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GIS-based modelling of odour emitted from the waste processing plant: case study

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Abstract. The emission of odours into the atmospheric air from the municipal economy and industrial plants, especially in urbanized areas, causes a serious problem, which the mankind has been struggling with for years. The excessive exposure of people to odours may result in many negative health effects, including, for example, headaches and vomiting. There are many different methods that are used in order to evaluate the odour nuisance. The results obtained through those methods can then be used to carry out a visualization and an analysis of a distribution of the odour concentrations in a given area by using the GIS (Geographic Information System). By their application to the spatial analysis of the impact of odours, we can enable the assessment of the magnitude and likelihood of the occurrence of odour nuisance. Modelling using GIS tools and spatial interpolation like IDW method and kriging can provide an alternative to the standard modelling tools, which generally use the emission values from sources that are identified as major emitters of odours. The work presents the result, based on the odour measurements data from waste processing plant, of the attempt to connect two different tools – the reference model OPERAT FB and GIS-based dispersion modelling performed using IDW method and ordinary kriging to analyse their behaviour in terms of limited observation values.

1 Introduction

Geographic Information System (GIS) has been widely used in many fields related to the environmental protection, including for example hydrology, meteorology and also to estimate a dispersion of air pollutants [1, 2]. GIS as an information processing technique, helps to collect, store, display, process and analyse spatial geographic data [3, 4]. That is why GIS is a suitable tool to also analyse and visualize environmental models based on spatial data. As an example, it can visually show pollution condition and environmental quality [3, 5].

Odours are a specific type of pollution in terms of the nuisance that is caused by them is mostly a derivative of their subjective perception [6]. Therefore, prediction and modelling odour dispersion is relatively difficult. There are several air pollution dispersion models, which simultaneously use GIS tools for instance to visualize the achieved data. The most

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commonly used ones are CALPUFF and AERMOD. Both of them are designed generally for air pollutants, but they also meet the requirements for the use of data about the odour concentrations or emissions. AERMOD and GIS were employed to model odour dispersion from biosolids reuse sites in Orange County in Virginia [8]. Some model based on odour dispersion calculations using a mathematical model CALPUFF and geostatistical analysis – ordinary kriging was used to characterize the odour nuisance caused by a distillery located in the south-west of Poland [7]. There are also other applications that integrate GIS and dispersion models – DUSTRAN use EPA atmospheric dispersion models and ArcGIS in order to stimulate the dust dispersion [9]. In India CALINE-4 model and TransCAD software, based on GIS was used to evaluate concentrations of vehicular pollutants [10]. In Poland the reference model based on Pasquill formula and adapted to the description of methodology for performing such calculations in accordance with Regulation of the Minister of Environment dated 26 January 2010 on reference values for some substances in the air is used [11].

Among the methods that are used in the world for the purpose of determining the olfactory impact of emission sources, there can be distinguished methods such as the dynamic olfactometry, field studies and questionnaire surveys [3]. All of them can be used to obtain a discrete data for subsequent modelling the impact of odours using GIS tools. By measuring the geographical coordinates at the measuring points it is possible to obtain a spatial nature of data and subsequently process them and visualize in GIS.

The goal of the study was to attempt to connect two independent but consistent tools - the reference model (OPERAT FB software) and a GIS-based odour dispersion modelling on selected area performed using Geographic Information System and to analyse their behaviour in terms of limited observations values.

