure 2), which are made up of several blocks. Such census sectors were taken as the unit area for the analysis. Then,

$$BS = \Sigma f s / n \qquad (3)$$

f = sampling frequency for the census sector

s = severity index for each sample

n = number of wells in the census sector

Range of BS = 0-3

Notice that any value calculated for each census sector is assumed to represent all blocks contained in that sector.

It has been assumed that the quality of the source is affected by the impact of existing cesspools (here called a "worsening actual mechanism" or *WAM*), a mechanism of socio-economic origin inasmuch as is computed from the household density not connected to the sewage disposal system. In order to reference the values with respect to the expected value for the city, the median of all household density for the whole city is subtracted from each value calculated as explained above. Moreover, to reduce the range of this variable, the values are divided by the maximum value found

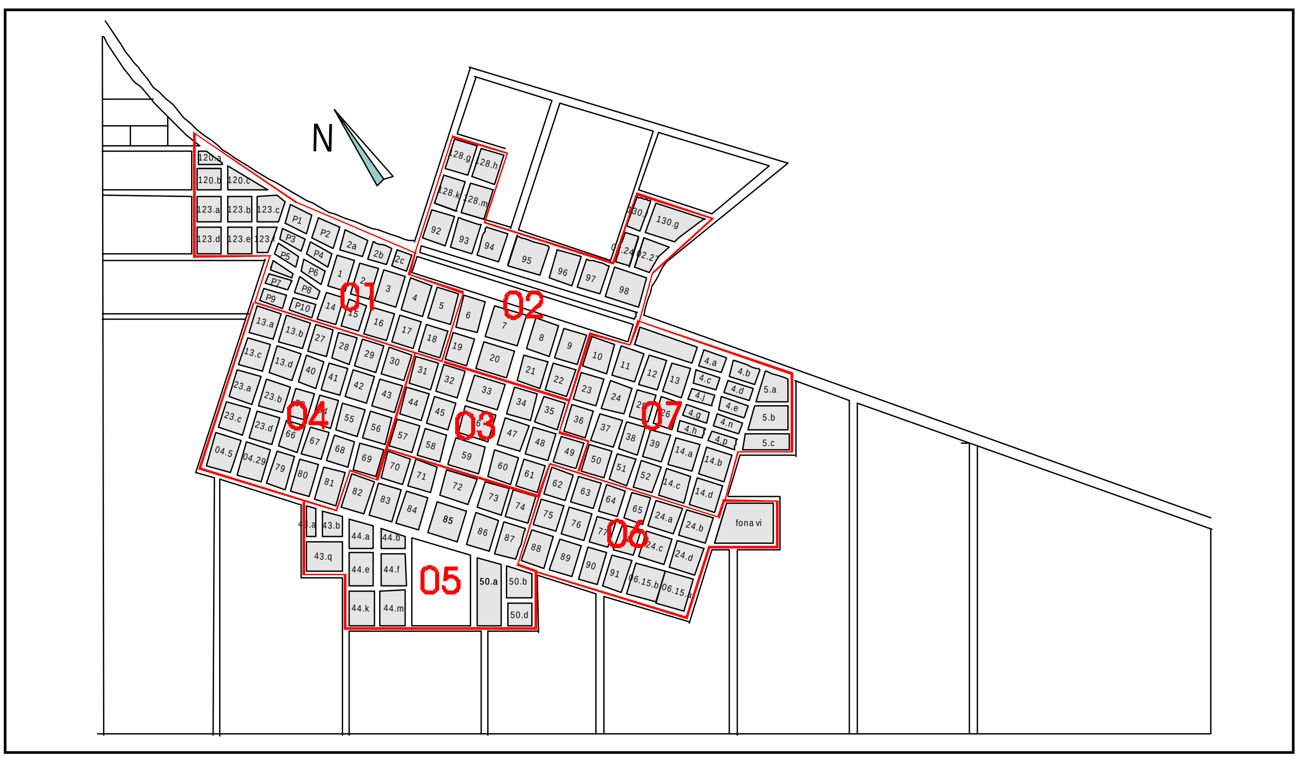

Figure 2. Identification and distribution of census sectors in Salliqueló (INDEC, 1998)

