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The use of ordinary kriging and inverse distance weighted interpolation to assess the odour impact of a poultry farming plant

Key words: odour nuisance, field olfactometry, GIS, kriging, IDW

Introduction

Rearing and breeding of livestock is often a source of a negative odour impact and can be a cause of odour nuisance (Grzelka, Sówka & Miller, 2018), with poultry farming being the most common cause of people's complaints about odorous air quality (Kośmider, Mazur-Chrzanowska & Wyszyński, 2012). Therefore, for many years in Poland work on the regulation of the legal issues related to the excessive odour emission associated with the operation of, among others, animal husbandry is underway. As a result of the taken actions, in 2019 the Ministry of the Environment has developed a project proposal called Anti-odour Act – A draft act on the minimum distance for planned projects of the agricultural sector, the functioning of which may be associated with the risk of odour nuisance (Ministerstwo Środowiska, 2019). The document defines the minimum distance of locating emerging agricultural sector projects from residential buildings or public facilities depending on the breeding stocking size. However, it does not indicate emission standards for odours or odorants characteristic for this type of activity and does not refer to existing facilities. For the EU Member States, best available techniques conclusions (Commission Implementing Decision (EU) 2017/302), created as a result of the reference document on best available techniques for intensive poultry and pigs breeding, are an important legislative tool. Best available techniques conclusions are a set of legally binding recommendations created for the needs of breeders. They refer to large farms with > 40,000 poultry stands. They indicate the need to create, implement and regularly review the odour management plan. For facilities that may cause a risk of odour nuisance, they recommend the use of countermeasures, i.e. end-of-pipe methods or special recommendations regarding animal nutrition and maintenance, and for newly emerging facilities they suggest maintaining appropriate distances from sensitive facilities, e.g. residential buildings (Commission Implementing Decision (EU) 2017/302).

Many methods are used to assess the odour nuisance of agricultural facilities (in particular those dealing with animal husbandry). One of the most commonly used are sensory methods, including dynamic olfactometry and field olfactometry (Korczyński et al., 2011; Gębicki, Byliński & Namieśnik, 2016; Sówka, Pachurka, Bezyk, Grzelka & Miller, 2017b). In the latter case, the test results obtained at the measuring points can be used in the analysis of spatial distributions, which allow, among others assessment of variability of pollution concentrations and assessment of air quality (Wong, Yuan & Perlin, 2004; Sówka, Grzelka, Bezyk & Miller, 2017a; Núñez-Alonso, Pérez-Arribas, Manzoor & Cáceres, 2019).

GIS-based model tools are used, among others, in the study of odour dispersion based on measurement data obtained by dynamic olfactometry and measurement data from the so-called field inspections (Sówka et al., 2017a, 2017b). However, there have been no attempts to perform geostatistical analyses based on the results of odour concentration measurements by field olfactometry. The aim of the study is to assess the suitability of the use of ordinary kriging and the inverse distance weighted method as potential ways of spatial data interpolation in analyses of the odour impact of objects from the poultry (turkeys and chickens) farming, slaughter and cutting industries, using data obtained from measurements conducted with the sensory method, i.e. field olfactometry.

Methodology and research area

The area covered by the study lies within the administrative boundaries of a small town in western Poland, in the Lubuskie Voivodeship. The measurement area is adjacent to the plant involved in the breeding, slaughtering and cutting of poultry – turkeys and chickens. The plant covers an area of about 3 ha, on its territory there are production buildings, warehouse buildings, intended for among others feed storage, wastewater treatment plant and administrative and production building. Biologically degradable wastewater from office buildings and social rooms as well as from the slaughterhouse plant is discharged to the wastewater treatment plant. On the south--west, west and north-west sides, single and multi-family residential buildings are located within 20–300 m from the plant's borders. The plant is adjacent to the forest from the north, east and south, and then, at a distance of about 100 m, there are farmlands. Figure 1 shows the research area.

