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MUNICIPAL WASTE MANAGEMENT IN POLAND IN THE LIGHT OF MULTI-DIMENSIONAL COMPARATIVE ANALYSIS

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Abstract. The paper is an attempt to show the present condition of municipal waste economy in spatial aspect with respect to voivodships. The data collected for chosen diagnostic variables have been transformed by zero unitarization method and in this way made comparable. The transformed variables have been used as a basis for the construction of the synthetic variable describing each voivodship. Then, the ranking arrangement has been obtained, which shows the situation concerning spatial differentiation of the condition of municipal waste economy in Poland. The final part of the paper presents the division of voivodships into three groups – of high, average and low level of municipal waste economy.

Key words: municipal waste, voivodship, diagnostic variable, synthetic variable, ranking

INTRODUCTION

Waste management, in particular municipal waste management, is an important element of bioeconomy. Bioeconomy assumes that any projects making it possible to preserve the cleanliness of the natural environment in combination with the use of secondary raw materials and at the same time bringing economic profits fit into its sphere of operation. "Proper management in this sphere may have a great impact on the course of economic-social processes, results achieved in management and the level of the society's welfare" [Adamowicz 2014].

The creation of municipal waste involves man's non-industrial activity [Rosik-Dulewska 2000]. This waste comes in solid and liquid forms. The Polish Act on waste dated December 14, 2012 (Journal of Laws from 2013, item 21) specifies the notion of municipal waste as waste generated in households, excluding end of use vehicles, as well as waste not containing hazardous waste, coming from other producers of waste which, due

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to its nature or composition, is similar to waste coming from households. This is paper, cardboard, glass waste, textiles, biodegradable waste (related to food) as well as residues from the cleaning of households.

Rational municipal waste management aims at the popularization of waste selection at the source of their creation, namely in households, and thus at enabling the execution of recycling. The analysis of waste management was conducted on the basis of data from all voivodships in Poland in 2014 (the last available statistical information). Because the phenomenon of municipal waste management is a complex phenomenon, namely a phenomenon which may be described taking into account more than one feature [Kukuła 2000], a set of features describing this phenomenon was selected. Therefore, the multi-facet description of the complex phenomenon, namely municipal waste management in particular Polish voivodships, is possible with the use of a method related to the multi-dimensional comparative analysis.

The purpose of the article is to present the condition of municipal waste management in Polish voivodships in 2014 and to create their ranking due to the examined phenomenon. The further purpose is to distinguish three groups of voivodships:

- Group 1 – voivodships characterized by a high level of municipal waste management;
- Group 2 – voivodships with a medium level of the examined phenomenon;
- Group 3 – voivodships with a low level of the examined phenomenon.

LINEAR METHOD OF ORDERING

The key issue in creating the ranking of objects (voivodships) in terms of the level of the complex phenomenon is the correct selection of diagnostic variables describing the examined phenomenon. Two criteria were followed when selecting the variables: substantive as well as statistical. The substantive criterion includes premises determining the importance of the selected variable. The selection made on the basis of this criterion is more of a subjective nature, namely depends on the opinion of the conducted research. The second criterion is of an objective nature because it assumes the requirement of meeting a sufficient level of the variable's variability which, after meeting the requirement, may belong to the set of diagnostic variables.

It is assumed that a given phenomenon is described by a properly selected set of s diagnostic variables: $[X_1, X_2, \ldots, X_s]$. The values of these variables were recorded for r observed objects (here – voivodships): $[0_1, 0_2, ..., 0_r]$. Thus we have data contained in the $\boldsymbol{X}$ matrix:

$$\boldsymbol{X} = [\boldsymbol{x_{ij}}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1s} \\ x_{21} & x_{22} & \cdots & x_{2S} \\ \cdots & \cdots & \cdots & \cdots \\ x_{r1} & x_{r2} & \cdots & x_{rS} \end{bmatrix} \tag{1}$$

where: $I = 1, \ldots, r$ as well as $j = 1, \ldots, s$.

