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# The Analysis and the Evaluation of Municipal Waste Management in Voivodship Cities in Poland

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## 1. Introduction

The formation of municipal waste and further waste management is a civilization challenge for mankind. According to the principle of sustainable development, waste should be reused (recycled). It will be possible owing to the implementation of its common selective collection (Kłos 2012). Resource exhaustion (especially metals) and its connection to the increasing demand for production materials and a general increase in consumption are a serious threat to the whole world (Hotta & Aoki-Suzuki 2014, Billard 2019). Efficient waste management and recycling are the only ways to keep resources (Minelgaitė & Liobikienė 2019).

The promotion of the circular economy is the reply for the improvement of current municipal waste management. The main aim of this idea is to limit the consumption of resources, energy, and the amount of waste and the emission of harmful substances. The activities consist of closing the circle of materials and energy flow and using them economically. The aims can be reached in a long-term perspective by proper designing, conservation, repairs, reuse, re-production, renovation and recycling, as well as changing social awareness (Bondaruk et al. 2017). The term reverse logistics, used in the literature, also fits into this philosophy. It is the body of management processes of the circulation of created waste and information connected with the circulations, starting from the places waste is created to places of its destination, where some values are gained back from the waste (from renovation, recycling or conversion) (Green et al. 2012, Plewa et al. 2014). The activities are the base of such waste management in which selective collection is the primary stage of recycling the collected materials. Ferronato et al. (2019) published the results of research concerning the introduction of successful solid waste management strategy in developing countries (Romania and

Bolivia). In the monography, the authors indicated the benefits of being a member of the European Union (economic support, regulations) in developing the recycling systems.

According to the 2008/98/EC directive, the key legal document of the European Law in waste management, the creation of "the recycling society", which aim would be to avoid producing waste and using waste as resources, is being strived. The change of the directive of the 30th May 2018 (Directive (UE) 2018/851) additionally encourages to save food (to collect unsold food products, food donations and other forms of redistribution), which consequently is supposed to reduce organic waste.

The data gained from the Central Statistical Office and cited in The National Waste Management Plan 2022 show that in Poland annually the percentage of stored municipal waste decreased from 94.21% in 2004 to 52.63% in 2014. Moreover, on the basis of the Marshals' report on the realization of their activities connected with waste management from 2013 and 2014, it is seen that the percentage of recycled waste increased (four fractions were assessed: paper, metals, plastic and glass) from 8.34% to 9.37% in total amount of collected municipal waste.

The regulation of the 13th September 1996 on the maintaining cleanliness and order in municipalities imposes obligations on municipalities inter alia to reach a level of recycling and preparation for reusing the following fractions of municipal waste: paper, metal, plastic and glass (so-called 4 fractions) of at least 50% of total weight of municipal waste to the 31st December 2020. Moreover, aims for other waste fractions were set. As one of the aims of municipal waste management, it was assumed that the amount of biodegradable waste and directed to storage will be limited so that not more than 35% of the waste produced in 1995 (the reference year) will be stored in 2020 (The National Waste Management Plan 2022). The regulation determines also the duty of selective collection of municipal waste.

To evaluate the municipal waste management one can apply rates that illustrate its accumulation, production, collection, selective collection and recycling per one inhabitant. The analyses are presented in works issued by the Central Statistical Offices. By comparing the calculated rates year to year in administrative units, one can evaluate the regularity of waste management.

The research set two aims. The first aim was to evaluate the condition of the management of municipal waste collected as mixed and municipal waste collected as separate (the mixed waste and the selected waste) with the use of modified rates created on the basis of Alankiewicz (2009). The second aim was to compare the selective collection of given fractions in particular voivodship cities in Poland (16 cities) with the use of spatial concentration coefficient and location quotient in order to assess the condition of municipal waste management. The monography concerns the possibility of using spatial planning tools to evaluate the condition of municipal waste management. The rates connected with the selective collection of waste for all voivodship cities in Poland were compared. Then, by using data from the Local Data Bank and theoretical assumptions on the concentration of spatial phenomena, the comparative assessment of the condition of the management of selectively collected waste was made.

## 2. The rules and methods for the evaluation of municipal waste management

The evaluation of the municipality's waste management depends to a large extent on an effective collection of waste and currently on a selective collection as well. De Feo et al. (2019) proposed a methodological approach useful in defining rates which can be used in communication campaigns organized in order to improve the effectiveness of selective municipal waste collection. For this reason, six economic-environmental indicators were determined. The methodology was used in collecting paper and cardboard in 12 cities of southern Italy. It was stated that the maximal amount of paper and cardboard that can be recycled from unsorted waste would bring back over 15 million Euro to Naples and Palermo. Moreover, maximal potential economic savings for every inhabitant was 25 Euro/capita per year. Catania was a city with the highest possible potential of saving carbon dioxide per inhabitant (> 60 kg $CO_2$eq./capita). The implemented innovative communicative method ("Greenopoli") assumes that school is the starting point for changing attitude as it enables direct access to potential and to the most important recipients (audience) of communication campaigns (De Feo et al. 2019).

The content of municipal waste depends to a large extent on the area urbanization degree from where the waste comes. Ying-Chu (2018) researched the influence of some urbanization indicators on the content of municipal waste using a linear regression model. The following rates were acknowledged as urbanization indicators: the household population, the area of urban planning, tap water penetration, sold electricity, number of operating factories, car density, education level and annual income. The five main elements of municipal waste were: paper, food waste, plastic, metal and glass. The results served as a valuable hint in evaluating changes in municipal waste content in relation to the urbanization indicators used in the research.

In China, the use of Aibolv mobile application, which realizes a new model of waste management "Internet + Recycling" and which enables easy access to selective collection systems for the producers and recipients, was suggested and checked. Owing to it, an individual can use various internet platforms to determine the date of waste collection. Then companies would take the waste from the person the given day. The “Internet + Recycling system allows units to have convenient access to formal systems of waste management. In the monography, the authors made a quantitative analysis of the balance of the waste mass and environmental results of recycling of some waste fractions (Gu et al. 2019).

Castillo-Giménez et al. (2019) estimated the efficiency and convergence in municipal waste treatment of the members of the European Union (27 countries) between 1995 and 2016. The efficiency rate (including waste storage, burning, recycling, composting and fermentation as waste treatment operation) was determined with Data Envelopment Analysis and Multi-Criteria-Decision-Making techniques at the national level. The convergence was evaluated using techniques suggested by Phillips and Sul (2007, 2009), and recently used by Kong et al. (2017). The highest results were gained by countries from Central Europe (Denmark, Germany, and Austria) and the worst results were given to Eastern Europe countries which joined the EU after 2000.

