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USE OF QUANTITATIVE AND QUALITATIVE WASTEWATER MONITORING IN WATER PROTECTION ON THE EXAMPLE OF LODZ

Widely understood protection of water, and in particular surface waters, most exposed to direct pollution, requires many operations carried out both in the catchment area and in sewage systems as well as wastewater treatment plants. Due to its character and working conditions, it should be monitored not only in terms of hydraulics, but also in terms of the quality of transported wastewater. During atmospheric precipitation, large volumes of domestic and industrial wastewater as well as rainwater in various proportions flow through the canals, changing not only their quantity but also their composition. In such cases, the issue of monitoring becomes particularly vital. The article presents an analysis of the needs and tasks resulting from the application of quantitative and qualitative monitoring in the assessment of the functioning of sewage systems. Methods and tools used in Lodz that may be useful in water protection are presented. The benefits of using this type of solutions as well as the limitations and difficulties are discussed.

Keywords: sewer system, wastewater monitoring, rainfall monitoring, predictive model

1. Introduction

In recent decades surface water protection has become particularly essential among others due to the decreasing world drinking water resources and simultaneously the growing population and its requirements for water quality. Water protection largely depends on the functioning of sewage systems, which should not only ensure the safe functioning of the city, but also determine the ecological safety of the receiver. Urban development, and therefore an increase of urbanized areas in the total catchment area, additionally highlights the impact

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of sewerage systems on water reservoirs. In the last two decades, both methods and devices used for monitoring wastewater systems have significantly progressed [1, 2, 3, 4, 5]. It should be noted, however, that the functioning of sewage systems carried out wastewater from urban areas is associated with the occurrence and character of rainfall, which should therefore also be constantly monitored [6, 7]. In addition to changes in the character of precipitation as a consequence of climate variations, changes in air temperature are also observed. This affects in some way the temperature of rainwater directed to the sewage system and the temperature in the wastewater receivers. This may alter, among other things, the morphology of the receiver as well as the kinetics of the chemical reactions taking place in it.

Pollutants introduced by wastewater sewer systems largely affect the chemical and ecological state of reservoirs [8, 9, 10]. Monitoring of sewer systems should therefore be carried out in terms of both the quantity and composition of transported sewage [11]. This is particularly important for the assessment of pollution load in surface waters pollution load coming from the sewage system and wastewater treatment plant. Only comprehensive knowledge of pollutant emissions allows to fully control and effectively counteract the pollution of water receivers and promotes the proper functioning of the sewage system, even in conditions of variable flows caused by precipitation events.

Climate change and uncontrolled or poorly controlled growth of urbanization are also the main reasons of combined sewer overflows activation, which significantly affect surface water pollution [12, 13]. Therefore, it is important to know the frequency of their activation as well as the volume of wastewater and load of contaminants discharged by them into the aquatic environment. In pursuit of achieving good ecological status of waters, the impact on the receiver of agricultural and natural areas should also be taken into account. However, in urbanized areas, the impact of sewage systems is clearly dominant compared in comparison with other sources of pollution [14].

2. Analysis of needs, tasks and benefits resulting from the application of quantitative and qualitative monitoring

Urban development and the increasing incidence of extreme rainfall events leads to sewage systems, including wastewater treatment plants, being increasingly overloaded, which reduces their operational safety. The condition of optimal use of their technical capabilities and determining the necessary scope of modernization and expansion is knowledge of the hydraulic conditions of the network operation and the composition of flowing wastewater. The database required for this is facilitated by on-line devices. Until recently, on-line monitoring was most often carried out mainly in wastewater treatment plants to control treatment processes [15], and its use in sewage disposal systems was sporadic and rarely described [16].

Currently, on-line monitoring can be carried out using, among other things:

- rain gauges that allow determining rainfall characteristics,
- filling sensors and flow meters in channels,
- on-line sensors measuring one or several indicators of wastewater pollution simultaneously (multi-parameter sensors).