A simple measure specified as the quotient of extreme values $I(X_j)$ is suggested for testing the degree of variability of diagnostic variables:

$$I(X_j) = \frac{\max_i x_{ij}}{\min_i x_{ij}}, \ \min_i x_{ij} > 0 \tag{2}$$

The level of variability of a given variable is considered sufficient when it meets the following inequality:

$$I(X_j) > 2 \ (j = 1, \ldots, s) \tag{3}$$

This means that the value of a given diagnostic variable in the best object (when the variable is a stimulus) needs to exceed its value in the worst object more than two times. The variables describing the shaping of complex phenomena have a diverse nature. They include variables the increased value of which should be associated with the increased level of the described phenomenon. They also include such variables the increased value of which should be assessed in negative terms. The former are stimuli, while the latter are inhibitors. This distinction was introduced for the first time by Zdzisław Hellwig in his pioneering work in 1968 [Hellwig 1968]. There is also a third type of variables known as neutral variables [Borys 1978]. This study contains only stimuli and inhibitors, neutral variables were omitted. Therefore, a Reader wishing to become familiar with the nature of a variable being a neutral variable is recommended the work by [Borys 1968].

The variables describing a complex phenomenon are usually expressed in various units and are characterized by a diverse order of magnitude. All this makes it impossible to directly use these variables to assess the complex phenomenon in a comprehensive manner. Normalization methods are used to standardize the order of magnitude of these variables as well as to deprive them of their denomination. A decision was taken to use the zero unitarization method among many methods of normalizing diagnostic features. This method is characterized by numerous features that may be classified as advantages [Kukuła 2000]. The point is to transform the original diagnostic variables into normalized variables ($X \rightarrow Z$). The advantages of the zero unitarization method include:

1. Linear quantification of diagnostic variables (stimulus, inhibitor and neutral variable).
2. The possibility to normalize features with negative, zero and positive values.
3. Each diagnostic variable after normalization accepts the value from a zero-one half-open interval. This is related to the standardization of various orders of magnitude of the original variables.
4. The existence of simple formulas converting the values of original variables into normalized values both for the stimulus, inhibitor and the neutral variable.

Normalized variables are used to create a synthetic variable, describing each object (voivodship) in a comprehensive manner. The arrangement of objects with respect to a synthetic variable (Q_i) makes it possible to create their ranking [Kukuła 2014].

Due to a different impact of the stimuli and the inhibitors on a complex phenomenon, their transformation process proceeds individually. Normalization for the stimuli (*S*) is performed with the application of the formula:

$$z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{4}$$

where: z_{ij} – normalized value of the *j* variable in the *i* object;
x_{ij} – value of the *j* diagnostic variable in the *i* object.

The following formula is used when normalizing the inhibitors (*D*):

$$\frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{5}$$

The values of normalized diagnostic variables obtained according to the formulas (4) and (5) meet the relations:

$$z_{ij} \in [0, 1] \tag{6}$$

$$z_{ij} = 0 < \Leftrightarrow I > x_{ij} = \min_i x_{ij}, X_j \in S \tag{7}$$

as well as $z_{ij} = 1 \Leftrightarrow x_{ij} = \max_i x_{ij}, X_{ij} \in S$ (8)

This means that the object with the worst result with regard to the *j* variable is valued with the zero number. In turn, an object showing the best result with regard to the *j* feature is valued the highest, thus its value is one. The situation for inhibitors is different:

$$z_{ij} = 0 \Leftrightarrow < I > x_{ij} = \max_i x_{ij}, X_j \in D \tag{9}$$

as well as $z_{ij} = 1 \Leftrightarrow x_{ij} = \min_i x_{ij}, X_j \in D$ (10)

The construction of a synthetic variable (Q_i) consists in averaging all normalized features for the *i* object:

$$Q_i = \frac{1}{s}\sum_{j=1}^{s} z_{ij} \quad (I = 1, \ldots, r) \tag{11}$$

The synthetic (aggregated) variable created in this manner also meets the relation:

$$Q_i \in [0, 1] \tag{12}$$

Due to the frequent lack of information making it possible to determine the weights for particular diagnostic variables, equal weights for all features are assumed, e.g. one. This is also the case in this research.