In Poland, to evaluate the level of waste management the segmentation evaluation method, which orders the criteria for the evaluation of the realization of the Municipal Waste Management Plan, was suggested. Making the plans is not required at present; however, the indicators worked out by the author can be used to evaluate the waste management led by the local government units (Alankiewicz, 2009). The rates include:

1. **Accumulation rate:** $\mathbf{R_A}$ – the amount of produced waste for 1 inhabitant.
2. **Collection rate** – $\mathbf{R_C}$ – determining the degree to which inhabitants are included in the mixed waste collection system (since the 1st July 2013, 100% of municipality inhabitants should be included in the mixed waste collection system).
3. **Selective collection rate**: $\mathbf{R_{SC}}$ – determining the degree to which inhabitants are included in the selective collection system.
4. **Recovery rate:** $\mathbf{R_R}$ – the amount of waste that underwent recovery.
5. **Storage rate:** $\mathbf{R_S}$ – the amount of disposed waste.
6. **Cost rate:** $\mathbf{R_{CO}}$ – costs for collecting waste, recovery and disposal that are ordered to be paid by inhabitants.

By using the suggested rates one can evaluate the realization of the rules that should be respected in a properly functioning waste management, i.e.:

- to evaluate the avoidance of producing waste – $\mathbf{R_A}$,
- to evaluate the reduction of waste – $\mathbf{R_C}$, $\mathbf{R_{SC}}$, $\mathbf{R_R}$,
- to evaluate the waste disposal that would ensure safety to people and the environment – $\mathbf{R_S}$,
- to evaluate “the polluter pays” principle – $\mathbf{R_{CO}}$.

Another attitude to the evaluation of waste management was suggested by Deluga (2018). To evaluate the way Koszalin inhabitants perceive waste management and also to show its condition, a survey method was used. It was stated that the majority of the inhabitants knows the rules for selecting waste. The necessity for the pro-ecological initiative was confirmed as the role of education about waste management is a key matter.

## 3. Materials and methods

To evaluate the condition of municipal waste management in voivodship cities, modified rates were suggested. The rates had been created under the influence of the assumptions of waste management by Alankiewicz (2009). To evaluate the level of municipal waste management (both mixed and selected), two rates were proposed:

$$W_1 = \frac{\mathrm{SW/1i}}{MW/1i} \tag{1}$$

where:
SW/1i – the mass of selected waste per 1 inhabitant,
MW/1i –the mass of mixed waste collected per 1 inhabitant.

$$W_2 = \frac{MW/1i - SW/1i}{SMW/1i} \tag{2}$$

where:
MW/1i and SW/1i – as in Formula 1),
SMW/1i – the mass of municipal waste collected (together mixed and selected) per 1 inhabitant.

$W_1$ rate can theoretically take the value in the <0,∞) range. Value 0 will be reached when SW/1i is 0, so there will be no waste selectively collected – the situation extremely undesirable. $W_1$ rate increases with the increase of the mass of selected waste and the decrease of the mass of mixed waste. $W_1 = 1$ value will mean that the mass of mixed waste per 1 inhabitant is the same as the mass of selected waste. The more above 1 the $W_1$ rate gets, the more effective the waste management is.

$W_2$ rate can take the value in the <-1,1> range. The value -1 reflects the perfect condition when all waste is selectively collected. The value 0 indicates the condition in which the mixed waste mass equals the selected waste mass. The value 1 is the extremely undesirable condition, i.e. when all the waste is collected as mixed.

Additionally, to evaluate a selective collection of waste, the concentration of spatial phenomena rate was used. In researching the spatial distribution of the phenomena, the aim is to determine the degree of the concentration of the analyzed phenomenon against a different phenomenon. From the comparison of the sets, one can notice to which degree the concentration of the analyzed phenomenon deviates from the concentration of the basic phenomenon. The concentration coefficient proposed by Florence is presented in the following formula (Kostrubiec 1972, Domański 1998):

$$C = \frac{\sum_{i=1}^{n}(x_i - y_i)}{100} \qquad (3)$$

where:
$C$ – concentration coefficient,
$x_i$ – the percentage share of the *i* unit in the global value of the research phenomenon,
$y_i$ – the percentage share of the *i* unit in the global value of the basic phenomenon,
$n$ – the number of individual units.

The concentration coefficient is a unit-less measure and it stays in the <0,1> range. When the research phenomenon is distributed such as the basic phenomenon – full dispersion – the rate is 0. In the case when the rate equals 1, the research phenomenon is concentrated in one unit area – full concentration (Kostrubiec 1977, Senetra & Cieślak 2004). The Lorenz curve illustrates the value of the concentration coefficient. If the research phenomenon is distributed evenly, then we get a straight line inclined at the angle of 45° starting at the beginning of the coordinate system. Each inclination from the proportion makes the curve convex (Fig. 1). While creating the diagram, one collates the research units in the order according to the value of the location quotient, starting from the highest. The location quotient (LQ) is a quotient of the percentage share of the research phenomenon and the percentage share of the basic phenomenon. Then, the percentage values set for every series, in the order determined by LQ, are cumulated. The cumulated series are marked on the axes – the research phenomenon on the vertical axis and the basis phenomenon on the vertical one (Domański 1998, Senetra & Cieślak 2004). The graphical concentration measurement is the surface between the straight line inclined at the angle of 45° and Lorenz curve. The ratio of this surface to the total surface of the upper triangle equals the concentration coefficient (Fig. 1).

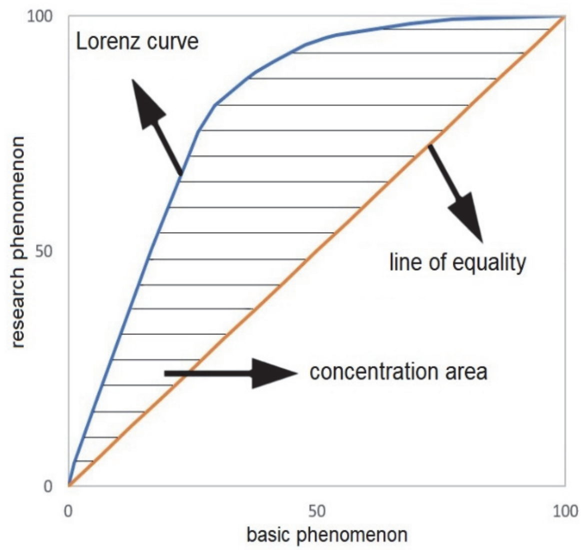


**Fig. 1.** Lorenz curve

For the need of the evaluation of the level of selectively collected waste in the total waste mass (mixed and selected) in particular cities, the authors used data applying to the general municipal waste and six fractions:

1. Paper and cardboard (PC).
2. Glass (G).
3. Plastic (P).
4. Waste electrical and electronic equipment (WEEE).
5. Bulky waste (BW).
6. Biodegradable waste (B).

