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Original Paper

Quantitative comparison of the amount of produced waste in selected Slovak municipalities: a case study

Dana Országhová[1*], Alexandra Ferenczi Vaňová[1], Renáta Krajčírová[1], Pavel Fľak[2]

[1] Slovak University of Agriculture in Nitra, Faculty of Economics and Management, Nitra, Slovak Republic
[2] Slovak Academy of Agriculture Sciences, Lužianky, Slovak Republic

ABSTRACT

The environment gives a clear challenge to the inhabitants of the planet that it is necessary to reduce the amount of generated waste. Disposal, separation and processing of waste, or landfilling of produced waste is connected to processes that require additional financial resources. The main goal of the contribution was to analyze the differences in the amount of total produced waste, municipal solid waste, and separated waste in selected Slovak municipalities. The data were obtained by the questionnaire method from 33 municipalities in the Nitra region, which provided data on the amount and type of waste in the period 2015 - 2017. Selected statistical methods, paired t-test, analysis of variance and Bonferroni test were used to analyze the obtained data. The results of the analysis show that there are significant differences in the volume of waste generated by municipalities together between individual years. Similarly, statistically significant differences were demonstrated between the amount of produced waste in relation to the size of the municipality according to the number of inhabitants. In the evaluated period, medium-sized municipalities showed the lowest amount of produced waste per inhabitant.

KEYWORDS: waste management, descriptive statistics, paired T-Test, analysis of variance, Bonferroni test

JEL CLASSIFICATION: C12, Q 53

INTRODUCTION

Preserving the environment without waste pollution requires significant adjustments in waste management, as well as changes in the consumer way of life. The processing and disposal of produced waste is one of the current challenges of every economy, which aims to minimize the amount of waste and obtain raw materials for recycling and reuse. Different ways of dealing with communal waste and its processing bring new possibilities for reducing the

[*] Corresponding author: doc. RNDr. Dana Országhová, CSc., Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, e-mail: dana.orszaghova@uniag.sk

impact of waste on the water, soil, Earth's atmosphere, and economic benefits of recycling for society [4].

Municipal waste management in the Slovak Republic is governed by the Act No. 79/2015 Coll., Waste Act [1]. The processing and disposal of produced waste also requires financial costs, therefore residents of municipalities and companies pay local taxes and a local fee for municipal waste and small construction waste, which are established according to Act No. 582/2004 Coll. [3] and Act No. 335/2022 Coll. [2]. The goal of waste management is that waste does not have a negative impact on the health of residents or the environment. This goal is associated with defined priorities: prevent waste, reuse waste, recycle, recover waste and dispose of waste [10].

Municipal solid waste is mixed waste and separately collected waste from households, which is sorted according to the determined components of municipal waste. Small construction waste is waste from normal maintenance work, for which the local fee for municipal waste and small construction waste is paid [6]. Landfills are considered the last resort in the hierarchy of waste management, which significantly affect the climate change of the entire planet because they release methane. The disposal of biological waste from households is often the result of food waste, which contributes to the formation of harmful gases in the waste. Improvements in municipal waste management between 1995 and 2008 led to significantly lower greenhouse gas emissions [11]. In the study [7], it is proven that appeals to "reduce waste" had the highest effectiveness in changing the attitude of consumers towards food waste.

Effective disposal of municipal solid waste contributes to environmental protection. The material and energy recovery of municipal solid waste is the subject of many researches that address the complex cycle of recycling, recovery and reuse of this type of waste within the circular economy [5], [9].

The production of mixed municipal waste in Slovakia in 2019 reached almost 2.37 million tons. According to the new law on waste, valid from January 2021, Slovakia must achieve 90% sorting of municipal waste and 65% recycling by 2035 [8]. The analyst of WOOD & Company Eva Sádovská informed that in 2021 inhabitants of Slovakia created 2.7 million tons of municipal solid waste, which is an average of 497 kg of garbage per inhabitant. Approximately 41% of waste from households ends up in landfills, which makes Slovakia one of the landfill superpowers in Europe [12].

Charges for municipal waste have a growing tendency, as more and more types of waste are sorted, which require ever higher financial costs for processing and disposal. Current high energy prices are a prerequisite for increasing fees for municipal waste.