in the city. Thus,

$$WAM = (\delta HWSD - Me1) / (\text{Max } \delta HWSD - Me1) \qquad (4)$$

$\delta HWSD$ = density of households without sewage disposal

$Me1$ = median of density of households without sewage disposal

Max = maximum value of density of households without sewage disposal

Range of WAM: 0-1

A "future worsening mechanism" for the source, or *WFM*, is also considered by assuming that, as population grows, more cesspools will be added. In blocks not connected to the actual sewage disposal system, the assumption was made that half of the free land (i.e., not yet built) will be occupied by a house provided with a cesspool. In blocks already connected to the sewage disposal system, the *WFM* is zero because new dwellers will not need cesspools. Then,

$$WFM = (\delta HWSD + ½\,\delta FL) - Me2 / (\text{Max } \delta HWSD + ½\,\delta FL) - Me2 \qquad (5)$$

δFL = Density of free land in blocks without sewage disposal

$Me2$ = Median of density of households without sewage disposal plus 50 percent of free land in block without sewage disposal

Other symbols as above.

Range of WFM = 0-1

SURVEY IN SALLIQUELO DATE:

BLOCK IDENTIFICATION:

HOUSEHOLD IDENTIFICATION IN BLOCK:

1) BUILDING QUALITY:

VERY GOOD………… GOOD………….. FEAR………….. BAD…………………………

2) NUMBER OF PEOPLE IN THE HOUSE: TOTAL:…………………………

0 - 3 YEARS OLD:…………………………..

4 -12 YEARS OLD:…………………………..

13 - 65 YEARS OLD:…………………………

MORE THAN 65 YERAS OLD:……………

3) IS THE HOUSE CONNECTED TO THE MUNICIPAL WATER SUPPLY? YES…………………

NO……………………………

IF NO ABOVE, WHAT IS THE DEPTH OF YOUR DOMESTIC WELL?……………………………………………

HAVE YOU EVER EXPERIENCED PROBLEMS/DISEASES FROM DRINKING WATER? ……….

WHAT TYPE OF PROBLEMS?……………………………………………………………………………

…………………………………………………………………………………………………

WHAT WHERE THE CONSEQUENCES FROM SUCH PROBLEMS/DISEASES?……………………………..

…………………………………………………………………………………………………

…………………………………………………………………………………………………

HOW DID YOU SOLVE THOSE CONSEQUENCES?……………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

4) **IS THE HOUSE CONNECTED TO THE MUNICIPAL SEWAGE DISPOSAL SYSTEM ?**

YES………………… NO…………………..

IF NO ABOVE, WHAT IS THE DEPTH OF THE CESSPOOL? …………………………………………………

5) **ASIDE FROM DRINKING, DO YOU USE WATER FOR ANYTHING ELSE?**
YES………………… NO……………………
WHAT TYPE OF USES?……………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

6) SUGGESTIONS/REMARKS YOU WOULD LIKE TO MAKE: …………………………………………………

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Figure 3. Poll form used in Salliqueló.

Like *WAM*, *WFM* values are related to the largest value found in the city.

The information used to define the source worsening mechanisms *WAM* and *WFM* came from an exhaustive polling questionnaire which is shown in Figure 3, covering each block in the urban area. The survey also provided elements to determine the exposure levels and the targets. The poll was carried out on one third of the households, which on the average was 5 households/block for a total of 700 households in the city. The assumption is made that whatever is valid for 1/3 of the households in the block represents the status of that block.