The synthetic variable (Q_i) characterizing the *i* object may have the value one only when the *i* object proves the best as compared to other objects within the scope of all the diagnostic variables:

$$\max_i z_{i1} = \max_i z_{i2} = ... = \max_i z_{is} = 1 \tag{13}$$

The synthetic variable for a given object (*i*) may assume the value zero only when this object proves the worst due to all diagnostic variables and the following equation takes place:

$$\min_i z_{i1} = \min_i z_{i2} = ... = \min_i z_{is} = 0 \tag{14}$$

With the ranking of r objects (here – 16 voivodships), it is reasonable to divide them into three groups: I – with a high, II – with a medium and III – with a low level of the examined complex phenomenon. The following algorithm should be used for this purpose [Kukuła 2015]:

1. Calculate the range of the synthetic variable:

   $R(Q_i) = \max_i Q_i - \min_i Q_i$

2. Determine the *k* value of the division parameter:

   $k = \frac{1}{3} R(Q_i)$

3. Determine the intervals of values of the synthetic variable for particular groups:
   - Group 1 (high level of the phenomenon): $Q_i \in (\max_i Q_i - k, \max_i Q_i]$;
   - Group 2 (medium level of the phenomenon): $Q_i \in (\max_i Q_i - 2k, \max_i Q_i - k]$;
   - Group 3 (low level of the phenomenon): $Q_i \in [\max_i Q_i - 3k, \max_i Q_i - 2k]$.

The selection of the diagnostic features was performed on the basis of two criteria: substantive as well as the sufficient level of the variables' variability. The diagnostic features were relativized. Due to the fact that the creation of municipal waste takes place in households, this event should be associated with people. Therefore, the number of people in the examined period (2014) is the point of reference for the first seven features. The only exception is the X_8 variable the intended use of which is the use in agricultural production, and thus the area of arable land in particular Polish voivodships is the point of reference in this case. This is the list of the selected variables:

X_1 – non-segregated municipal waste in kg per 1 inhabitant;
X_2 – segregated municipal waste (paper and cardboard) in kg per 1,000 inhabitants;

X_3 – segregated municipal waste (glass) in kg per 1,000 inhabitants;
X_4 – segregated municipal waste (plastic) in kg per 1,000 inhabitants;
X_5 – segregated municipal waste (metal) in kg per 10,000 inhabitants;
X_6 – segregated municipal waste (textiles) in kg per 10,000 inhabitants;
X_7 – segregated municipal waste (biodegradable) in kg per 1,000 inhabitants;
X_8 – area of arable land per 1 t of sludge from municipal waste treatment plant, used in crop cultivation.

Due to their nature, the variables X_1 as well as X_8 belong to the set of inhibitors (D), while others (X_2, …, X_7) should be classified into the set of stimuli (S).

RESEARCH RESULTS

EU regulations regarding municipal waste management impose the necessity to comply with certain principles on EU member states. One of them applies to the obligation of selective waste collection which makes it possible to conduct the recycling of waste from paper, cardboard, glass. metal as well as plastic and clothes. This issue is the subject of research. The selected eight variables should be associated with the preparation of waste for recycling. All this remains in strict association with EU recommendations regarding municipal waste management. Waste management is a complex phenomenon the assessment of which requires a multi-facet approach – therefore, eight diagnostic variables were selected. These variables vary among one another in the order of magnitude as well as the units in which they are expressed. The normalization procedure should be conducted in order to make them comparable. The normalization process of the selected diagnostic features was conducted with the use of original data contained in Table 1. Formulas (4) and (5) were used in the normalization. The normalization results are presented in Table 2. The normalized diagnostic variables make it possible to determine the values of synthetic variables [formula (11)] which constitute the aggregated assessment of the complex phenomenon, namely the condition of municipal waste management in particular Polish voivodships. The determined values of the synthetic variable contained in Table 3 are the basis for creating the ranking of Polish voivodships due to the assessment of the condition of the municipal waste management implemented in these units. The ranking of Polish voivodships based on the following criterion, namely the condition of municipal waste management in 2014, is presented in Table 4. The voivodships were also divided into three groups:

- Group 1 contains objects with a high level of municipal waste management;
- Group 2 contains objects with a medium level of municipal waste management;
- Group 3 contains objects with a low level of municipal waste management.