MATERIAL AND METHODS

The main research source was data from a questionnaire that was conducted in selected municipalities of the Nitra region in the period 2018-2019 (total n = 33). The municipalities provided data on the amount and types of waste in the period 2015-2017. The questionnaire contained following questions, which were used as sorting criteria: Name of the municipality, Number of inhabitants, and Area of the territory of the municipality.

In the paper, there are analyzed data obtained to these selected questions:

1. Enter the amount of total produced waste (in tons) according to years 2017, 2016, 2015:
a) Of which, the amount of municipal solid waste (in tons),
b) Of which, the amount according to individual types of waste: Paper, Glass, Plastics, Iron waste, Electrical waste, Construction waste, Bulk waste, Hazardous waste, Other.
2. Enter the amount of total separated waste (in tons) according to years 2017, 2016, 2015:
a) Of this amount of municipal solid waste (in t),
b) Of which, the amount by individual type: Paper, Glass, Plastics, Iron waste, Electrical waste, Construction waste, Bulk waste, Hazardous waste, Other.

The research objectives were as follows:
- analyzing and determining the significance of differences in the amount of individual types of waste in municipalities within 2015-2017,
- comparison of the amount of produced waste in relation to the size of the municipality.

In analyses, the villages were divided into 3 groups according to the number of inhabitants:
- Small villages (n = 9): up to 1,000 inhabitants,
- Middle villages (n = 11): from 1,001 to 2,000 inhabitants,
- Big villages (n = 13): over 2,001 inhabitants.

The analysis of municipal waste data was done using methods of descriptive statistics, paired t-test, one-way analysis of variance and Bonferroni test of multiple comparisons.

RESULTS

The results of the analysis are presented according to the type of waste together for all municipalities, by individual years 2015, 2016, 2017 and by the size of the municipality. Following abbreviations were used for the types of waste: TPW – Total produced waste, MSW – Municipal solid waste, TSW – Total separated waste. For the respective year, the waste abbreviation is supplemented with numbers, e.g.: TPW15 – Total produced waste in year 2015.

In the first part, there are presented statistical characteristics for individual types of waste for all municipalities together: total produced waste, solid municipal waste and total separated waste. The data shows that between 2015 and 2016 there was an increase in produced and separated waste. Subsequently, between 2016 and 2017, there was a decrease in produced and separated waste. There was a decrease in the volume of municipal solid waste between 2015 and 2016, followed by an increase in 2017 (Table 1).

Table 1 Basic statistical characteristics of TPW, MSW and TSW

Year	$\bar{x}$	SD	$SE_{\bar{x}}$	C.V.	Asymmetry, A	Excess, E
Total produced waste, n = 33						
2015	508.85	311.65	54.252	61.246	0.992	0.822
2016	602.36	415.27	72.289	68.940	2.278	6.873
2017	582.54	305.03	53.099	52.362	0.884	0.789
Municipal solid waste, n = 33						
2015	319.89	244.35	42.536	76.387	1.024	-0.084
2016	298.95	260.12	45.281	87.012	2.622	8.358
2017	307.81	230.05	40.046	74.737	1.465	1.574
Total separated waste, n = 33						

2015	388.20	255.46	44.470	65.807	1.175	1.658
2016	500.18	400.31	69.685	80.034	2.873	10.635
2017	476.52	273.83	47.667	57.464	1.306	2.805

$A_{0.05}(30) = 0.916$, $A_{0.01}(30) = 1.236$, $E_{0.05}(30) = 1.832$, $E_{0.01}(30) = 2.472$

In Table 1, the values for asymmetry are positive for all types of waste, i.e. the data distribution is skewed to the left, statistically significant to highly significant (in the sample there are more small values and few larger ones in the set). In the case of excess, the values are also positive (except for one case: MSW 2015), so it is a leptokurtic distribution (most of the values in the sample are close to the average).

Using a paired t-test, the significance of the differences was proved between individual type of waste and between year. Based on the results of the paired t-test, statistically significant or highly significant differences were found in four analyzed cases: between TPW15 - TPW16, TPW15 - TPW17, TSW15 - TSW16, and TSW15 - TSW17 (Table 2).

