NITROUS OXIDE POLLUTION: A GEOSTATISTICAL METHOD TO ASSESS SPATIAL DISTRIBUTION OF ANAESTHETIC GASES AND HOSPITAL STAFF EXPOSURE

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ABSTRACT

In this study we evaluated the diffusion of nitrous oxide in a few operating rooms, using spatial data modelling techniques, in order to assess hospital staff exposure and to promote risk management. Indoor air sampling was carried out, during routine operating activity, by means of transportable infrared spectrometer, with geostatistical techniques. We detected high average concentrations of nitrous oxide (from 8 ppm to 445 ppm, with a peak of 1345 ppm). Linear geostatistical iso-value maps of the anaesthetic gas expected values showed an evident nitrous oxide-rising trend near the anaesthetic machines, near walls and doors, near HVAC opening, etc. Operators' attention to maintenance procedures of the anaesthetic machines, and to hazard management of the operating room, can reduce health risks of the hospital staff exposed. To conclude, we have to underline that an assessment performed only on "*mean"* samples and calculated through descriptive statistics, would not allow any inferences in the complex spatial structure and physical kinetics evidenced by geostatistical methods.

KEYWORDS

Hospital, Operating Theatre, Air Pollution, Exposure Assessment.

INTRODUCTION

Hospitals differ from commercial and residential buildings and they are, in many ways, unique environments [1].The technological progress recently occurred in the biomedical field has determined not only a therapeutic improvement, but also a change in the concept of "*hospital*". Innovations in medical technology have improved hospital services, but have also determined some previously unrecognised potential risk factors[2]. Furthermore, while continuos modernisation and updating of hospital equipment and instruments has occurred, structure and maintenance of hospital facilities has changed very little. Due to the necessity of night-and-day continuos activity, hospitals rarely shut down for cleaning, repairs and renovations, and maintenance is therefore more difficult. So, quality of indoor air inside hospital buildings is an important factor considering its health relevance affecting patients' well-being, working performance of hospital workers (for whom exposure is an undesired consequence of their working environment), and safety of visitors [3]. More specifically, workers in hospital environment, such as operating theatres, have potential exposure to numerous chemical hazards [4]. Many epidemiological surveys have shown, even if not in a conclusive way, a relationship between occupational exposure of operating theatre personnel to anaesthetics (such as, among others, nitrous oxide) and onset of toxic symptoms or increased mutagenic risk due to headache, loss of attention and concentration [5], depression, and malignant diseases [6]. In addition, epidemiological data suggest an association between nitrous oxide exposure and adverse pregnancy outcome [7,8]. The Italian Ministry of Health recommends that exposure to nitrous oxide (N_2O) be limited to a time-weighted average air

concentration (TLV-TWA) of 100 and 50 ppm, for already existing and for newly constructed or renovated operating rooms respectively [9].
The purpose of the study is to analyse and evaluate the distribution of nitrous oxide indoor pollution in the operating rooms of an Italian hospital, in order to assess exposure health risk for hospital staff. To best characterise the investigated phenomena, we proposed to view it as spatial process, expecting the informative content of measurement location to be helpful in identifying the possible sources of the nitrous oxide.

METHODS

The study was carried out in the operating theatres of a hospital of about 400 beds, following Hospital Management's request to determine the gaseous anaesthetic risk in operating room environment**.** The concentration of N_2O has been measured, during routine operating activity, by means of a transportable infrared spectrometer based on "photoacoustic" measurement of infrared absorption and confirmed by another infrared spectrometer and gas-chromatography/mass-spectrometry system [10].The probes, during sampling, were simultaneously located at breathing height above floor level (1.5 m). Data were taken at 1 minute internal average intervals, and N_2O concentrations are expressed as TWA in ppm.
In this study, data were analysed using ordinary descriptive statistics and, at the same time, spatial structure of estimated N_2O levels was studied modelling the spatial variability, following geostatistical analysis principles [11]. Often, environmental sampling data are studied using only descriptive statistics, as "average" values, without analysing spatial and temporal data distribution. Geostatistical techniques, by modelling spatial phenomena, reduce the number of the necessary samplers and permit to estimate environmental sampling values in places where it is difficult or impossible put a sampler.
Geostatistics, in fact, offer a variety of methods to model such processes as realisation of random functions [12]; and geostatistical methods analyse the behaviour of variables and their spatial correlations, and model the spatial structure of their variability, in order to estimate values (biological, physical or chemical) in a different matrix (air, water or soil) not directly measured or in order to expect future levels of indoor pollutants [13].
The most popular geostatistical techniques are now Linear Geostatistic and Stationary Geostatistic, but when it is necessary to estimate directional trend of values it is useful to adopt Non Stationary or Non Linear Geostatistics: according to these theories, all measures can be interpreted as an aleatory function. It is important to remark that likelihood interpretation of the spatial phenomena is not an image of physics reality. In the spatial correlation of variables (spatial variability or "variogram function"), the value of the chemical substance measured, during sampling, in one site, allows the estimation of values of the same substance in nearby sites.

