Original Research

Ammonia Emission Rates from Buildings with Pigs Intensively Reared on Slats

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Abstract

The objective of this study was a data revision concerning ammonia emissions from slatted pig fattener houses, as well as an evaluation of an ammonia emission index. An obtained emission rate of 3 kg $NH_3 \cdot (\text{fattener} \cdot \text{year})^{-1}$ was used for assessing pig fattener farms' impact on air quality. Maps of ammonia maximum and average concentration were drawn. The model calculation in the net of receptors was performed for three variants of farm scale: 1,000, 5,000, and 10,000 pig fatteners in four regions of northern Poland. Based on the maps of ammonia concentration isolines, the distances of odor nuisances were indicated.

Keywords: ammonia, emissions, indices, pigs, slats

Introduction

Agricultural operations are known to be sources of many types of particle and gas emissions that can ultimately an influence local and regional air quality [1]. Animal rearing farms can be qualified as a main source of the above-mentioned nuisances. Because of the production scale, poultry and pig farm are the highest sources of emissions.

The main pollutants emitted by ventilation of pig houses, reported in the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (ILF BREF), are: ammonia (NH_3), methane (CH_4), and nitrogen monoxide (N_2O) [2]. Additionally, swine houses are also sources of emission of dust, microorganism aerosols, and different odor-causing substances. Organic dusts in livestock buildings comprise grain and other plant-derived particles, animal hair, urine, faeces, microorganisms, and other particles. Dust particles may carry hazardous material such as pathogenic bacteria, viruses, endotoxin, or other organic substances [3]. The representative odorous compounds related to pig production are ammonia (NH_3), amines, sulfuric compounds (hydrogen sulfide, methyl mercaptan, dimethyl sulfide – DMS, dimethyl sulfide – DMDS), volatile fatty acids, and phenolic compounds [4].

Depending on farm fattener livestock, European Union regulations transposed into the polish law regulations point so-called IPPC installations that due to the production level, may significantly impact the environment and which must meet the requirements of best available techniques (BAT). There are also pig farms that should be subjected to the environmental impact study (EIS) procedure. Directive 96/61/EC [5] classifies installations of over 2,000 fatteners as an IPPC installation operation that requires special consent, called integrated permission. Pursuant to Directive 85/337/EEC [6], farms over 3,000 fatteners must be subjected to the EIS procedure. Polish law [7] contains more severe criteria for subjecting pig farms to the EIS. It is obligatory to perform EIS for farms exceeding 210 animal units (AU) (1500 fatteners), whereas for farms of 40 AU located in high-density building areas or exceeding 60 AU EIS may be the obligation [7].

The objective of this study was to evaluate ammonia emission rates from pig houses with slats. Currently detailed data describing emission rates that could be used in the EIS procedure and, especially, in air pollution receptor modeling, is missing.

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The purpose of this paper was also the assessment of ammonia impact on air quality. To determine the effect of pig fattener houses on air quality, model calculations of immissions in the air for farms of different pigs fattener numbers were performed using wind roses in selected regions of northern Poland. Isoline maps of pollutant concentrations were drawn. Similarly, distances in which ammonia odor nuisances may occur were indicated.

Materials and Methods

Analysis of literature and documents dealing with best available techniques, as well as current law regulations focusing on air quality, allowed determine the indexes of emission rates. The indexes given in mg·(pig·h)$^{-1}$ were converted into kg·(pig·year)$^{-1}$ taking into consideration the fact that pig houses are settled for 8,760 h during the year. The emission indexes expressed in mg or kg per animal unit (AU=500 kg live animal weight) were converted to kg·(pig·year)$^{-1}$ with the assumption that 1 fattener=0.14 AU, according to current law regulations [7].

The index of ammonia emission rate was used to construct a model (isolines maps) of emission range.

Calculations were performed for three variants of the farm scale:

- variant 1 – 1,000 pig fatteners (1 pig house)
- variant 2 – 5,000 pig fatteners (5 pig houses)
- variant 3 – 10,000 pig fatteners (10 pig houses)

It was assumed that a single pig house dimensions are 10x80 m, the distance between pig houses in rows is 20 m, and in column 30 m. Pig houses are equipped with slats and mechanical ventilation that consists of 14 roof fans of 0.65 m diameter, maximum flow is 12,000 m^3·h^{-1}, average outflow gases velocity ca. 5 m·s^{-1}, and the outlet of ventilation canal is situated 6 m above ground level. The configuration of pig houses in respective variants is illustrated in Fig. 1.

For the dispersion assessment of air pollutants emitted from the fans battery as well as for the graphic results presentation OPERAT FB software (version 5.0.1), attested by the Environmental Protection Institute in Warsaw, under n. BA/147/96, compliant with requirements of the Regulation of 26 January 2010, issued by Minister of the Environment (J.Law. 2010.16.87) was used [8]. OPERAT FB allows performance of complete calculations of air pollutant concentrations, for instance:

- calculations of 1-hour concentrations
- exceeding frequency of admissible 1-hour concentrations
- calculations of percentage contribution of particular emitters and pollution background in gaseous pollutant concentrations and dust fallout
- location of receptor points in orthogonal net or at axis with chosen direction
- calculations of maximum and average concentrations as well as conditions of their appearance for the point, linear and surface sources of emission.