2. Characteristics of selected methods used in the study

2.1 Dynamic olfactometry and reference model

The dynamic olfactometry is one of the odour concentration measurement techniques that can be used to obtain a discrete data for subsequent modelling in GIS. Procedures for determination of odour concentration by this method are described in the standard *PN-EN 13725:2007 Air quality. Determination of odour concentration, with the use of dynamic olfactometry method* [12]. In this sensory method a team of evaluators assess air samples containing odorants in various concentrations. The evaluators are selected in accordance with guidelines given in the standard, with the use of certified reference material (n-butanol in nitrogen). In the simplest version of the method – "yes – no" - the evaluators are about to signal, whether they sense the smell in the presented gas stream. The gases are diluted with an odourless air dynamically. The initial dilution is chosen in the way, it is not possible to determine the presence of odour. The dilutions are decreasing. Among presented samples there are so called "blind samples", in which instead of an odour, a clean, odourless air is presented. One measurement consists of four series. The results are calculated as the result of one measurement team – the average of all individual measurements. It is also the odour concentration in a given sample given in ou_E/m^3 units [6, 12, 13]. On the base of the determined odour concentrations it is possible to calculate the odour emission from individual sources and overall odour emission from the studied facility as well as to calculate odour concentrations at reception points by using available dispersion models according [11].

2.2 GIS-based modelling

Spatial interpolation is one of the most advanced procedures in GIS systems. Using this method it is possible to estimate the analysed magnitude for areas where measurements were not performed. Interpolation is a part of the science of geostatistics, which combines geography and statistics. The basis of the geostatistics is the Tobler law that says that objects that are adjacent each other in time and / or in space are more alike than objects that are farther apart [1, 14, 15]. Geosatistics can convert the point data into the spatial data. Geostatistics can estimate the value of the data at the points where, due to time, cost, or technical limitations performance of the measurements is impossible. It assumes that the spatial variability of natural phenomena can be modelled using the spatial autocorrelation, so it is possible to get the results as a continuous surface. It is important to properly select appropriate interpolation functions and choose how to determine the weight to be attributed to the surrounding areas [15]. We can distinguish such methods of interpolation like deterministic and probabilistic. The first includes Inverse Distance Weighted (IDW) method, radial basis function, trend surface analysis, second consists of different sorts of kriging – simple kriging, ordinary kriging, block kriging and point kriging [14]. Since the kriging method is based on the statistical properties of the measured points it provides an accuracy analysis of the predictions while IDW interpolation (based on a linear combination of nearby observations) does not [16].

2.2.1 Inverse-distance weighting method (IDW)

The main assumption of the IDW (Inverse-distance weighting) method is that each sample has an impact on their surroundings. In IDW method the value of the variable in the interpolation point is determined as a weighted average of the surrounding sampling points. The weight of the variables decreases with distance. The use of higher value of the power increases the influence of closer measurement points. This makes it possible to calculate the variable at any point in the field on the basis of the measurement data [15, 17, 18]. The effect of the calculation depends on such interpolation parameters as the value of the power, the number of neighbours and a radius of search [17].

The advantages of the IDW are simplicity and speed of execution. It gives reliable results whilst maintaining the values of samples. It characteristic is not to exceed the interpolated values. This is important, for example, for measurements that use a strict numerical scale [17].

2.2.2 Kriging

Kriging is a geostatistical interpolation method of moving weighted average. Kriging technique is applied to the local estimation. In the process of estimation there are included only data located near the area of estimation. In this method a set of the weightings assigned to the samples minimalizes the variance of the estimation. The variance of the estimation is calculated as a function of the adopted model of an empirical variogram and mutual location of samples and reciprocally relative to a point or a block which is the subject of estimation [14, 15]. Kriging is a stepwise process. In the first stage the empirical variogram should be calculated. Then the theoretical model, also referred as the geostatistical must be matched. The hardest step is the spatial autocorrelation that fit the theoretical function to the course of the variogram. In the kriging a set of kriging linear equations is solved, which results in receive a kriging weights (coefficients). The coefficients in the kriging equation represent the covariance between samples in the area of estimation and between samples and the area of estimation [14, 15].

3. Research methodology and results discussion

Odour concentrations measurements were taken in the area of the waste processing plant, located on the suburbs of a chosen city in Poland. The plant is located in distance approximately 1200 m to the west to nearest residential buildings and surrounded by fields and bands of green. Volume flow rates (m^3/s) and odour concentrations (ou_E/m^3) were measured in four regular measurement series at a certain time (according to VDI 3883) [19, 20]. Modelling parameters in the software OPERAT FB based on parameters of the gases (Table 1), odour emission rate; meteorological conditions and topography; pollution transport in the atmosphere. The determined coefficient of aerodynamic roughness of z_0 = 0,55 m was assumed.

