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ASSESSMENT OF SEGREGATED WASTE ACCUMULATION EFFICIENCY IN SELECTED SUBURBAN COMMUNITIES

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Summary

Among solid wastes one may distinguish mixed wastes, segregated wastes (collected selectively) and biodegradable wastes originating from open-air markets, green areas or cemeteries. Mixed wastes have constituted the largest proportion in the stream of municipal solid waste (MSW), both before and after the changes in waste management system in Poland introduced on 1 July 2013. The other group, regarding the collected wastes volume, is so-called segregation. It has been forecasted that in the nearest future the amount of segregated wastes will be successively growing. The article presents the analysis of selectively collected wastes (paper, plastics, glass and metal) indicators from lower administrative units of Liszki and Mogilany communities. The degree of segregated wastes accumulation efficiency was assessed on the basis of conducted computation. The communities selected for the analysis are suburban municipalities, situated in the area of Krakow agglomeration in the immediate vicinity of the main city of the Malopolskie voivodeship.

The main aim of the work was an assessment of selective accumulation of municipal solid wastes in suburban communities. Values of quantitative indices, characterizing mixed and segregated municipal solid waste generated by the inhabitants of individual lower administrative units of the studied communities were subjected to a detailed analysis. The data assumed for the investigations cover the period from July 2012 to June 2013.

As results from conducted analyses actual indices of wastes accumulation differ from the indices determined on the basis of statistical data and the data stated in the Waste Management Plans, which may evidence a high ecological awareness of the analysed areas inhabitants. The efficiency of

selective waste accumulation in the analysed communities was on a similar level and exceeded 20%, i.e. was twice higher than the average for Poland.

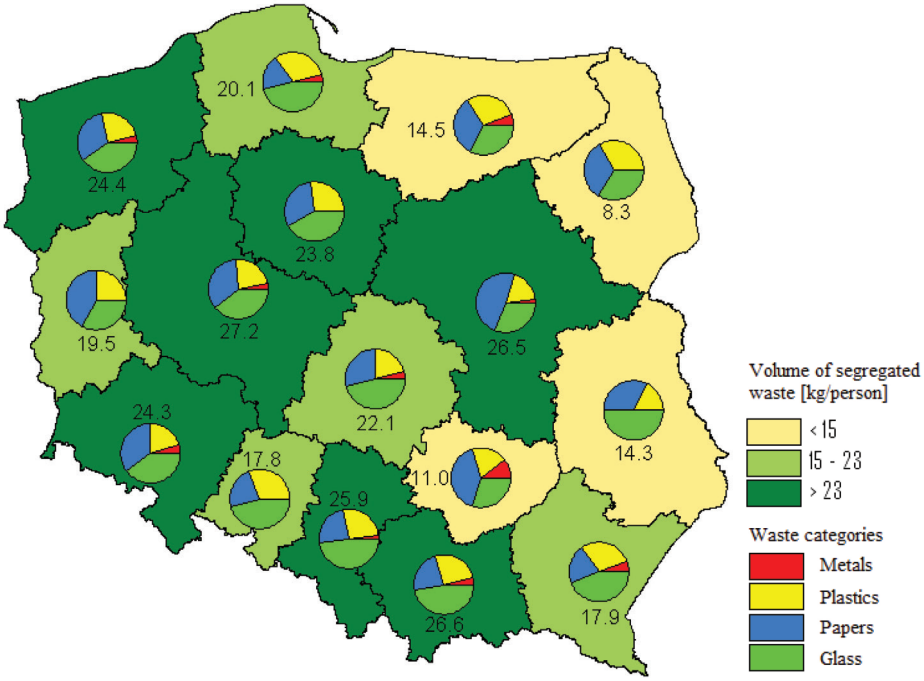
Key words: waste management, municipal solid waste, segregated waste, suburban areas