The ammonia concentration calculations were carried out for ground level. According to methods presented in Regulation of 5 December [8], concentration of a gaseous substance in the point of coordinates X_p, Y_p, at ground level should be calculated in accordance with the following formula (Pasquille equation):

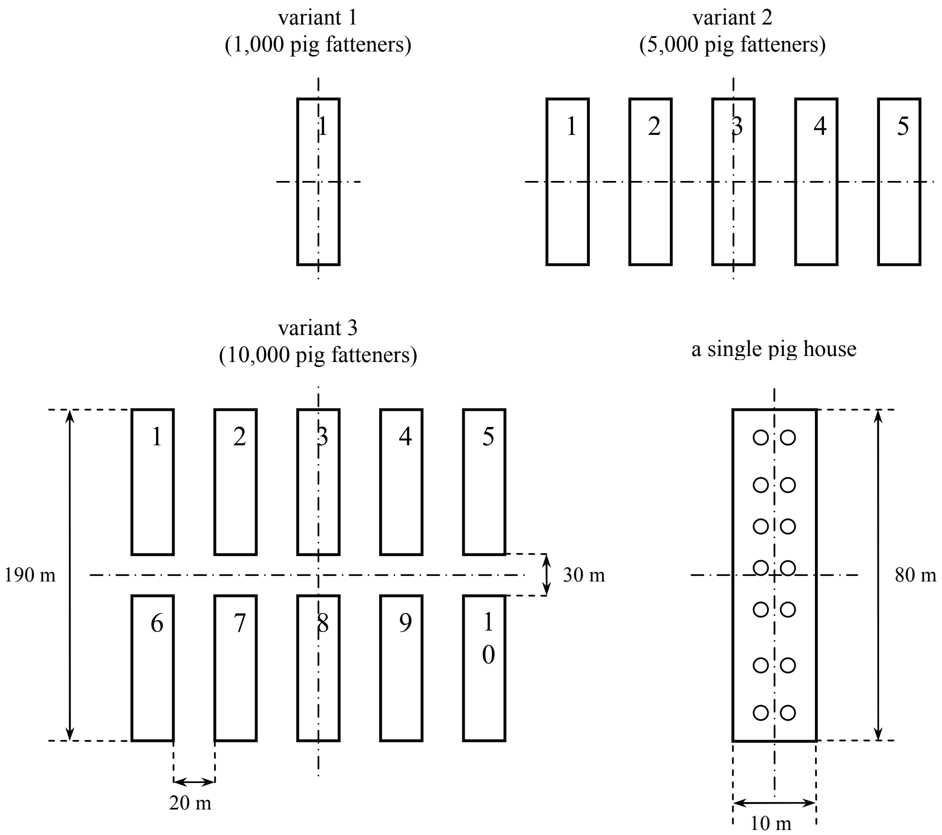

Fig. 1. Pig house configuration chart in 3 emission calculation variants, single pig house dimensions, and ventilation outlets.

$$S_{xy} = \frac{E_g}{\pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \cdot 1000 \ [\mu g \cdot m^{-3}]$$

S_{xy} – substance concentration in the point with coordinates x, y, z, [$\mu g \cdot m^{-3}$]
E_g – maximum emission of gaseous substance [$mg \cdot s^{-1}$]
u – average wind velocity [$m \cdot s^{-1}$]
σ_y – horizontal atmospheric diffusion rate [m]
σ_z – vertical atmospheric diffusion rate [m]
y – component of the distance between the emitter and the calculated point [m]
H – effective height of the emitter [m]
exp– exponential function

The calculations of the distribution of ammonia maximum concentrations (1 hour and 1 year) in the air considering the statistics of meteorological conditions were carried out in order to check whether the pollutant concentration on the ground level meets the following demand:

$$S_{mm} < D_1$$

S_{mm} – the highest maximum concentration in the air [$\mu g \cdot m^{-3}$]
D_1 – limit value of substance or admissible 1-hour concentration [$\mu g \cdot m^{-3}$]

The reference values or admissible concentrations of substances in the air are not violated if the exceeding frequency of admissible 1-hour concentrations (D_1) does not exceed 0.274% of time per year for sulfur dioxide and 0.2% for other substances [8].

The calculations of ammonia concentrations were carried out in an orthogonal (1000x1000 m) net of receptors arranged in 25x25 m squares. The Y axis corresponded to the northern direction while the X axis indicated the eastern direction. The geometric center of a pig house in variant 1 is found in the point x=500, y=500. The calculations were performed for the selected regions of northern Poland. The wind roses for Olsztyn, Bydgoszcz, Szczecinek, and Szczecin regions were used. The level of emission was calculated on the ground of average index 3 kg $NH_3 \cdot (\text{fattener} \cdot \text{year})^{-1}$. The index of 1-hour maximum emission was calculated on the basis of total ammonia emission divided by number of hours in the year.