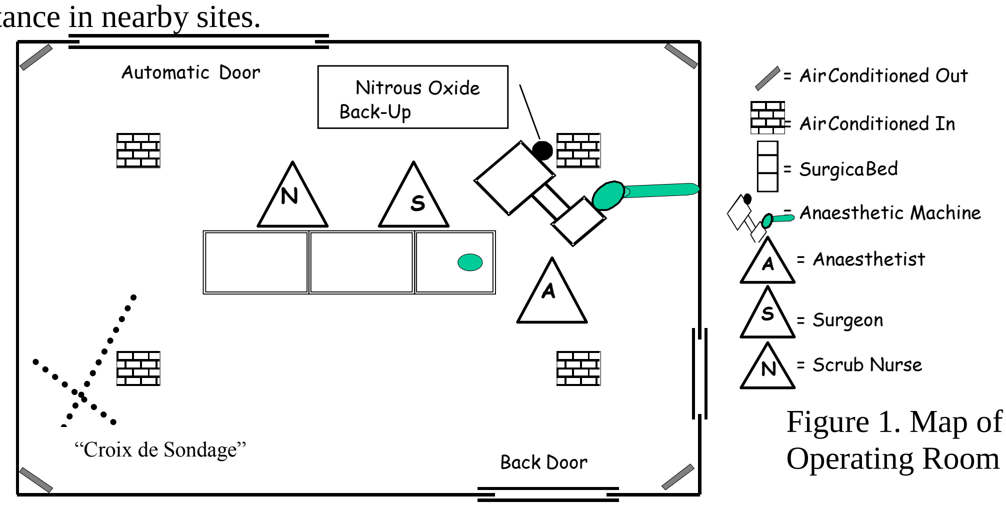

Figure 1. Map of the B Operating Room

Directional variograms were computed according to the results of the sampling technique called "Croix de Sondage" (Figure 1) and variogram models were proposed as structures for spatial variability of N_2O [14]. "Croix de Sondage", in this study, was carried out by placing samplers at regular distances in order to form a cross on a corner of the whole sampling site. After this first sampling, a regular grid (*Spatial Geostatistics - FAIk Kriging*) was planned, putting sampler' probes (16sampling sites) at the same height as far Croix de Sondage sampling and at the distance showed by the variogram **(**about 120 centimetres; this choice was made in order to guarantee the most prudential predictability of the estimate of measured values, as well as the most accurate.) (Figure 2) [15].

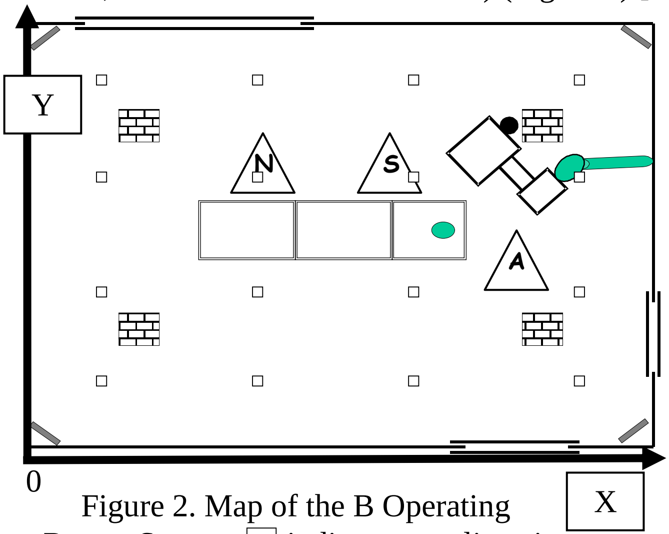

Figure 2. Map of the B Operating Room. Squares □ indicate sampling sites

Such model parameters consist in the distance beyond which the measured values should be considered independent (called "range") and the variance between independent samples (called "sill"). Furthermore, the structure of spatial variability which differs geometrically is called "anisotropic" [16].
Four series of N2O sampling, for each one of four operating rooms, were carried out and the results were analysed by means of descriptive statistics [17]. Finally, expected values at the nodes of a regular grid were calculated to plot contour and iso-value maps of estimated N_2O levels in B Operating Room [15].

