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A DYNAMIC ODOUR MAPPING SYSTEM AS A TOOL TO SUPPORT LOCAL AUTHORITIES AND WASTEWATER TREATMENT PLANTS IN ODOUR IMPACT MANAGEMENT

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Abstract: Wastewater treatment plant may be a source of nuisance for neighbouring urban areas. Complaints from residents force local authorities and wastewater treatment plants to take action to reduce odour impacts. The need for understanding and assessing the impacts is limited by the available budget. The article presents a low-cost Dynamic Odour Mapping System developed and implemented in one of the wastewater treatment plants serving the city of Bydgoszcz with a population of nearly 350,000. The system consists of four main units: low-cost sensors measuring H_2S and NH_3, an emission modelling system, an odour dispersion modelling system and an odour dispersion dynamic map. Low-cost sensors supported the identification of the main emission sources at the plant and are used for dynamic emission estimation of H_2S and NH_3. Developed algorithms for emission assessment, using sensors data, provide real-time information for the modelling system. Calpuff software is used for H_2S and NH_3 dispersion modelling and its results are presented on the map in historical and nowcasting mode. The main feature that distinguishes the Dynamic Odour Mapping System from others is its dynamic data processing and near real-time information publication. The article describes the main features of the system and discusses its innovative part, how it responds to the needs of the local community, and further directions for development.

Key words: *odour dispersion modelling, low-cost sensors air quality mapping, wastewater treatment plant.*

INTRODUCTION

Municipal wastewater treatment plants (WWTP) are one of the most common sources of odour emissions. Regardless of the modern technological solutions applied to minimise the odour nuisance associated with this type of facility, they may cause unpleasant olfactory experiences for the residents of neighbouring settlements and may even be perceived as a health hazard. The problem of odorous air pollution around WWTPs is mainly due to: processes of anaerobic decomposition of organic substances contained in wastewater, causing the formation of odorous compounds (hydrogen sulphide (H_2S), ammonia (NH_3), mercaptans, aldehydes, ketones and fatty acids), improperly conducted wastewater treatment processes at the WWTP, increasing public awareness and related expectations regarding the quality of the environment.

A lack of Polish and EU legal regulations unambiguously defining the methods of assessing the environmental impact of odour facilities, as well as the lack of a specific odour standard, cause the approach to the abovementioned assessment to vary. In practice, sensorial, instrumental, and mathematical methods are used to assess the odorous impact of industrial activities, which may potentially cause odour nuisance to the environment (Bax C., Sironi S., Capelli L, 2020).

The sensorial method (dynamic olfactometry) can be used for the determination of the odour concentration of a gaseous sample in the European odour unit per cubic metre ($ou_E m^{-3}$), following the European standard EN 13725 “Stationary source emissions - Determination of odour concentration by dynamic olfactometry and odour emission rate” (Standard EN 13725:2022). Determining the volumetric flow rate of the gas at the source enables the calculation of odour emission in odour units per second ($ou_E s^{-1}$), which can be used as input data for modelling. However, this method requires a specialised piece of equipment (olfactometer) and measurements carried out by a panel of human assessors (being the sensors), which is connected with the relatively high costs of this type of research. The sensorial method also cannot be used continuously, which is important in the case of sources characterised by temporal variabilities, such as sewage treatment plants.

The technological advances made in recent years in constructing low-cost sensors to measure environmental parameters have created new possibilities for building measurement systems. Such measurements can be carried out continuously. However, they cannot determine the concentration of the odour mixture in $ou_E m^{-3}$. Still, it is possible to determine the concentration of selected individual chemical compounds in μgm^{-3}. Based on the literature (Baawain, M., Al-Mamun, A., Omidvarborna, H. *et al.*, 2019), it can be assumed that hydrogen sulphide is the leading substance for wastewater treatment plants. Knowing the concentration of hydrogen sulphide (in μgm^{-3}) at the odour detection threshold allows its concentration to be determined in $ou_E m^{-3}$ (according to EN 13725, the odour concentration at the detection threshold is by definition equal to 1 $ou_E m^{-3}$), as a multiple of the detection threshold.