The basic data applied to facilitate receptor modeling of air pollutants were as follows:

- average wind rose of particular region (Fig. 2)
- air pollution background – 10% of limit value: 5 $\mu g NH_3 \cdot m^{-3}$
- emitter parameters: roof fans – outlet 6 m above ground level, diameter 0.65 m, no covers on the outlets, average outflow gas velocity ca. 5 $m \cdot s^{-1}$, air specific heat 1.3 $kJ \cdot m^{-3} K^{-1}$, outflow gas temperature 293 K
- aerodynamic terrain roughness coefficient z_0=0.035, corresponds to fields surroundings
- average annual temperature in a particular region

The limit values of ammonia given by the environment protection law regulations [8] as admissible 1-hour concentration and mean annual concentration are 400 $\mu g \cdot m^{-3}$ and 50 $\mu g \cdot m^{-3}$, respectively.

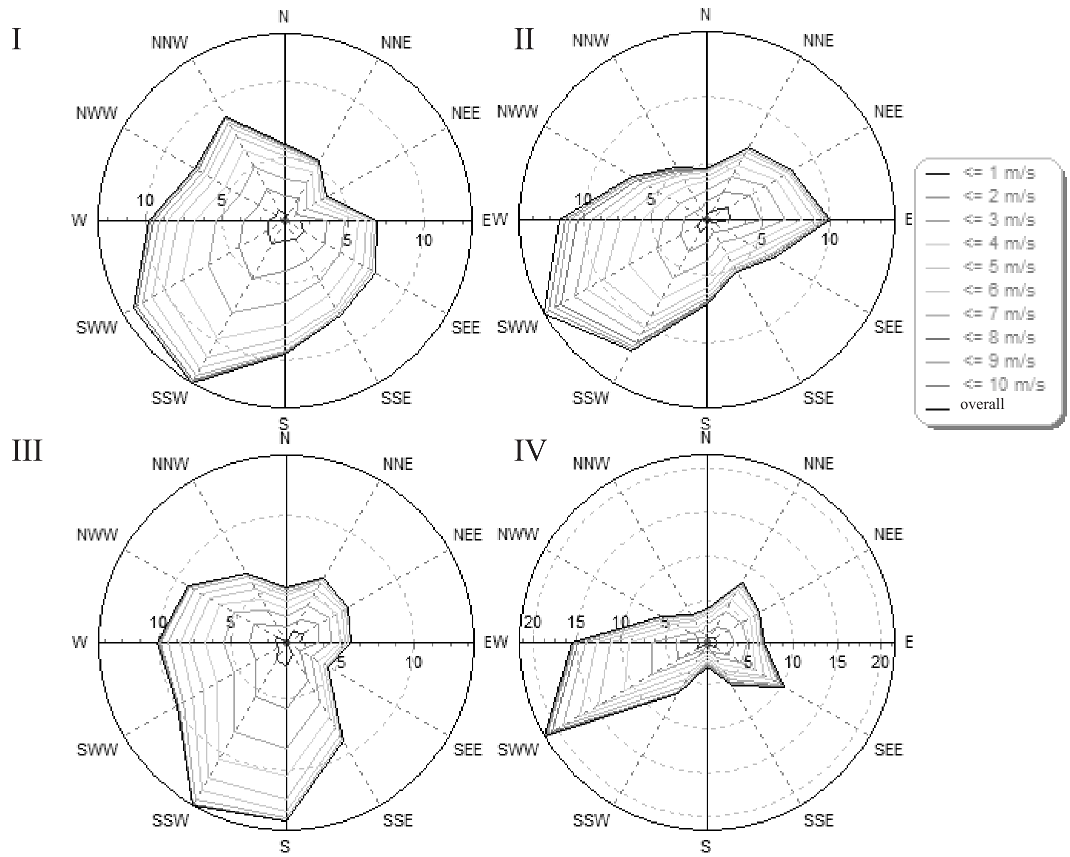

Fig. 2. Average annual wind roses of meteorology stations: Olsztyn Dajtki (I), Bydgoszcz (II), Szczecinek (III), Szczecin Dąbie (IV) [9].

Table 1. Indices of emissions from pig fattener houses with fully slatted floors, according to ILF BREF [2].

Substance	Emission [kg·(fattener·year)$^{-1}$]
ammonia NH_3	1.35-3.0
methane CH_4	2.8-4.5
nitrogen oxide N_2O	0.02-0.15

The regulations on work safety and hygiene [10] indicate that short-term exposure limit (STEL) for ammonia is 28 mg·m^{-3} and the occupational exposure limit (OEL) of ammonia is 14 mg·m^{-3}. The mentioned values are many fold higher than the 1-hour concentration limit value defined by environmental protection regulations [8]. Ammonia is classified in class C of the olfactometry safety coefficient [11], which means that less than 50% of people would recognize the smell of ammonia in OEL conditions [12]. The ammonia detection threshold is 0.4 mg·m^{-3} (400 μg·m^{-3}) [13].