For effective control of the impact of wastewater sewer systems on receiver waters, it is important to define criteria for the selection of monitoring points [17]. Depending on the applied solutions a lot of information can be obtain, among others, for:

- recognition of the dynamics of flow variabilities in the sewers,
- composition of wastewater flowing through the sewage network both in dry and wet weather,
- monitoring of wastewater inflow to the treatment plant,
- calibration of computer programs used for network modeling,
- analysis of the "first flush" phenomenon of pollution in the sewage system,
- assessment of the functioning of sewage systems in the hydraulic aspect [18, 19], as well as pollutant emission [1],
- RTC system implementation (Real Time Control) in sewer networks [20].

In accordance with PN-EN 752: 2017 "External sewage systems", when conducting research and analyses relating to the functioning of sewage systems and determining the needs for their modernization, should be used simulation models that require accurate data from measurement campaigns. The use of on-line sensors measuring the concentrations of selected wastewater pollution indicators, especially in the case of combined sewer system, allows for a significant cost reduction of sampling, their transport and laboratory tests [21].

The use of quantitative and qualitative monitoring of wastewater sewer systems is extremely important for the functioning of wastewater treatment plants. Variations of quantity and composition of inflowing wastewater, sewer system modernization and changes within the catchment area may reflected in the inflow characteristic to the wastewater treatment plant and influence on hydraulic and pollution load.

3. Methods and tools used in Lodz

3.1. Characteristics of Lodz wastewater sewer system and the scope of its monitoring.

Lodz is equipped with mixed sewer system. A combined sewer system (43 km^2) exist in the central districts and a separated system in the rest of the city. There are 18 combined sewer overflows, which discharge excess raw wastewater directly to Lodz rivers during heavy rainfall. The main receiver of all wastewater from the city, both the treated wastewater from the Lodz treatment plant and the raw wastewater coming from heavy rainfall, which is directed to the receiver from combined sewer overflows is the Ner River. Currently, all overflows are equipped with flow meters, which allow to monitor the functioning of these facilities, determine the frequency of their activity and the volume of discharged wastewater (Fig. 1).

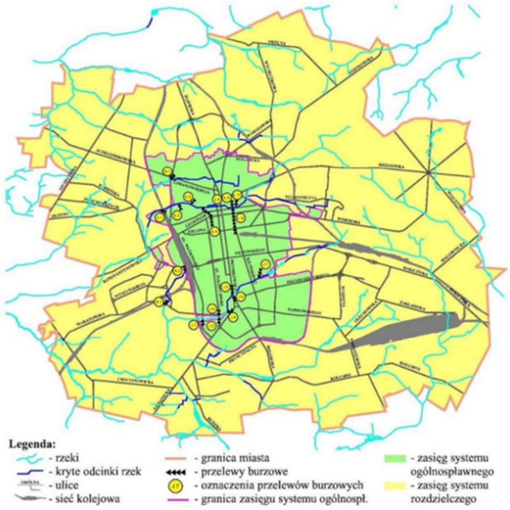


Fig. 1. Location of combined sewer overflows in Lodz [22]

In addition the measurements mentioned above carried out by the network operator, the monitoring of the sewer system in Lodz is also carried out by the Institute of Environmental Engineering and Building Installations at the Lodz University of Technology at two research stations:

- the station on the J1 overflow equipped with a flow meter and on-line sensors (Solitax and UVvis) for measuring the wastewater composition and a sampler for the automatic collection of wastewater samples,
- a station at the outlet from the stormwater drainage system of the "Liściasta" district with a rainwater settler, equipped at its inlet with a sampler for collecting wastewater, a wastewater fill sensor and flow velocity sensor in the sewer and at its outlet equipped with a sampler and a wastewater fill sensor in the settler.

3.2. Rainfall monitoring and its use.

Lodz has an urban rain gauges network (18 devices) belonging to the Lodz Infrastructure Company. Additionally, three rain gauges belonging to the Lodz University of Technology and 12 rain gauges owned by the University of Lodz are located in the city (Fig. 2.). This type of data allows not only to determine the character of precipitation, but also to indicate the direction of precipitation and its spatial unevenness, which has a significant impact on the functioning of the sewage system. Much more favorable for the operation of the sewer system is opposite direction of rainfall movement in relation to the direction of wastewater flow [7]. According to observations, during the year the air masses come to Lodz from the west (20% of observations), south-west (15%) and from the east (14%) [23], which in some way helps in removal of excess stormwater from the city area.

