Odour nuisance: decision support tools to anticipate and represent levels of odour nuisance on a territory

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Several activities can cause unpleasant odours: waste storage and treatment, refinery, animal breeding, slaughterhouse, sewage treatment plant, pulp mill, fertilizer plant… Even if these unpleasant odours very rarely have toxic effects, they have an impact on the image of the emitting activity, the quality of life and, to a larger extent, on the functioning of the territory. It is this last observation, and the population's growing demand for the quality of its living environment that has led decision-makers and industrialists to address the problem of odour emissions.
Until now, there is no standard method for assessing odour nuisance on a territory. Several methods exist and their use depends on the objectives and resources of the stakeholders. Few models have been developed to predict odour nuisance on a territory.
The purpose of this article is to explain the interest of predictive methods in the evaluation of odour nuisance on a territory. For this purpose, this article presents an example of a method that anticipates and maps the levels of odour nuisance on a territory and the economic consequences that it causes. Based on a risk analysis method, the model uses AHP method, a multi-criteria approach, to assess the effect (nuisance) of the exposure on receptors. (Popa 2013). This method provides a paradigm shift from a posteriori measurement of odour nuisance to a preventive approach used as a decision support tool.

Keywords: odour, odour nuisance, odour annoyance, risk, vulnerability, predictive model, multi-criteria approach, GIS.

1. Introduction

In recent years, the number of odour complaints is strongly increasing. This observation may be the result of urban expansion that brings habitations closer to industrial zones (Popa 2013), a certain awareness of environmental issues that is developing on a world scale (Dartiguepeyrou 2013), or an increase in our standard of living in line with an increase in our demands (Jaubert 2010). Populations are nowadays increasingly attentive to the quality of their living environment (Conti, Guarino, and Bacenetti 2020). Even if there is no notion of toxicity behind these unpleasant odours, they have an impact on the image of the emitting activity, the quality of life and, to a larger extent, on the functioning of the territory.

A predictive model for assessing odour nuisance was developed and validated around a rendering plant (Popa 2013). Based on a risk analysis method, the objective was to measure and predict the odour impact of an existing or future industry on a territory. It was used to represent the level of odour nuisance and its consequences on the territory, in order to have a better management of the industrial site in terms of emissions, but also to provide decision support to stakeholders by choosing the location of future odour-emitting installations in the most relevant way possible.

The article is structured as follows: a first section introduces the concept of annoyance and the process that leads to odour nuisance. The next section presents the different methods available to assess and quantify odour nuisance. A third section presents the example of a predictive model for odour nuisance assessment that allows a proactive management of odour problems by going beyond individual representations. A final section discusses concluding remarks and perspectives.

2. Notion of odour nuisance

From a semantic point of view, the terms “annoyance” and “nuisance” are often overused. It is fundamental to clearly define the concepts they cover. This article is based on Van Harreveld's definitions, which are now used by the UK Institute of Air Quality Management (IAQM).

This requires to start from the notion of odour. Odour is a subjective and affective interpretation by the brain, resulting from the stimulation of the olfactory system by an odorous compound or a mixture of odorous compounds (Delva, Cobut, and Fanlo 2017). This stimulation can lead to a positive or negative perception depending on the characteristics of the individual, his or her experience, the context of the perception, etc. If the feeling is negative, the odour then constitutes an annoyance.

Van Harreveld defined the annoyance as “the complex of human reactions that occurs as a result of an immediate exposure to an ambient stressor (odour) that, once perceived, causes negative cognitive appraisal that requires a degree of coping” (Van Harreveld 2001). The IAQM specifies that annoyance is “the expression of disturbed well-being induced by adverse olfactory perception in environmental settings. Odour annoyance occurs when a person exposed to an odour perceives the odour as unwanted”. Annoyance may, or may not lead to nuisance and to complaint action (Bull 2018).

Odour nuisance indicates the cumulative effect on humans, caused by repeated events of annoyance over an extended period of time, that leads to modified behaviour. Nuisance occurs when odour is perceived in the living environment (home, work, etc.) and (Van Harreveld 2001):

- The appraisal of the odour is negative;
- The perception occurs repeatedly;
- It is difficult to avoid perception of the odour;
- The odour is considered a negative effect on their well-being.