Table 2 Paired t-tests of waste type between years

Waste type and year	*t*	Waste type and year	*t*	Waste type and year	*t*
TPW15 - TPW16	-2,32*	MSW15 - MSW16	0.81	TSW15 - TSW16	-2.98*
TPW15 - TPW17	4.76**	MSW15 - MSW17	-0.78	TSW15 - TSW17	6.47**
TPW16 - TPW17	0.62	MSW16 - MSW17	0.52	TSW16 - TSW17	-0.78

$t_{0.05}(32) = 2.037$, $t_{0.01}(32) = 2.738$

In the following section there are results of descriptive statistics for individual types of waste according to the defined size of the village: small, middle and big villages.

In small villages, an increase in total produced waste occurred every year. There was a decrease in the volume of total municipal waste in 2016 and then an increase in 2017. Total separated waste showed an increasing trend in individual years. Asymmetry for produced and separated waste is negative, so it is a right-skewed distribution (a higher number of larger values than smaller ones in the sample). Asymmetry for municipal waste is positive, the distribution is left-skewed (a higher number of smaller values and few larger ones). Excess is negative for all three types of waste, so the data distribution is flatter (platykurtic). In the sample there are many low and high values, and they are not close to the average (Table 3).

Table 3 Basic statistical characteristics of TPW, MSW and TSW for small villages

Year	$\bar{x}$	SD	$SE_{\bar{x}}$	C.V.	Asymmetry, A	Excess, E
Total produced waste, n = 9						
2015	229.05	113.21	37.737	49.427	-0.270	-1.539
2016	264.67	104.90	34.968	39.636	-0.867	-0.617
2017	283.43	119.16	39.718	42.041	-0.706	-0.894
Municipal solid waste, n = 9						
2015	113.35	62.730	20.910	55.340	0.297	-0.542
2016	106.91	53.777	17.926	50.303	0.103	-0.997
2017	113.66	62.380	20.793	54.881	0.042	-1.266
Total separated waste, n = 9						
2015	216.38	129.05	43.016	59.639	-0.3109	-1.576
2016	253.55	107.62	35.873	42.445	-0.5258	-1.112
2017	270.99	122.28	40.761	45.125	-0.3804	-1.296

$A_{0.05}(10) = 1.786$, $A_{0.01}(10) = 2.599$, $E_{0.05}(10) = 3.572$, $E_{0.01}(10) = 5.198$

Data on the amount of total produced waste per inhabitant enable comparison of developments within individual years. A graphic representation of the amount of TPW per inhabitant in small villages by year is in the Figure 1. It is a growing trend in the amount of total produced waste in the examined period in small villages.

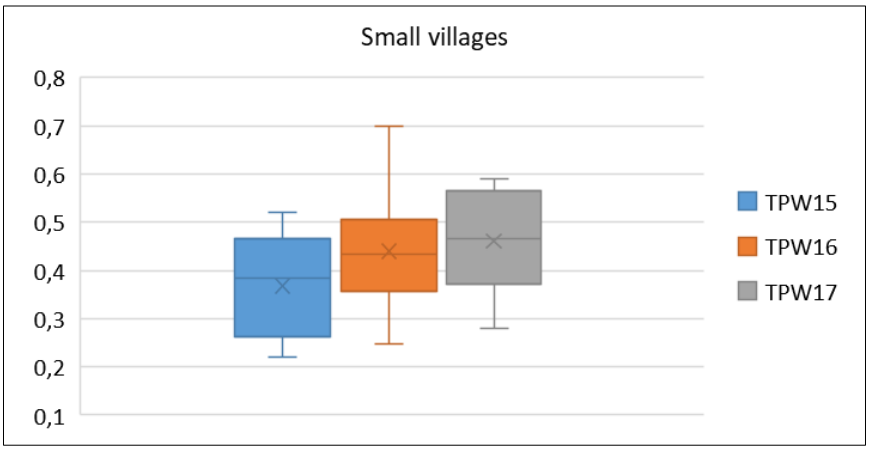

Figure 1 Total produced waste (TPW) per capita in small villages (2015 – 2016)

A growing trend in all types of waste was evaluated in medium-sized municipalities (Table 4). Figure 2 shows that the development of the amount of total produced waste (TPW) per inhabitant was slightly stabilized in 2017 after an increase in 2016.