In order to estimate the odour concentration in the areas adjacent to the plant, field olfactometry measurements were carried out using a Nasal Ranger® portable field olfactometer. As part of the

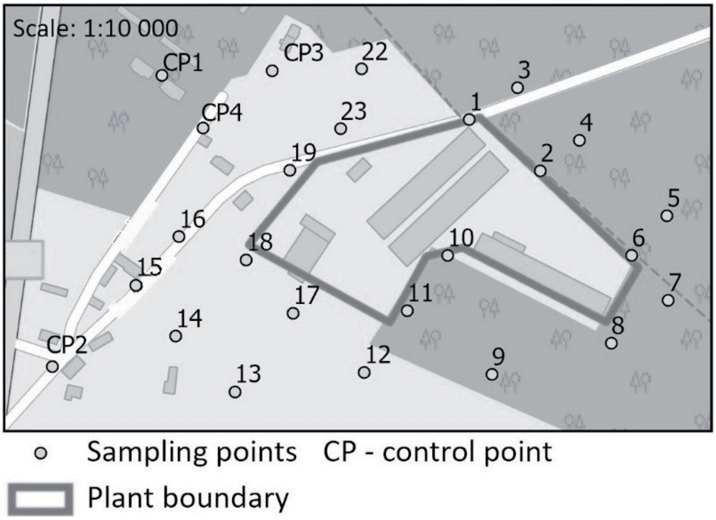

FIGURE 1. Map of the examined area with the location of the measuring points (OpenStreetMap, 2019)

study, measurements were carried out in two series: the first in the autumn–winter season (November 2018) and the second in the spring–summer season (May 2019). Table 1 summarizes the meteorological conditions recorded before the measurements were made for each series.

Taking into account the accessibility of the terrain and topographic conditions, a measuring grid with a 100 m step was created, consisting of 25 measuring points, of which four were control points coinciding with the places designated for earlier questionnaire surveys. The measurements were carried out by a team previously trained in the use of equipment and tested for olfactory sensitivity in accordance with the standard PN-EN 13725:2007. Each individual measurement was started with the intake and exhalation of air in the BLANK position for a period of 1 min, and then, starting from the D/T 60 value (dilution-to-threshold level), it was tested whether the odour was perceptible in the air. Between successive, decreasing dilutions, BLANK trials were presented. The measurement was completed when the odour was noted. The D/T values at which the odour was perceptible were used in further calculations of the odour concentration for

TABLE 1. Meteorological data

Parameter	Unit	Series 1 (November 2018)	Series 2 (May 2019)
Temperature	°C	–2.5	22.6
Relative humidity	%	54.5	47.3
Wind speed	$m \cdot s^{-1}$	2.5	1.9
Wind direction	–	NE	N

a given measuring point. The measurement results were entered into the protocol, in which the character of the identified odour was also noted. The obtained results of odour concentrations using field olfactometry were used for spatial analyses. Point measurement data has been transformed into a continuous surface using data interpolation methods. Two methods were used: the inverse distance weighted (IDW) and the ordinary kriging (OK).

The IDW method is an example of the commonly used deterministic method of interpolation of spatial data (Huisman & de By, 2009). With this method, values at unknown measurement points are calculated as a weighted average of known measurement points. Its main assumption is that each point has a certain impact on its surroundings (Sówka et al., 2017a). This impact decreases with distance. The IDW method is based on Tobler's law, which says that points that are closer together in time or space are more correlated with each other than those that are away from each other (Zhu, 2016). Thus, the closer the estimated points are to the known points, the higher the weight is assigned to them, the further away it is in space, the weight is lower. The spatial correlation described by Tobler's law is expressed by the following equations (Xie et al., 2017):

$$u(x, y) = \frac{\sum_{n=1}^{N} \frac{u_n(x_n, y_n)}{d_n}}{\sum_{n=1}^{N} \frac{1}{d_n}}$$

$$d_n = \sqrt{\left\{\left[(x - x_n)\right]^2 + (y - y_n)^2\right\}^i}$$

where:
$u(x, y)$ – value in an unknown location,
d_n – distance between points,
N – number of unknown locations,
i – exponential function, usually equal 2.

Kriging techniques belonging to geostatistical methods, similarly to the deterministic IDW method, predict values at unknown points based on weighted averages obtained from known measurement points, with the difference that they depend on the spatial variability of the studied data (Zhu, 2016). Spatial data variability is described by the phenomenon of autocorrelation, which allows determining statistical relationships between the analysed points (ESRI, 2016). Autocorrelation is based directly on Tobler's law mentioned earlier. Kriging methods are considered as best linear unbiased estimators. The OK method is considered as the standard kriging method, which assumes that the mean of data set is unknown (Zhu, 2016; Borkowski & Kwiatkowska-Malina, 2017). Using this method, values at unknown locations are calculated using the following equation (ESRI, 2016):

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where:
$\hat{Z}(s_0)$ – estimated value,
s_0 – estimated point,
λ_i – weight for the point at i-th location,
$Z(s_i)$ – measured value at the i-th location.