Results

The ILF BREF document does not present detailed data on pollutant emissions into the air from pig farms. Nevertheless, ILF BREF is a basic document for issuing administrative permits for the operation of large pig farms. It indicates only the scopes of ammonia, methane, and nitrogen oxide I indices of emission (Table 1).

Table 2 shows a literature review of ammonia emission indices from pig fattener houses.

Since some emission indices are given with the standard deviation values and others are given as a numerical value or a range of values, Table 3 provides numerical values of the indices only and the conversions into kg NH_3·(fattener·year)$^{-1}$ are made with the accuracy of 1 g which does not, however, correspond to the accuracy of every literature emissions index.

Analyzing the indices given in Table 2, as well as the basic statistical values indicated in lines 22-24, it was considered that the index of 3 kg NH_3·(fattener·year)$^{-1}$ is the most representative as well as the most applicable factor of ammonia emissions from pig fattener houses. This index corresponds to the maximum ammonia emissions noted in reference document [2], and is a little higher than the index given by the European Environmental Agency (EEA): 2.89 kg NH_3·(fattener·year)$^{-1}$ [21, 22].

The list of the calculated 1-hour and annual maximum concentrations, as well as the exceeding frequency of admissible 1-hour concentrations, is presented in Table 3.

The graphic presentation of calculation results, isolines of ammonia concentration are drawn in Figs. 3-6. The disposal value (D_a – R) of ammonia average annual concentration is 45 μg NH_3·m^{-3}.

Discussion of Results

The calculation of the spread of ammonia indicates that in the analyzed variants the average admissible concentrations were not exceeded. The maximum concentration range (1-hour) in variant I showed that the reference value was not exceeded. In variant II, the maximum hourly concentration reached the limit, and in variant III ammonia concentration comes to the levels exceeding the limit value. Despite the cases of exceeded values, frequency was less than 0.2% of the time per year. Therefore, it can be stated that in each calculation variant the limit values of ammonia were not violated.

Table 2. Ammonia emission indices from slatted livestock buildings of pig fatteners.

n.	Emission index			References
	according to literature		conversion kg·(pig·year)$^{-1}$	
1.	1.35	kg·(fattener·year)$^{-1}$	1.350	[2]
2.	185	mg·(fattener ·h)$^{-1}$	1.621	[14]
3.	33.33*	gNH_3-N·(AU·d)$^{-1}$	2.068	[15]
4.	5.75*	g·(fattener·d)$^{-1}$	2.099	[16]
5.	6.9	g·(fattener·day)$^{-1}$	2.519	[17]
6.	7	g·(fattener·day)$^{-1}$	2.555	[18]
7.	299.25	mg·(fattener·h)$^{-1}$	2.621	[19]
8.	308	mg·(fattener·h)$^{-1}$	2.698	[14]
9.	319	mg·(fattener·h)$^{-1}$	2.794	[14]
10.	320.1	mg·(fattener·h)$^{-1}$	2.803	[20]
11.	2.89	kg·(fattener·year)$^{-1}$	2.890	[21, 22]
12.	3.0	kg·(fattener·year)$^{-1}$	3.000	[2]
13.	3.0	kg·(fattener·year)$^{-1}$	3.000	[23]
14.	3.180	kg·(fattener·year)$^{-1}$	3,18	[24]
15	3,2*	kg·(fattener·year)$^{-1}$	3.200	[25]
16	385	mg·(fattener·h)$^{-1}$	3.373	[14]
17	3	g·(AU·h)$^{-1}$	3.679	[26]
18	11.3	g·(fattener·day)$^{-1}$	4.125	[17]
19	11.9	g·(fattener·day)$^{-1}$	4.344	[17]
20	4.824	kg·(fattener·year)$^{-1}$	4.824	[27]
21	46.9	kg·(AU·year)$^{-1}$	6.566	[28]
22	arithmetical mean		3.110	
23	arithmetical mean (calculated without extreme values)		3.021	
24	median of series		2.890	

* mean value

Table 3. The highest values of 1-hour and average ammonia concentrations, and frequency of exceeding limits in three variants of farm scale (X, Y – coordinates of the receptors net).