INTRODUCTION

Municipal solid wastes constitute a mixture of many materials with diversified properties, depending on many factors. For a reliable presentation of the structure of wastes generated in a given area, one should conduct a number of quantitative and qualitative studies (Jędrczak and Szpadt, 2006). Developing a detailed characteristics of the technological properties of waste is crucial for the process of creating waste management plans and for the selection process of their disposal methods. Conducting analyses of the quantity and composition of wastes is of key importance for making decisions about construction and location of waste processing facilities (Strzelczyk, 2014). Knowledge of waste characteristics allows also to find a systemic and optimal solution which would allow to recover and recycle the recyclables and subsequently to dispose safely of the remains from waste sorting (Jamróz, Generowicz 2012). Characteristics of the composition, amount and properties of wastes is possible only on the basis of research conducted in a yearly cycle in a given settlement unit. Despite the analyses conducted so far both in Poland and abroad, there are no satisfactory and sufficient theoretical bases for determining waste properties in cities (Rosik-Dulewska 2012), and particularly in rural areas. Analyses of wastes generated in rural areas in Poland are conducted unsystematically or occasionally. It is due to the fact that such analyses are expensive, whereas only 22% of all municipal wastes generated in Poland come from rural areas, despite the fact that these areas make up 93% of total area of Poland and are inhabited by about 40% of the population (Environmental protection, 2013).

We particularly lack the knowledge about the accumulation and morphological composition of wastes gathered selectively in Poland. Selective waste accumulation in Poland is a relatively fresh phenomenon and many people are sceptical about it. In Poland wastes are gathered in various systems (single or multi-coloured bags, in special containers, so called "bells", etc.). Investigations on wastes collected in "bells" or multi-coloured bags most frequently come down to determining the degree of these wastes collection efficiency. The degree of efficiency is determined by the ratio of selectively collected waste volume to the volume of all collected solid municipal waste. Central Statistical Office (CSO) data indicate than in 2010 the degree of efficiency of selective waste collection in Poland was 8.56%, whereas in 2012 it increased to 10% (Environment

protection 2011, 2013). In 2010 in the area of Malopolskie voivodeship a total of 88.7 thousand Mg of wastes was collected selectively, which constitutes 12% of the total volume of collected municipal waste (PGOWM,2012).



Source: Malinowski (2013), based on Environmental protection (2012)

Figure 1. Volume of accumulated segregated wastes in Poland in 2011

Boer (2013) states that a dynamic development of selective waste collection will occur in the nearest years and in 2020 the efficiency degree will reach about 30%. Achieving high levels of the selective waste collection efficiency translates directly into the required level of recycling and recovery of packaging materials (paper, plastic, glass and metal), which until 2020 should reach 50% and, according to the EU plans, until 2030 – 70%. Currently many communities in Poland, where before 2013 no selective waste collection was conducted, face a real problem trying to reach the required level of recycling and recovery of packaging materials (in 2014 the level is 14%). Malinowska (2012) states that in rural areas, the volume of selectively collected wastes per one inhabitant is growing gradually, it was 0.6 kg·(person·year)$^{-1}$ in 2002, whereas in 2007 is exceeded 2 kg ·(person·year)$^{-1}$. Malinowski (2013) states that in 2011 selectively collected waste accumulation by volume indicator (Fig.1) was the highest in Wielkopolskie (27.2 kg·(person·year)$^{-1}$, in Malopolskie (26.6 kg·(person·year)$^{-1}$),

in Mazowieckie (26.5 kg·(person·year)$^{-1}$) and in Śląskie voivodeships (25.9 kg·(person·year)$^{-1}$, whereas the lowest in the Podlaskie voivodeship (8.3 kg·(person·year)$^{-1}$). Waste were the most rarely segregated by the rural area and large housing estates dwellers, whereas the most frequently by inhabitants of family houses in suburban areas - 58.2% (CBOS, 2008).

