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## ASSESSMENT OF THE MUNICIPAL WASTE COLLECTION PROCESS BASED ON IRREGULARITIES IN NOTIFICATIONS SENT BY RESIDENTS. A CASE STUDY IN WROCŁAW, POLAND

Socio-economic changes generate the need for the rationalization of economic processes. The risk of failure to achieve the appropriate recycling level by Poland in 2020 required by the EU gives rise to the necessity of the analysis and improvement of processes carried out in the framework of the waste management system. The municipal waste collection comprising transport processes to the indicated locations and processes of waste collection from waste collection points (WCP) has a significant influence on the achieved recycling level. Therefore, the authors attempted to assess the municipal waste collection process in Wrocław. The assessment was carried out based on irregularities in notifications related to waste collection sent by the residents of Wrocław to a company managing the waste collection. The application of the indicator of notifications per resident and the indicator of notifications per WCP as well as carrying out the analysis of time dependences of notifications number enabled the authors to identify the areas in Wrocław characterized by a high intensity of notifications and the reasons for this phenomenon.

### 1. INTRODUCTION

The socio-economic development of Poland determines the need for proper waste management. Therefore, a new municipal waste management system was implemented in Poland on 1 July 2013. In this article, the authors attempted to assess the municipal waste collection process within the area of the city of Wrocław.

Statistics available in the Eurostat databases concerning the municipal waste generated in EU countries reveal that their amount per capita from 2014 to 2017 shows an upward trend. The same phenomenon of the amount of waste increasing with each year also occurs in Wrocław where, in 2018, the amount of collected municipal waste

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amounted to 320 812 Mg. The observable increase in the amount of waste is mainly due to an increasing population [1], economic development [2, 3], and increasing consumerism [4]. Therefore, a properly organized waste management becomes increasingly important every year. According to a hierarchy of waste management set out in the EU directive, the basic and most important actions of each country should consist of striving for waste prevention and recycling. However, taking into consideration the issue of constantly growing amounts of waste, it can be stated that waste management carried out by different countries is insufficient and requires changes.

Waste management is the subject of many articles. Such issues as the occurrence of illegal landfills, incorrect arrangement of containers [5–7], the number and capacity of used containers [8] as well as the possibility of processing waste in households [9] are addressed in the literature. Furthermore, the awareness of people concerning the impact of waste on the environment and their opinions on waste management are very often taken into account [10–12]. Apart from that, research is conducted in terms of the composition of collected waste [13] and the values of mass and volume indicators of waste accumulation [14, 15]. Furthermore, the authors attempt to indicate factors influencing the effectiveness of waste management. Economic, environmental, political, sociological, technological, and educational factors are named the most frequently [16]. Concerning them, the following factors are specified: the policy of the government, government finances, availability of land, habits of the residents, availability of technology and human resources as well as knowledge on waste management [17].

According to Eurostat databases, Poland holds one of the last places in the ranking of EU countries in terms of the amount of generated waste per capita. Despite that, the waste management carried out therein is insufficiently effective which is reflected most of all by the fact of being one of 18 countries threatened with the failure to achieve the required recycling level of 50% in 2020 (The Early Warning Report for Poland). In 2018, this level for the city of Wrocław amounted to 35%.

When considering the amount of waste generated during 2017 in households on the territory of Poland presented in databases of Local Data Bank, the Lower Silesian Voivodeship is one of four voivodeships with the highest amount of generated wastes. However, taking into consideration the amount of waste per capita, it achieves the highest score among all voivodeships. This result may be largely affected by the activities carried out in Wrocław due to its surface area and population. In the analyzed scientific works concerning proper waste management, the proper execution of the waste collection process is named as one of the main factors. Therefore, the frequency and time of waste collection are subjected to analysis [18–20], locations of waste collection points are determined [21, 22] and optimum routes of waste collection trucks are also planned [23, 24]. A poor organization of the waste collection process can harm the segregation level.