n.	Region	Parameter	Value	X [m]	Y [m]
variant I (1000 pig fatteners)					
1	Olsztyn	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	133.5	500	400
2		average year concentration [$\mu g \cdot m^{-3}$]	5.8	550	525
3		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
4	Bydgoszcz	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	133.9	500	400
5		average year concentration [$\mu g \cdot m^{-3}$]	6.1	550	525
6		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
7	Szczecinek	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	133.7	500	400
8		average year concentration [$\mu g \cdot m^{-3}$]	6.3	525	550
9		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
10	Szczecin	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	134.4	500	400
11		average year concentration [$\mu g \cdot m^{-3}$]	8.0	550	525
12		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
variant II (5000 pig fatteners)					
13	Olsztyn	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	399.8	250	500
14		average year concentration [$\mu g \cdot m^{-3}$]	23.2	525	550
15		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
16	Bydgoszcz	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	400.8	250	500
17		average year concentration [$\mu g \cdot m^{-3}$]	20.7	550	550
18		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.01	250	500
19	Szczecinek	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	400.3	250	500
20		average year concentration [$\mu g \cdot m^{-3}$]	24.8	525	575
21		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
22	Szczecin	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	401.9	250	500
23		average year concentration [$\mu g \cdot m^{-3}$]	27.1	600	525
24		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.00	-	-
variant III (10 000 pig fatteners)					
25	Olsztyn	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	460.1	675	225
26		average year concentration [$\mu g \cdot m^{-3}$]	38.6	525	500
27		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.3	575	675
28	Bydgoszcz	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	461.0	675	225
29		average year concentration [$\mu g \cdot m^{-3}$]	33.0	525	500
30		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.2	575	675
31	Szczecinek	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	460.5	675	225
32		average year concentration [$\mu g \cdot m^{-3}$]	39.3	525	500
33		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.39	575	675
34	Szczecin	maximum 1-hour concentration [$\mu g \cdot m^{-3}$]	461.8	675	225
35		average year concentration [$\mu g \cdot m^{-3}$]	35.6	600	575
36		exceeding frequency of D_1=400 $\mu g \cdot m^{-3}$ [%]	0.11	400	650

Separate maximum 1-hour isolines for each region are not presented in Fig. 6 because their concentrations distribution was almost identical in each variant. The reason for such a result is the fact that the calculations of 1-hour concentrations are not based on wind roses.

The results also indicated that outside the pig houses in each variant there is no danger of exceeding ammonia concentrations determined by the applicable work safety and hygiene regulations. All of the 1-hour maximum concentrations were less than STEL values, and all the average concentrations were below the OEL limit.

Conclusions

The analysis of maximum concentration isoline maps suggests that the pig operation with 1,000 places for pig fatteners cannot be a source of ammonia odor nuisance.

Ammonia may reach the level of detection threshold at a distance of about 250 m from the complex of pig houses for 5,000 pig fatteners. Fattening farms for 10,000 pigs will cause a periodic ammonia odor disturbance at a distance exceeding 0.5 km.

It should be indicated that isolines of maximum ammonia concentration were drawn on the basis of average emission divided by the number of hours in the year. The ILF BREF does not present any data on maximum emission levels. The index of ammonia emission of 3 kg NH_3·(fattener·year)$^{-1}$ was evaluated on the basis of different indexes, including average indexes and temporary indexes of emission (Table 2). For this reason the obtained ammonia emission index should be considered as a universal. Notwithstanding, implementation of this index might lead to a slight overestimation of average-year emissions and underestimation of maximum 1-hour concentrations.