The justification for choosing the fractions is their highest share in the mass of selective waste. Moreover, they are the most common waste selectively collected. In the first stage of the research, the concentration coefficient of all selectively collected waste in the research cities was calculated (Formulas 4, 5, 6) The basic phenomenon (BPH) was determined as the quotient of the sum of mixed waste and selected waste in every city, and the sum of the waste in all cities (4). The research phenomenon (RPH) was determined as the quotient of the amount of selected waste in every city and the sum of selected waste in all cities (5).

$$BPH = \frac{MSW\ in\ city\ i}{MSW\ in\ all\ cities} \tag{4}$$

where:
MSW – the mass of mixed and selected waste all together.

$$RPH = \frac{\text{SW in city i}}{\text{SW in all cities}} \tag{5}$$

where:
SW – the mass of selected waste.

The concentration coefficient (calculated according to Formula 3) takes the form presented with Formula 6.

$$Csw = \frac{\sum_{i=1}^{16}|RPH - BPH|}{100} \tag{6}$$

where:
$\sum_{i=1}^{16}|RPH - BPH|$–the sum of the absolute difference of the research phenomenon and the basic phenomenon.

For the evaluation of the degree of the concentration coefficient of the selectively collected waste in the division into six fractions, a similar methodological attempt was used. In this case the basic phenomenon (BPH) for all distinct fractions is the RPH value used in Formula 5 as the research phenomenon. The research phenomenon (RPH) for all selected fractions was defined in the following way:

1. Selected waste "paper and cardboard" – PC:

$$RPH_{PC} = \frac{SW_{PC}\text{ in city i}}{SW_{PC}\text{ in all cities}} \tag{7}$$

where:
$SW_{PC}$ – the mass of selected waste PC.

2. Selected waste "glass" – G:

$$RPH_{G} = \frac{SW_{G}\text{ in city i}}{SW_{G}\text{ in all cities}} \tag{8}$$

where:
$SW_{G}$ – the mass of selected waste G.

3. Selected waste "plastic" – P:

$$RPH_{P} = \frac{SW_{P}\text{ in city i}}{SW_{P}\text{ in all cities}} \tag{9}$$

where:
$SW_{P}$ – the mass of selected waste P.

4. Selected waste "waste electrical and electronic equipment" – WEEE:

$$RPH_{WEEE} = \frac{SW_{WEEE} \text{ in city i}}{SW_{WEEE} \text{ in all cities}} \quad (10)$$

where:
$SW_{WEEE}$ – the mass of selected waste WEEE.

5. Selected waste "bulky waste" – BW:

$$RPH_{BW} = \frac{SW_{BW} \text{ in city i}}{SW_{BW} \text{ in all cities}} \quad (11)$$

where:
$SW_{BW}$ – the mass of selected waste BW.

6. Selected waste „biodegradable waste" – B:

$$RPH_{B} = \frac{SW_{B} \text{ in city i}}{SW_{B} \text{ in all cities}} \quad (12)$$

where:
$SW_B$ – the mass of selected waste B.

## 4. Results and discussion

### 4.1. The evaluation of municipal waste management of mixed and selected waste in voivodship cities

For the evaluation, the data from the Local Data Bank (www.stat. gov.pl, access 17th December 2018) concerning municipal waste (mixed and selected waste) as well as information on the population in voivodship cities in Poland, were used. The value of $W_1$ and $W_2$ rates was calculated and presented in Table 1.

**Table 1.** The value of $W_1$ and $W_2$ rates in voivodship cities

| No. | City | MW/1i | SW/1i | $W_1$ | $W_2$ |
|---|---|---|---|---|---|
| 1 | Wrocław | 349.78 | 146.05 | 0.4175 | 0.4109 |
| 2 | Bydgoszcz | 238.92 | 94.72 | 0.3965 | 0.4322 |
| 3 | Lublin | 247.40 | 87.82 | 0.3550 | 0.4760 |
| 4 | Zielona Góra | 308.49 | 70.55 | 0.2287 | 0.6277 |
| 5 | Łódź | 260.58 | 100.39 | 0.3853 | 0.4438 |
| 6 | Kraków | 283.33 | 160.84 | 0.5677 | 0.2679 |
| 7 | Warszawa | 335.17 | 106.88 | 0.3189 | 0.5164 |
| 8 | Opole | 244.17 | 137.60 | 0.5635 | 0.2792 |
| 9 | Rzeszów | 270.57 | 107.13 | 0.3959 | 0.4327 |

**Table 1.** cont.

| No. | City | MW/1i | SW/1i | $W_1$ | $W_2$ |
|---|---|---|---|---|---|
| 10 | Białystok | 161.94 | 110.91 | 0.6849 | 0.1870 |
| 11 | Gdańsk | 295.18 | 112.59 | 0.3814 | 0.4478 |
| 12 | Katowice | 345.85 | 94.91 | 0.2744 | 0.5693 |
| 13 | Kielce | 261.51 | 80.72 | 0.3087 | 0.5283 |
| 14 | Olsztyn | 314.96 | 85.26 | 0.2707 | 0.5739 |
| 15 | Poznań | 299.14 | 115.86 | 0.3873 | 0.4417 |
| 16 | Szczecin | 317.09 | 88.04 | 0.2776 | 0.5654 |

The value of $W_1$ rate is the highest in the following cities: Białystok, Kraków and Opole, which means that in the cities there is a high percentage of selected waste. In the case of Białystok, the $W_1$ rate is high also because the city is characterized by a low amount of mixed municipal waste – 161.94 kg/inhabitant. The lowest rate occurred in Zielona Góra, Olsztyn, Katowice and Szczecin. A very low $W_1$ rate occurred in Zielona Góra due to the fact that there is a large percentage of mixed waste per inhabitant (308.49 kg) and a small amount of selected waste (70.55 kg/inhabitant). In none of the cities, the rate was above 1. The range of the $W_1$ value was divided into five even evaluation categories (Table 2). In two categories, which were marked with the lowest and low value (V and IV category), there are 12 voivodship cities. However, in I category, with the highest value, there is only one city – Białystok. That means that the majority of cities stay on the equally low level considering the evaluation of the relation of selected waste (per inhabitant) to the amount of mixed waste (per inhabitant).

**Table 2.** The range of evaluation of $W_1$ rate

| Evaluation category | $W_1$ range | Cities |
|---|---|---|
| I – the highest | 0.5938-0.6849 | Białystok |
| II – high | 0.5025-0.5937 | Kraków, Opole |
| III – average | 0.4113-0.5024 | Wrocław |
| IV – low | 0.3200-0.4112 | Bydgoszcz, Lublin, Łódź, Rzeszów, Gdańsk, Poznań |
| V – the lowest | 0.2287-0.3199 | Zielona Góra, Warszawa, Katowice, Kielce, Olsztyn,Szczecin |

In evaluating the condition of waste management with the use of $W_2$ rate, similar conclusions were drawn. The value of the rate did not reach results below zero, which means that there is more selected waste than mixed one in none of the analyzed cities. $W_2$ is the lowest in Białystok and Kraków, which proves the high percentage of selected waste in the total amount of municipal waste (both mixed and selected). The highest $W_2$ rate value was reached in Zielona Góra, Olsztyn, Katowice and Szczecin. It means that in the cities there is a large difference between the mass of mixed waste per inhabitant and the mass of selected waste per inhabitant. Similarly, like for $W_1$ rate, the range of $W_2$ rate was divided into five even brackets (Table 3).