The authors aimed to assess the municipal waste collection process in the city of Wrocław. The assessment was carried out based on irregularities in notifications sent by residents to a company responsible for managing municipal waste collection system

and maintaining cleanliness in Wrocław. The analysis of the number of notifications received from districts enabled the identification of areas characterized by the highest intensity of occurring irregularities resulting from the transportation process executed improperly by the company responsible for waste collection. Based on the change in the number of notifications over time, an attempt will be made to identify the reasons for the improperly executed waste collection process. Furthermore, the indicator of the number of notifications per capita and the indicator of the number of notifications per waste collection point will be taken into account in the assessment.

## 2. OVERALL DESCRIPTION OF WROCLAW IN THE CONTEXT OF WASTE MANAGEMENT

Wrocław, a city of the surface area of 293 km<sup>2</sup>, is the capital city of Lower Silesian Voivodeship located in south-western Poland. Based on the resolution of the City Council of 1991, Wrocław was divided administratively into 48 districts. Along with the adoption of the act changing the existing Polish municipal waste management system, a necessity arose to appoint an entity in charge of managing municipal waste collection system and maintaining cleanliness in Wrocław. Therefore, a special purpose vehicle in charge of municipal waste was created. Its main tasks include the organization of tenders relating to the collection of wastes from property owners, surveillance over waste collection process, and analysis of the state of municipal waste management.

### 2.1. MUNICIPAL WASTE COLLECTION RULES IN WROCLAW

As a part of the waste management fee paid by every resident, a list of wastes collected directly from the properties with their minimum collection frequency has been defined (Table 1). Depending on the type of building and the declared number of residents, waste is collected in containers with different capacity or in bags. Containers and bags are marked with different colors depending on the type of waste.

Table 1

List of wastes with their minimum collection frequency and container/bag colors

Waste type	Collection frequency	Container/bag color
Mixed waste	once a week	black
Plastics, metals and packaging waste	every two weeks	yellow
Paper and cardboard	once a month	blue
Biowaste	once a week	brown
Glass	every two weeks	green

The waste management fee includes as well the collection of the high volume waste from the properties when needed. This type of wastes is collected in containers with high capacity, which are temporary used on request. Additionally in Wrocław, there are two Selective Municipal Waste Collection Points to which wastes such as used electronic equipment, construction waste, used tires, and other wastes specified in the regulations can be delivered by residents.

To improve the collection process, Wrocław was divided into four sectors of waste collection. A tender is organized for each sector in the framework of which a company in charge of collection, transport, and management of municipal waste generated in the properties located within the borders of a given sector is selected. As a result of the tenders that are carried out, three companies were selected, being in charge of individual city sectors (Fig. 1). Main tasks of these companies are ensuring recycling of collected wastes and their preparation to reuse (selective waste collection) and waste transfer to Regional Municipal Waste Treatment Installations.