The weights are calculated based on linear equations that assume the minimization of the expected data variability. To determine data variability, this method, like all techniques in this family, uses variogram analysis.

Cross-validation was performed to verify the correctness of the mentioned interpolation methods. This validation allows comparing and determining the quality of interpolations performed. It involves removing known measurement points from the data set and their estimation using a selected interpolation model. The differences between the measured and estimated values at these points are used to calculate useful statistics that allow the analysis of performed interpolations (Ding et al., 2018). The mean error and the root mean square error were the basic parameters used in validation of obtained interpolation results. The ME index was used for analysing interpolation errors, while the RMSE was used to compare interpolation quality.

Results and discussion

Table 2 summarizes the results of measurements carried out in two measuring series from all measuring points and the characteristic types of odours noted during field tests. The odour character was described in accordance with the odour descriptors contained in the Nasal Ranger® manual. The conducted measurements show that during the research performed in the autumn/winter season, the smell of poultry manure and smoky was characteristic, there were also woody and grain silage odours identified. However, during the spring/summer season, only the smell of poultry manure was noticeable in the field. The range of measured odour concentrations for the poultry manure odour, which is characteristic of the plant's production profile, was in the range of 4–78 ou·m^{-3} during the first measurement series and was recorded at seven measurement points, while in the second measurement series the range of the recorded concentration of odour for poultry manure was 2–78 ou·m^{-3} and was recorded at 11 measuring points. The maximum odour concentration in the first series for the character of the poultry manure odour was reported at measuring point 1 (78 ou·m^{-3}), and in series 2 at measuring points 1 and 3.

The odour concentration values obtained at the measuring points where the poultry manure odour was noted were used as input for the calculation of statistical surfaces representing the distribution of odour concentrations in the examined variants using the ordinary kriging (OK) method and the inverse distance weighted (IDW) method.

Figures 2–5 show the results of interpolation of measurement data obtained during the sampling campaigns with the use of dynamic olfactometry. Figures 2 and 3 show the results of the inverse distance weighted method for measurement series 1 and 2 respectively. Figures 4 and 5 show the results of surface modelling with the use of the ordinary kriging method for measuring series 1 and 2 respectively.

Interpolations carried out for selected scenarios allowed to obtain a spatial representation of given odour concentrations. Visualization of odour concentrations on the obtained distributions was presented using eight classes representing a given concentration level (from $\leq$ 10 to $\leq$ 80 ou$_E$·m^{-3}). The obtained distributions allow for spatial analysis of odour concentrations and allow for

TABLE 2. A summary of odour concentrations measured by field olfactometry at measuring points in the autumn–winter and spring–summer seasons

Measuring point	Latitude	Longitude	Odour concentration [ou·m^{-3}]	Odour descriptor	Odour concentration [ou·m^{-3}]	Odour descriptor
			series 1 (November 2018)		series 2 (May 2019)	
1	51.4473	15.1131	78	poultry manure	78	poultry manure
2	51.4469	15.1139	4	poultry manure	22	poultry manure
3	51.4475	15.1136	22	poultry manure	78	poultry manure
4	51.4471	15.1144	43	poultry manure	43	poultry manure
5	51.4466	15.1154	7	poultry manure	43	poultry manure
6	51.4463	15.1150	7	poultry manure	11	poultry manure
7	51.4459	15.1154	2	woody	43	poultry manure
8	51.4456	15.1147	BL*	–	43	poultry manure
9	51.4454	15.1133	4	burnt wood	7	poultry manure
10	51.4463	15.1128	BL	–	2	poultry manure
11	51.4459	15.1123	4	burnt wood	4	poultry manure
12	51.4454	15.1118	BL	–	BL	–
13	51.4453	15.1103	2	smoky	BL	–
14	51.4457	15.1096	BL	–	BL	–
15	51.4461	15.1092	2	smoky	BL	–
16	51.4464	15.1097	2	smoky	BL	–
17	51.4459	15.1110	2	smoky	BL	–
18	51.4462	15.1105	2	grain silage	BL	–
19	51.4469	15.1110	BL	–	BL	–
20 = CP4	51.4472	15.1100	BL	–	BL	–
21 = CP3	51.4476	15.1108	BL	–	BL	–
22	51.4476	15.1118	1,73	smoky	BL	–
23	51.4472	15.1116	1,73	smoky	BL	–
CP1	51.4476	15.1095	BL	–	BL	–
CP2	51.4455	15.1082	BL	–	BL	–

*BL – below the limit of quantification.

