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Risk of a false decision on conformity of an environmental compartment due to measurement uncertainty of concentrations of two or more pollutants

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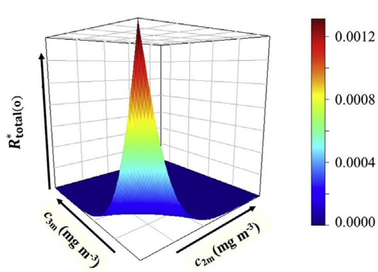
HIGHLIGHTS

- Evaluation of total risks of false decisions on conformity of an environmental compartment is developed.
- The total risks due to measurement uncertainty of concentrations of two or more pollutants are considered.
- As a case study, the total risks are evaluated at control of total suspended particulate matter (TSPM) concentration in air.
- The study concerns three independent stone quarries as pollutant sources.
- The total probabilities of under- and overestimation of TSPM concentration in air are calculated.

GRAPHICAL ABSTRACT



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ABSTRACT

Risks of false decisions in conformity assessment of an environmental compartment due to measurement uncertainty of concentrations of two or more pollutants are discussed. Even if the assessment of conformity for each pollutant in the compartment is successful, the total probability of a false decision concerning the compartment as a whole might still be significant. A model of the total probability of a false decision, formulated on the base of the law of total probability, is used, for example, for a study of test results of total suspended particulate matter (TSPM) concentration in ambient air near to three independent stone quarries located in Israel, as the sources of the air pollution. Total probabilities of underestimation of TSPM concentration (total risk of the inhabitants) and overestimation (total risk of the stone producers) are evaluated as a combination of the particular risks of air conformity assessment concerning TSPM concentration for each quarry. These probabilities characterize conformity of the TSPM concentration in the region of the quarries as a whole. Core code developed in R programming environment for the calculations is provided.

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1. Introduction

Actual ('true') concentration c_i of the i-th pollutant, $i = 1, 2, \ldots, n$, in an environmental compartment, e.g. ambient air (Duursma and Carroll (1996); TIMBRE project, Online), should not exceed a regulation or legal tolerance upper limit T_{Ui}. 'Concentration' is used here as a generic term (Cvitaš, 1996; Tolhurst, 2005; Fuentes-Arderiu, 2013). Comparing a chemical analytical test/measurement result c_{im} of the i-th pollutant concentration with the T_{Ui} value, one should decide whether the compartment conforms to the regulation or not. Since any result c_{im} has an associated measurement uncertainty (Ellison and Williams, 2012; Magnusson et al., 2012), several kinds of risk of a false decision on conformity of the compartment may arise.

The probability of a decision that the actual pollutant concentration does not exceed the limit since $c_{im} \le T_{Ui}$, when it is not correct (i.e. $c_i > T_{Ui}$), is named 'consumer's risk'. The 'consumer' in the present paper is a habitant whose quality of life (including health) depends on adequate control of the pollutant. Thus, the consumer's risk is the probability of underestimation of c_i due to measurement uncertainty associated with c_{im}.

On the other hand, the probability of falsely rejecting the decision on conformity of the compartment to the regulation (i.e. $c_{im} > T_{Ui}$ when $c_i \le T_{Ui}$) is the 'producer's risk'. The 'producer' here is a plant or another organization – a source of the environment pollution, obliged to pay a fine and/or to invest money for an unnecessary reduction of the pollutant concentration in the case of false nonconformity. The producer's risk is therefore the probability of overestimation of c_i due to measurement uncertainty in c_{im}.

For a specified compartment, e.g. ambient air in a certain location at a certain time, such risks are referred to as the 'specific consumer's risk' of underestimation $R^*_{ci(\mathrm{u})}$ and the 'specific producer's risk' of overestimation $R^*_{ci(\mathrm{o})}$ for i-th particular pollutant concentration. The risks of incorrect conformity assessment of a compartment randomly drawn from a statistical population of such compartments are the 'global consumer's risk' of underestimation $R_{ci(\mathrm{u})}$ and the 'global producer's risk' of overestimation $R_{ci(\mathrm{o})}$, respectively, as they characterize the environmental quality globally. Evaluation of the particular risks (both specific and global) is described in the JCGM 106 (2012) based on a Bayesian approach to conformity assessment.