Jaubert points out that nuisance is effective when an odour “polarizes our attention and prevents us from concentrating on our activities” (Jaubert 2005). Nuisance has an impact on people's well-being and negative effect on health. Confronted with this nuisance, some residents complain or try to take legal action, while others try to moderate their own emotional reaction (EAUK 2002; Van der Linden and Hoefnagel 1989).

Industries should take into account odour nuisance they may generate. However, industrialists or local decision-makers must frequently respond to local residents complaining about odour. Non-compliance with regulations and/or lack of communication may lead to a conflict between the local residents and the industry (Rognon and Pourtier 2010).

The notion of odour nuisance is difficult to characterize since it depends not only on the chemical or physical properties of the compound and the characteristics of the territory, but also on a process of perception and evaluation by populations (Jaubert 2010). When questioning residents annoyed by an odour, opinions differ on the description of odours, the acceptable or intolerable characteristics, the date of the last odorous episode, etc.

Evaluating odour nuisance must respond to complaints from the population and provides elements to propose and plan solutions to the industry (Jaubert 2010). The complexity of the process that leads to odour nuisance requires to be evaluated with the contribution of local residents (Rognon and Pourtier 2014) to obtain the opinion of each individual, while taking into account his or her experiences, memories and expectations regarding the territory studied (Delva, Cobut, and Fanlo 2017). Therefore, this evaluation should answer several questions (ADEME 2005):

- What is the origin of the odour?
- What is the relative contribution of a site's odours to other sources?
- Have the solutions implemented to reduce annoyance been effective?
- What are the relationships between the mode of exploitation, meteorology and the odour nuisance perceived by local residents?
- Which particular operating or manufacturing conditions are causing annoyance and complaints?

3. Assessment of odour nuisance

To this day, there is no standard method to assess odour nuisance on a territory. Several methods exist to evaluate the odour nuisance felt by the population. Each has its advantages, limitations and preferential applications (Bull 2018). These methods are called empirical or *posteriori methods*, i.e. they assess the odour nuisance after the odour episode. To summarize the methods found in the literature, five categories of methods are distinguished: surveys, local sniffing team, complaint analysis, indexes and dose-response model:

- Surveys of the population are used to report the current state of perceptions of residents

about their environment. They are useful for assessing the importance of odour annoyance in relation to other sources of annoyance (noise, light, neighbourhood, etc.) (Rognon and Pourtier 2014, 2010; ADEME 2005);

- A local sniffing team, through its regular odour observations, represents a structure for monitoring odours and odour annoyance. It measures the importance of the nuisance according to the different operating conditions of the industry and the meteorology (ADEME 2005; Rognon and Pourtier 2010);
- The complaint, whether formal or informal, is the most direct expression of the nuisance. Complaints from local residents can be analysed to monitor their evolution and assess the importance of the problem, to identify and prevent exceptional odour emission situations (Delva, Cobut, and Fanlo 2017; ADEME 2005; Rognon and Pourtier 2010);
- The calculation of indexes based on the results of surveys or local sniffing teams is the simplest way to quantify odour nuisance. There are used to estimate nuisance levels or define a percentage of the population annoyed on a territory. Several types of indexes exist: annoyance index, nuisance index, odour comfort index, global theoretical nuisance index, nuisance potential index (ADEME 2005; Popa 2013);
- Dose-response model describes the complex relationship between odour formation and resulting annoyance based on a correlation between exposure and population response. Exposure is described by an atmospheric dispersion model (dose) and population response (effect) is obtained using conventional survey methods and complaint analysis (Van Harreveld 2001; Popa 2013).

These methods highlight six main objectives:

- Identification of the odour source using local residents;
- Counting odour episodes. The calculation of episodes can be done through the analysis of spontaneous and solicited complaints or observations of residents;
- Calculation of the level of nuisance felt for each observer based on the number of odorous episodes, the meteorology or the operating conditions of the industrial site;
- Creation of an image of the perception of local residents. From the level of nuisance obtained for each observer, an image of the odour nuisance can be obtained in the affected area;
- Monitoring the evolution of the odour nuisance. It can be used to monitor the improvement measures taken by the industrial;
- Opening a dialogue between the different actors. Through survey methods and local sniffing teams, a dialogue between residents, industry and local decision-makers is emerging.

These empirical methods are mainly carried out in the receiving environment, after a crisis situation, where it is possible to characterize the perception of local residents. They are based on an individual representation of the odour nuisance. They do not evaluate the overall nuisance on a territory (Popa 2013), because they are based on a small sample of the population and under different conditions of perception for each individual (Sucker, Both, and Winneke 2001).

