Outline of a new empirical approach to calculate separation distances for use in the Austrian guide line to avoid odour nuisance

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Abstract

In Austria a new guide line is under development to calculate the separation distance between livestock and residential areas to avoid odour annoyance. On the basis of dispersion model calculations for 6 sites by the Austrian odour dispersion model (AODM) a regression model is developed, using a power function. One of the requirements for this empirical model is the aspiration to substitute the complex calculation with a dispersion model by the new empirical model. The approach is outlined here, and the good fit with the AODM calculations is demonstrated.

Keywords: Guide line, separation distance, odour, dispersion model

1. Introduction

Complaints by the neighbourhood due to odour emissions of livestock buildings are a major concern in rural areas. To handle odour annoyance, a separation distance between the odour source (livestock) and residential areas is used to reduce the ambient odour concentration to a certain protection level. With livestock farming, two regulatory approaches are common. The first one is a guide line approach, the second one a dispersion modelling approach.

The empirical approach presented here is a regression model which is based on dispersion calculations by the Austrian Odour Dispersion Model (AODM; Schauberger et al., 2000). The calculations are performed for six sites in Austria to evaluate the necessity of a regionalisation of the parameters of the regression model. In this paper, the methodologies of the guide line and the empirical approach will be outlined, and the separation distances, calculated by the AODM, are compared to those of the new empirical approach.

2. Materials and methods

2.1 Meteorological data

Meteorological data (one-year time series of wind direction, wind speed and stability class according to the system of Reuter (1970)) have been taken from six Austrian stations chosen with respect to the main geographical areas in Austria (Eastern flatlands, North-Alpine foreland, Inner-Alpine valleys, South-Alpine basins and valleys) and with respect to the livestock density for pigs and cattle (Fig. 1). Details of the Reuter scheme are given in Section 4.6 of Piringer and Joffre (2005); a discussion of stability classes determined by different methods is found in Piringer et al. (2007).

2.2 Odour emission rate

The calculations have been done for all six sites with 8 different odour emission rates 400, 800, 1 500, 3 000, 6 000, 12 000, and 24 000 OU s^{-1}. The source geometry is a single point source with a height of 6 m. The emission rate is assumed to be constant in time.

2.3 Dispersion model

The separation distances to test the approach are calculated with the Austrian Odour Dispersion Model (AODM). The model is described in detail in Schauberger et al. (2000; 2001). The selected dispersion model calculates the mean ambient odour concentration. AODM is a Gaussian-based model to predict ambient odour concentrations for an integration time of half an hour.

For odour sensation the relevant integration time is about the duration of one single human breath (about 5 s). Therefore the temporal fluctuations of the odour concentration have to be taken into account. The mean ambient odour concentrations of the dispersion model are transformed to maximum values for a time interval of half an hour. The peak concentrations further downwind are modified by an exponential attenuation function which depends on the stability of the atmosphere and the travel time (wind velocity) (Schauberger et al., 2000).

The separation distance S^{disp} for a certain exceedance probability is calculated for 36 wind direction classes (10° class width), for all meteorological sites, and for following exceedance probabilities p_P (3%, 4%, 8%, 12%, 15%, 16%, 20%, and 24%) with an odour concentration threshold of 1 OU/m³.

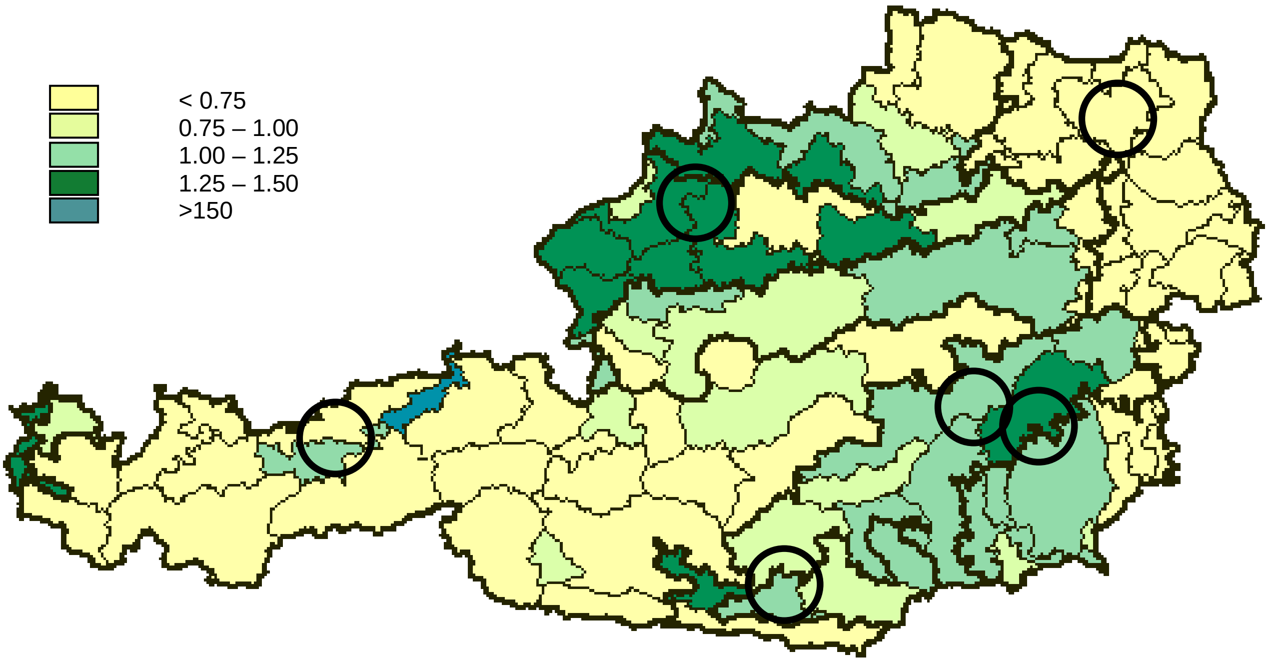

Figure 1 Geographical distribution of the 6 meteorological stations, which were used for the calculations by the dispersion model and the livestock density related to the agricultural used land (LU/ha) in Austria in 2009 (Wagner, 2010). The sites from West to East are: Jenbach, Wels, Klagenfurt, Weiz, Gersdorf, and Gänserndorf