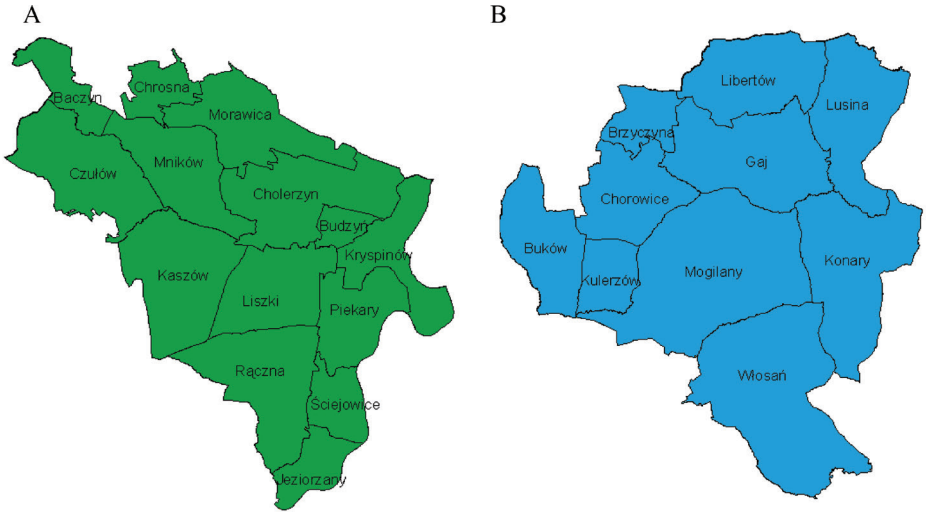
A new system of municipal waste management introduced in Poland on 1 July 2013 by the act amending the act on maintaining cleanliness and order in municipalities dated 13 December 1996 (Dz. U. 201 nr 152.poz.897) aimed at ordering and improvement of municipal waste collection system, but also increasing the volume of selectively collected wastes through introducing a financial bonus for persons who would decide to segregate their household wastes. Currently the fee for waste collection for the people who segregate their wastes ranges from 2.5 to 15 PLN per person, depending on the number of inhabitants. Average fee is 8.5 PLN per person. On the other hand, if wastes are not collected selectively, the fee grows on average by 40% (Terek and Piotrowska, 2013). If the fee is calculated for the amount of consumed water, for persons selectively collecting wastes it is between 2.1 and 7 PLN/m^3 of consumed water. If the inhabitants do not decide to collect their wastes selectively, the fee increases on average by 37% and ranges from 5 to 14 PLN/m^3 of consumed water. On the other hand, if the fee is calculated on the basis of the living area, the fees range from 0.4 to 0.7 PLN/m^2 if wastes are collected selectively or between 0.6 -0.9 PLN/m^2 in the variant without waste segregation (Terek and Piotrowska, 2013). Hadryjańska (2006) reports that in rural communities, where selective waste collection (e.g. in plastic bags) was introduced on average 60% of the inhabitants decide to use the opportunity.

Table 1. Basic characteristics of the analysed municipalities

L.p.	Factor	Unit	Commune	
			Liszki	**Mogilany**
1.	Area	[km^2]	72.03	43.55
2.	Population	[person]	16 465	12 912
3.	Population in productive age	[%]	65	64
4.	Cultivate areas	[%]	71	61
5.	Forests	[%]	6	14
6.	Protected areas	[%]	33	0,24
7.	The share of population with higher educaton	[%]	3.54	5.02
8.	The share of population with secondary education	[%]	14.28	14.35
9.	Population density	[person·(km^{-2})]	229	296

Source: Kopytko (2014)

Figure 2. Location of the analysed municipalities in the Krakow county



Source: Kopytko (2014)

Figure 3. Administrative division of the analysed communities (A – Liszki, B – Mogilany)

AIM AND SCOPE OF WORK

The main aim of conducted analysis was an assessment of the efficiency of selective collection of municipal wastes in suburban communities on an example of Liszki and Mogilany communities. The communities chosen for the analysis are rural communities, but they do not reveal the features of a typically agricultural area, as evidenced in the first place by a high population density (Tab.1). Moreover, both communities are situated in the immediate vicinity of Krakow (Figs. 2 and 3).

In both an organized municipal waste management system has been functioning for many years. It included a selective waste collection. Detailed analysis covered the values of quantitative indicators characterizing mixed and segregated municipal wastes generated by the inhabitants of the communities located close to Krakow but also the irregularity of their accumulation. The basis for the realization of the objective were the data on the volume of mixed and segregated municipal wastes collected from lower administrative units of Liszki and Mogilany communities, obtained from PW MIKI enterprise. PW MIKI enterprise was collecting wastes until the end of June 2013 from on average of 51.8% of Liszki community inhabitants (mixed wastes were collected twice a month, segregated once a month) and 48.3% of Mogilany community inhabitants (mixed wastes twice a month, segregated once a month). Over 90% of the served inhabitants accumulated their wastes selectively, i.e. to four different bags (PE) of various colours meant respectively for glass, metal, paper and plastics (Photo 1).