The methods and models presented above evaluate the odour nuisance after the odour episode has occurred. In the literature, many odour assessment methods measure odour exposure (impact). Few methods measure the resulting effect: the nuisance - and even fewer can anticipate it.

4. Prediction of odour nuisance

Posteriori methods do not allow a proactive management of the issue. However, the current context demonstrates that we need tools to anticipate these situations. Anticipating nuisance can be beneficial for both the decision-maker and the industrialist:

- The decision-maker can estimate the odorous impact of an industrial project on its territory, determine a preferred location or define new urban development projects accordingly;
- For the industrialist, it could be used for a better management of its emissions, to determine the impact of an extension project, or to justify, or not, odour emission reduction processes.

Some predictive methods for assessing odour nuisance have been developed. Most of them predict the nuisance caused by an existing

industry based on on-site measurements. This section of the paper presents an example of a predictive model able to predict odour nuisance caused by an industry that is not yet in place. This work was carried out within the framework of a Ph. D. thesis and validated on the territory of Agen (France) around a rendering plant (Popa 2013).

4.1 Odour nuisance considered as risk

Anticipate the odour nuisance caused by an industry requires an odour process description, from emission to its effect on local residents. For this purpose, the model is based on the methods used in the assessment of major risks. The basic concept in risk assessment is that the overall risk depends on the events probability (hazard) as well as the probable consequences (stakes) if this event occurs (Tixier et al. 2006)(see Eq. (1)).

$$\text{Risk} = \text{Hazard} \otimes \text{Stakes} \quad (1)$$

To quantify this risk, we can translate this equation into the following (see Eq. (2)):

$$\text{Risk} = \text{Hazard potential} \otimes \text{Stakes vulnerability} \quad (2)$$

This equation allows to translate the hazard and the stakes present into a typology which can qualify and quantify them. The risk is translated into an index that can be mapped (Tena-Chollet et al. 2013).

Applied to the odour domain, the risk of odour nuisance becomes the combination of the hazard potential, considered as the probability of exposure with a given intensity (impact), and the stakes as the effect on receptors. Both these aspects are juxtaposed in the Source-Pathway-Receptor concept (S-P-R) which is now part of the guidelines for environmental risk assessment and management (Bull 2018; Gormley, Pollard, and Rocks 2011). The S-P-R concept describes the potential relationship between the characteristics of odour source (S), the pathway (P) that represents the exposure on the territory and the receptors (R) that could be impacted (Bull 2018).

Popa (2013) employed the concept of risk to define the risk of odour nuisance as the relationship between the odour annoyance potential and the vulnerability of local populations (see Eq. (3)).

$$\text{Risk of odour nuisance} = \text{Odour annoyance potential} \otimes \text{Human stakes vulnerability} \quad (3)$$

- The hazard potential corresponds to the odour annoyance potential, i.e. the characteristics of the odour compounds emitted (intensity, frequency, hedonic tone) and their dispersion over the territory. The hazard potential describes the impact of the odour according to its occurrence, in time and space.
- Stakes vulnerability corresponds to the sensitivity of an individual to an odour. This sensitivity is a function of a set of complex processes (neurosensory, cognitive, memory, social, cultural...). Human stakes vulnerability is defined by a set of socio-economic variables that describe the population according to where it is located, the type of habitat it occupies and the length of time they have lived there.

This approach takes into account both the annoyance and the populations affected. It characterizes both the source (S) and the receptors (R) of the S-P-R concept. To model the impact of the odour on the territory (P), most studies and regulations are based on atmospheric dispersion software (Capelli et al. 2013). These software simulate the transport of odorous molecules in the atmosphere and thus the concentration of odours on the ground in a defined spatial and temporal domain (Invernizzi, Capelli, and Sironi 2016).

4.2 Evaluate the effect of the annoyance

To assess the effect (nuisance) of this exposure on receptors, Popa's model uses a highly multi-criteria approach. Its model is based on Saaty's multi-criteria AHP method, a method generally used when the decision is subjective, the human aspects predominant, and especially when all relationships are not demonstrable (Popa 2013). It hierarchically decomposes the odour nuisance problem to identify the elements that contribute to its explanation. By considering odour nuisance as a risk, the first level of its hierarchical structure has two parts: odour annoyance potential and the human stakes vulnerability (see Figure 1).