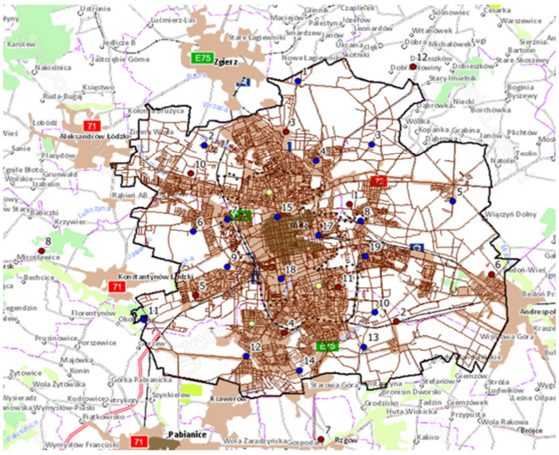


Fig. 2. Location of rain gauges in Lodz (blue - Lodz Infrastructure Company rain gauges, red - University of Lodz, yellow – Lodz Univarsity of Technology)

Currently, cities increasingly need to have digital models of sewer networks. Thanks to them it is possible to assess their functioning, as well as determine the needs for modernization and design guidelines. According to the current requirements contained in the Regulation of the Minister of the Environment (RME) of November 18, 2014 on the conditions which must be met during discharging wastewater into water or into the ground,, and on substances that are particularly harmful to the aquatic environment [24] to assess the functioning of sewer systems in the case of lack of data from observation of their functioning over longer period of time, it is recommended to use verified computer models. However, for these models to be useful and generate reliable results, it is required to correctly map the network and have accurate input data, including precipitation data, needed to calibrate the combined sewage and rainwater drainage network. Currently, many Polish cities do not yet have a pluviometric network, and have only, for example, one rain gauge (or only a few) for the entire city. In this case, it is difficult to determine the spatio-temporal characteristics of precipitation, which is especially important for large catchments area. That model calibration based only on one rain gauge usually causes overstatement of results [25]. Examples of the results of simulation flow rate in the sewage system in comparison with the actual rainfall data (spatial precipitation, point precipitation) conducted in the use of the US EPA SWMM program at the outlet from the Bałutka catchment (609 ha) are shown in Figure 3. Results of the simulation of flow in the combined network for this catchment showed a better fit in the case of spatial precipitation, which confirms the usefulness of using extensive rainfall monitoring in the city.

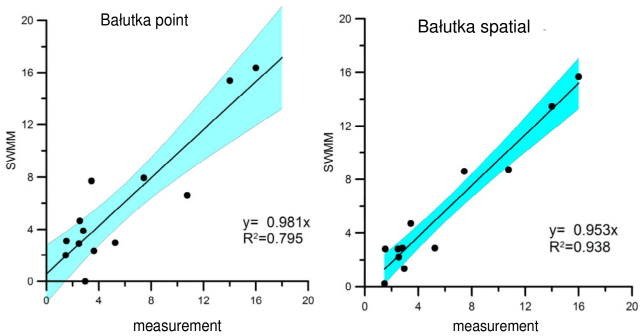
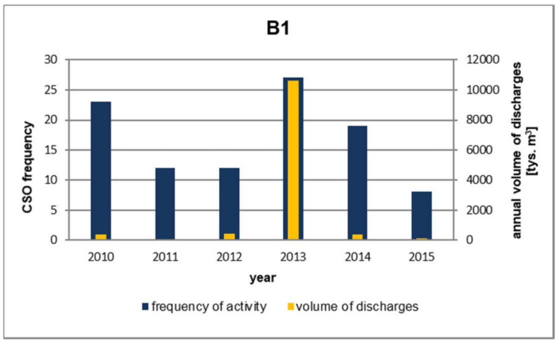


Fig. 3. Comparison of modeling results with real data of wastewater flow at the outlet of the Bałutka catchment area (flow stream in [m3/s]) [25]