In the case of $W_2$ rate, one can notice the similarities with the results of the $W_1$ evaluation. In IV category, in both cases, four out of six cities appeared in both studies: Zielona Góra, Katowice, Olsztyn and Szczecin. In I category, in both analyzed rates, the highest mark was received by Białystok.

**Table 3.** The range of evaluation of $W_2$ rate

| Evaluation category | $W_2$ range | Cities |
|---|---|---|
| I – the highest | 0.1870-0.2751 | Kraków, Białystok |
| II – high | 0.2752-0.3632 | Opole |
| III – average | 0.3633-0.4514 | Wrocław, Bydgoszcz, Lublin, Łódź, Rzeszów, Gdańsk, Poznań |
| IV – low | 0.4515-0.5395 | Warszawa, Kielce |
| V – the lowest | 0.5396-0.6277 | Zielona Góra, Katowice, Olsztyn, Szczecin |

In the next stage of the research, the selective collection of waste was evaluated with the use of the concentration coefficient. In this case, data concerning the amounts of mixed and selected waste in kilograms was used (not expressed per inhabitant, as it had been done while determining $W_1$ and $W_2$ rate). Table 4 presents the data for calculating the location quotient (LQ) for particular cities. According to methodological assumptions, the data was used in the following stages to calculate the concentration coefficient ($C_{SW}$) of the selected waste in the cities (Formulas 4, 5 and 6) (Tab. 5). Moreover, data from the Central Statistical Office was used as well (www.stat.gov.pl., access 17$^{th}$ December 2018).

A very low level of concentration coefficient (0.07) means that there are no units in which waste management is vividly inappropriate. On the basis of the calculated location quotients presented in Table 5, a graph of the curve of the space concentration of selected waste against all municipal waste in voivodship cities was created (Fig. 2).

**Table 4.** The data for calculating the location quotient and concentration coefficient of selected waste in voivodship cities in Poland

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BPH | 10.46 | 3.89 | 3.77 | 1.75 | 8.28 | 11.59 | 25.68 | 1.62 | 2.36 | 2.68 | 6.26 | 4.33 | 2.23 | 2.29 | 7.40 | 5.41 |
| RPH | 11.27 | 4.04 | 3.61 | 1.19 | 8.42 | 14.91 | 22.71 | 2.13 | 2.45 | 3.98 | 6.32 | 3.41 | 1.93 | 1.78 | 7.55 | 4.30 |
| RPH-BPH | 0.81 | 0.15 | -0.16 | -0.56 | 0.14 | 3.32 | -2.97 | 0.51 | 0.09 | 1.30 | 0.06 | -0.92 | -0.30 | -0.51 | 0.15 | -1.11 |
| RPH/BPH | 1.08 | 1.04 | 0.96 | 0.68 | 1.02 | 1.29 | 0.88 | 1.31 | 1.04 | 1.49 | 1.01 | 0.79 | 0.87 | 0.78 | 1.02 | 0.79 |

**Table 5.** The location quotients, cumulated percentage share of the phenomena and the calculations of concentration coefficient

| Cities according to LQ | 10 | 8 | 6 | 1 | 9 | 2 | 15 | 5 | 11 | 3 | 7 | 13 | 12 | 16 | 14 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LQ | 1.49 | 1.31 | 1.29 | 1.08 | 1.04 | 1.04 | 1.02 | 1.02 | 1.01 | 0.96 | 0.88 | 0.87 | 0.79 | 0.79 | 0.78 | 0.68 |
| RPH | 3.98 | 6.11 | 21.02 | 32.29 | 34.74 | 38.78 | 46.33 | 54.75 | 61.07 | 64.68 | 87.39 | 89.32 | 92.73 | 97.03 | 98.81 | 100.00 |
| BPH | 2.68 | 4.30 | 15.89 | 26.35 | 28.71 | 32.60 | 40.00 | 48.28 | 54.54 | 58.31 | 93.99 | 86.22 | 90.55 | 95.96 | 98.25 | 100.00 |
| $C_{SW} = 6.53/100 = 0.07$ | | | | | | | | | | | | | | | | |

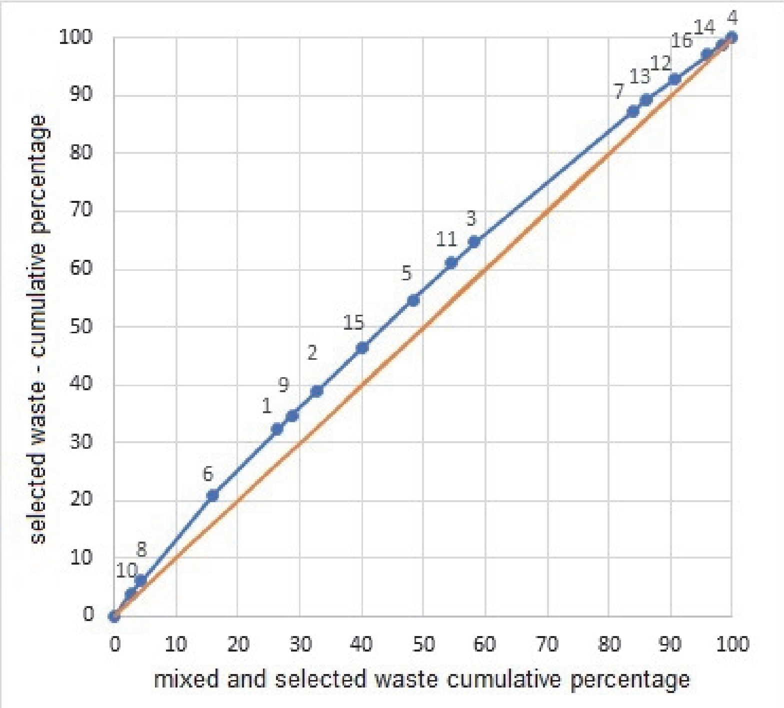


**Fig. 2.** The curve of the space concentration of selected waste against all municipal waste in cities

The concentration curve deviates from the straight line a bit which should be seen that the research phenomenon (the relation of selected waste mass in a city to the mass of all waste in all cities) is similarly concentrated to the basic phenomenon (the relation of mixed and selected waste mass in a city to the mass of all waste in the city). However, the best situation occurred in Białystok (the first object in Figure 2) and the worst situation was in Zielona Góra (the last object in Figure 2). The order of the cities on the graph is reflected by the height of the location quotient (LQ) for each of them. The quotient can be a convenient tool for evaluating the situation in every unit against all the analyzed units. The comparison of the order of the cities gained from the evaluation made with the use of $W_1$, $W_2$ rates and the location quotient (LQ) is shown in Table 6.