METHODOLOGY

A data fusion concept combining dispersion modelling with sensor network data was applied to the development of a dynamic air quality map, which was a goal of ISSOP research and development project financed by the National Centre for Research and Development (NCBR) and carried out by Atmoterm in the period 2016-2020. The advantage of this solution, in comparison with the systems based only on a network of sensors, are: greater reliability of the results, lower operating costs, greater system stability, the possibility to determine concentrations at any point of the analysed area, the determination of the contribution different emission sources or their groups. The original ISSOP system was prepared to monitor and predict PM2.5, PM10, NO_2, CO, ozone and VOC concentrations. The respective LUMA sensors were developed to run the system effectively.

One of the extensions of the system is a Dynamic Odour Mapping System (DOMS) focused on H_2S and NH_3 concentrations as well as odour units. The system provides nowcasting/forecasting data and also allows analysis of historical data. In addition to the data fusion algorithm the LUMA sensors are also implemented in this case as auxiliary data sources for emission correction. The system was developed in response to enquiries received regarding a cost-effective tool for monitoring odour nuisance in residential areas adjacent to the waste water treatment plant.

Modelling system setup

The modelling system consists of the CALMET meteorological diagnostic model, the WRF prognostic model, the CALPUFF dispersion model and a dedicated set of pre/postprocessing tools. A simplified diagram of the system is shown in the figure below.

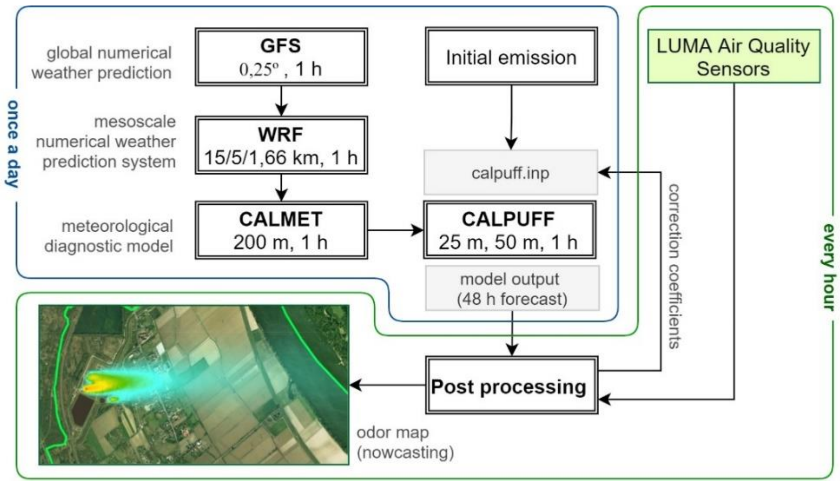

Figure 1. Simplified modelling system diagram

The meteorological data set is determined in the CALMET model in version 7. The input data for the CALMET model includes a geophysical data file and a meteorological data file. The geophysical model was prepared on the basis of SRTM and Corine Land Cover 2018 data. The input meteorological datasets for the CALMET model are determined in the WRF forecast model version 4.2. The meteorological boundary and initial conditions for the mesoscale WRF model are obtained from the global GFS model with a spatial resolution of 0.25º × 0.25º and a time resolution of 1 hour. Calculations in the WRF model are performed once a day for 48 hours of the forecast period for 3 mutually nested domains (d01 - 15 km resolution covering Central Europe area, d02 - 5 km resolution covering the country territory and d03 - 1.66 km resolution covers the area of the city where the WWTP is located). WRF model settings include Thompson 7-class microphysics scheme, Yonsei University-Pleim-Chang (YSU) PBL scheme, Kain-Fritsch cumulus scheme (d01) and RRTMG long wave and shortwave radiation scheme.

Pollutants dispersion modelling is determined using CALPUFF model developed by Sigma Research Corporation. Emissions are introduced to the model through dedicated emission files calpuff.inp which include emitter's parameters (location, elevation, stack parameters) and emission characterisation. Each emission source is modelled independently. CALPUFF model calculations are initiated daily using the initial emissions estimated with the first approximation.