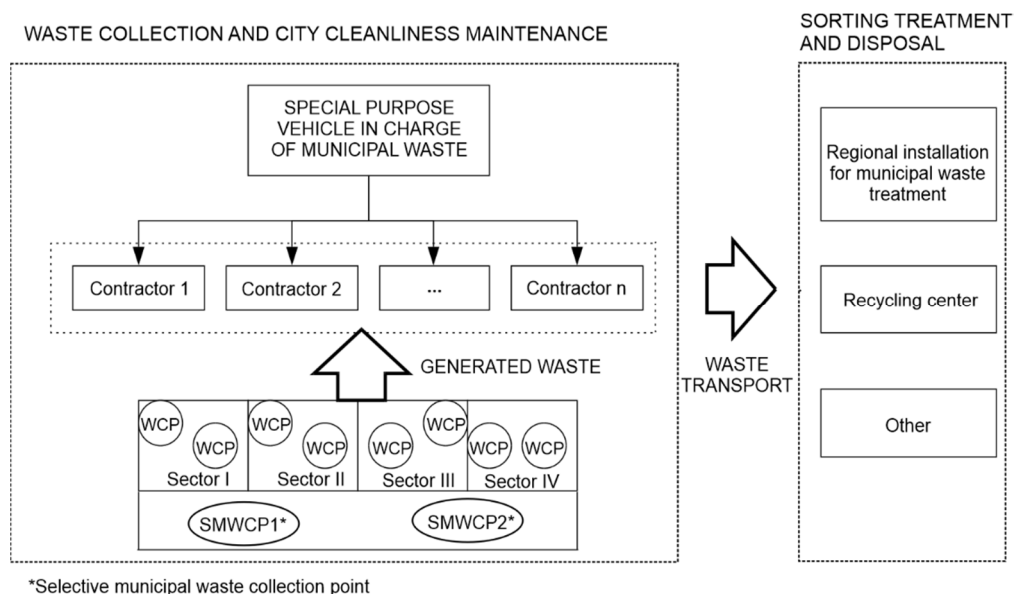


Fig. 1. Waste management in Wrocław

The data provided by the Local Data Bank from 2017 show that, in Lower Silesia Voivodeship, 891 772 Mg of wastes from households were collected, as much as 31% of which are wastes generated in Wrocław. Based on the reports of the mayor on the execution of tasks relating to waste management in the years 2014–2018, an increase of the recycling level achieved by Wrocław can be seen. However, the risk of failure to achieve the required recycling level in 2020 occurring in Poland indicates the need for continuous improvement of processes related to waste management.

## 2.2 ANALYSIS OF THE NUMBER OF WASTE CONTAINERS AND WASTE COLLECTION POINTS

The number of waste containers allocated per individual properties changes dynamically depending on the declared number of residents, waste collection frequency, the capacity of containers, and the waste accumulation volume indicator. To analyze the number of containers, the data from 18 March 2019 were used. Apart from containers, population, and waste collection points (WCP), i.e., separate areas intended for waste storage were also subjected to the analysis. The number of WCP and the number of containers were collected during inventory processes on 18 March 2019.

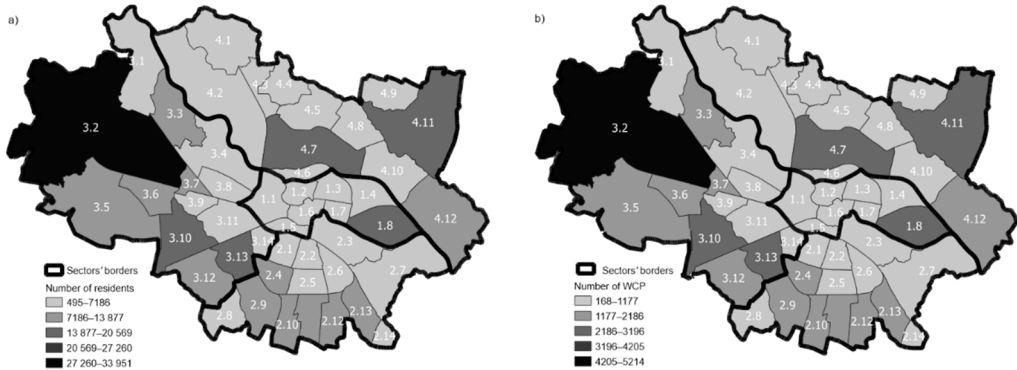


Fig. 2. Choropleth map of the number of residents (a) and the number of WCP (b) in particular districts

The population of Wroclaw according to the data of the Central Statistical Office of Poland of 31 December 2018 amounts to 612 063 people. On 18 March 2019, the occurrence of 262 142 containers and 55 180 WCP was reported. The data from the conducted inventory were used to fix the number of containers and waste collection points. GIS mapping was used to determine the belonging of a waste collection point to a given district. Figure 2 shows the number of WCP and the number of residents in particular districts. The maps show districts with the lowest and highest numbers of WCP and also districts with large and small populations.