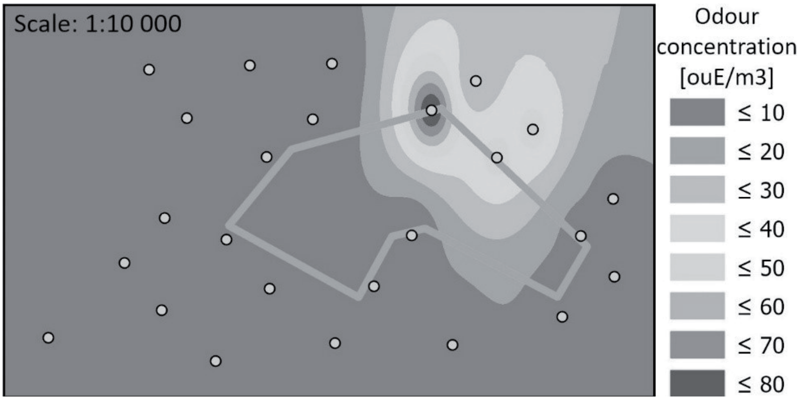

FIGURE 2. Spatial representation of odour concentrations using the IDW method for measurement series 1

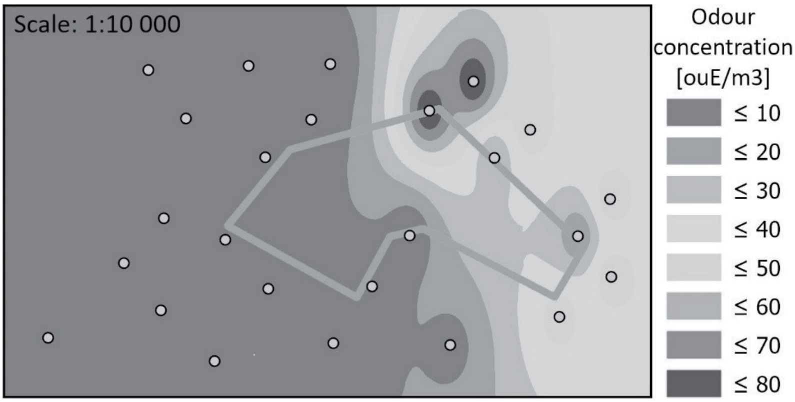

FIGURE 3. Spatial representation of odour concentrations using the IDW method for measurement series 2

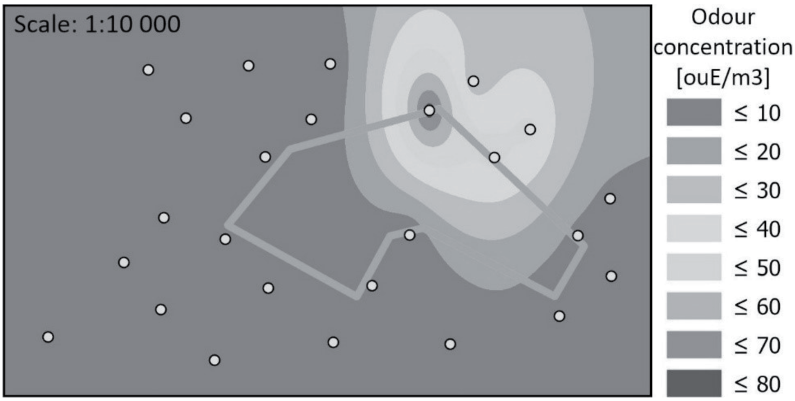

FIGURE 4. Spatial representation of odour concentrations using the OK method for measurement series 1