The source (S) was then computed by adding up the biological and hydrochemical sources (BS, HS), and multiplying by the sum of the actual and future worsening mechanisms (WAM, WFM). One was added to WAM and WFM to highlight the worsening features:

$$S = (BS + HS)\,[(WAM + WFM) + 1] \tag{6}$$

Range of S = 0-∞

Exposure characterization

The exposure is not only related to the probability of physical contact (primary exposure factor, *PEF*) but also to socio-economic variables (*SEF*). The *PEF* is given by the number of households that do not have access to safe water supply (*HNWS*) relative to the total number of households in the block (H):

$$PEF = HNWS/H \tag{7}$$

Range of values for PEF = 0-1

The *SEF* is a bit trickier to evaluate. It has to be related to attitudes and consciousness about the issue of water resources uses and potential risks. The *SEF* was assumed to be as follows:

$$SEF = CE + EL + HE + HS + SC + RT + 1 \tag{8}$$

CE = consciousness about exposure, which was evaluated from the poll answers (assuming that as the consciousness level decreases, the exposure gets worse),

EL = educational level of the family chief or the eldest, taking the elementary school cycle (completed or not) as the threshold index,

HE = household equipment. INDEC (1998) indicates which households are of the “B” type, meaning low-quality construction and assumed to be prone to exposure,

HS = household stacking, which INDEC (1998) defines as houses that hold more than 3 people/room,

SC = secondary contact, which emerges after considering in-house water uses other than direct drinking (irrigation, washing, swimming pools filling up, etc.),

RT = risky targets, which refers mainly to children (0-4 years old) and older people (> 65 years old)

Note: all *SEF* parameters are relative with respect to the total for each block.

The exposure (E) is estimated as the product of *PEF* and *SEF*, added to one to avoid zero values:

$$E = PEF\ SEF + 1 \tag{9}$$

Range of values for E: 1-8

Target Characterization

Targets were computed as the number of people per unit area. As done with the source worsening mechanisms, the current population was taken into account as well as its future growth (half of the unconstructed land will be occupied by houses with a population density as it is today). Therefore, the target equation is as follows:

$$T = \delta P + \delta(1/2\ FL\ P/H) \tag{10}$$

δP = current population density per block

FL = free land per block

P = number of people per block

H = number of households per block

This expression has no maximum.

Finally, Equation 1 was computed to define the risk for each block. The results were displayed as thematic maps of each primary variable in Equation 1 (Figure 4, for example, shows the source *S* characterization), and as a summary map showing the values for the entire polynomial expression.