## 3. THE ANALYSIS OF THE NUMBER OF IRREGULARITIES IN NOTIFICATIONS IN TERMS OF WASTE MANAGEMENT

Irregularities in notifications presented in the current point and the next points refer to the period from July 2018 to February 2019. One of the important factors that should be taken into account while analyzing waste management in a given area are the opinions of its residents. The process of the acquisition of information of such type is carried

out most frequently by conducting surveys and/or interviews [5, 10–12] which, however, imply certain limitations. Their effectiveness is strictly related to the questions asked which, when incorrectly formulated, may result in the omission of important problems. Thus the notifications of residents through the analysis of their reports addressed to the company responsible for monitoring the state of waste management were taken into account.

At the beginning of the functioning of the new waste management system in Wrocław, after a special purpose vehicle in charge of municipal waste was created, no categorization system of notifications received from residents was used. All remarks were addressed to the e-mail address or reported by phone to the company. To speed up the notification collection process and to facilitate their analysis, a notification form has been posted on the website. It introduced a division of notifications received into 10 categories. Within the period from July 2018 to February 2019, 4291 notifications of irregularities in the waste collection from residents were recorded, when the total number of them was 12 637 taking into account all categories. Data from 8 chosen months was used as only in this period of time no modifications in categories were made. Additionally, this period is also connected with a project in which analyzed notifications were one of the considered subjects. Before July 2018, the data was not classified in a presented way with the use of notification form and cannot be used in the analysis. There is no data after February 2019, the project mentioned before ended and the categories in notification form changed. Thus adding data after February 2019 to the analysis could distort the results. Some of the categories were canceled to simplify the system. Notifications used in this paper are taken from the special purpose vehicle in charge of municipal waste in Wrocław.

Change in the number of notifications in the following months is presented in Fig. 3. The share of particular types of notifications from July 2018 to February 2019 is:

Waste collection	34.19%,
District Council Administrator Zone – high volume waste	17.92%,
District Council Administrator Zone – green waste	7%,
cleaning of the city – outside areas	3.65%,
cleaning of the city – roadway	8.31%,
waste segregation	0.43%,
containers/waste collection bags	21.19%,
declarations	0.03%,
snow cleaning of the city	1.93%,
other	5.35%,

Most notifications (31.67%) within the considered period concerned waste collection. It confirms the occurrence of irregularities in the waste collection process following established waste collection schedules. Therefore, in the further part of the article, a more detailed analysis of this type of irregularities has been carried out.

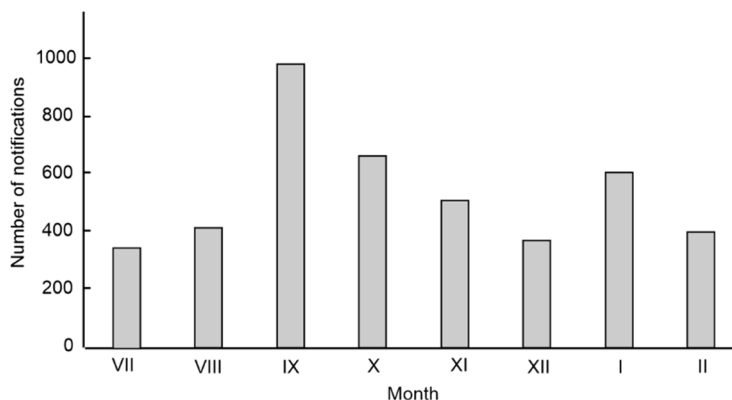


Fig. 3. Total number of irregularities in notifications from July 2018 to February 2019

In September, a rapid increase in notifications number is visible. This number gradually decreases to December and then increases again in January almost to the level of notifications from October. In Table 2, the total number of notifications from July 2018 to February 2019 assigned to particular sectors is shown.