As a result of the evaluation made with the use of $W_1$ and $W_2$ rates, the same order of the cities occurred. It means that one can use one rate for the evaluation. The evaluation made using the theory of the concentration of spatial phenomena gave similar results. In ten cases (green color in Table 6), the same order was gained for all rates. In six cases (yellow color in Table 6), slight changes were observed (+/- one position).

**Table 6.** The comparison of $W_1$, $W_2$ rates and location quotients (LQ)

| Cities order | $W_1$ | $W_2$ | LQ |
|---|---|---|---|
| 1 | Białystok | Białystok | Białystok |
| 2 | Kraków | Kraków | Opole |
| 3 | Opole | Opole | Kraków |
| 4 | Wrocław | Wrocław | Wrocław |
| 5 | Bydgoszcz | Bydgoszcz | Rzeszów |
| 6 | Rzeszów | Rzeszów | Bydgoszcz |
| 7 | Poznań | Poznań | Poznań |
| 8 | Łódź | Łódź | Łódź |
| 9 | Gdańsk | Gdańsk | Gdańsk |
| 10 | Lublin | Lublin | Lublin |
| 11 | Warszawa | Warszawa | Warszawa |
| 12 | Kielce | Kielce | Kielce |
| 13 | Szczecin | Szczecin | Katowice |
| 14 | Katowice | Katowice | Szczecin |
| 15 | Olsztyn | Olsztyn | Olsztyn |
| 16 | Zielona Góra | Zielona Góra | Zielona Góra |

### 4.2. The evaluation of chosen fractions of the selected waste

Next, the evaluation of selected waste for six chosen fractions was made with the use of concentration coefficient. Tables 7 and 8 contain data necessary for calculating the location quotients (LQ) and concentration coefficients (Formulas 7-12). In Table 8, however, data necessary for preparing graphs for particular fractions selectively collected in research cities were presented (Figure 3).

**Table 7.** The data necessary for calculating the location quotient and the concentration coefficient of the selected waste

| Cities | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BPH** | 11.27 | 4.04 | 3.61 | 1.19 | 8.42 | 14.91 | 22.71 | 2.13 | 2.45 | 3.98 | 6.32 | 3.41 | 1.93 | 1.78 | 7.55 | 4.30 |
| **RPH** | | | | | | | | | | | | | | | | |
| **PC** | 32.68 | 1.52 | 2.17 | 4.96 | 0.80 | 2.58 | 0.77 | 0.44 | 1.38 | 2.29 | 5.48 | 5.64 | 1.56 | 4.72 | 20.30 | 12.71 |
| $RPH_{PC}$-BPH | 21.41 | -2.52 | -1.44 | 3.77 | -7.62 | -12.33 | -21.94 | -1.69 | -1.07 | -1.69 | -0.84 | 2.23 | -0.37 | 2.94 | 12.75 | 8.41 |
| LQ | 2.90 | 0.38 | 0.60 | 4.17 | 0.10 | 0.17 | 0.03 | 0.21 | 0.56 | 0.58 | 0.87 | 1.65 | 0.81 | 2.65 | 2.69 | 2.96 |
| [1]) | **3** | **12** | **9** | **1** | **15** | **14** | **16** | **13** | **11** | **10** | **7** | **6** | **8** | **5** | **4** | **2** |
| **G** | 14.00 | 7.15 | 1.79 | 1.72 | 3.05 | 10.88 | 16.31 | 2.31 | 2.55 | 4.51 | 6.54 | 3.43 | 3.32 | 1.83 | 14.12 | 6.49 |
| $RPH_{G}$-BPH | 2.73 | 3.11 | -1.82 | 0.53 | -5.37 | -4.03 | -6.40 | 0.18 | 0.10 | 0.53 | 0.22 | 0.02 | 1.39 | 0.05 | 6.57 | 2.19 |
| LQ | 1.24 | 1.77 | 0.50 | 1.45 | 0.36 | 0.73 | 0.72 | 1.08 | 1.04 | 1.03 | 1.03 | 1.01 | 1.72 | 1.03 | 1.87 | 1.51 |
| [1]) | **6** | **2** | **15** | **5** | **16** | **13** | **14** | **7** | **8** | **9** | **10** | **12** | **3** | **11** | **1** | **4** |
| **P** | 1.20 | 1.47 | 1.83 | 8.47 | 3.97 | 6.40 | 1.95 | 0.63 | 3.05 | 6.40 | 6.77 | 2.46 | 7.18 | 7.15 | 31.32 | 9.75 |
| $RPH_{P}$-BPH | -10.07 | -2.57 | -1.78 | 7.28 | -4.45 | -8.51 | -20.76 | -1.50 | 0.60 | 2.42 | 0.45 | -0.95 | 5.25 | 5.37 | 23.77 | 5.45 |
| LQ | 0.11 | 0.36 | 0.51 | 7.12 | 0.47 | 0.43 | 0.09 | 0.30 | 1.24 | 1.61 | 1.07 | 0.72 | 3.72 | 4.02 | 4.15 | 2.27 |
| [1]) | **15** | **13** | **10** | **1** | **11** | **12** | **16** | **14** | **7** | **6** | **8** | **9** | **4** | **3** | **2** | **5** |
| **WEEE** | 3.68 | 3.42 | 3.87 | 0.48 | 3.27 | 5.84 | 56.00 | 1.33 | 1.42 | 2.04 | 6.77 | 5.19 | 0.72 | 0.37 | 3.75 | 1.85 |
| $RPH_{WEEE}$-BPH | -7.59 | -0.62 | 0.26 | -0.71 | -5.15 | -9.07 | 33.29 | -0.80 | -1.03 | -1.94 | 0.45 | 1.78 | -1.21 | -1.41 | -3.80 | -2.45 |
| LQ | 0.33 | 0.85 | 1.07 | 0.40 | 0.39 | 0.39 | 2.47 | 0.62 | 0.58 | 0.51 | 1.07 | 1.52 | 0.37 | 0.21 | 0.50 | 0.43 |
| [1]) | **15** | **5** | **4** | **11** | **12** | **13** | **1** | **6** | **7** | **8** | **3** | **2** | **14** | **16** | **9** | **10** |
| **BW** | 9.30 | 4.12 | 2.69 | 1.94 | 5.74 | 10.49 | 32.92 | 1.55 | 1.31 | 4.55 | 4.70 | 5.57 | 1.70 | 3.32 | 5.27 | |
| $RPH_{BW}$-BPH | -1.97 | 0.08 | -0.92 | 0.75 | -2.68 | -4.42 | 10.21 | -0.58 | -1.14 | 0.57 | -1.62 | 2.16 | -0.23 | 1.54 | -2.28 | 0.53 |
| LQ | 0.83 | 1.02 | 0.75 | 1.63 | 0.68 | 0.70 | 1.45 | 0.73 | 0.53 | 1.14 | 0.74 | 1.63 | 0.88 | 1.87 | 0.70 | 1.12 |
| [1]) | **9** | **7** | **10** | **3** | **15** | **13** | **4** | **12** | **16** | **5** | **11** | **2** | **8** | **1** | **14** | **6** |
| **B** | 10.53 | 6.01 | 4.04 | 0.05 | 11.96 | 16.35 | 11.50 | 2.67 | 0.82 | 3.25 | 13.56 | 2.69 | 1.40 | 1.15 | 9.18 | 4.84 |
| $RPH_{B}$-BPH | -0.74 | 1.97 | 0.43 | -1.14 | 3.54 | 1.44 | -11.21 | 0.54 | -1.63 | -0.73 | 7.24 | -0.72 | -0.53 | -0.63 | 1.63 | 0.54 |
| LQ | 0.93 | 1.49 | 1.12 | 0.04 | 1.42 | 1.10 | 0.51 | 1.25 | 0.33 | 0.82 | 2.15 | 0.79 | 0.73 | 0.65 | 1.22 | 1.13 |
| [1]) | **9** | **2** | **7** | **16** | **3** | **8** | **14** | **4** | **15** | **10** | **1** | **11** | **12** | **13** | **5** | **6** |