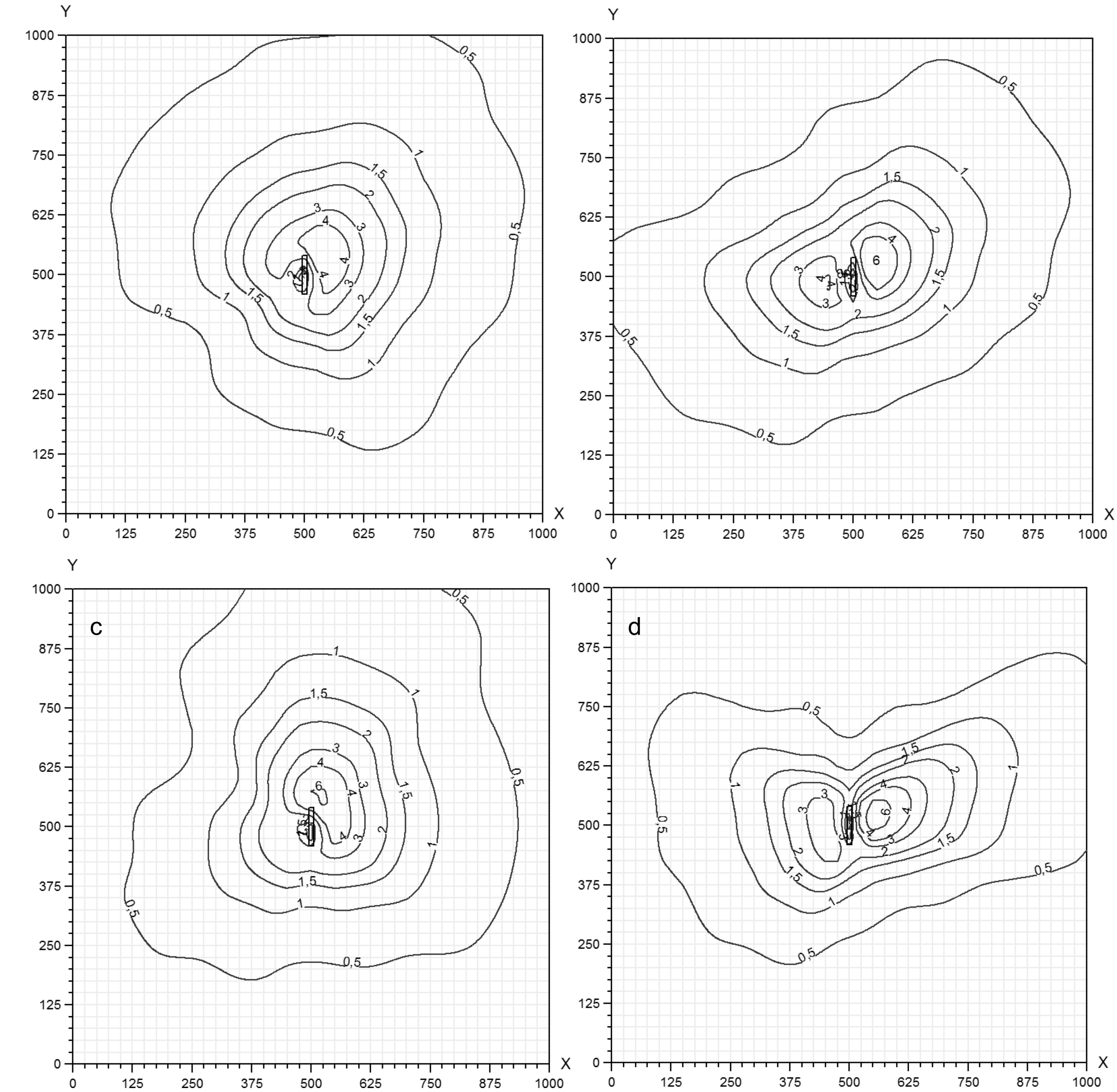

Fig. 3. Variant 1 (1 pig house for 1000 fatteners), isolines of ammonia average concentration [µg NH_3·m^{-3}], a) Olsztyn, b) Bydgoszcz, c) Szczecinek, d) Szczecin, axis X,Y [m].

There is a need to describe emission indexes of the other substances related to pig fattener rearing, especially sulfuric odor compounds like hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl sulfide.

The data on emissions levels could be used for detailed research on the impact of pig farms on the environment and air odor quality, as well as environmental impact studies that should be performed for every farm exceeding 210 AU.