Table 2

Total number of notifications from July 2018 to February 2019 in sectors

Sector	Number of notifications	Average number of notifications per month	Standard deviation	Coefficient of variation [%]
I	471	59	19	31
II	2504	313	209	67
III	906	113	23	20
IV	410	51	15	29
I–IV	4291	536	214	40
I, III, IV	1787	223	35	16

The highest number of notifications is observed in Sector II. It is also characterized by a high coefficient of variation whose value reaches 67%. It shows that there is a high diversity of notifications number during considered months. Notifications from Sector II significantly affect the entire system. Considering the total number of notifications from all four sectors, the average number of notifications per month is 536 with a standard deviation of 214 and the coefficient of variation at the level of 40%. Large dispersion of results around the average and wide diversity occurs. However considering only Sectors I, III, and IV, the average number of notifications per month is 223 with a standard deviation of 35 and the coefficient of variation at the level of 16%. There is a low dispersion of results, which are close to the average. The total number of notifications from Sectors I, II, III, and IV and the total number of notifications from Sectors I, III, and IV

over the following months have a downward trend (Fig. 4). The extremely high number of notifications from Sector II exceeds the total number of notifications from other sectors. Rapid changes in notifications number are also noticed only in this sector.

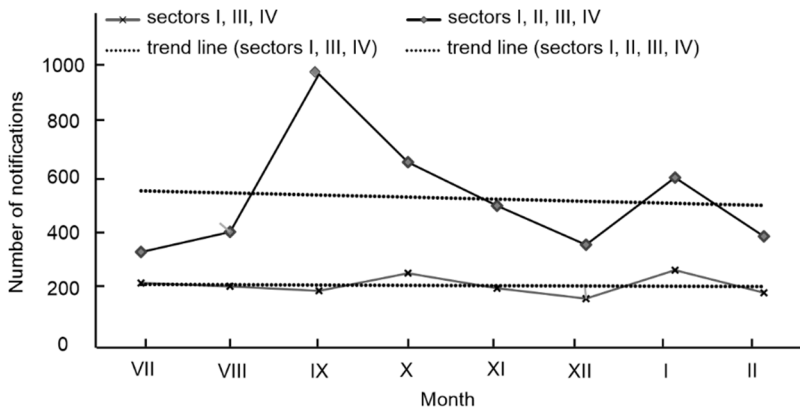


Fig. 4. Total number of notifications from Sectors I, II, III, IV and from Sectors I, III, IV from July 2018 to February 2019

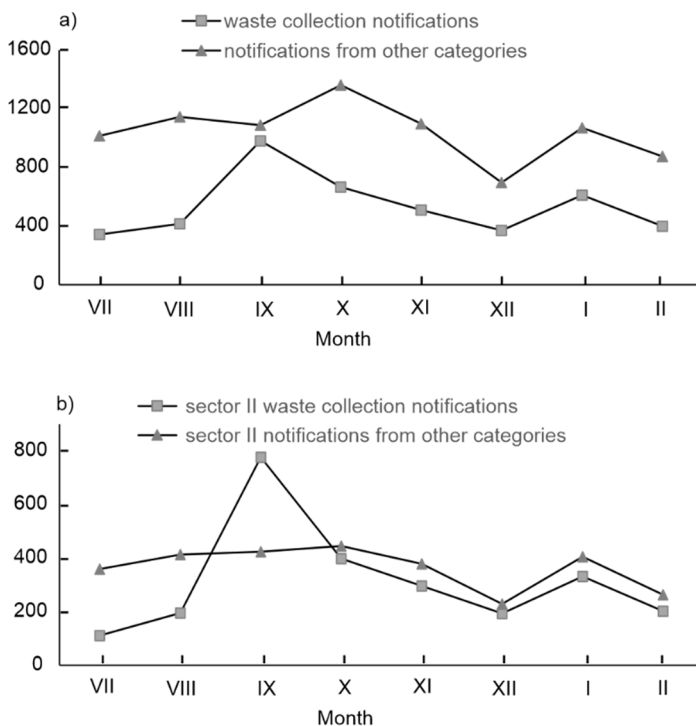


Fig. 5. Number of waste collection notifications compared with the number of notifications from other categories for all sectors (a) and for Sector II (b)



A strong impact of irregularities in Sector II on the overall assessment of the waste collection system in Wrocław is clearly visible. In the following analysis, not only the division into sectors and the notifications number were taken into account but also districts, the number of residents, and the number of WCP. The waste collection notifications have also been compared with notifications from other categories.