Source: www.miki.krakow.pl

Photo 1. Special bags for segregated wastes supplied by PWMIKI enterprise to the inhabitants of the analysed municipalities

MATERIAL AND METHODS

The data on collected mixed and segregated wastes volume were acquired owing to a computer programme, used in the enterprise, at vehicle scales with measuring accuracy ± 20kg. Acquired information concerns the period from July 2012 to June 2013. The scope of research covers the last year prior to introducing changes in waste management system. On the basis of obtained data, monthly and quarterly indicators of waste accumulation were determined per lower units of local administration. Some of these units were aggregated into groups because there was no possibility to separate the data (garbage trucks collected the wastes from several administrative units during one trip).

Indicator of waste volume accumulation a_{ij} (mixed wastes ($a_{ij\,(z)}$) or accumulated selectively ($a_{ij(s)}$)) is the amount of wastes accumulated in a determined period of time, expressed in mass units, per one inhabitant, area square meter or other conversion unit. Indicator of waste volume accumulation was computed according to the formula (BN 87/9103-04):

$$a_{ij(z,s)} = \frac{\sum_{i=1}^{d} m_{ij(z,s)}}{M_i \cdot d_{i(z,s)}} \cdot 365 \ (\text{kg}\cdot(\text{person}\cdot\text{year})^{-1}) \tag{1}$$

where: $m_{ij\,(z,s)}$ – net weight of collected municipal wastes (mixed (z) or segregated (s)) from a community (i) in a month or quarter (j) established on the basis of analysis of the data from the computer programme (kg); M_i – number of served inhabitants; $d_{i(z,s)}$ – number of days of waste accumulation (the period between subsequent waste collections).

The analysis of mixed and selectively accumulated wastes volume was used to determine the efficiency of segregated waste collection ($e_{ij(s)}$). The efficiency is expressed by the ratio of waste volume collected as so called segregation to the sum of all collected municipal wastes volumes over a determined period of time. The efficiency was calculated from the formula below for the subsequent months, quarters and the whole year of investigations:

$$e_{ij(s)} = \frac{m_{ij(s)}}{m_{ij(z)} + m_{ij(s)}} \cdot 100 \ \ (\%) \tag{2}$$

Monthly indicators of waste accumulation were used to calculate the irregularity of waste accumulation coefficient (k_{ij}). The coefficient of irregularity of waste accumulation for subsequent months was computed from the following formula:

$$k_{ij(z,s)} = \frac{a_{ij(s)}}{\frac{1}{12}\sum_{i=1}^{4} a_{ij(s)}} \tag{3}$$

Statistical analysis of the research results was conducted in STATISTICA 10 programme.

RESULTS AND DISCUSSION

The indicator of mixed wastes volume accumulation in Liszki community was 166.1 ± 17.6 kg·(person·year)$^{-1}$ and the value is by about 60 kg·(person·year)$^{-1}$ higher than computed on the basis of information in the Central Statistical Office - Local Databank (CSO DB). The lowest value of the indicator: 91 ± 14kg ·(person ·year)$^{-1}$ characterised the administrative units of Ściejowice and Jeziorzany. The highest value of the indicator 1091 ± 173.5kg·(person·year)$^{-1}$ was noted for Liszki administrative unit. The reason for such high value of the indicator in this administrative unit is a big number of enterprises operating in this area. The indicator of mixed municipal wastes accumulation obtained for Mogilany community is 182.7 ± 13 kg·(person ·year)$^{-1}$, i.e. 30% higher than the indicator determined on the basis of CSO local databank. The highest value of the indicator in the municipality area characterises Mogilany administrative unit, where 480.9 ± 62kg of mixed municipal wastes per year was noted per one inhabitant. The lowest waste accumulation: 98.65 ± 21.3 kg·(person·year)$^{-1}$ occurs along the Gaj-Włosań-Lusina route. The accumulation indicators computed for individual quarters and the whole period of investigations were compiled in Table 2. Malinowski (2013) states that in 2011-2012 an average Krakow city dweller generated over 550 kg·(person·year)$^{-1}$ of mixed municipal wastes, whereas the inhabitants of rural areas adjoining Krakow over thrice less (145 kg·(person ·year)$^{-1}$). High values of mixed municipal wastes accumulation volume in Liszki and Mogilany communities confirm the suburban character of these communities. D'Obyrn and Szalińska (2005) reported that the indicators of mixed municipal waste accumulation in rural areas are even twice lower than computed for the analysed municipalities. In a majority of the analysed smaller administrative units the most of mixed wastes is generated in spring (the end of heating season, Eastertime and spring cleaning period). The differences between the indicator obtained for the spring season and the other seasons for the smaller administrative units of Budzyń, Krusinów, Mników, Baczyn, Chrosna, Ściejowice, Jeziorzany, Chorowice, Kulerzów, Gaj, Włosań and Lusina are statistically non-significant.