Group 1, characterized by a high level of municipal waste management, includes six Polish voivodships: Lubuskie, Śląskie, Podkarpackie, Opolskie, Wielkopolskie and Zachodniopomorskie. Group 2, with a medium level of municipal waste management, includes seven Polish voivodships: Kujawsko-pomorskie, Łódzkie, Pomorskie, Lubelskie, Małopolskie, Dolnośląskie and Mazowieckie. Group 3, with a low level of municipal waste management, includes only three Polish voivodships: Warmińsko-mazurskie, Świętokrzyskie and Podlaskie.

Table 1. Values of diagnostic variables describing the condition of municipal waste economy in Poland in 2014 (X_1, …, X_8)

Voivodship	$X_1 \in D$	$X_2 \in S$	$X_3 \in S$	$X_4 \in S$	$X_5 \in S$	$X_6 \in S$	$X_7 \in S$	$X_8 \in D$
Dolnośląskie	269	8.25	11.00	10.32	3.44	0	17.54	169.3
Kujawsko-pomorskie	212	3.83	11.01	6.22	4.78	9.57	21.53	158.0
Lubelskie	142	3.72	7.92	4.66	9.31	9.31	8.38	231.2
Lubuskie	252	15.68	12.74	10.78	9.80	9.80	17.64	166.2
Łódzkie	189	3.59	10.78	6.39	3.99	7.99	21.16	164.7
Małopolskie	178	4.16	12.17	8.31	5.94	8.91	9.80	419.4
Mazowieckie	216	7.12	7.50	5.06	9.37	7.50	12.00	265.0
Opolskie	205	5.00	13.99	8.99	0	9.99	22.98	83.4
Podkarpackie	145	4.23	10.80	6.58	9.39	14.09	5.17	153.6
Podlaskie	198	3.36	6.71	3.36	0	8.39	5.87	269.8
Pomorskie	245	5.65	10.86	8.69	0	8.69	19.98	119.5
Śląskie	258	7.41	12.87	12.87	8.72	10.90	26.60	179.5
Świętokrzyskie	117	6.33	6.33	11.87	0	7.92	1.58	313.2
Warmińsko-mazurskie	216	4.85	7.62	6.93	6.93	6.93	11.77	272.2
Wielkopolskie	246	8.93	14.40	10.65	2.88	8.64	13.82	126.5
Zachodniopomorskie	263	7.58	12.24	8.16	5.83	11.66	15.16	99.9
$I(X_j)$								
×	2.299	4.667	2.275	3.830	3.403*	2.033*	16.835	5.029

*As the minimum of the variables X_5 and X_6 equals zero, the computations to obtain $I(X_5)$ and $I(X_6)$ are carried out on the basis of the subsequent least values of these variables.

Source: Own calculations on the basis of the information contained in *Environment Protection 2015*, GUS Warszawa, 63–64, 199.

Table 2. Values of normalized diagnostic variables (Z_1, …, Z_8)

Voivodship	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8
Dolnośląskie	0	0.397	0.579	0.732	0.351	0	0.638	0.744
Kujawsko-pomorskie	0.375	0.038	0.580	0.301	0.488	0.679	0.797	0.778
Lubelskie	0.836	0.029	0.197	0.137	0.950	0.661	0.272	0.560
Lubuskie	0.112	1.000	0.794	0.780	1.000	0.696	0.642	0.754
Łódzkie	0.526	0.019	0.551	0.319	0.407	0.567	0.783	0.758
Małopolskie	0.599	0.065	0.724	0.521	0.606	0.632	0.329	0
Mazowieckie	0.349	0.305	0.145	0.179	0.956	0.532	0.416	0.460
Opolskie	0.421	0.133	0.949	0.592	0	0.709	0.855	1.000
Podkarpackie	0.816	0.071	0.554	0.339	0.958	1.000	0.143	0.791
Podlaskie	0.467	0	0.047	0	0	0.595	0.171	0.445
Pomorskie	0.158	0.186	0.561	0.560	0	0.617	0.735	0.893
Śląskie	0.072	0.329	0.810	1.000	0.890	0.774	1.000	0.714
Świętokrzyskie	1.000	0.241	0	0.895	0	0.562	0	0.316
Warmińsko-mazurskie	0.349	0.121	0.160	0.275	0.707	0.492	0.407	0.438
Wielkopolskie	0.151	0.452	1.000	0.767	0.294	0.613	0.489	0.872
Zachodniopomorskie	0.039	0.343	0.732	0.505	0.595	0.828	0.543	0.951

Source: Own calculations on the basis of the information contained in Table 1.