The irregularities in notifications concerning waste collection were referred to as the total number of notifications from the other nine categories (Fig. 5a). It can be seen that notifications from all categories without waste collection do not have sudden increases in their number except that in January. Numerous notifications connected with snow cleaning in January and a period after the Christmas holidays may explain this increase. Only waste collection notifications show a high increase and it is only in one month, in September. Results from Table 2 showed that irregularities from Sector II have a strong impact on the entire system. Notifications for all categories without waste collection in Sector II do not show any rapid changes (Fig. 5). Only in January (the period after Christmas holidays), the number of notifications is slightly higher than that in the month before. However, waste collection notifications show that in September some unwanted events occurred in Sector II, which led to a high rapid increase in the number of notifications.

The estimated number of notifications is presented on the choropleth map shown in Fig. 6. In a more detailed analysis of notifications taking into account not only the sectors but also districts, it is possible to indicate areas characterized by the frequent occurrence of the problem with the correct execution of waste collection schedules.

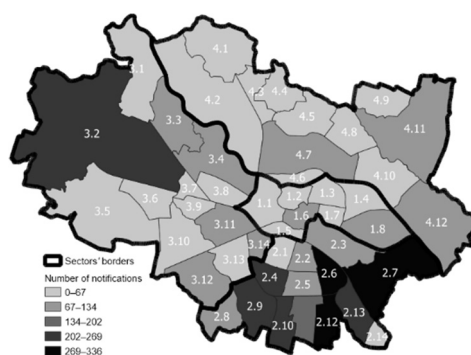


Fig. 6. The number of notifications from particular districts

To indicate areas with frequent occurrence of irregularities, one should not rely on the number of notifications only because it is correlated with the number of residents of a given district. Districts with a high number of residents can demonstrate a much higher number of notifications than those with a low number of residents. Therefore, considering only the number of notifications may lead to an incorrect indication of problematic areas. For that reason, demographic data and inventories of WCP were used for the

analysis as reference points of the real scale of waste collection problems occurring within the area of particular districts. The following indicators have been defined:

Indicator of notifications per a resident  $W_r$

$$W_r = \frac{n}{r}$$

where  $n$  is the district's number of notifications,  $r$  – district's number of residents.

Indicator of the number of notifications per WCP  $W_{WCP}$

$$W_{WCP} = \frac{n}{p}$$

where  $p$  is the district's number of WCP.

Detailed statistics based on the analysis of notifications are shown in Table 3. The division presented below was adopted from the companies in charge of particular sectors.

Table 3

The analysis of notifications concerning contractors in charge of waste collection

Contractor	Number of notifications	Number of waste collection points	Number of residents	Notifications per waste collection point	Notifications per resident
Sectors I, IV	959	18 048	264 371	0.05	0.004
Sector II	2426	14 869	149 292	0.16	0.016
Sector III	906	22 263	198 400	0.04	0.005

The obtained results indicate Sector II as the area with the highest total number of notifications. The contractor responsible for waste collection from this sector services the lowest number of residents and the lowest number of WCP among all three contractors conducting activity in Wrocław. Despite that, the sector that it services has the highest indicator of notifications per resident and the indicator of notifications per WCP. In Figure 7, a choropleth map is shown with an estimated number of notifications per one resident  $W_r$  and notifications per WCP  $W_{WCP}$ . The area of Sector II is visibly distinguished for both indicators.