Emissions

The emissions from the WWTP are not continuous or cyclical, they are episodic (e.g. unloading or discharges of wastewater, etc.), which significantly complicates the modelling process, especially in terms of modulating emissions over time. Therefore, it was decided to use measurement data from detectors located as close as possible to the emission source. The measurement data, read hourly via the API, allows for the correction of the initial emissions estimated to the first approximation. The emissions adjustment is made at the post-processing stage. All operations on the output dataset are performed with the use of CALSUM and CALPOST postprocessors and specially developed Python scripts.

Sensors development

For H_2S measurements Alphasense H2S-B4 sensors have been implemented into LUMA device. Winsen ZE03-NH3 sensors have been applied for NH_3 measurements. The Dynamic Odour Map System uses sensors in two modes: for dynamic emission correction and for assimilation process. Sensors located close to the main emission sources support emission calculations; sensors placed at the boundary of the WWTP site are used in fusion process in modelling.

Mapping system

The open-source TerriaMap project was used to present the modelling results in the form of spatial concentration distribution maps. Data is collected on an ongoing basis via a special API from the LUMA sensors service system and from the modelling system. Data is saved and then is undergoing geoprocessing through data pasteurization. The system ensures scalability thorough application of docker services for all components of the data processing and visualization system.

IMPLEMENTATION OF THE SYSTEM AND RESULTS

The system has been implemented in a Wastewater Treatment Plant (WWTP) located in Bydgoszcz City in 2020. The project was initiated by the complaints of residents living close to the WWTP and financed by City budget. The implementation consisted of two steps: pilot study and full operation phase.

Pilot study

In the first step, the prototypes of low-cost sensors for H_2S and NH_3 measurement were designed, produced and calibrated. The calibration process was carried out for the detection of the leading substance H_2S in field conditions. The reference device was the Draeger PAC 6500 instrument. The field calibration process has been conducted in the Wastewater Plant and has lasted 4 days. The results showed very good agreement of designed devices (LUMA sensors) with the reference device with accuracy of 0.1 ppm. For the NH_3, factory calibration parameters provided by the sensor manufacturers were used. The final location of sensors has been selected based on measurements and information received from WWTP officers (figure below). Selected locations included the main emission sources: 1, 3.1, 3.2, 18, 5 and the boundary of the WWTP close to the nearest residential houses (no. 2 – the gate).

Figure 2. Location of the LUMA sensors

Operation phase

Operation phase which includes launching a modelling run and map presentation in public portal, started in the December 2021. The analysis of LUMA sensors measurements helped to design the parameters of the odour mapping portal. Scale levels for H_2S odour impact have been established. Detection threshold for H_2S was set up at 1 μgm^{-3} (AIHA, 2013). According to the British guidelines on odour management (Environment Agency: H4 Odour Management, 2011) 3 ou was applied as the comparative level for 1-hour concentrations for WWTP (moderately offensive odours). Exposure above this level may be associated with the potential for odour nuisance.

The modelling system is running with variable density grid. At WWTP site and in the surrounding area the receptor grid resolution is 25 m, at the remaining area it is 50 m. The discrete receptors corresponding to the sensor's locations were added to the grid. Initial emissions implemented in the model based on F.L. Colomer et al. (2012) and C. Zhang et al. (2017) are being corrected using the LUMA sensors measurements. The concentration values obtained from the model and the sensors at the measuring points are read. Then the normalized concentration difference for the partial results is determined, obtained from the calculations carried out for each emission source independently. In the last step, a matrix of correction factors for the initial emission is built, scaling and summation of the results is performed.

Model runs in the forecast mode and the forecast includes 48 hours ahead. Results of modelling are presented in the public portal: the Dynamic Odour Mapping System. The DOMS enables presentation of dynamic concentrations changes on an hourly basis using a time slider. The System presents results for the current day, two past days and two days ahead. Map for H_2S concentrations is available in two units: μgm^{-3} and in odour units: oum^{-3}. User can select a layer for presentation and obtain information on concentration in a selected place by clicking at the point on the map (figure 3).