Indicators of segregated waste accumulation in Liszki community during the analysed period is 42.5 kg ± 5.8 kg·(person·year)$^{-1}$. Segregated waste accumulation in Mogilany community is higher and reaches 48.3 ± 7.1 kg·(person·year)$^{-1}$. The highest value of the indicator – 117.1 ± 35.3 kg·(person·year)$^{-1}$ was registered in Mogilany administrative unit, whereas the lowest values 23.1 ± 4.65 kg·(person·year)$^{-1}$ were noted for Gaj-Włosań-Lusina route. De-

tailed compilation of the computed indicators, including its seasonal variability, was presented in Table 2. The value of segregated waste accumulation volume indicator in the analysed communities is almost twice higher than the national average, which in the analogous period was about 25 kg·(person·year)$^{-1}$. For both communities, the quarterly indicator of segregated waste accumulation assumes the highest values in the spring season. Like in case of mixed waste accumulation volume indicator, the difference between the spring and other seasons is statistically significant.

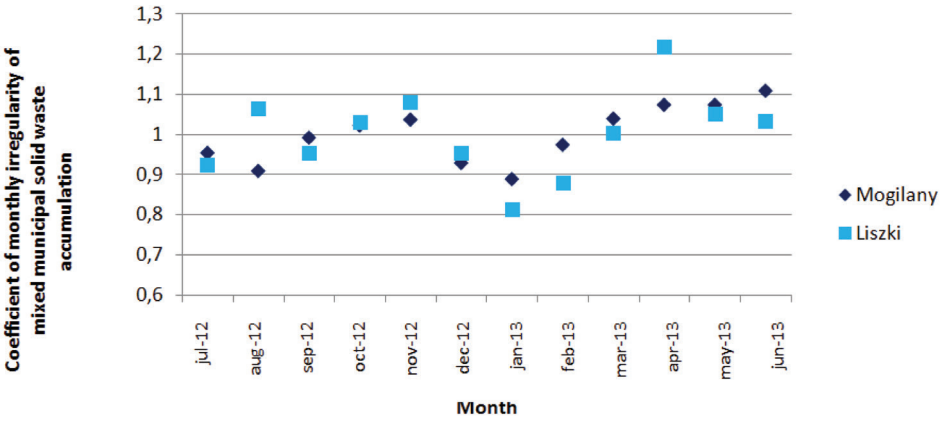


Figure 4. Coefficient of monthly irregularity of mixed municipal solid waste accumulation

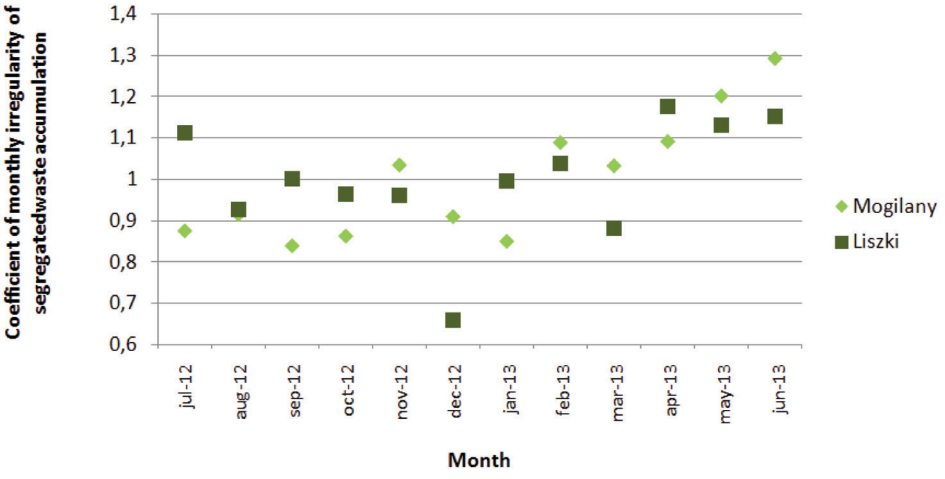


Figure 5. Coefficients of monthly irregularity of segregated waste accumulation

Table 2. Detailed analysis of the indicators of accumulation and degree of segregated waste accumulation efficiency