Table 4 Basic statistical characteristics of TPW, MSW and TSW for middle villages

Year	$\overline{x}$	SD	$SE_{\overline{x}}$	C.V.	Asymmetry, A	Excess, E
Total produced waste, n = 11						
2015	361.94	82.032	24.734	22.665	-0.424	-1.188
2016	459.50	83.136	25.066	18.093	-0.082	-0.958
2017	467.82	74.356	22.419	15.894	0.177	-1.171
Municipal solid waste, n = 11						
2015	202.97	69.100	20.834	34.045	0.073	-0.906
2016	216.11	42.498	12.814	19.665	0.724	-0.591
2017	224.36	48.683	14.679	21.699	0.929	-0.369
Total separated waste, n = 11						
2015	346.58	114.10	34.403	32.923	-1.161	0.508
2016	432.38	118.86	35.838	27.490	-1.509	2.229
2017	450.72	111.61	33.651	24.762	-1.168	1.181

$A_{0.05}(10) = 1.786$, $A_{0.01}(10) = 2.599$, $E_{0.05}(10) = 3.572$, $E_{0.01}(10) = 5.198$

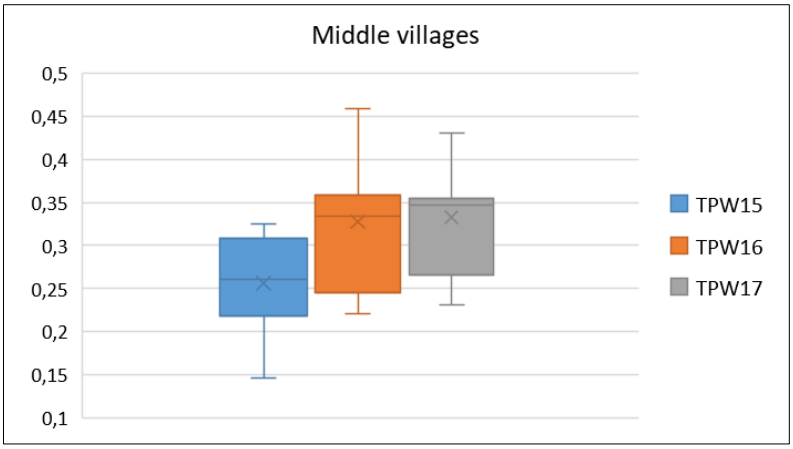

Figure 2 Total produced waste (TPW) per capita in middle villages (2015 – 2016)

In big municipalities the development of the amount of waste for each type has a different character. Asymmetry for all types of waste is positive, i.e. the distribution is left-skewed (the sample contains a larger number of smaller values and few larger ones) (Table 5).

Table 5 Basic statistical characteristics of TPW, MSW and TSW for big villages

Year	$\bar{x}$	SD	$SE_{\bar{x}}$	C.V.	Asymmetry, A	Excess, E
Total produced waste, n = 13						
2015	826.88	238.30	66.091	28.819	1.482	1.309
2016	957.03	454.16	125.96	47.455	2.252	4.178
2017	886.70	233.79	64.843	26.367	1.449	0.919
Municipal solid waste, n = 13						
2015	561.81	211.41	58.633	37.629	0.275	-1.637
2016	501.99	313.67	86.997	62.486	2.004	3.544
2017	512.83	237.42	65.849	46.296	0.837	-0.819
Total separated waste, n = 13						
2015	542.37	320.31	88.838	59.058	0.404	-0.505
2016	728.29	549.21	152.32	75.412	1.802	3.416
2017	640.64	343.70	95.325	53.650	0.582	0.455

$A_{0.05}(15) = 1.366$, $A_{0.01}(15) = 1.905$, $E_{0.05}(15) = 2.733$, $E_{0.01}(15) = 3.810$

The development of the amount of total produced waste (TPW) per inhabitant for big villages is shown in Figure 3. In 2016, several outliers can be seen. The amount of TPW per inhabitant increased in 2016 and subsequently decreased in 2017.