RESULTS

The descriptive statistic results of Croix de Sondage are summarised in Table 1. It shows the average, minimum and maximum concentration values of N_2O in all operating rooms.

Table 1. Croix de Sondage sampling series of indoor N_2O average, min. and max. levels in ppm

Operating Rooms	Observations	Average	Min.	Max.	S.E.
A	4480	8	0	45	10
B	5680	45	0	165	18
C	5264	99	0	305	39
D	4688	445	15	1345	102

The calculated variogram shows that there is an elderly variability for a distance between the samplers of about 120 centimetres, whereas for a distance of about 200 centimetres the phenomena have no correlations and become stationary. The presence of a little trend was suitable to estimate as no-stationary the phenomena observed and to utilise FAI-k method modelling geostatistic variogram and iso-value maps. As an example of geostatistic modelling, we have illustrated the geostatistical sampling of N_2O (only B Operating Theatre) during:

- anaesthesia induction (intubation)
- desired surgical plane of anaesthesia
- end of the operation

Parameters in models of the N_2O's spatial structure appeared not to be constant, as shown in Table 2.

Table 2. Variogram modelling: the parameters resulted for each model of N_2O anaesthesia

N_2O	Sill	Anisotropy	Model	Range	Nugget	IGF
anaesthesia induction	2.07138	2.4	Gaussian	409.5	1.73838	0.0667
surgical plane of anaesthesia	14.3106	11.0	Gaussian	311.4	4.0608	0.0289
end of the operation	225.96	1.0	Gaussian	412.9	244.04	0.1020

Notice that the main structure of the spatial variability model is the same for all measurements and that range and anisotropy values proposed show little different variability, whereas the sill values appear to be more dispersed. Moreover, the Indicative Goodness of Fit (IGF), which gives a measure of how well the model adjusts the directional variograms, lies in almost all models in proximity of its target value zero, in agreement with the hypotheses of a well characterised and constant spatial structure.

The directional variograms and variogram clouds (variance) are shown in Figure 3, referred to the N_2O measurements during the different phases of anaesthesia in the B operating room.

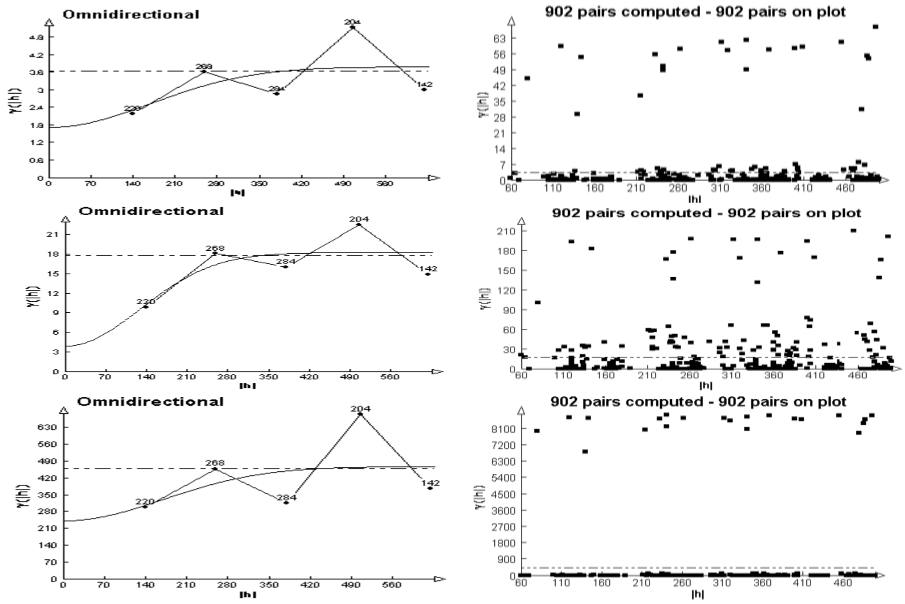

Figure 3. Directional variograms and variogram clouds of N_2O during anaesthesia induction (Omnidirectional, up), surgical plane of anaesthesia (Omnidirectional, meddle) and at the end of the operation (Omnidirectional, down)