[1]) – the order according to the location quotient (LQ)

**Table 8.** The location quotients, cumulated percentage share of the phenomena and the calculation of the concentration coefficient

| Cities | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Paper and cardboard – PC** | | | | | | | | | | | | | | | | | $C_{PC}$ |
| [1]) | **4** | **16** | **1** | **15** | **14** | **12** | **11** | **13** | **3** | **10** | **9** | **2** | **8** | **6** | **5** | **7** | |
| $RPH_{PC}$[2]) | 4.96 | 17.67 | 50.35 | 70.65 | 75.37 | 81.01 | 86.49 | 88.05 | 90.22 | 92.51 | 93.89 | 95.41 | 95.85 | 98.43 | 99.23 | 100.00 | **0.52** |
| BPH[2]) | 1.19 | 5.49 | 16.76 | 24.31 | 26.09 | 29.50 | 35.82 | 37.75 | 41.36 | 45.34 | 47.79 | 51.83 | 53.96 | 68.87 | 77.29 | 100.00 | |
| **Glass – G** | | | | | | | | | | | | | | | | | $C_G$ |
| [1]) | **15** | **2** | **13** | **16** | **4** | **1** | **8** | **9** | **10** | **11** | **14** | **12** | **6** | **7** | **3** | **5** | |
| $BPH_G$[2]) | 14.12 | 21.27 | 24.59 | 31.08 | 32.80 | 46.80 | 49.11 | 51.66 | 56.17 | 62.71 | 64.54 | 67.97 | 78.85 | 95.16 | 96.95 | 100.00 | **0.18** |
| BPH[2]) | 7.55 | 11.59 | 13.52 | 17.82 | 19.01 | 30.28 | 32.41 | 34.86 | 38.84 | 45.16 | 46.94 | 50.35 | 65.26 | 87.97 | 91.58 | 100.00 | |
| **Plastic – P** | | | | | | | | | | | | | | | | | $C_P$ |
| [1]) | **4** | **15** | **14** | **13** | **16** | **10** | **9** | **11** | **12** | **3** | **5** | **6** | **2** | **8** | **1** | **7** | |
| $RPH_P$[2]) | 8.47 | 39.79 | 46.94 | 54.12 | 63.87 | 70.27 | 73.32 | 80.09 | 82.55 | 84.38 | 88.35 | 94.75 | 96.22 | 96.85 | 98.05 | 100.00 | **0.51** |
| BPH[2]) | 1.19 | 8.74 | 10.52 | 12.45 | 16.75 | 20.73 | 23.18 | 29.50 | 32.91 | 36.52 | 44.94 | 59.85 | 63.89 | 66.02 | 77.29 | 100.00 | |
| **Waste electrical and electronic equipment– WEEE** | | | | | | | | | | | | | | | | | $C_{WEEE}$ |
| [1]) | **7** | **12** | **11** | **3** | **2** | **8** | **9** | **10** | **15** | **16** | **4** | **5** | **6** | **13** | **1** | **14** | |
| $RPH_{WEEE}$[2]) | 56.00 | 61.19 | 67.96 | 71.83 | 75.25 | 76.58 | 78.00 | 80.04 | 83.79 | 85.64 | 86.12 | 89.39 | 95.23 | 95.95 | 99.63 | 100.00 | **0.36** |
| BPH[2]) | 22.71 | 26.12 | 32.44 | 36.05 | 40.09 | 42.22 | 44.67 | 48.65 | 56.20 | 60.50 | 61.69 | 70.11 | 85.02 | 86.95 | 98.22 | 100.00 | |
| **Bulky waste – BW** | | | | | | | | | | | | | | | | | $C_W$ |
| [1]) | **14** | **12** | **4** | **7** | **10** | **16** | **2** | **13** | **1** | **3** | **11** | **8** | **6** | **15** | **5** | **9** | |
| $RPH_{BW}$[2]) | 3.32 | 8.89 | 10.83 | 43.75 | 48.30 | 53.13 | 57.25 | 58.95 | 68.25 | 70.94 | 75.64 | 77.19 | 87.68 | 92.95 | 98.69 | 100.00 | **0.16** |
| BPH[2]) | 1.78 | 5.19 | 6.38 | 29.09 | 33.07 | 37.37 | 41.41 | 43.34 | 54.61 | 58.22 | 64.54 | 66.67 | 81.58 | 89.13 | 97.55 | 100.00 | |
| **Biodegradable waste – B** | | | | | | | | | | | | | | | | | $C_B$ |
| [1]) | **11** | **2** | **5** | **8** | **15** | **16** | **3** | **6** | **1** | **10** | **12** | **13** | **14** | **7** | **9** | **4** | |
| $RPH_B$[2]) | 13.56 | 19.57 | 31.53 | 34.20 | 43.38 | 48.22 | 52.26 | 68.61 | 79.14 | 82.39 | 85.08 | 86.48 | 87.63 | 99.13 | 99.95 | 100.00 | **0.17** |
| BPH[2]) | 6.32 | 10.36 | 18.78 | 20.91 | 28.46 | 32.76 | 36.37 | 51.28 | 62.55 | 66.53 | 69.94 | 71.87 | 73.65 | 96.36 | 98.81 | 100.00 | |

[1]) order of the cities according to the location quotient (LQ); [2]) – cumulative percentage