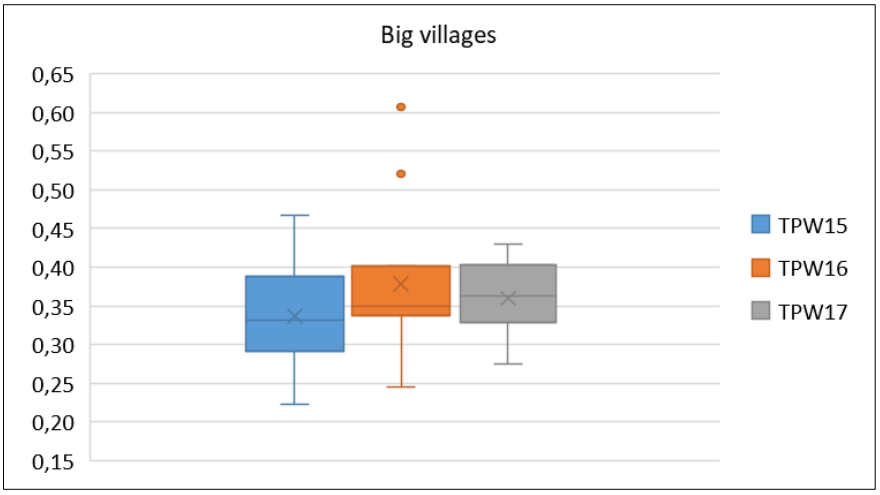

Figure 3 Total produced waste (TPW) per capita in big villages (2015 – 2016)

Following results were obtained by analyzing data on produced waste between municipalities in relation to the number of their inhabitants. Using the method of one-way analysis of variance for evaluated traits and via Bonferroni tests, we examined the significance of differences in the amount of waste within each year and the type of waste in relation to the size of the municipality. The results show that there are statistically significant differences between municipalities in the production of individual types of waste within a given year. The differences are significant at the chosen level of significance $\alpha = 0.01$. Statistically insignificant differences at the 0.01 level were also insignificant at the 0.05 level (Table 6).

Table 6 One-way analyses of variance for evaluated traits via Bonferroni multiple comparison test between sizes of villages

	MS/F	**Group**	**Error**	**Means and Bonferroni test**		
		$f_G = 2$	$f_e = 30$	1 - small	2 - middle	3 - big
Total produced waste						
TPW15	**MS**	1128436	28375	229.05	361.94	826.88
	F	39.77**		3 : (1, 2)**		
TPW16	**MS**	1443028	87743	264.67	459.50	957.03
	F	16.45**		3 : (1, 2)**		
TPW17	**MS**	1076326	27493	283.43	467.82	886.70
	F	39.15**		3 : (1, 2)**		
Municipal solid waste						
MSW15	**MS**	647562	20518	113.35	202.97	561.81
	F	31.56**		3 : (1, 2)**		
MSW16	**MS**	471660	40729	106.91	216.12	501.99
	F	11.58**		3 : (1, 2)**		
MSW17	**MS**	481132	24375	113.66	224.36	512.83
	F	19.74**		3 : (1, 2)**		
Total separated waste						
TSW15	**MS**	296863	49820	216.38	346.58	542.37
	F	5.96**		3 : 1**		
TSW16	**MS**	637216	128452	253.55	432.38	728.29
	F	4.96**		3 : 1**		
TSW17	**MS**	368827	55392	270.99	450.72	640.64
	F	6.66**		3 : 1**		

$F_{0.05}(2, 30) = 3.316$, $F_{0.01}(2, 30) = 5.390$

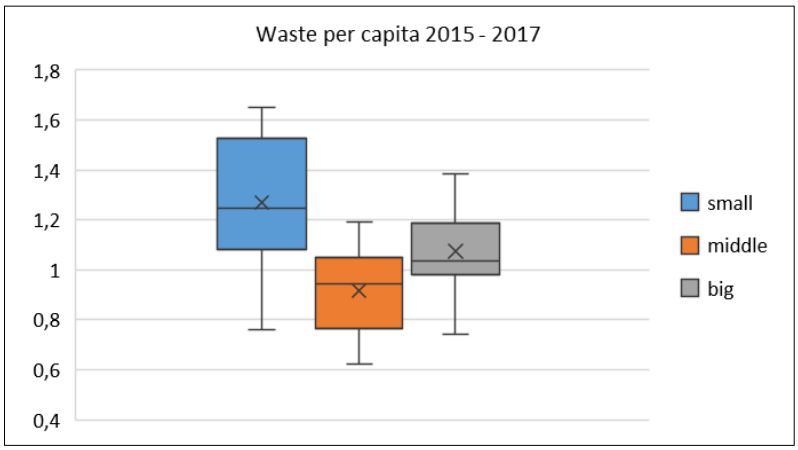

Figure 4 TPW per inhabitant in 3 years according to the size of the municipality (in tons)

To compare the amount of total produced waste between municipalities, we used data on the amount of TPW per capita in each year and determine the sum for three years 2015-2017 (in tons). It is evident from the graph (Figure 4) that individual groups of municipalities achieved different results in waste production per inhabitant in 3 years. The best values were shown by medium-sized municipalities, which have the analyzed parameter in the range 0.62 - 1.19 (t). In the second place there are big municipalities, which have the amount of produced waste per inhabitant in the sum of 3 years in the range of 0.74 - 1.38 (t). The worst results achieved small municipalities with analyzed parameter in the range of 0.76 - 1.65 (t).