The dashed line, in figure 3, shows the before-hand expected overall variance of the whole sample, and represents the value expected if all samples were independent. In direction showed (omnidirectional) the observed variability lies below the overall variance until about 250-300 centimetres. This is an example of isotropic process (a process presenting a symmetrical spatial structure): measurements are strongly correlated within 250-300 centimetres to the all directions. Owing to difficulties filtering trends and applying universal kriging, FAI-k was used in this study. Generalised covariance models for 0 and 1 k-order (stationary and no-stationary models) of N_2O during sampling phases are illustrated in table 4.

Table 4. Generalised Covariance Models of N_2O sampling during anaesthesia in B room

N_2O	K order	Average Rank	Quadratic Errors	B_0 Nugget	B_1 Linear	B_3 Cubic	B_s Spline	Jacknife ≈ 1
anaest.-induct.	1	1.8750	2907.2504	0	- 13.4359	0	0	0.8987
plane of anaest.	0	1.7500	665.2343	638.7920	0	0	0	0.9256
end-operation	0	1.6875	738.4765	410.9529	- 0.4042	0	0	1.0016

Finally, figures 4, 5 and 6 show an example of 2D/3D (Orthonomic-z Axis) contour and iso-value maps of N_2O levels estimated values obtained by value's estimation at the nodes of a regular grid based on the models of spatial variability proposed. The dark grey areas, in figures, indicate higher levels of N_2O , the light grey areas indicate lower levels of N_2O.

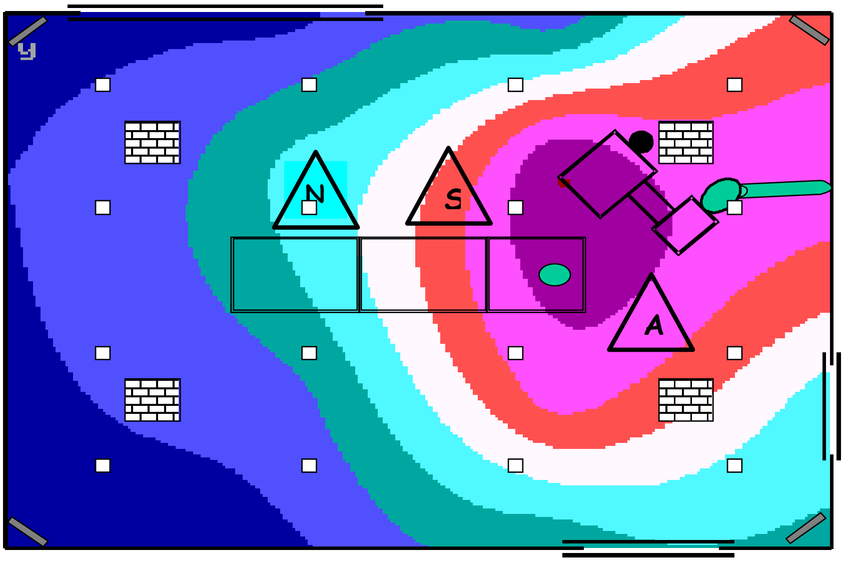

Figure 4. Iso-value map of N_2O levels estimated in Operating B Room during anaesthesia induction.

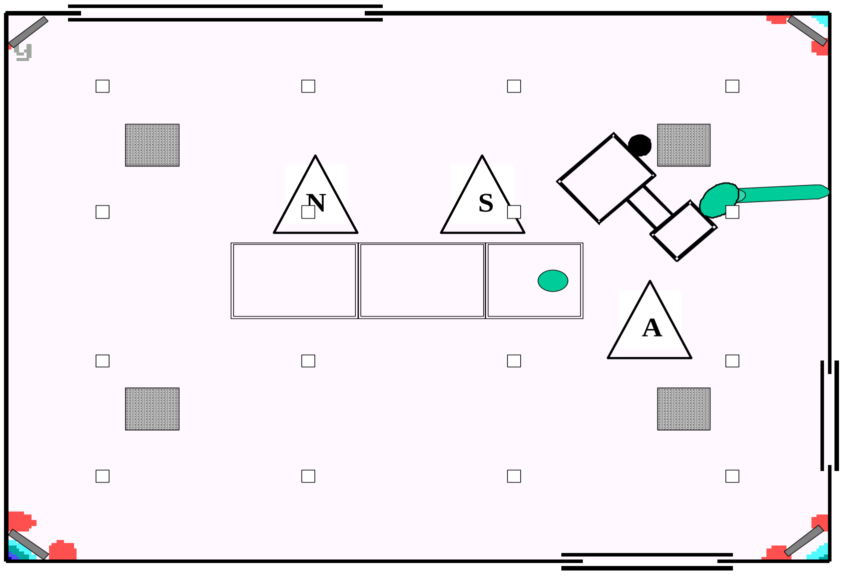

Figure 5. Iso-value map of N_2O levels estimated in Operating B Room during surgical plane of anaesthesia.