Table 1. Characteristic of the emitters and basic parameters of the emitted gases.

Emitter No.	Emitter high [m]	Emitter diameter [m]	Speed of the gaseses [m/s]	Volumetric heat capacity [kJ/m^3/K]	Emitter location X [m]	
					X [m]	Y [m]
E1	10.5	0.345	2.29	1.30	463.5	240.9
E2	11	0.345	2.29	1.30	463	232.8
E3	12.5	0.345	2.29	1.30	462.5	224.7
E4	13	0.345	2.29	1.30	463.5	218.1
E5	13	0.345	2.29	1.30	465.1	203.5
E6	11	0.345	2.29	1.30	466.1	193.9
E7	13	0.345	2.29	1.30	465.6	187.8
E8	11	0.345	2.29	1.30	466.6	182.8
E9	10.5	0.345	2.29	1.30	467.1	174.7
E10	1.5	0.18	0.04	1.30	366.6	371.6
E11	3	0.18	0.04	1.30	382.8	291.9

In the next step, for verification used tool (OPERAT FB software), the Geographic Information System (GIS) – based model of the odour plume and potential impacts on the offsite receptors was developed in the present study. Integrated modelling approach involving GIS to highlight odour concentrations estimation by physically connection of two rasters - results of measured concentrations simulated in OPERAT FB and a raster datasets covering an area under research – has been used. Results of odour dispersion modelling (displayed as concentration predicted map) are obtained from an application of ArcGIS spatial analyst tools such as ordinary kriging and inverse-distance weighting method (IDW). Measurement data were used to estimate the annual average odour concentrations (modeled by OPERAT FB) and graphically represented in GIS software as a raster (Fig. 1). Calculations are made in grid format receptors (size 1800 m × 1800 m and step 50 meters. The model was developed by physical connection in GIS environment the OPERAT FB modeling output and a visualizing odour impact area. The geographic coordinate system WGS 84 / UTM zone 33N (for Poland) was assigned to the data frame.

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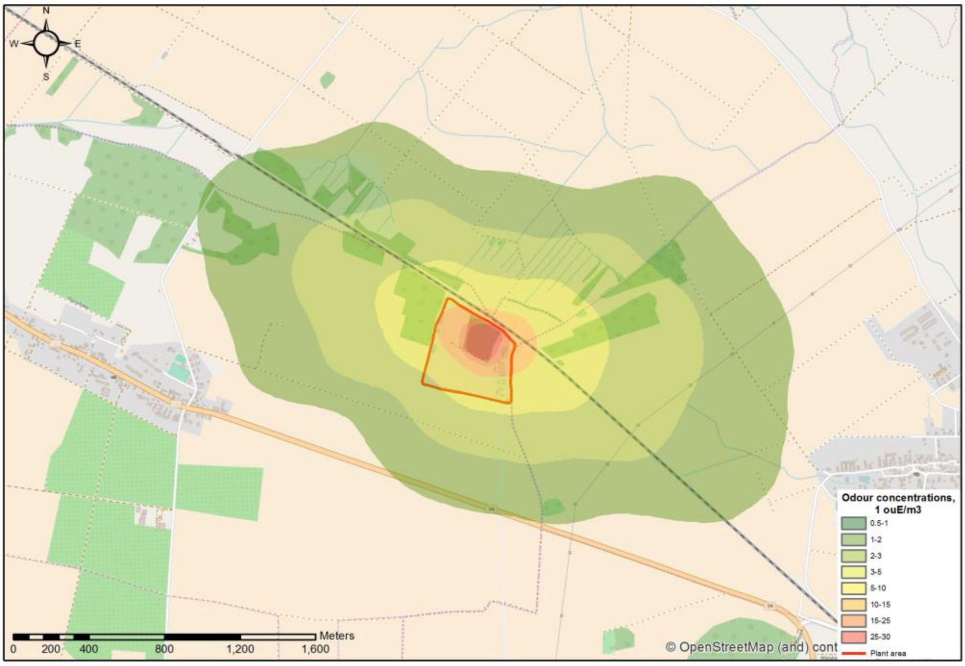

Fig. 1. Annual average odour concentration calculated with reference model (OPERAT FB software). Map source: OpenStreetMap.