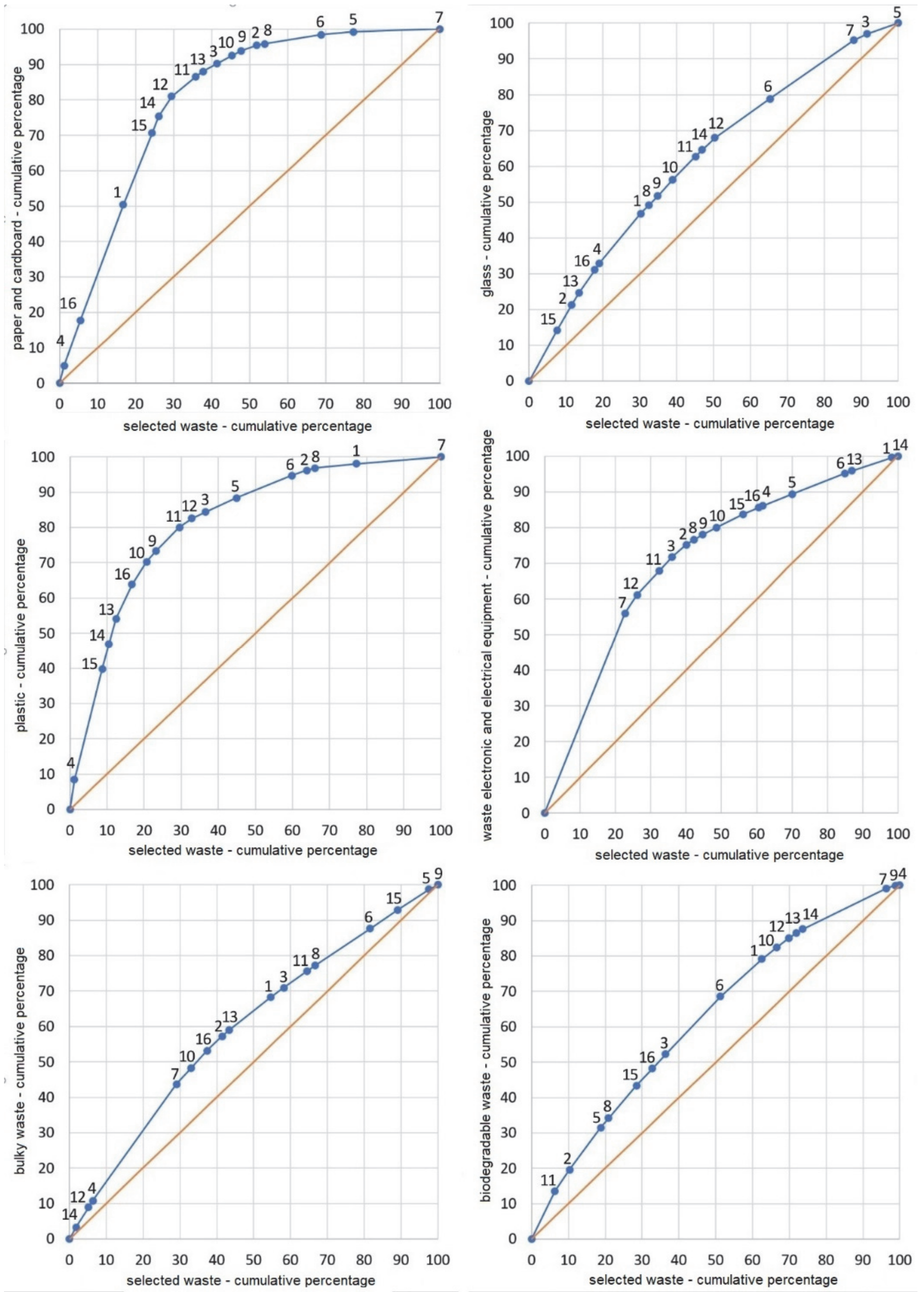


**Fig. 3.** The curves of space concentration of the research fractions of the selected waste against all selected waste in the cities

The analysis of location quotients (LQ), concentration coefficients and the graphs of space concentration of particular fractions of the selected waste against all selected waste shows that none of the fractions reached the concentration coefficient similar to the concentration coefficient of selected waste against all waste (mixed and selected), which was $C_{SW} = 0.07$. The highest concentration coefficient had paper and cardboard fraction ($C_{PC} = 0.52$), which means that the research phenomenon was concentrated in a few research cities. The graph of the concentration curve proves the fact. The curve is considerably deviated from the 45$^o$ starting from the beginning of the coordinate system (Fig. 3). The range of values of location quotients (LQ) of the fraction for every city (0.03-4.17) was broad. High location quotient indicates a high concentration of the phenomenon (selective collection of paper and cardboard) in the basic phenomenon (the relation of all selected waste in a given city to the amount of selected waste in all cities). It meant that in the city the selective collection is on a high level. A slightly lower concentration coefficient was calculated for plastic fraction ($C_P = 0.51$), and the location quotient stayed in the range (0.09-7.12). The lowest concentration coefficient occurred in three fractions: glass ($C_G = 0.18$), bulky waste ($C_{BW} = 0.16$) and biodegradable waste ($C_B = 0.17$). The low concentration coefficients indicate a similar level of collecting the waste fractions in all cities.

## 5. Summary and conclusions

The evaluation of the condition of the municipal mixed and selected waste management in voivodship cities in Poland with the use of suggested $W_1$ and $W_2$ rates and using the concentration of spatial phenomena, allowed for drawing the following conclusions:

1. $W_1$ rate does not reflect the real level of the collection of selected waste and the condition of waste management as $W_1$ rate value gets zero in each case when selected waste does not occur, regardless of the amount of collected mixed waste (also per one inhabitant). The rate can be used in a comparative assessment of administrative units or in evaluating the same unit in due time. The change of the rate shows the dynamics (tendency) of the relation of the amount of selected waste to mixed waste.
2. The second proposed rate ($W_2$) determines the differences between mixed waste and selected waste related to all selected municipal waste (both mixed and selected). In none of the evaluated cities, the relation was negative, which means that nowhere does the mass of selected waste exceed the mass of mixed waste. The rate, just like the previous one, can also be used in a comparative assessment or to show the dynamics of the phenomenon.
3. The evaluation made with the use of both rates gave similar results. The ranking of the cities determined on the basis of $W_1$ and $W_2$ rates was identical.

4. The research using the concentration of spatial phenomena and the concentration coefficient gave similar results as the evaluation made with $W_1$ and $W_2$ rates. In this case, the ranking of the cities is the same in ten cases and in the rest six cases it differs with only one position. It is worth to mention that the evaluation was made on the basis of data about waste mass (both mixed and selected) given in absolute units (kilograms). The populations of the cities were not considered.
5. The graphs of the concentration of research phenomena and the values of the location quotients (LQ) can be very useful and valuable tools not only for evaluating the condition of waste management. They can be fine hints for giving recommendations for particular spatial units. A low location quotient (LQ), in comparison to other units, indicates irregularities and necessity of intensifying activities in a given range. The rate can be treated as a kind of ranking for the whole considered system without making further calculations. Its changes in the following years inform about the changes in the level of the phenomenon and about taking or not taking corrective actions (recommendations). The tool can be used in constant monitoring and planning waste management from a global perspective for connected units and considered processes.
6. The evaluation of selected waste management, with the division into six fractions (paper and cardboard, plastic, glass, waste electrical and electronic equipment, bulky waste and biodegradable waste) was made only on the basis of the concentration of spatial phenomena. The concentration graphs, generated after calculations had been made, indicate the concentration of a particular fraction of selected waste.