3.3. Network flow monitoring.

In most major cities in Poland, combined sewer systems with overflows function in the central districts. Operation of these systems creates many problems, especially during the rainfall due to hydraulic overload of sewers and with the pollution load discharged to the receiver. The flow meters located in the area of combined sewer overflows in Lodz, allow to determine both the frequency of their activity and the volume of discharged wastewater, which is particularly important in the case of surface water protection. According to RME, the number of activations of these facilities should not exceed 10 per year. Therefore, quantitative monitoring allows to determine the correct operation of overflows or, if necessary, to indicate exceedances in their functioning (Fig. 4).
Based on the measured data, the frequency of combined sewer overflows (CSOs) can be analysed at various time intervals. In Lodz, most CSOs usually operate in the summer months, and the volume of discharged wastewater is greatly varied. In example the B1 overflow in both June and July, works on average around 3.5 times, but the volume of wastewater emitted to the receiver is several times higher in June. Without quantitative monitoring, obtaining such information would be very difficult.

a)



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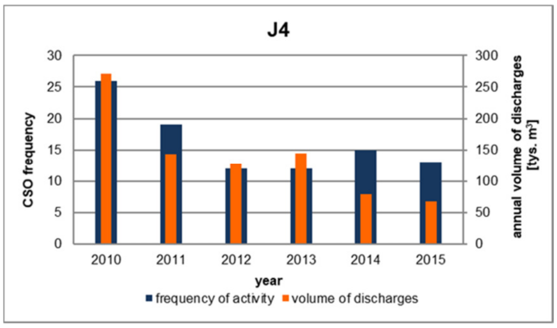

Fig. 4. Annual average frequency and volume of wastewater discharged by combined sewer overflow in the years 2010 - 2015, a) B1, b) J4 [26]

With this type of data, it is possible to determine the parameters relevant to the functioning of the network: flow variability (Fig. 5), hourly and daily unevenness coefficients, etc. The use of this data together with precipitation data in modeling systems enables their calibration (Fig. 6). This allows, among others, to identify overloads and establish the required storage capacity of the system and the possible channel retention capacity.

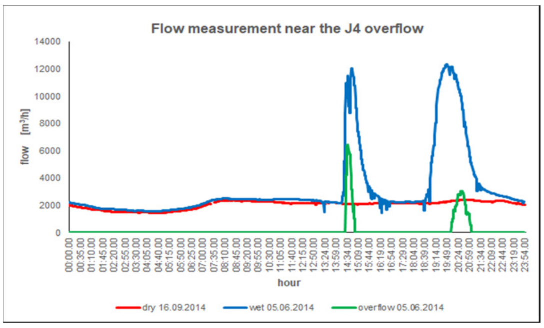

Fig. 5. Dynamics of flow variabilities during the day with dry and wet weather and an example of PB J4 functioning.

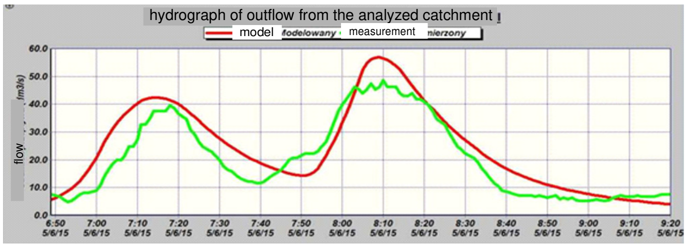

Figure 6. The results of measurements and modeling of the intensity of rainwater runoff from the Liściesta catchment [27]

3.4. Qualitative monitoring of wastewater in the sewage system

During measurements of the first tested indicator a method of measuring UV absorption with a wavelength of 254 nm (according to DIN 38402 C2) is used, while the measurement of the second one is carried out in a combination of the absorption process and infrared rays dispersion (according to DIN 27027). The probes are calibrated using the results of laboratory tests on the composition of the wastewater collected with the sampler installed on the bench. The data obtained from the monitoring allow for the analysis of the concentrations of the measured indicators in dry and wet weather, as well as their changes depending on the day of the week, month, season, etc. (Fig. 7).