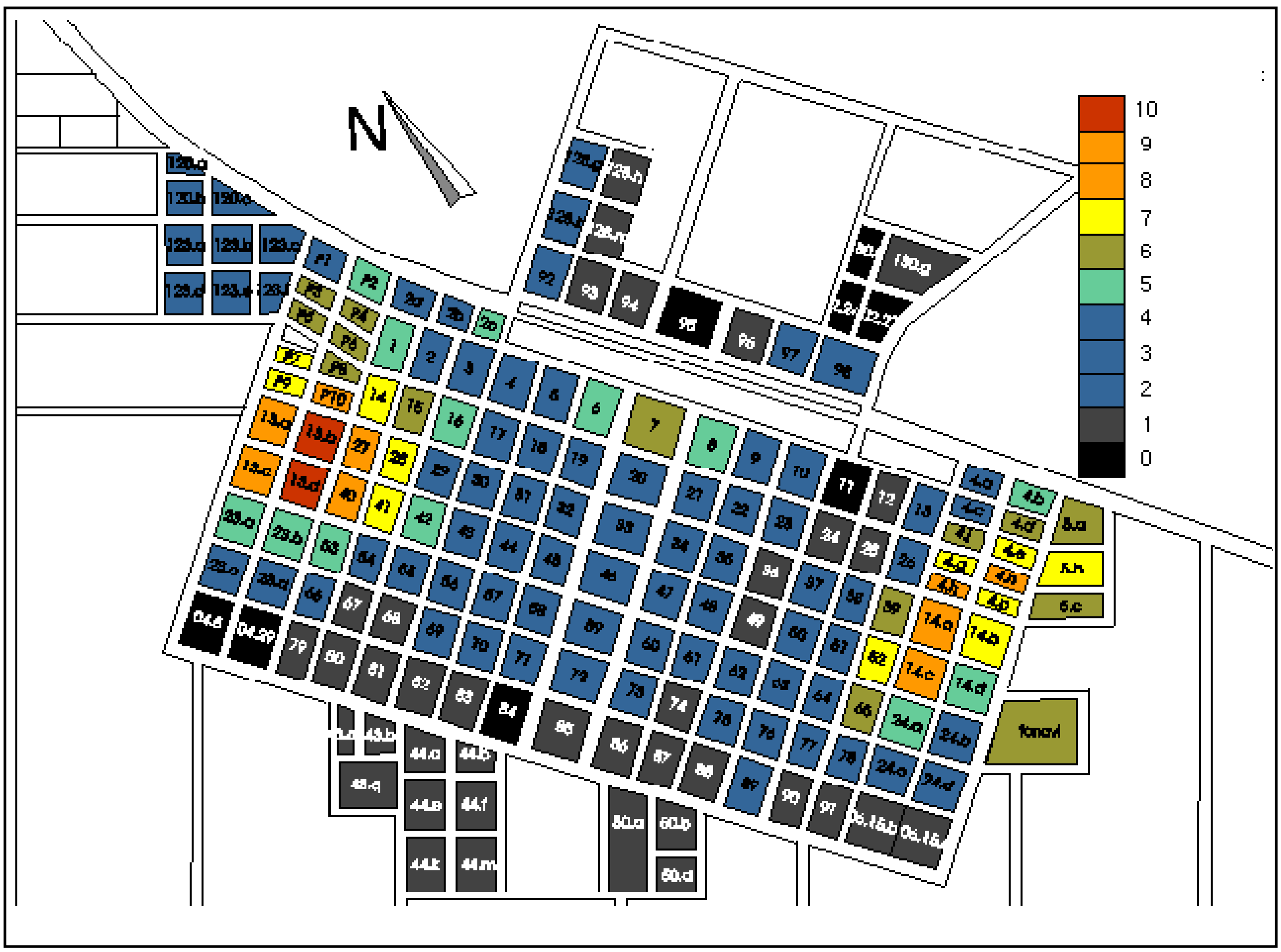

Figure 4. Thematic map showing the caracterization of the hydrochemical source (cold colors: low risk; hot colors: high risk).

In order to facilitate the visualization, the values from Equation 1 were transformed into a chromatic scale of ten levels of severity, from low risk (cold colors) to high-risk (hot colors).

DISCUSSION AND CONCLUSIONS

The methodology described is a trade-off between robustness on one hand, and simplicity, information requirements, and reduced execution costs on the other hand. The thematic maps obtained represent a useful tool for urban planning, either by inspecting the distribution of the primary variables or the resulting risk map.

The source, i.e., the groundwater, has been treated as a homogeneous black box system to which any person is exposed. Actually, water quality depends on the depth of the domestic wells and the proximity to cesspools. Another uncertainty is the underlying assumption that no other source exists or, better said, that the regular supply water is safe. This appears to be the case in Salliqueló, where the water supply is rather homogeneous in quality.

It should be pointed out that, because of the scaling procedure used for each variable, this methodology does not render absolute values for the water-related risk.

It is also difficult to evaluate the relative weight of the variables, much more when it comes to estimating the indirect exposure (notably, *SEF*), or where the degree of severity is diverse (such as in evaluating the source). The different ranges (HS = 0-∞, BS = 0-3) would seem to give more importance to *HS* with respect to *BS*. However, the calculated values for *BS* are relatively small (the extreme value of infinity is a theoretical one). As a matter of fact, *BS* turned out to be numerically more relevant than *HS*, which agreed with local hospital records (Carlino, 2000) showing a great incidence of waterborne pathologies (chiefly, diarrhea). Except for *HS* and *BS*, the other variables have equivalent weights.

Using the census sectors defined by INDEC (1998) turned out to be a limitation in that it did not allow a more precise definition of the *BS*. Indeed, the bacteriological contamination is a form of point-pollution that should not be extrapolated to much larger areas. However, it had to be treated that way in order to be consistent throughout the analysis.

This risk analysis takes into account behavioral and socio-economic factors (educational level, household quality, household stacking, etc.) as indicators of the exposure pattern. It may be argued that those factors have to be standardized somehow, which is true unless one realizes that the objective is not the estimate of an absolute risk. The aim is to find a simple way of displaying the spatial variability of risk, which was done and found to match previous scattered information and the general perception.

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