The highest  $W_r$  values within the range from 0.043 to 0.054 occur in Sector II in districts 2.12 and 2.7. High values of this indicator within the range from 0.032 to 0.043 are also observed in districts 2.10, 2.6 and 2.13. However, the number of residents of Wrocław is difficult to indicate precisely due to, among others, a continuously growing number of university students and foreigners staying in Wrocław for work purposes,

whose stay is not taken into consideration in population registers based on the registration of residence. Therefore, the indicator of notifications per resident may entail certain inaccuracies.

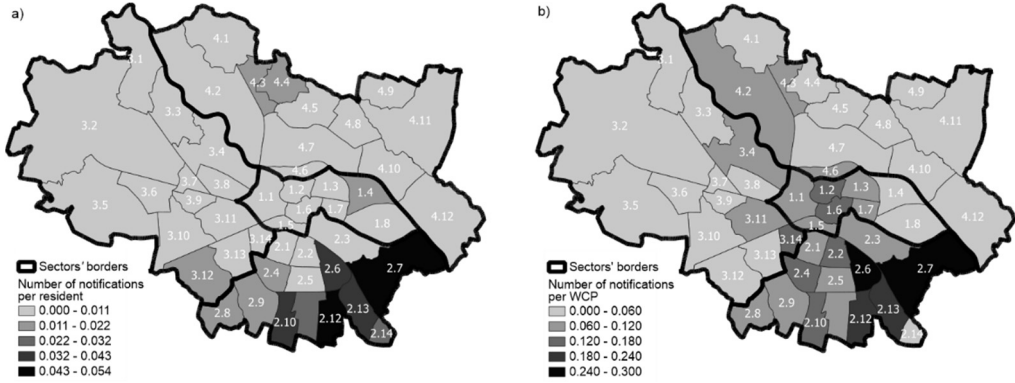


Fig. 7. The number of notifications per resident (a) and number of notifications per WCP (b)

Given the described inaccuracy of the indicator of notifications per resident for the assessment of the waste collection process, the indicator of notifications per WCP was also used (Fig. 7b). Referring to the notifications from each district to WCP located within its borders, it is possible to distinguish the problematic areas without correlating notifications. The calculated Pearson correlation coefficient between the number of waste collection points and the number of notifications amounting to 0.41 indicates a weak level of linear correlation of these two sets of variables. The number of WCP occurring in a given district does not determine the number of notifications sent from the residents.

The obtained values of the indicator reveal that the highest number of notifications per WCP comes from districts 2.6 and 2.7, as well as 2.12 and 2.13. Therefore, districts distinguished during the analysis of notifications with the use of the indicator of notifications per resident were indicated. However, some differences in the comparison of the obtained results with those obtained in the case of the indicator of notifications per resident can be seen. The indicator  $W_{WCP}$  has a high value in districts 2.6, 2.7, 2.12, and 2.13 just as the indicator  $W_r$  but it presents the intensity of irregularities in other regions of the city in a different way. Moreover, it distinguished most of the districts of Sector I as those that are characterized by the occurrence of irregularities that were not indicated with the use of the indicator  $W_r$ .

Districts of Sector I may demonstrate irregularities during the analysis of the value of the indicator of notifications per WCP due to their location in the city center. This area is characterized by a high building density and a high number of addresses participating in one WCP. For district 3.2, both indicators took values from a range of the lowest values despite the occurrence of one of the highest number of notifications from

this district. For districts 2.6, 2.7, 2.12, 2.13, the change in the number of notifications over time was examined. The rapid growth of the number of notifications in September was observed decreasing gradually over the next few months and then increasing slightly in January (Fig. 8).