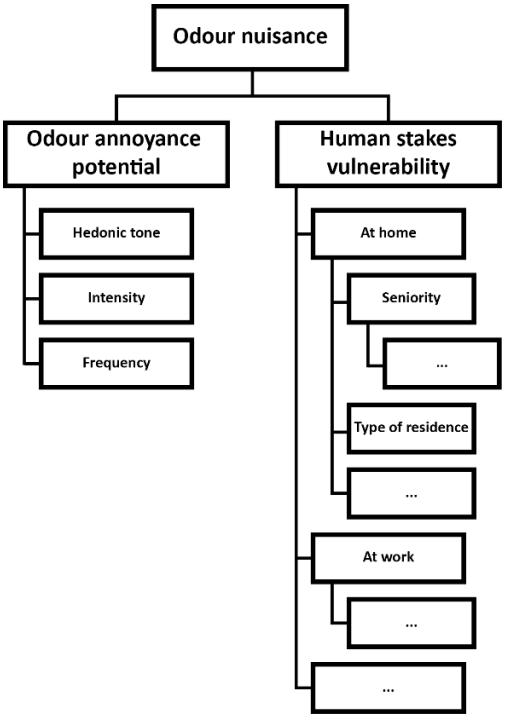

Fig. 1. Simplified representation of the hierarchical structure (Popa, 2013)

Each sub-section is then organized into several elements according to their importance in the assessment of odour nuisance. The sub-elements that describe the vulnerability of populations correspond to socio-economic variables that play a role in the feeling of nuisance. These geographical variables describe the territory but also the practices of the population according to where they are, i.e. at home, at work, in shops, during leisure or in transport. These variables are quantified and geolocalized. A total of 64 variables organized in the hierarchical structure describe the type of housing, seniority in housing, attendance at shops, services or leisure facilities. These include, for example, the number of people living in a house, the number of owners, and the theoretical capacity of the different establishments receiving public. Each element of the hierarchical structure is weighted on the basis of expert opinion according to its importance in the assessment of nuisance. At each level of decomposition of the hierarchical structure, an equation aggregates the quantified and weighted variables. They are finally integrated into a global function to calculate a human stakes index.

Figure 2 illustrates the aggregation of the odour annoyance index and the human stakes vulnerability index to calculate and map level of nuisance on a territory (see Figure 2).

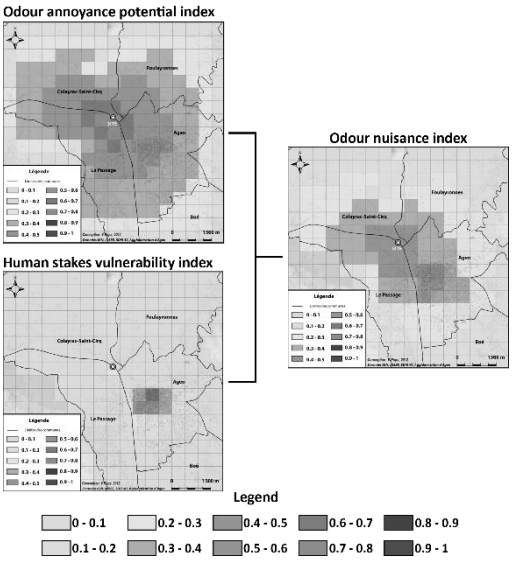

Fig. 2. Aggregation of indexes and cartography of odour nuisance levels (Popa, 2013)

Beyond predicting a risk of nuisance, Popa's method evaluates the economic damage resulting from it. It measures the potential economic consequences of the odour nuisance on the affected area. The economic damage is transcribed as an aggregation between the odour nuisance and the economic stakes vulnerability (see Figure 3).