Units and Nomenclature

AU – animal unit (1 AU=500 kg of livestock)
BAT – best available technique
BREF – document on best available techniques
D_a – limit value of substance or admissible 1-year average concentration
D_1 – limit value of substance or admissible 1-hour concentration
EIS – environmental impact study
IPPC – integrated pollution prevention and control
R – air pollution background
S_{mm} – the highest maximum concentration in the air [$\mu g \cdot m^{-3}$]
X – abscissa of coordinate system
Y – ordinate of coordinate system
z_0 – aerodynamic terrain roughness coefficient

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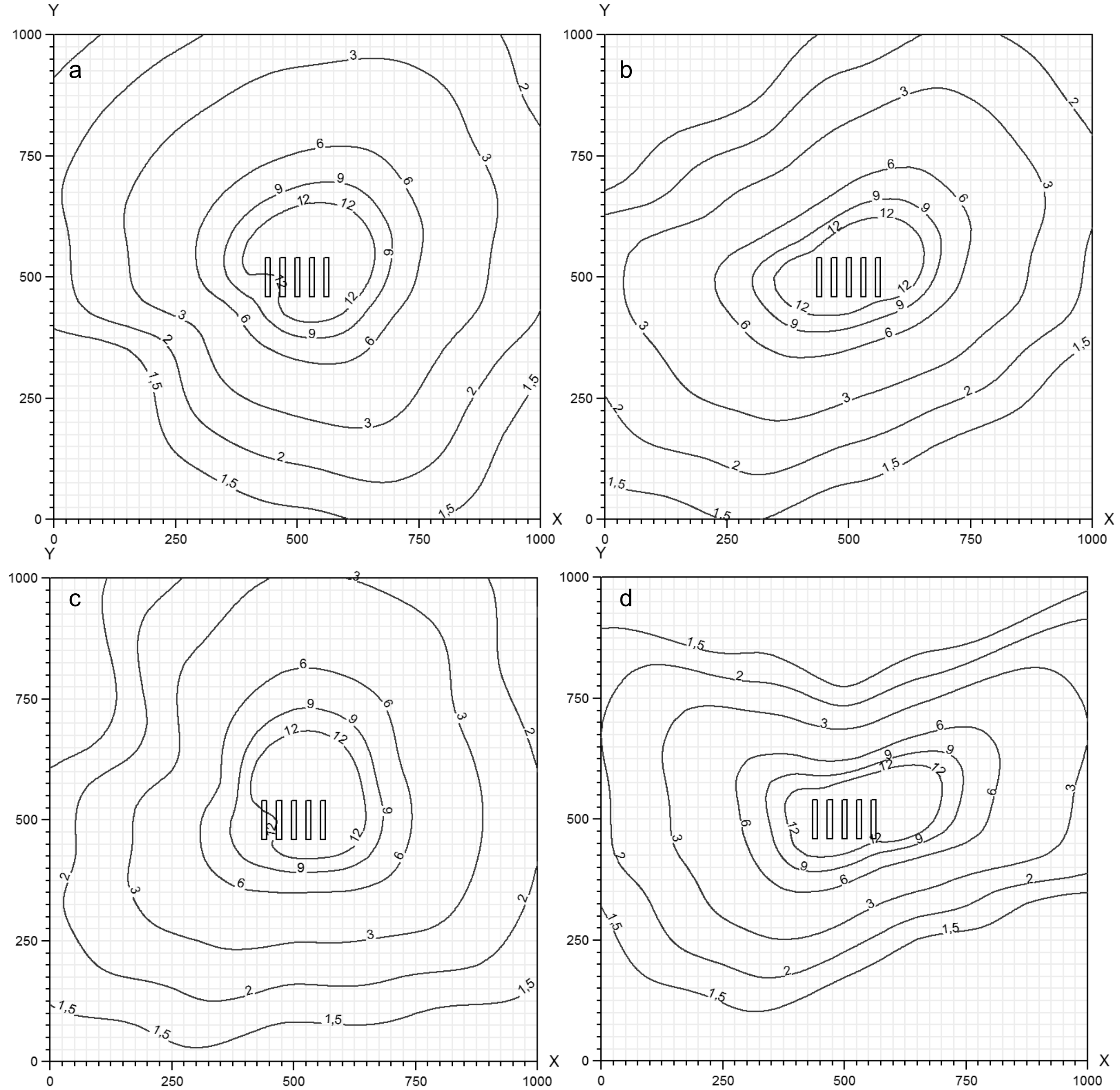