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## Abstract

Proper municipal waste management is one of the most important civilization challenges of a mankind in the light of the rules of sustainable development. The circular economy of waste management determines the improvement of current situation on condition that extracting resources and energy and the amount of the emission of harmful substances are limited. The reverse logistics is an important element of the management - the body of the processes of waste flow management and information connected with the flows, starting from the places where the waste is created to their place of destination in order to recycle various values (through reparation, recycling or conversion).

The research set two aims. The first aim was to evaluate the condition of the management of municipal waste collected as mixed and municipal waste collected as separate (the mixed waste and the selected waste) with the use of modified rates created on the basis of Alankiewicz (2009). The second aim was to compare the selective collection of given fractions in particular voivodship cities in Poland (16 cities) with the use of spatial concentration coefficient and location quotient in order to assess the condition of municipal waste management. The fractions are as follows: paper and cardboard, glass, plastic, waste electrical and electronic equipment, bulky waste and biodegradable waste. The justification of the choice of the fractions is their highest share in the mass of selected waste and the fact that they are the most common waste selectively collected. The research was conducted in all voivodship cities in Poland.

The gained results prove a vast diversification of the effectiveness of municipal waste selective collection in voivodship cities in Poland. For all rates the results were similar. Moreover, coincident results were gained in the research conducted with the use of spatial concentration and the location quotients, used for the first time in this kind of analyses. This proved that the methodology can be used in such research. The concentration graphs for research phenomena and the values of location quotients (LQ) can be valuable and useful tools not only in evaluating the condition of waste management. They can be valuable tips for working out the recommendations for particular spatial units. Low location quotient (LQ), in comparison with other units, signifies that there are abnormalities and that there is a necessity to intensify activities in a given range. The rate can be treated as a kind of a ranking for the whole considered system without the necessity of making further calculations. Its changes in the following years would inform about changes in the level of the phenomenon and about taking or not taking corrective actions (recommendations). The tool can be used in constant monitoring and planning waste management in a global perspective for related units and considered processes. In the case of the six research fractions of a selective collection of waste, the evaluation was made only with the use of the theory of spatial phenomena concentration. The reliable results were gained. The results were coincident with general trends set with the use of modified rates determined by Alankiewicz. That is the base for the evaluation of the effectiveness and recommendations for selective collection of waste in voivodship cities in Poland.

**Keywords:**
municipal waste, selected waste, mixed waste, spatial phenomena concentration

## Analiza i ocena stanu gospodarki odpadami komunalnymi w miastach wojewódzkich Polski

### Streszczenie

Prawidłowa gospodarka odpadami komunalnymi jest jednym z ważniejszych wyzwań cywilizacyjnych w świetle zasad zrównoważonego rozwoju. Gospodarka odpadami o obiegu zamkniętym jest warunkiem poprawy obecnej sytuacji. Jest to warunek ograniczenia zużycia zasobów i energii oraz ilości powstających odpadów i emisji szkodliwych substancji. Ważnym elementem tej gospodarki jest logistyka zwrotna – ogół procesów zarządzania przepływami powstałych odpadów i informacji związanych z tymi przepływami, poczynając od miejsc, w których one powstają do miejsc ich przeznaczenia w celu odzyskania z nich różnych wartości (poprzez naprawę, recykling lub przetworzenie).

W pracy założono dwa cele. Pierwszym celem była ocena stanu gospodarki zmieszanymi odpadami zebranymi i odpadami zebranymi selektywnie (w dalszej części opracowania nazywanymi: zmieszanymi i selektywnymi) za pomocą zmodyfikowanych wskaźników opracowanych na podstawie Alankiewicza (2009). Drugim celem było porównanie selektywnej zbiórki wybranych frakcji odpadów w poszczególnych miastach wojewódzkich Polski (16 miast) za pomocą współczynnika koncentracji przestrzennej oraz ilorazu lokalizacji. Frakcjami tymi są: papier i tektura, szkło, tworzywa sztuczne, zużyte urządzenia elektryczne i elektroniczne, odpady wielkogabarytowe, odpady biodegradowalne. Uzasadnieniem wyboru frakcji jest ich najwyższy udział w masie odpadów selektywnych, a także fakt, że są najpowszechniejszymi odpadami zbieranymi selektywnie. Badania przeprowadzono dla wszystkich miast wojewódzkich w Polsce.

Uzyskane wyniki potwierdzają znaczne zróżnicowanie efektywności selektywnej zbiórki odpadów komunalnych w miastach wojewódzkich w Polsce. Uzyskano podobne wyniki dla wszystkich zastosowanych wskaźników. Ponadto zbieżne wyniki uzyskane za pomocą koncentracji przestrzennej i ilorazów lokalizacji, zastosowane po raz pierwszy do tego typu analiz, potwierdzają możliwość stosowania tej metodyki. Wykresy koncentracji dla badanych zjawisk i wartości ilorazów lokalizacji (IL) mogą być bardzo przydatnymi i cennymi narzędziami, nie tylko do oceny stanu gospodarki odpadami. Mogą być cenną wskazówką do opracowania zaleceń dla poszczególnych jednostek przestrzennych. Niski iloraz lokalizacji (IL), w porównaniu z innymi jednostkami, świadczy o nieprawidłowościach i konieczności zintensyfikowania działań w danym zakresie.

Wskaźnik ten może być traktowany jako swoisty ranking dla całego rozpatrywanego systemu bez konieczności dokonywania dalszych kalkulacji. Jego zmiany w kolejnych latach informują o zmianach poziomu zjawiska oraz o podejmowaniu lub nie podejmowaniu działań naprawczych (zaleceń). Narzędzie to może służyć do stałego monitorowania i planowania gospodarki odpadami w ujęciu globalnym, dla powiązanych ze sobą jednostek i rozpatrywanych procesów. W przypadku sześciu badanych frakcji selektywnej zbiórki odpadów, oceny dokonano jedynie przy zastosowaniu teorii koncentracji zjawisk przestrzennych. Otrzymano wiarygodne wyniki zbieżne z ogólnymi trendami wyznaczonymi przy pomocy zmodyfikowanych wskaźników Alankiewicza. Jest to podstawą do oceny skuteczności i zaleceń w zakresie selektywnego zbierania odpadów w miastach wojewódzkich Polski.

**Słowa kluczowe:**
odpady komunalne, odpady zbierane selektywnie, odpady zmieszane,
koncentracja zjawisk przestrzennych