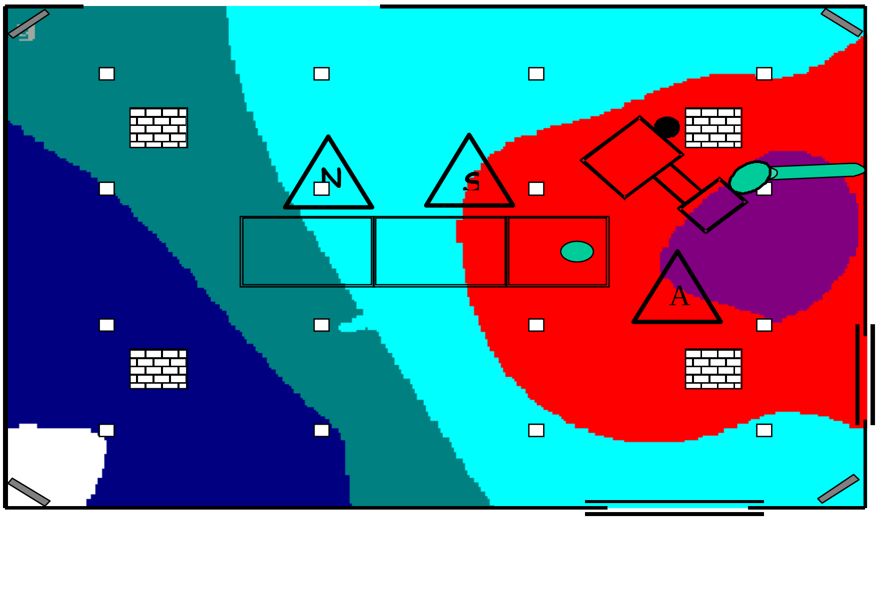

Figure 6. Iso-value map of N_2O levels estimated in Operating B Room at the end of the anaesthesia and the operation

DISCUSSION

The indoor average concentrations of N_2O ranged from 8 (Room A) to 445 ppm (Room D) (Table 1). These results, in particular, may suggest leakages or emissions from anaesthetic masks, from nitrous oxide cylinders, or from failure of the air conditioning system (HVAC) and from errors and omissions in estimated maintenance procedures (filter exhausts of the aspiration system not replaced, etc.). Without such leakages, the critical factors for the air quality is the efficacy of the air conditioning and filtration system. The evaluation of the air conditioning plant efficacy cannot be done only on the basis of the number of air exchanges, that does not take into account the real route of the air in the room. In fact, during the operation, the N_2O is higher near the air conditioning openings (see Figure 5), than in the centre of the room. On the other end, during anaesthesia induction and at the end of the operation, the air conditioning plant is not efficacy in order to ventilate and "clean" the indoor environment (Figures 4 and 6). The complex gas dynamic and non stationary distribution justify the frequent reports of headache, drowsiness and loss of attention among the operating theatre staff, in spite of low N_2O levels (highest areas are close to anaesthetist, surgeon and scrub nurse). In conclusion, in order to assess the health risk for the Operating Theatre Staff correlated to indoor exposure to nitrous oxide, we monitored and evaluated the N_2O indoor using the geostatistical analysis approach. We have to remark, in fact, that an assessment performed only on "*mean*" samples at the centre of the investigated rooms would not allow any inference of the complex spatial structure and physical kinetics evidenced by geostatistical methods. Therefore, emphasis must be placed on primary prevention strategies in hospital environment. Material replacements, engineering controls, safe work practices, HVAC specifically designed for Operating Room environment and use of individual or general protective equipment are needed to reduce exposures.

ACKNOWLEDGEMENTS

We would like to thank Dr. P. Rossi and Miss I. Pititto for their precious collaboration for the accomplishment of the study.

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