2.4 Empirical model

The empirical model calculates the separation distance S^{mod} (in m) as a function of the emission rate of the odour source E (in OU/s) according to

$$S^{\text{mod}} = a^{\text{mod}}\, E^{b^{\text{mod}}} \tag{1}$$

with the factor a^{mod} and the exponent b^{mod}. These two parameters are determined by a regression analysis. For the regression analysis, the relative frequency of the wind direction p_W and the mean wind velocity W of the wind sector, as well as the exceeding probability of the odour perception p_P are used as predictors.

To determine the factor a^{mod} and the exponent b^{mod}, the calculations by the dispersion model of the separation distance S^{disp} are used. The separation distances are calculated for 36 wind directions, for six meteorological sites, for eight exceedance probabilities p_P (between 3 and 24%), and for 7 odour emission rates (between 400 and 24 000 OU s^{-1}). This results in a dataset of $N = 5991$, which is used to derive the coefficients of the separation distance S^{mod} (Eq. 1) for the empirical model.

The two regression equations for the factor a^{mod} and the exponent b^{mod} are given by

$$a^{\text{mod}} = p_P^a (b\ p_W^c + d\ W + e) \text{ and} \tag{2}$$

$$b^{\text{mod}} = \frac{1}{f\ p_W + g\ p_P + h} \tag{3}$$

The fitting of the empirical functions is done by a multivariate non-linear fitting procedure, using the Richardson extrapolation (DataFit 9.0.59, Oakdale Engineering, USA). The regression analysis is evaluated by the coefficient of determination r^2 and the F statistics.

The fitted coefficients (± standard deviation) are summarised in Table 1. The coefficient of determination r^2 is 0.896, the F value is 73 480 for the entire dataset.

Table 1: Coefficients (± standard deviation) of the regression equation for the factor a^{mod} (a to e) and the exponent b^{mod} *(f to h)*

	Coefficient (± SD)
Factor a^{mod}	
a	-0.386 ± 0.006
b	165 ± 68
c	0.0289 ± 0.0116
d	-3.63 ± 0.05
e	-150 ± 68
Exponent b^{mod}	
f	-0.0381 ± 0.0003
g	0.0191 ± 0.0004
h	2.31 ± 0.01

The performance of the empirical model is investigated by the relative model error Δ

$$\Delta = \frac{S^{\text{mod}} - S^{disp}}{S^{disp}} \tag{4}$$

with the calculated separation distance by the dispersion model AODM S^{disp} and the modelled separation distance S^{mod} according to Eq.(1).

3. Results

The results of the regression analysis (Table 2) of the entire dataset are quite encouraging. 41.8% of the modelled separation distances of the entire data set are within ± 10% of those calculated with the AODM, 93.6% and 99.6% are within ± 50% and ± 100%, respectively. There are no under estimations larger than 50%, and only 0.4% of all data show an over estimation of more than 100%. The relative frequency of the relative model error peaks around 0. The relative error is nearly evenly distributed between overestimations ($S^{mod} > S^{disp}$) and underestimations ($S^{mod} < S^{disp}$) by 58%

and 42%, respectively. Table 2 indicates that the differences between the entire data set and the single sites are not significant.

Table 2: Statistics of the fitting procedure for the entire data set and for the six meteorological sites.

Parameter	Entire data set	Wels	Weiz	Gersdorf	Gänserndorf	Klagenfurt	Jenbach
Coefficient of determination r^2	0.896	0.890	0.912	0.917	0.861	0.92	0.865
Portion of the dataset (%) for							
$-0.1 < \Delta \leq 0.1$	41.8	34.8	48.0	45.4	33.8	46.8	36.4
$-0.5 < \Delta \leq 0.5$	93.6	93.0	94.3	98.3	96.0	89.3	89.5
$\Delta > 0$	58.0	68.0	53.4	53.2	53.1	66.0	58.3
$\Delta > 1$	0.04	0.03	0.03	0.01	0.04	0.24	0.08
Maximum underestimation	-0.5	-0.4	-0.3	-0.5	-0.5	-0.3	-0.3
Maximum overestimation	1.5	1.5	1.3	1.2	1.3	1.5	1.1

4. Conclusions

The empirical regression model calculates the separation distance between livestock buildings and residential areas for a certain protection level which is defined by an odour exceedance probability p_p (%) and an odour concentration threshold of 1 OU/m³. The separation distance S^{mod} (m) is calculated by four predictors. The meteorological situation is described by the relative frequency of the wind direction of a 10° sector p_W (%) and the mean wind velocity of the sector W (m/s), the odour exceedance probability p_p (%), and the emission rate E (OU/s).

$$S^{\text{mod}} = p_P^{-0.386}\left(165\, p_W^{0.0289} - 3.63\, W - 150\right) E^{\frac{1}{-0.0381\, p_W + 0.0191\, p_P + 2.31}} \quad (5)$$

This empirical model provides a best fit assessment of the separation distance compared to the used dispersion model AODM (Section 2.3).

A full version of this investigation has been submitted to *Atmospheric Environment*.

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