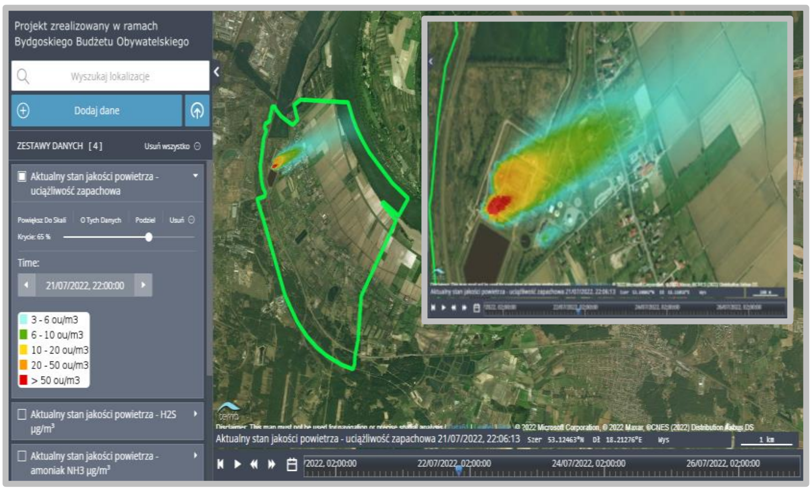

Figure 3. The Dynamic Odour Mapping System

Results

The preliminary analysis was prepared after the DOMS system operation for six months. Bearing in mind the main objective of the DOMS which is to monitor odour nuisance in residential areas adjacent to the wastewater treatment plant, the analysis is focused on odour impact assessment at two neighbouring locations: the school and the district council building. The figure below presents time series modelling results of 1-hour H_2S odour concentrations at two locations and the comparative level of 3 oum^{-3}. H_2S concentrations range from 0 oum^{-3} to 36,7 oum^{-3}. Zero values are observed with wind directions towards the WWTP. H_2S concentrations are generally higher during summer than during the winter season. The comparative level is exceeded in both locations. However, the 98^{th}-percentile will be calculated after the full year of the system operation and the conclusions will be prepared.

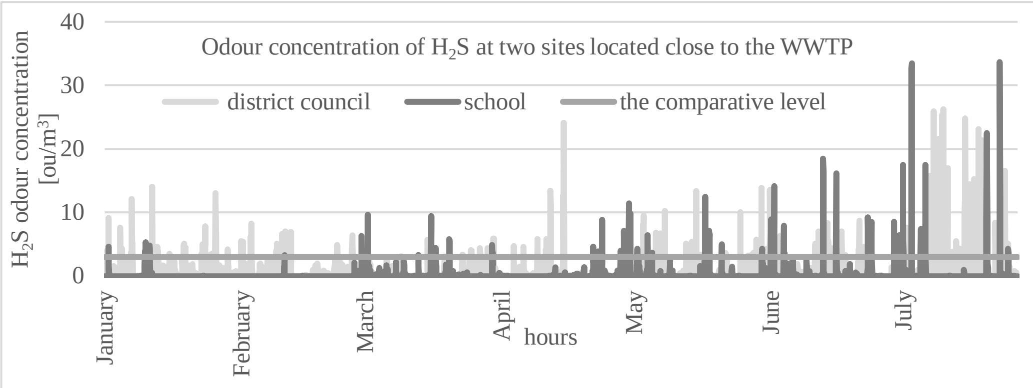

Figure 4. Time series of H_2S odour 1-hour concentration from 1.01.2022 to 26.07.2022

CONCLUSIONS AND RECOMMENDATIONS

1. The Dynamic Odour Map System enables the identification of possible problems associated with odour nuisance episodes caused by WWTP.
2. The Dynamic Odour Map System is a useful tool for public information system concerning odour problems, especially with limited budget availability. The main advantages of DOMS are: the possibility to determine concentrations at any point of the analysed area, real time and forecast data delivery, lower costs than traditional measurement systems and the determination of the contribution of different emission sources or their groups.
3. The System may support the WWTP in emission management. It enables identification of the main emisison sources and gives information about impact of the installation on the neighbouring area.
4. Sensors may be implemented in the modelling system in two different ways: for dynamic emission correction calculation and in fusion process.
5. Further studies are planned on improvement of emission inventory from WWTP and model verification.

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