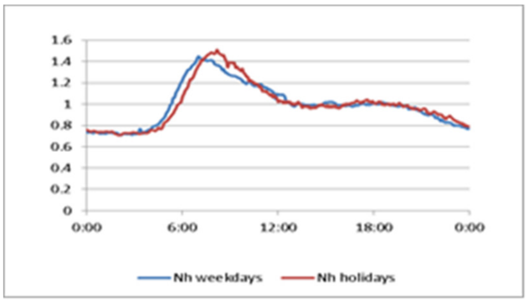

Fig. 7. Hourly unevenness coefficient for COD dissolved in dry weather [11]

Data from quantitative and qualitative suchej [13]monitoring allow to assess pollution loads transported through the network and their variability during rainfall events (e.g. occurrence of the "first flush" of pollution). For example, the J1 transfer on 27-28.04.2013 caused the discharge of 2598 m^3 of untreated wastewater transporting 992 kg of total suspended solids and 658 kg of organic substances expressed as COD. Data analysis obtained from qualitative monitoring confirmed the occurrence of the first flush phenomenon (Fig. 8), whose capture to the retention tank and subsequent referral to the wastewater treatment plant would significantly protect the receiver against the pollution inflow.

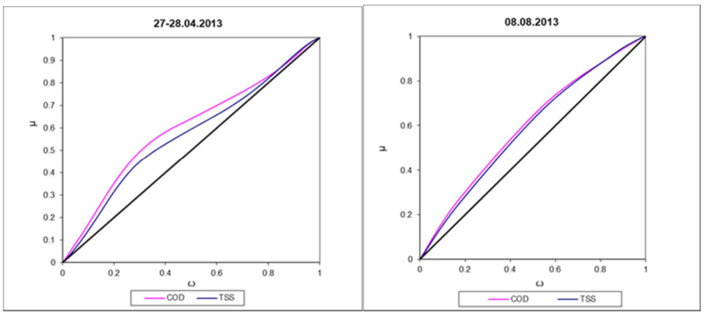

Fig. 8. An example of the occurrence of the first flush pollution phenomenon on the J1 overflow

The inflow of a large amount of pollutants in very short time, even if there are no toxic substances among them, can cause significant difficulties in the treatment process. Changes in the quality and quantity of sewage flowing into WWTP are not repeatable, they depend primarily on rainfall characteristic and the length of the dry weather period before precipitation, which determines the amount of pollution built-up on the catchment and wash-off during rainfall. Even on the same catchment, in the case of different precipitation, the first flush phenomenon may not be observed, it may be pronounced or the so-called the last wave phenomenon may occur, moreover, the flow of pollutants may be different for basic quality parameters of sewage (Fig. 5).

3.5. The use of monitoring data for pollutant load prediction.

Continuous monitoring of CSOs and storm water drainage outlets is costly, labour-intensive and sometimes complicated for technical reasons. That is why simpler, less expensive, but equally accurate methods for estimating the quantity and composition of wastewater emitted to the receiver are increasingly being sought [2, 28, 29]. For this aim mathematical models are used, which allow to know and predict pollutant emissions and simultaneously limit the range of measurement campaigns. Based on the monitoring data, among others models for pollutant emissions from combined overflows and storm water drainage were developed for the Lodz catchment area. The predictive model of pollutant emissions from CSOs was based on three variables: height and maximum intensity of precipitation as well as volume of wastewater discharged from the overflow. These parameters were selected after a series of analyses using the PCA (Principal Component Analysis) method and multiple regression. On their basis, a mathematical formula to forecast the load of emitted pollutants for total suspended solids and COD was developed [30]. In addition to the parameters included in the model, other parameters such as the rainfall duration, its average intensity and the time of dry weather before precipitation were taken into account for the analysis. The results of the conducted analyses indicated that the above-mentioned parameters turned out to be less important. In addition, Pearson correlations between rainfall parameters and concentration as well as the load of total suspended solids and COD were also made. The results showed practically no relationship between the concentration of the studied indicators and rainfall parameters, while strongly marked the dependence of the load on the height and maximum intensity of precipitation as well as volume of discharge, which was confirmed by the formula of the model.