Commune	Admin. units	Indicator of mixed municipal solid waste accumulation [kg·(person·year)$^{-1}$]					Indicator of segregated waste accumulation [kg·(person·year)$^{-1}$]					The degree of segregated waste accumulation efficiency [%]				
		per year	Summer	Autumn	Winter	Spring	per year	Summer	Autumn	Winter	Spring	per year	Summer	Autumn	Winter	Spring
Liszki	Budzyń, Kryspinów	**163.63**	152.56	151.26	147.94	202.74	**36.44**	46.93	22.53	35.23	41.08	**18.22**	23.43	11.92	19.8	18.21
	Cholerzyn	**113.05**	114.26	111.79	112.91	113.23	**36.14**	37.21	35.22	28.29	43.82	**24.22**	24.44	23.82	28.23	26.79
	Liszki	**1091.12**	1111.66	1068.66	985.03	1199.14	**137.43**	152.51	115.72	121.71	159.79	**11.19**	12.18	9.69	44.53	11.94
	Czułów, Kaszów	**98.54**	100.15	95.85	90.5	107.65	**43**	45.35	36.2	38.05	52.4	**30.38**	31.14	26.96	29.44	32.66
	Mników, Baczyn, Chrosna	**115.46**	106.15	109	110.84	135.86	**40.99**	34.69	31.61	52.01	45.66	**26.2**	24.16	22.16	31.09	24.38
	Morawica	**214.59**	204.13	298.74	148.33	207.16	**-**	-	-	-	-	**-**	-	-	-	-
	Piekary	**121.39**	110.82	119.83	126.41	128.48	**57.06**	69.78	53.85	51.77	52.81	**31.97**	38.66	31.03	29.03	28.89
	Rączna	**99.34**	100.56	99.54	86.28	110.99	**47.42**	43.85	46.18	46.48	53.16	**32.31**	30.21	31.68	34.88	32.38
	Ściejowice, Jeziorzany	**91.26**	88.31	87.79	86.46	102.49	**46.29**	35.4	46.16	47.42	56.18	**33.65**	28.49	34.46	35.45	35.65
	Mean ± SD	**166.1 ± 17.6**	**162.7 ± 12**	**169.7 ± 10.5**	**149.2 ± 16**	**149.2 ± 17**	**42.5 ± 5.8**	**43.1** ± 4	**36.6 ± 7.4**	**41.3 ± 3.4**	**49** ± 1	**20.4** ± 2.7	**21** ± 2.6	**17.6** ± 2	**21.8** ± 3	**21.2** ± 1

Commune	Admin. units	Indicator of mixed municipal solid waste accumulation [kg·(person·year)$^{-1}$]					Indicator of segregated waste accumulation [kg·(person·year)$^{-1}$]					The degree of segregated waste accumulation efficiency [%]				
		per year	**Summer**	**Autumn**	**Winter**	**Spring**	**per year**	**Summer**	**Autumn**	**Winter**	**Spring**	**per year**	**Summer**	**Autumn**	**Winter**	**Spring**
Mogilany	Buków, Konary	**175.5**	163.24	170.59	171.64	196.53	**49.86**	48.32	41.44	49.84	59.86	**22.13**	22.87	19.42	22.46	23.36
	Chorowice, Kulerzów	**128.9**	113.89	114.12	124.27	163.34	**50.75**	47.84	40.35	49.22	65.59	**28.25**	29.63	25.86	28.38	29.81
	Gaj, Włosań, Lusina	**98.65**	97.56	84.09	96.63	116.3	**23.09**	23.76	21.58	19.6	27.39	**18.96**	19.58	22.23	16.78	19.1
	Libertów	**110.71**	111.84	107.03	128.61	95.38	**25.21**	25.38	27.28	34.05	14.11	**18.54**	18.55	20.44	20.78	9.5
	Mogilany	**480.87**	456.07	525.29	426.21	515.9	**117.08**	80.89	120.05	106.9	160.49	**19.58**	15.1	18.59	19.93	23.81
	Mean ± SD	**182.7 ± 13**	**173.8 ± 7**	**181.9 ± 10.8**	**176.7 ± 14**	**198.4 ± 3.7**	**48.3 ± 7.1**	**42.4 ± 1.8**	**45.2 ± 4.2**	**47.9** ± 6	**57.7 ± 4.8**	**20.8 ± 1.6**	**19.6 ± 1.6**	**19.9 ± 1.4**	**21.2 ± 1.3**	**22.5 ± 1.2**