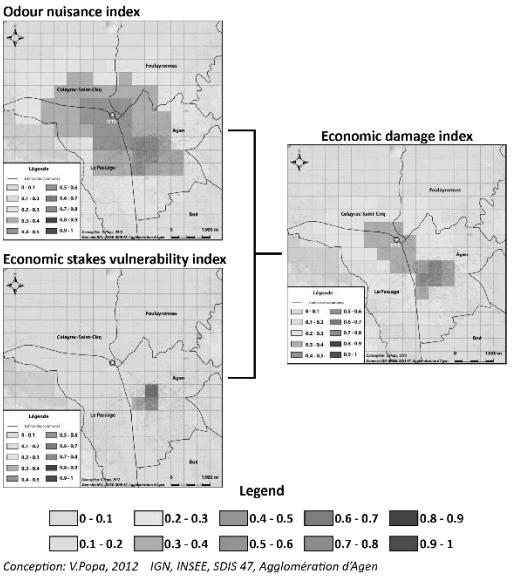

Fig. 3. Aggregation of indexes and cartography of economic damage levels (Popa, 2013)

The economic stakes vulnerability are defined by a second hierarchical structure which is decomposed by type of activity based on the nomenclature of French activities (NAF). The

SIRENE database describing the 11 million French companies is used to calculate the index. The variables used correspond to the companies and their location, turnover and number of employees.

4.3 Synthesis

This model anticipates and maps levels of odour nuisance using concepts and methods specific to the field of risk analysis. It integrates in the assessment both the odour annoyance and the sensitivity of populations to predict the effect on a population. This predictive model locate receptors and qualify levels of sensitivity to odour nuisance according to: population density and socio-economic characteristics (Popa 2013). This geographical approach allows a collective representation of the odour nuisance, which takes into account the characteristics of the territory and the way in which stakes are distributed there.

Thus, this model goes beyond individual representations of empirical methods, but also other predictive models by assessing the nuisance before the industry is established. Collective and predictive representation of nuisance also means that it does not represent the real perception of the entire population. This model provides a global vision of the nuisance process and its consequences on the territory (Popa 2013).

The spatial and temporal representation of odour nuisance levels on a territory provides a decision-making tool for the different actors involved. The objective is to anticipate the nuisance rather than having to manage it. This predictive approach can be useful in operational conditions:

- Assess the level of odour nuisance on a territory;
- Define the preferred location of a future industrial project;
- Manage site emissions;
- Estimate the impact of the abatement measures;
- Assess the impact of an extension project.

5. Conclusion

Popa's model integrates the different stages of the odour nuisance genesis process, in line with the Source-Pathway-Receptor concept. This concept, based on risk analysis methods, provides a spatial and temporal representation of the odour nuisance and its consequences on the territory. This geographical approach allows a collective representation of the odour nuisance of local populations.

Popa's model highlights the interest of predictive models in the evaluation of odour nuisance. According to the literature, this is the only method able to predict the odour nuisance induced by an industry even before it is established. We observe a paradigm shift from *a posteriori* measurement of odour nuisance to a preventive approach used as a decision support tool. Predictive models are destined to stakeholders and industrialists to proactively manage odour problems.

This does not mean that other methods should be abandoned. It is important to remember that each model is a simplification of the real situation. No method provides an unequivocal answer. The United Kingdom Institute for Air Quality (IAQM) therefore recommends using empirical observation tools, where available and applicable, and combining them with a model. The subjective nature of odour and the large differences in population response lead to the use of several assessment tools in a study. The combined use of these tools is used to validate and increase the robustness of the model.

For example, empirical methods can be used to corroborate or refine the results of the model, atmospheric dispersion software provides the extent of the odour plume and some other characteristics. Using these different assessment tools in combination can minimise individual limitations and improve the reliability of conclusions.

6. Perspectives

This model has only been validated on one site and paves the way for several new improvements. To provide a decision support tool for the stakeholders involved, the model must be tested and validated on other territories with different characteristics in terms of population, type of odour, topography, etc. It should be adapted to different geographical situations and take into account the industrial past of the territory. A historical reflection must be carried out. Depending on the history and industrial past of a territory, the relationship to odours can be radically different and the odour can be accepted or rejected. Indeed, the odours of a sector of activity that has been in place for several decades, even centuries, and that represents a source of income for a territory will be more easily accepted compared to a newly installed industry.

As mentioned above, the human and economic stakes of the territory is assessed using 64 variables. This large number of variables makes the model difficult to transpose from one territory to another. To make the model operational, another objective is to simplify the hierarchical structure by reducing the number of variables while maintaining the validity of the model.

Another perspective concerns the application of such a model in developing countries where we observe an elevation of living standards and an increasing environmental requirement. It is then necessary to think about the construction of the model according to the availability of data. Several tracks must be explored to assess the sensitivity of populations based on land use and inhabitant density.

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