Table 3. Values of the synthetic variable for voivodships

Voivodship	$\sum_{j=1}^{8} z_{ij}$	$Q_i = \frac{1}{8}\sum_{j=1}^{8} z_{ij}$
Dolnośląskie	3.441	0.4301
Kujawsko-pomorskie	4.036	0.5045
Lubelskie	3.642	0.4553
Lubuskie	5.778	0.7223
Łódzkie	3.930	0.4913
Małopolskie	3.476	0.4345
Mazowieckie	3.342	0.4178
Opolskie	4.659	0.5824
Podkarpackie	4.672	0.5840
Podlaskie	1.725	0.2156
Pomorskie	3.710	0.4638
Śląskie	5.589	0.6986
Świętokrzyskie	3.014	0.3768
Warmińsko-mazurskie	3.049	0.3811
Wielkopolskie	4.638	0.5798
Zachodniopomorskie	4.536	0.5670

Source: Own elaboration on the basis of the information contained in Table 2.

Table 4. Ranking arrangement of voivodships with respect to the level of municipal waste economy in Poland in 2014

Rank position	Object (voivodship)	Synthetic variable (Q_i)	Part of a group
1	Lubuskie	0.7223	
2	Śląskie	0.6986	Group I
3	Podkarpackie	0.5840	(six voivodships)
4	Opolskie	0.5824	$\overline{Q}_{II} = 0.4568$
5	Wielkopolskie	0.5798	
6	Zachodniopomorskie	0.5670	
7	Kujawsko-pomorskie	0.5045	
8	Łódzkie	0.4913	
9	Pomorskie	0.4638	Group II
10	Lubelskie	0.4553	(7 voivodships)
11	Małopolskie	0.4345	$\overline{Q}_{II} = 0.4568$
12	Dolnośląskie	0.4301	
13	Mazowieckie	0.4178	
14	Warmińsko-mazurskie	0.3811	Group III
15	Świętokrzyskie	0.3768	(3 voivodships)
16	Podlaskie	0.2156	$\overline{Q}_{III} = 0.3245$
	$I(Q) = \frac{\max_i Q_i}{\min_i Q_i}$	3.3502	

Source: Own elaboration on the basis of the information contained in Table 3.

When analysing the results contained in Table 4 (the ranking), three questions may be formulated:

- Is the quality of municipal waste management in Poland spatially diverse?
- How may the degree of these differences be assessed?
- What is the spatial layout of the Polish voivodships due to the condition of the examined phenomenon?

When responding to the first question, it should be stated that the quality of municipal waste management in particular Polish voivodships is varied. Are the differences significant? In order to answer the second question, we should use the quotient of extreme values of the synthetic variable – $I(Q_i)$. According to this measure, the Polish voivodship occupying the first position in the ranking – the Lubuskie voivodship, represents a result more than three times higher than the last Polish voivodship in the ranking – the Podlaskie voivodship. When comparing various rankings, it should be stated that the degree of diversity is moderate [$I(Q_i) \cong 3.35$]. This is the result of the work of all Polish voivodships to pursue the EU directives regarding municipal waste management.

With reference to the spatial analysis of the examined phenomenon, it is necessary to view Table 1. It is easy to note that voivodships from the first and the second group dominate in terms of quantity (13 voivodships in total). These are voivodships with a high and a medium level of waste management which form on the map of Poland a wide strip from the north to the south. The weakest voivodships in terms of the level of municipal waste management occupy the north-eastern region (the Podlaskie and the Warmińsko-mazurskie voivodships) as well as the central region (the Świętokrzyskie voivodship).

The next EU regulation applies to the slow reduction in municipal waste on landfills. Data in Table 5 shows what is the place of Poland among selected EU states in terms of

Table 5. Percentage of municipal waste in the total waste produced in chosen countries of the European Union

Countries	% of municipal waste
UE-28	30.2
Germany	0.2
Belgium	0.9
Netherlands	1.5
Denmark	1.6
Austria	4.0
Estonia	13.7
France	28.3
Great Britain	34.2
Italy	36.9
Portugal	50.5
Poland	52.9
Czech Republic	56.4
Spain	60.1
Lithuania	62.4
Hangary	64.6
Bulgaria	69.0
Slovakia	70.1
Romania	78.3
Latvia	83.0

Source: Own elaboration on the basis of the information contained in *Environment Protection 2015*, GUS, Warszawa, 489.

the percentage of municipal waste collected on landfills as compared to the overall mass of generated municipal waste. The increase in this percentage should be assessed in negative terms taking into account the welfare of the environment.