$$L_{TSS} = 1.8 \cdot R_{depth}^{-0.37} \cdot i_{max}^{0.21} \cdot V_{CSO}^{0.97} \quad (1)$$

$$Ł_{ChZT} = 1.6 \cdot H_{op}^{-0.3} \cdot i_{max}^{0.22} \cdot V_{PB}^{0.95} \quad (2)$$

where:
R_{depth} - rainfall height [mm]
i_{max} - maximum rainfall intensity [mm/h]
V_{CSO} - volume of discharged wastewater [m^3]

According to the developed model, the prediction of pollutant load emitted by a combined sewer overflow depends mainly on the volume of wastewater in power close to 1. It should be remembered that for a single CSO event, the volume of wastewater has a various importance relative to the load of emitted pollutants. This is due to the fact that precipitation parameters and the "first flush" phenomenon significantly influance the concentration of pollutants in surface runoff and CSO. The proposed model provides reliable results on pollutant emissions (R^2 = 0.79 for total suspended solids, and for COD R^2 = 0.80) in the case of the catchment area for which it was developed. For other catchments, this model can be used after adjusting the proporcional coefficient, which depends, among others, on the catchment characteristics, the way it is managed, sources of pollution, and the characteristics of the wastewater system and the overflow itself.

4. Advantages and disadvantages

On-line quantitative and qualitative monitoring used in sewage systems allows, among others, for:

- limitation of measurement campaigns,
- limitation of costs of wastewater laboratory tests,
- creating a large measurement database for analyzing of the functioning network,
- capturing all occurring variabilities of amount and composition of wastewater in both dry and wet weather.

These advantages are particularly important in the case of storm water drainage and combined sewer system due to the unpredictability of precipitation phenomena and high dynamics of changes in the composition of wastewater and rainwater in these systems. The large advantage of using measurements directly in the medium is the high quality of the obtained data and the possibility of their transmission directly to e.g. a dispatcher, which allows making quick decisions regarding the operation of the system. It should be added that the simultaneous possession of rainfall monitoring gives the possibility of earlier network preparation and sewage treatment plant for sudden rainwater inflows. Despite the many benefits resulting form the use a such monitoring, some disadvantages should also be noted. Belong to them:

- still relatively high price, despite the dynamic development of measuring methods and technical solutions,
- sensors susceptibility to dirt, clogging and mechanical damage,
- lack of power supply or other factors preventing the measurement or causing erroneous data (e.g. indication of the instantaneous concentration value exceeding the repeatedly measured average minute concentration persistent for a very short time of the order of a minute or 2 minutes, most likely due to hanging up around the sensor of large things like rag, foil, etc),
- the need for periodic calibration for some types of equipment,
- in case of on-line sensors for measuring the pollution concentration indicators, limited range of indicators measured and the need to select it,
- location difficulties (e.g. lack of technical possibilities for mounting the sensor due to hydraulic conditions, no possibility of power supply, operational difficulties, difficulties with data transmission),
- difficulties associated with these installation (sewer condition, hydraulic conditions,sewer deposits),
- the need for periodic inspections and repairs.

Despite the possible operational problems and significant purchase costs, monitoring is already becoming the basis for suitable network management, especially in unforeseen situations, e.g. during heavy rainfalls. The benefits of having quantitative-qualitative monitoring (or even quantitative in the initial phase of its creation) are definitely higher than the potential disadvantages.

5. Conclusions

The examples of the on-line monitoring application included in the article have shown its great usefulness in determining rainfall characteristics, assessing of the wastewater sewer system functioning, and pollutant emissions directed to the receiver. On-line measurements allow to build a wide base for these purposes. The city's monitoring gives the possibility to observate changes taking place in the sewer system in real time and to reduce the costs associated with the wastewater analysis process. Despite the presented operational problems, having quantitative and qualitative monitoring is cost-effective and increasingly necessary due to the protection of surface waters. Sustainable development of city drainage systems will require the use of various forms of monitoring, interrelated to one another (rainfalls, flows in the network as well as to wastewater composition).

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