To compare all municipalities with each other it was again applied mentioned indicator: the amount of total produced waste per inhabitant together for 3 years. The names of municipalities were anonymized and denoted as follows: small villages from S1 to S9, middle villages from M1 to M11, and big villages from B1 to B13. Then municipalities were ranked according to the amount of TPW per inhabitant for three observed years together (Figure 5). Overall, in the research sample the TPW range is from 0.62 t (medium village M10) to 1.65 t (small village S3). In the first part of the graph, there are medium-sized municipalities (they produce less waste per inhabitant). Small municipalities are in the second part of the list, even to the bottom of it (they produce more waste per inhabitant).

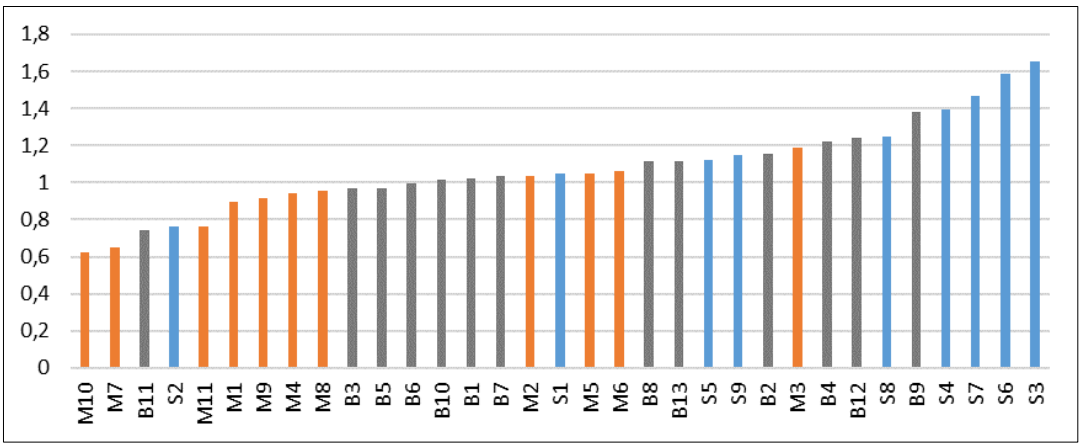

Figure 5 Villages ranked by TPW per capita (total over 3 years)

The percentage comparison within all municipalities shows:
- Middle-sized municipalities (63% of them) are in the first third of the list with lower waste production,
- Big municipalities (54% of them) are in the first half of the list with lower waste production,
- Small municipalities (78% of them) are in the second half of the list (higher waste production).

CONCLUSION

The generated waste in municipalities is associated with many processes: sorting, processing, recycling, evaluation, disposal, or storage. Residents of municipalities pay fees for waste disposal, which are determined based on the type of waste and the method of its processing or disposal.

In this contribution municipalities' data on produced waste were analyzed according to the type of waste in relation to the particular years 2015-2017. The results of the paired t-test confirmed statistically significant differences in the amount of waste according to the type of waste and years in the four analyzed cases.

Data on produced waste in the period 2015-2017 were analyzed in relation to the size of the village, which was defined in accordance with the number of inhabitants: small, middle and big village. Using the Bonferroni multiple comparison test, statistically significant differences were confirmed in waste production between individual municipalities in relation to their size. The best results in waste production were shown by medium-sized municipalities, which had the lowest waste production per inhabitant. The worst results were achieved by small municipalities, which have the highest waste production per inhabitant. Medium-sized municipalities could communicate their experience about wastes with other municipalities.

To preserve the quality of life of people, flora and fauna, it is necessary to change people's approach to the environment so that the generated waste does not damage it. The logical solution is not to create waste, or to create it in a minimal amount. It is important to separate consistently the generated waste into components and then evaluate them. Separating as much waste as possible is also a motivation for residents to reduce local waste fees.

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