When analysing the data contained in Table 5, it may be easily seen that leading EU states in terms of economic development are significantly below 50% of the value of this percentage. Some of them, such as: Germany (0.2%), Belgium (0.9%), the Netherlands (1.5%), Denmark (1.6%) as well as Austria (4%) store only minute quantity of waste because the vast majority of waste is directly subjected to conversion, neutralization or energy recovery processes. This is favourable for the environment and connected with certain benefits. Poland has approached the barrier of 50% but has not exceeded it yet (52.9% in 2013). It may be comforting to know that Poland has the lowest percentage of municipal waste storage from among former states participants of Comecon and today's EU member states. For comparison, data from the same period was presented for: the Czech Republic (56.4%), Hungary (64.6%), Bulgaria (69%), Slovakia (70.1%) and Romania (78.3%).

CONCLUSIONS

In order to implement EU recommendations regarding municipal waste management, the spatial distribution of the degree of the development of this phenomenon in Poland should be viewed. The ranking of objects (here – voivodships) is the up-to-date picture of the condition of municipal waste management in particular Polish voivodships. Several detailed comments and remarks being the effect of the completed research may be found below.

1. The quality of municipal waste management shows certain spatial diversities.
2. The degree of the diversification of Polish voivodships with respect to the discussed complex phenomenon seems to be relatively low which indicates the value of the measure being the quotient of extreme values of the synthetic variable [$I(Q_i) \cong 3.35$].
3. Objects with a high and a medium level of municipal waste management (13) dominate in the set of 16 examined voivodships. Only three Polish voivodships belong to the weakest group. Such spatial distribution of the assessments of the quality level of waste management should be assessed as positive.
4. The first group, with the best assessments, is composed of 6 Polish voivodships forming a strip running from the north-west through the central part to the south of Poland.
5. The comparison of Poland with selected EU states in terms of the percentage of stored municipal waste as compared to its overall mass is not very favourable for Poland. Poland still stores relatively too much waste (see Table 5). The only positive aspect in these comparisons is the statement that Poland still has the lowest percentage of stored waste from among former states of the Comecon – today's EU member states, although the barrier of 50% is still being exceeded.
6. A multi-dimensional statistical analysis plays an important role – not to be underestimated, in the research on regional complex phenomena, including research related to waste management.
7. The following actions should be undertaken to improve the municipal waste management in Poland:
   - popularize and tighten the system of selective waste collection;

- reduce the mass of stored waste (reduce the percentage of stored municipal waste significantly below 50%);
- increase investment expenses related to the conversion of municipal waste (incineration plants, mechanical-biological waste conversion, composting plants, fermentation devices);
- eliminate illegal waste dumps.

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GOSPODARKA ODPADAMI KOMUNALNYMI W POLSCE W ŚWIETLE WIELOWYMIAROWEJ ANALIZY PORÓWNAWCZEJ

Streszczenie. Autor stawia przed sobą zadanie ukazania aktualnego stanu gospodarki odpadami komunalnymi w ujęciu przestrzennym województw. Zebrane dane o zmiennych diagnostycznych sprowadzono do stanu porównywalności za pomocą ich normowania metodą unitaryzacji zerowanej. Unormowane zmienne stanowią podstawę budowy zmiennej syntetycznej opisującej każde województwo. Przy użyciu tych zmiennych zbudowano ranking województw przedstawiający sytuację w zakresie przestrzennych zróżnicowań stanu gospodarki komunalnej w Polsce. W końcowej fazie badań podzielono województwa na trzy grupy o: wysokim, przeciętnym i niskim poziomie gospodarowania odpadami komunalnymi.

Słowa kluczowe: odpady komunalne, województwo, zmienna diagnostyczna, zmienna syntetyczna, ranking

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