* indicators computed for the whole period of investigations

Coefficients of monthly irregularity of mixed and segregated waste accumulation from the smaller administrative units of Liszki and Mogilany communities were presented in Figures 4 and 5. The highest value of mixed waste accumulation irregularity coefficient (1.22) was registered in Liszki community in April, while for Mogilany community in June – 1.11. For of both communities the coefficient of monthly irregularity assumes its lowest value in January (Liszki – 0.81; Mogilany – 0.89). Values of the coefficient in the individual months and in both analysed communities are approximate (Fig.4). The highest value of the coefficient of monthly irregularity of segregated wastes accumulation in Liszki community (1.18), like for mixed wastes occurs in April, whereas in Mogilany community (1.29) in June. The lowest value of the coefficient for Liszki community (0.66) was registered in December, whereas for Mogilany (0.84) in September. The difference between the maximum and minimum value of the coefficient in the analysed communities is much higher for segregated wastes, which evidences a considerable quantitative diversification of the stream volume of these wastes during a year. Moreover, the course of the coefficient of segregated waste accumulation irregularity in both municipalities is greatly diversified (no distinctive trend is noticeable).

The highest degree of intensity of selective waste accumulation (Tab.2) in Liszki community characterizes its smaller administrative units: Rączna, Piekary, Ściejowice and Jeziorzany, where it ranges from 28.5 to 35.6%. Average degree of efficiency of segregated waste accumulation in Liszki community is 20.4%. In some smaller administrative units of Mogilany community the values of the efficiency degree are clearly higher than in the same units of Liszki community, yet an average degree of efficiency in Mogilany community is 20.8%. Efficiency degree of selective waste collection in both analysed communities is therefore higher than the national average (8%) and average for the voivodeship (12%). Administrative units of Chorowice and Kulerzów reached the highest efficiency: 28 ± 3.7%.

Quarterly indicator of selective waste accumulation efficiency (Tab.2) in most of the analysed lower administrative units was the highest in the spring season. The lowest value in Liszki community was noted for the autumn season.

It is surprising that in Mogilany community the lower value of the degree of selective waste accumulation efficiency is noted in the summer season, which generally favours waste segregation. The reason may be morphological composition of the wastes from these communities. Malinowski (2013) reports that the volume of selectively accumulated wastes increases in the summer season, however in some communities the proportion of packaging wastes of light plastics increases at the cost of percent content of heavy glass packaging.

CONCLUSIONS

Changes introduced in the legal system should improve the state of waste management in Poland. Local self-governments and firms operating in so called "garbage branch" on the basis of maintaining cleanliness and order in municipalities act (Dz.U. 2011. poz.897), are obliged to design and construct the waste management plants, including Points of Selective Collection of Municipal Waste, Regional Facilities for Municipal Waste Treatment and other. A key element of proper planning of this type investments is research conducted on the properties of wastes collected from a given settlement unit, particularly determining the percent of the waste stream made up by waste fractions which inhabitants may sort in their households. Analysis of real waste accumulation volumes allows the enterprises to prepare for community tendering procedures for waste collection. In this way companies may lower the costs involved in services provided for the inhabitants, which in result will lead to diminishing the fees connected with waste collection. In result of conducted analysis the Authors formulated the following conclusions:

1. Real values of mixed waste accumulation indicators in the analysed communities are higher than the indicators computed on the basis of CSO data.
2. The efficiency of selective waste accumulation of the analysed communities is on a similar level and exceeds 20%. Values of the indicator of waste segregation efficiency evidence a considerable ecological awareness of the inhabitants in both communities.

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