However, when concentrations of two or more pollutants are controlled, pollutant-by-pollutant evaluation of the risks is not complete in general, as it does not give an answer to the question of the probability of a false decision on the overall compartment conformity. If conformity assessment for each i-th pollutant concentration of a compartment is successful, i.e. the particular specific R^*_{ci} or global R_{ci} risks of both under- and overestimation are small enough, the total probability of a false decision concerning conformity of the compartment as a whole (the *total* specific R^*_{total} or *total* global R_{total} risk) might still be significant.

A scheme summarizing the used terminology is shown in Fig. 1, where the particular risks described in the JCGM 106 (2012) are shown at the top of the scheme. The *total risk evaluation*, as the task of the IUPAC Project (2016), is highlighted by an ellipse at the bottom of the scheme.

Using the law of total probability for the case of independent quantities (pollutant concentration values and corresponding measurement results) the total risk of underestimation can be evaluated as a combination of the particular risks (Kuselman et al., 2017a). For example, for three pollutions $i = 1, 2, 3$, assuming independent actual values of each pollutant concentration c_i and independent corresponding measurement results c_{im}, the total specific risk of underestimation is:

$$R^*_{\mathrm{total(u)}} = R^*_{c1(\mathrm{u})} + R^*_{c2(\mathrm{u})} + R^*_{c3(\mathrm{u})} - R^*_{c1(\mathrm{u})}R^*_{c2(\mathrm{u})} - R^*_{c1(\mathrm{u})}R^*_{c3(\mathrm{u})} - R^*_{c2(\mathrm{u})}R^*_{c3(\mathrm{u})} + R^*_{c1(\mathrm{u})}R^*_{c2(\mathrm{u})}R^*_{c3(\mathrm{u})} \quad (1)$$

E.g., for all the particular specific risks $R^*_{ci(\mathrm{u})} = 0.05$, the total specific risk by formula (1) is $R^*_{\mathrm{total}} = 0.14$. Total global risk of underestimation for the three pollutants is:

$$R_{\mathrm{total(u)}} = P(\mathrm{C}_2)P(\mathrm{C}_3)R_{c1(\mathrm{u})} + P(\mathrm{C}_1)P(\mathrm{C}_3)R_{c2(\mathrm{u})} + P(\mathrm{C}_1)P(\mathrm{C}_2)R_{c3(\mathrm{u})} - P(\mathrm{C}_3)R_{c1(\mathrm{u})}R_{c2(\mathrm{u})} - P(\mathrm{C}_2)R_{c1(\mathrm{u})}R_{c3(\mathrm{u})} - P(\mathrm{C}_1)R_{c2(\mathrm{u})}R_{c3(\mathrm{u})} + R_{c1(\mathrm{u})}R_{c2(\mathrm{u})}R_{c3(\mathrm{u})}, \quad (2)$$

where $P(\mathrm{C}_i)$ is the probability that a measurement result c_{im} is acceptable, i.e. $c_{im} \le T_{Ui}$. For example, for the particular risks $R_{ci} = 0.05$ and probabilities $P(\mathrm{C}_i) = 0.90$ for all i, formula (2) gives $R_{\mathrm{total}} = 0.12$.

General expressions for evaluating the total risk of underestimation for any number n of the material components (or pollutants of an environmental compartment) are also provided in the mentioned above reference. Treatment of correlated measurement results for total risk evaluation is discussed in the paper by Kuselman et al. (2017b).

In the present paper, the total risk of overestimation (producer's risk) is formulated in the same Bayesian framework for uncorrelated test results as it was applied in the previous work (Kuselman et al., 2017a) for underestimation (consumer's risk). Core code developed in R programming environment (The R project, Online) for corresponding calculations is also provided. As a case study, total risk values are calculated for conformity assessment of concentration of total suspended particulate matter (TSPM) in ambient air from three independent stone quarries in Israel. In this study TSPM contributed by the i-th quarry, $i = 1, 2, 3$, is considered as the i-th pollutant. While particular risk values of false decisions on conformity of the i-th TSPM concentration, evaluated earlier (Kuselman et al., 2012a), were related to each i-th pollutant (i-th quarry) separately, the total risk values discussed below allow characterization of conformity of the TSPM concentration in the region of the quarries as a whole. That is important as for the Regulator (The Ministry of Environmental Protection, Online) protecting the inhabitants' quality of life in the area surrounding the quarries, as for The Manufacturers Association (Online) acting in the interests of the stone producers in the country.