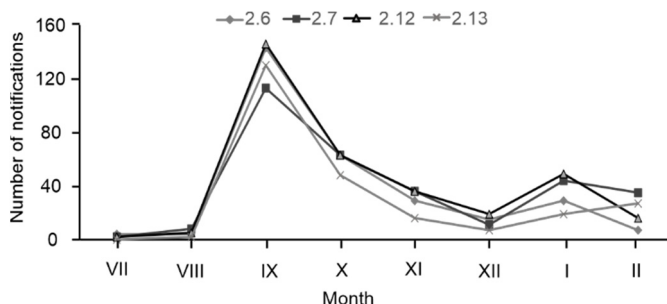


Fig. 8. The change in the number of notifications over time for districts 2.6, 2.7, 2.12, 2.13

In September, the company so far in charge of Sector II in districts indicated in the analysis was using the services of a subcontractor. When this company was taken over by another company, a decision was made to resign from the services of a subcontractor. It was, therefore, necessary to hire new waste collection truck drivers in areas so far serviced by the subcontractor. The waste collection obligation was taken over on 1 September 2018 without the acquisition of tacit knowledge obtained by previous employees. It explains the rapid growth of the number of notifications in September. A lack of knowledge of the serviced area by the employees responsible for waste collection and thereby a lack of awareness of the occurrence of factors that could hinder the collection process led to the failure to fulfill the waste collection obligation following the requirements. Figure 8 also confirms that irregularities from Sector II have a strong impact on the entire system. Comparison of this figure with Fig. 3 which shows the total number of notifications from all sectors over time, it can be noticed that there are upward and downward trends in the same months.

Deeper analysis has shown that rapid change in the number of notifications in September was seen from the first week, but the extreme value has been achieved in the second week. From the third week, a slow decrease in notifications number can be seen.

While analyzing the change in the number of notifications upon time for the other districts with high values of considered indicators, a rapid change in their number was not observed. They are maintained at a high level, however, they do not demonstrate high growth in any month. It indicates the occurrence of undesirable factors affecting the failure to execute the waste collection process following expectations in these areas. Indication of these factors requires conducting additional studies. Most of all, high values of  $W_{WCP}$  in the districts of Sector II result from the change of the company responsible for waste collection in this sector, which was confirmed by the conducted analysis of notifications over time.

#### 4. CONCLUSION

Increasing amounts of waste and the necessity to achieve the required recycling level create the need for the continuous analysis of the municipal waste management system to indicate areas requiring improvement. Improper execution of waste collection, constituting one of the first links of the waste removal chain, has a significant impact on failing to comply with legal requirements relating to waste. An attempt was made to assess the municipal waste collection process in Wrocław. It was based on notifications from residents addressed to the company supervising the correct execution of processes related to the collection of municipal waste and maintenance of cleanliness. In the conducted assessment, the number of notifications concerning waste collection from particular districts, the number of residents, the number of containers, and the number of WCP were taken into consideration.

Two types of indicators were used: the indicator of notifications per resident  $W_r$  and the indicator of notifications per WCP  $W_{WCP}$ . The conducted analyses of the number of notifications with the use of choropleth maps and indicators revealed the most frequent occurrence of irregularities in districts of Sector II. While conducting the analysis of the number of notifications over the next few months, it was noticed that the high number of notifications in a part of these districts resulted from the change of the company responsible for waste collection in Sector II. Therefore, good knowledge of the area of waste collection by the company in charge of this sector is a key factor affecting the proper execution of the waste collection process. Also, the high number of notifications in one sector negatively impacts the overall assessment of the system.

The  $W_{WCP}$  factor indicates a frequent occurrence of irregularities not only in Sector II, but also in Sector I. This indicator better indicates the problematic areas of the waste collection because it is independent of the number of residents. These areas should be subjected to studies in terms of factors affecting the improper execution of municipal waste collection processes. Identification of these factors will allow carrying out a multi-criteria assessment of the waste collection process in particular districts.

The conducted assessment enabled indicating those districts characterized by a greater number of notifications from residents. In these districts, it is necessary to implement changes in processes executed by the contractor providing waste collection services therein. The elimination of ineffectively conducted waste collection in Wrocław will contribute to the elimination of the risk of failure to achieve the required recycling level in 2020.

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