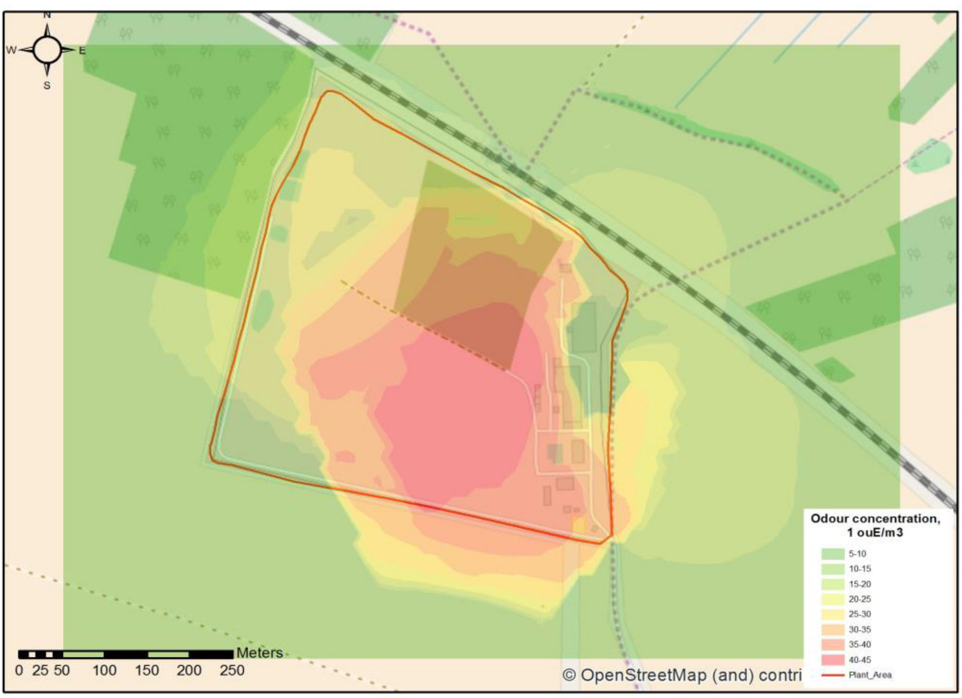

Fig. 2. Odour dispersion model built with ordinary kriging in GIS software. Map source: OpenStreetMap.