Fig. 4. Variant 2 (5 pig houses, 5000 fatteners), isolines of ammonia average concentration [$\mu g\ NH_3 \cdot m^{-3}$], a) Olsztyn, b) Bydgoszcz, c) Szczecinek, d) Szczecin, axis X,Y [m].

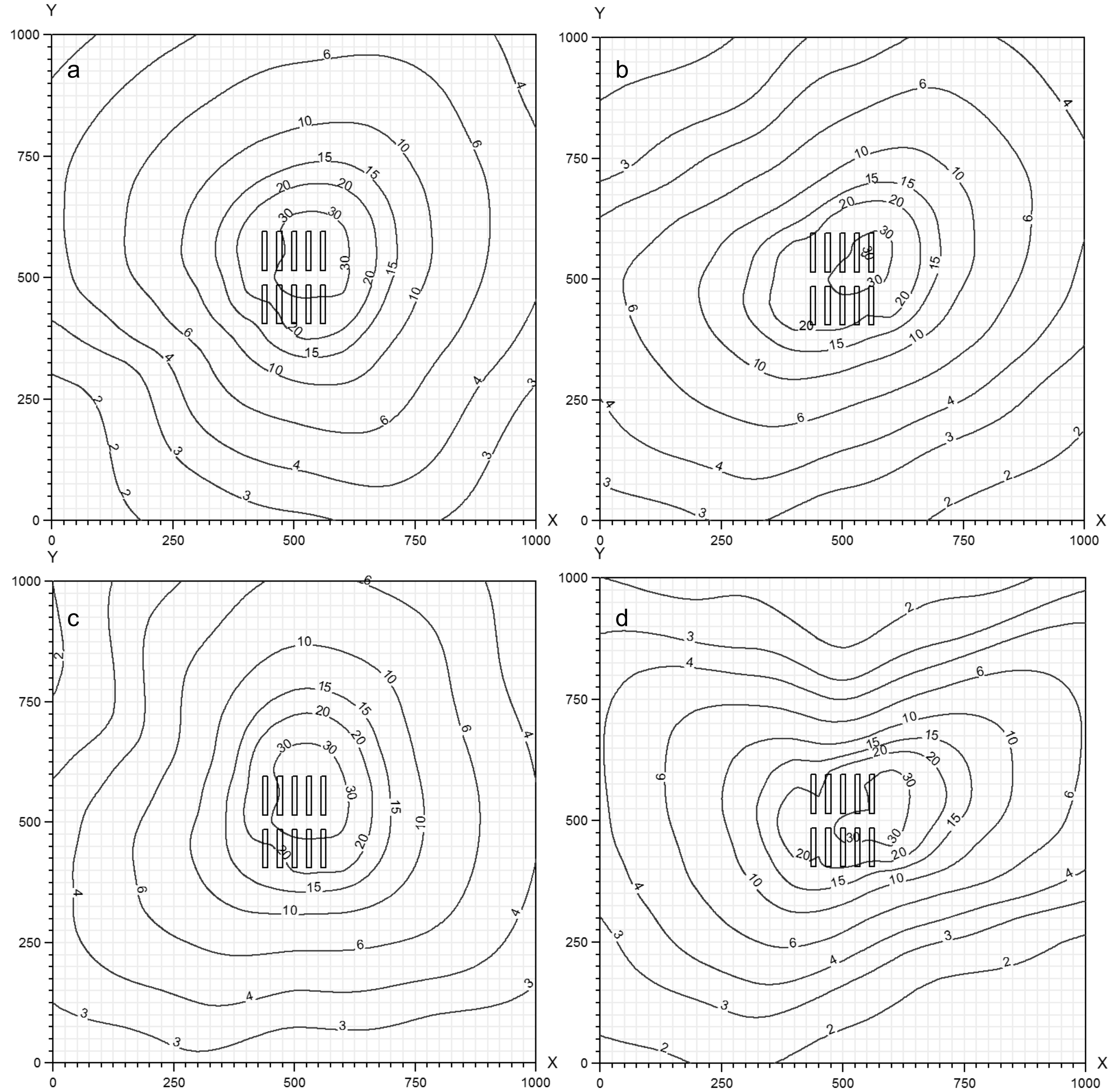

Fig. 5. Variant 2 (10 pig houses, 10,000 fatteners), isolines of ammonia average concentration [μg $NH_3 \cdot m^{-3}$], a) Olsztyn, b) Bydgoszcz, c) Szczecinek, d) Szczecin, axis X,Y [m].

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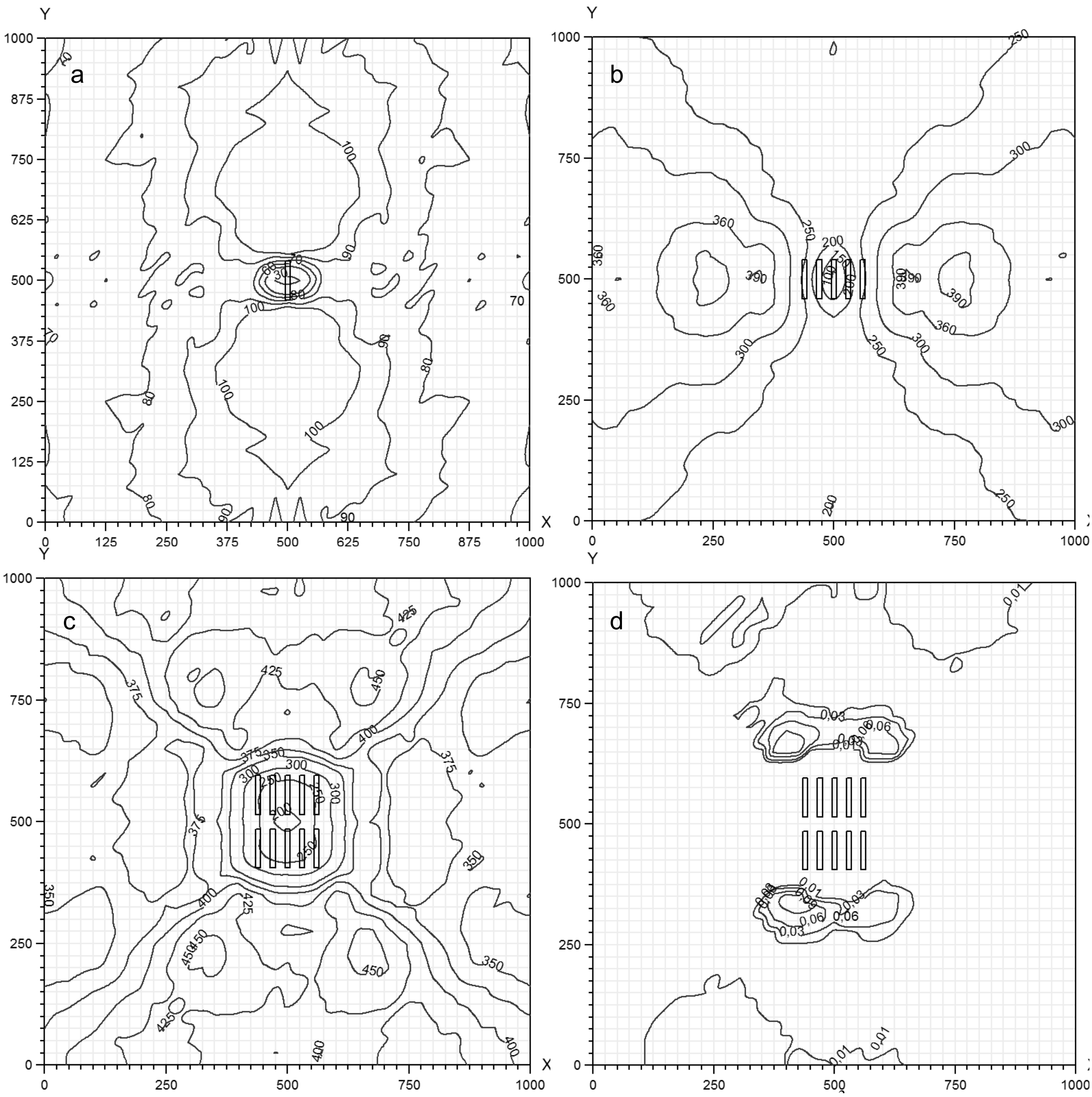

Fig. 6. Isolines of maximum 1-hour ammonia concentrations [µg $NH_3 \cdot m^{-3}$], a) variant I, b) variant II, c) variant III, exceeding frequency [%] of admissible 1-hour concentration of 400 µg·m^{-3} in variant III (d), axis X,Y [m].

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