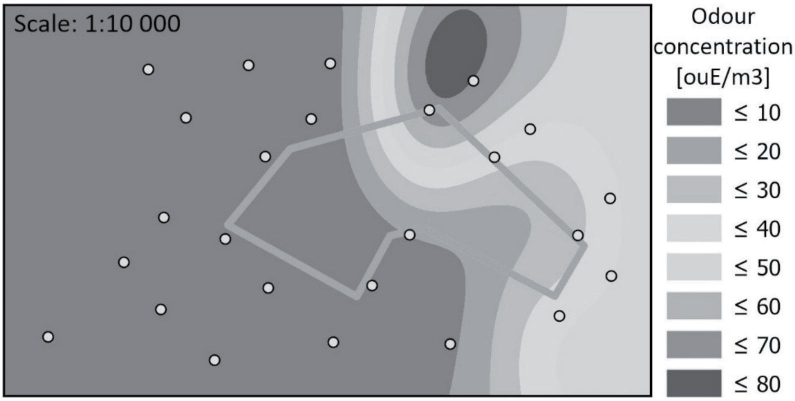

FIGURE 5. Spatial representation of odour concentrations using the OK method for measurement series 2

obtaining information on concentrations in places not covered by measurements during sampling campaigns. The visualization of IDW (Fig. 2) and OK (Fig. 4) method for series 1 are similar in terms of spatial distribution. The biggest visual difference can be found between IDW (Fig. 3) and OK (Fig. 5) during the second measurement series.

In order to validate the continuous surface modelling carried out, cross-validation was performed for all four variants. The validation results are summarized in Table 3.

Results gathered from the preformed cross-validation shows that the ME index, which allows the assessment of the average interpolation error, obtained the lowest values in the case of the first series of measurements for both methods (IDW: 0.17; OK: 0.21). The highest values were obtained in the second measurement series (IDW: –0.53; OK: –0.58). This indicator is largely dependent on the data analysed, therefore the differences in the cases taken into account are observed due to the differences in data variability between the two measurement series. Due to the fact that this indicator to compare data interpolation methods should be used when the RMSE parameters are equal (Ding et al. 2018), which did not take place in the analysed situations, the RMSE parameter was used as the main comparative indicator. The RMSE indicator was used to compare the models used in terms of interpolation quality and correct model matching. Lower values indicate higher quality of obtained interpolations (Ding et al., 2018). The lowest values of this indicator were obtained in the case of OK method, 14.47 and 14.20 for series 1 and 2. The IDW method is character-

TABLE 3. The cross-validation results for used interpolation methods (series 1 and 2)

Measure	IDW, series 1	IDW, series 2	OK, series 1	OK, series 2
ME	0.17	–0.53	0.21	–0.58
RMSE	14.82	16.33	14.47	14.20

ized by slightly higher values, in series 1 this indicator reaches the value of 14.82 while 16.33 in series 2 and it is the highest of all analysed cases. The order of the best match is: OK series 1 > OK series 2 > IDW series 1 > IDW series 2. Despite the fact that RMSE indicator was lower in case of kriging technique, in both cases values of RMSE were relatively high. The reason of that is the high spatial variability of input data, odour concentration used in interpolation techniques vary from 2 to 78 $ou_E \cdot m^{-3}$, which can cause increased prediction errors. To prevent that it is recommended to increase amount of sampling points during field olfactometry. When analysing obtained continuous surfaces (Figs. 2–5) it is clear that ordinary kriging gives better spatial visualization of odour concentration in the cases under consideration. Obtained visualization and values from cross-validation indicate possible application of ordinary kriging in spatial presentation of odour pollutants obtained from field olfactometry.

Conclusions

The obtained visualizations and the results of the cross-validation carried out for the method of weighted inverse distances and ordinary kriging indicate a potential better use of the ordinary kriging method in spatial modelling of continuous surfaces using measurement data obtained using field olfactometry. Due to high concentration variability, both methods were burdened with measurement errors obtained during cross-validation.

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Summary

The use of ordinary kriging and inverse distance weighted interpolation to assess the odour impact of a poultry farming plant. The aim of the study was to determine the usefulness of spatial data interpolation methods in analyses of the odour impact of animal husbandry facilities. The interpolation methods of data obtained from measurements using the field olfactometry technique were the ordinary kriging method (OK) and the inverse distance weighted method (IDW). The quality of the analyses that have been obtained indicates the potentially better use of the OK method in the presentation of spatial odour concentration distributions.

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