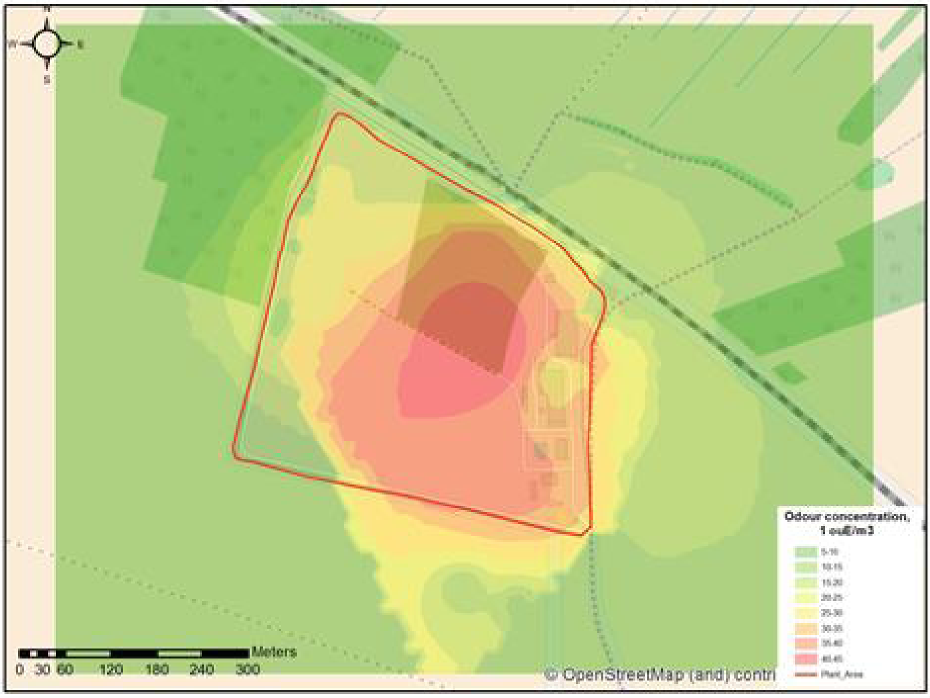

Fig. 3. Odour dispersion model built with Inverse-distance weighting method in GIS software. Map source: OpenStreetMap.

Then, the odour dispersion modelling results were incorporated into the GIS environment. The geostatistical analysis was used to predict concentration values at locations with odour concentrations determinated and calculated on the basis of dynamic olfactometry measurements at a limited number of points. The atmospheric odour dispersion model was obtained by performing spatial analysis by use of the ordinary kriging and IDW method from GIS (ArcMap10.3.1) (Fig. 2, 3). Suitable areas were created as a weighted raster were minimum error variances (root mean square error, mean absolute error, variance of errors) of kriging interpolation have been adopted. The geostatistical interpolation was provided with the prediction error characteristics as follows: the root mean square standardized of the value is 0.6454; the mean standardized error is equal 0.0386; the average normal value is 0.215. All the errors were used to measure the best accuracy of model predictions.

In the study contour plots of modelled odour concentrations are well predicted by the OPERAT FB and GIS tool. The OPERAT FB model shows a similar trend in measured grid distance but provides a significant underprediction effect in sight distance. The analysis of the results showed that interpolated concentration data points on the boundary isolines obtained from calculations by using the OPERAT FB software, mainly in the south-east polygon, have a more widespread interpolated surface i.e. 1200–1600 m from the studied facility compared to GIS model. It might be caused by the overestimation despite there was no objective basis for the predicting in the measurement scales and meteorological characteristics (e.g. direction and maximum wind speed). In the hot-spot area in the framework of plant the odour concentrations are on level of 20-30 ou_E/m^3 (using OPERAT FB software) and above average amount in the GIS interpolation (30–45 ou_E/m^3). In the GIS interpolation prediction map the lower concentration points are very close (200–-300 m) to the waste processing plant area. The differences in interpolation polygon areas between the kriging and IDW method are not significant (visualization effect). The

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contour (isoline) differences were especially in the bottom central quadrant of the map where the odours from emitters were sampled most rarely. In general, kriging as Gaussian process regression works better when input data is close to Gaussian distribution. Interpolated
a raster surface from odour sampling points using a kriging/IDW technique is calculated with high precision in the range of applied measurement data, but it may be a down fall in prediction variables because depends on the number of points and size of the search area. In all of the interpolation cases, the higher the density of sampled cells is, the more accurate will be the interpolated value.

4. Conclusions

The success of the odour dispersion model prediction depends on the comprehensive input data including odor emission rates, meteorological data, sources and surface characteristics, as well as the quality and relevance of the dispersion model. The comparison and performance of two different, but consistent tools for application in spatial analysis and modeling odour dispersion, the OPERAT FB software and ordinary kriging and IDW in the GIS environment, was evaluated in this study. Interpolated a raster surface from odour sampling points using a kriging/IDW technique is calculated with high precision in the range of applied measurement data, but it may be a down fall in prediction variables because depends on the number of points and size of the search area. Consequently, the available interpolation techniques (kriging/IDW) would work better depending on the statistical properties of the data.

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