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SPATIAL AND NON-SPATIAL ANALYSIS OF SOCIO-DEMOGRAPHIC ASPECTS INFLUENCING MUNICIPAL SOLID WASTE GENERATION IN THE CZECH REPUBLIC

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ABSTRACT
Municipal solid waste generation has been analyzed in broad range of studies but most of the studies neglect the spatial aspect of analyzed datasets. This paper's aim is to explore spatial dependency in relations between municipal solid waste generation and socio-demographic aspects. The results obtained using geographically weighted regression are compared with results of widely used ordinary least square regression. Even though both methods found the same significant socio-demographic aspects, we were able to explain much higher share of intermunicipal variability using the geographically weighted regression because this method is able to consider changing strength and even direction of relation in different spatial units. Geographically weighted regression can therefore better mirror the local situation and could be successfully utilized to plan waste management activities at local scale.

1. INTRODUCTION

Based on a broad range of studies (e.g. Aphale et al., 2015; or Khan et al., 2016) and using various perspectives and methods, after decades of scientific discussions municipal solid waste (MSW) generation and its variability remains in the spotlight. Regarding these discussions, significant variability in MSW generation can be explained by wide spectrum of factors. Selection of these factors is influenced by local conditions, data availability, units used in the analysis as well as by consideration of a researcher. In general, factors explaining MSW generation are divided into two broad categories - individual and situational characteristics (Schultz et al., 1995). Beigl (2004), Hage and Soderholm (2008), Sterner and Bartelings (1999), or Khan et al. (2016) analysed the impact of individual characteristics such as socioeconomic and demographic factors, Bach et al. (2004), Gellynck et al. (2011), Kipperberg (2007), or Starr and Nicolson (2015) focused on waste management organization and charging policy as situational characteristics. Another approach is represented by Sjöström and Östblom (2010), or Arbulú et al. (2015), who studied the relation between solid waste generation and economic growth.

However, most of these studies neglect the possible spatially dependency in MSW generation. The impact of particular characteristics may differ at various geographical locations on the country, region or even municipality level. For example, education may be positively correlated with MSW generation in one country or municipality and negatively in another one. In the second case, the spatial non-stationarity exists in the data. The number of studies dealing with spatial variation in MSW data has been rather limited so far (e.g. Ismaila et al., 2015 or Keser et al., 2012).

The aim of this paper is to assess if global statistical methods give relevant picture about waste management practice and if they are suitable for understanding of waste generation patterns. In our research, we focus on the three socio-demographic factors household size, sex ratio and tertiary education and how they are able to explain MSW generation. To assess the influence of socio-demographic factors on MSW generation we used two different approaches – ordinary least square regression (OLS) and geographically weighted regression (GWR). While OLS gives one statement about relation between analysed variables for the whole area and can therefore represent a global statistical method, GWR as a representative of local statistical methods reflects relations between variables varying in space.

2. MATERIAL AND METHOD

2.1 Data collection

We used MSW generation per capita and year in kilo-

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grams as dependent variable for non-spatial as well as spatial data analysis. MSW includes mixed municipal waste and separately collected fractions of MSW belonging to the group 20 of the List of Waste. The data for dependent variable were obtained from the state database on waste management "Waste Management Information System" (ISOH). To the system, every waste producer who produces more than 100 kg of hazardous or 100 tons of non-hazardous waste yearly must report his production (SMOCR, 2011). Regarding MSW generation, municipalities are seen as waste producers and they are bound to report into the system if they surpass the aforementioned limit. In 2011 about 4% of all Czech municipalities did not report its waste production because of their low MSW generation. However, all these municipalities are rather small and only 1% of state population lives there.

Based on previous study by Rybová and Slavík (2016), we selected three socio-demographic characteristics as independent variables - average household size (HHS; number of persons per household), sex ratio (IMA; computed as a number of men per 100 women) and proportion of people with tertiary education (TER; computed from the population aged 15 and more years, in %). In Czech conditions, these three variables are significantly correlated with MSW generation. Because all three indicators on municipal level could not be obtained from routine yearly statistics collected by Czech Statistical Office or any other institution, we used the values from the Population and Housing Census. In the Czech Republic, the last Census was organized by Czech Statistical Office in 2011 (Czech Statistical Office, 2013). That is the reason why we could analyse the relationship between dependent and independent variables for this year only.

The initial sample consisted of all Czech municipalities (6,251 in 2011), but for the analysis it was reduced to approximately 5,500 municipalities. First, we removed all municipalities reporting the absence of (or a zero value for) municipal waste (resulting in a new total of 5,820) from the state database on waste management ISOH. Then we sorted the sample based on municipal waste per capita level and removed extreme values from the top and bottom of the list (trimming top and bottom municipalities from the list, which differed by more than three standard deviations from the average). Lastly, we removed 13 cities, mostly regional capitals, because the data from ISOH and Census were available for different administrative units that complicated the comparability and they are also too heterogenous to be sufficiently described by a single value of each variable.

The resulting sample consists of 5,445 municipalities, which still represents 87% of all Czech municipalities. Table 1 depicts the basic information about the sample and characteristics of used variables. The average MSW generation in 2011 was 276 kg per capita.

From Table 1 it is obvious that even after removal of outliers there is considerable variability in MSW generation among Czech municipalities. The local distribution is presented in Figure 1. Even from this picture we can assume that there is some kind of spatial non-stationarity. Spatial clusters of municipalities with higher MSW production are located especially in Bohemian (western) part of the Czech Republic. In the eastern part of the country the variability as well as the average MSW production is lower.

2.2 Non-spatial data analysis

In the non-spatial part of the analysis, we applied OLS to get global regression coefficient estimates. The spatial dependency was omitted in this case. The estimated model has a form:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \dots + \beta_k X_{ki} + \varepsilon_i \quad (1)$$

where Y_i are observations of dependent variable, X_{1i}, X_{2i}, ..., X_{ki} are observations of independent variables, β_0, β_1, ..., β_k are the underlying regression coefficients and ε_i are random errors.

Stability of error variability was tested via Glejser test and its normality via Kolmogorov-Smirnov test. Linearity was examined using a scatterplot between the standardized predicted values and the standardized residuals (Lebersorger and Beigl, 2011). The computations were made using IBM SPSS Statistics 20.

2.3 Spatial data analysis

To test the spatial stationarity of the data, we used the Koenker's studentized Breusch-Pagan statistic. Significant result of this test indicates statistically significant hetero-

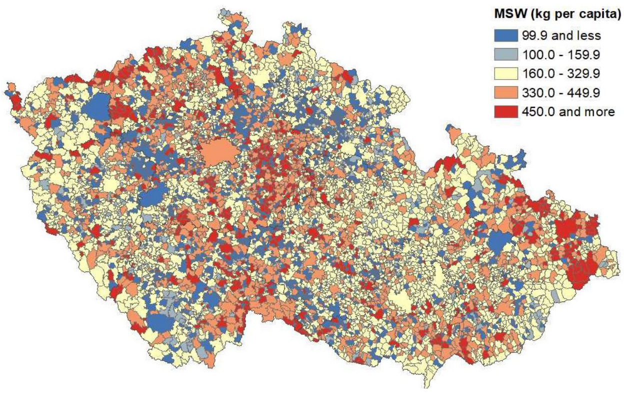

FIGURE 1: MSW generation in Czech municipalities, 2011.

TABLE 1: Basic statistical characteristics of MSW generation and selected socio-demographic indicators, Czech municipalities, 2011.

Variable	Minimum	Lower quartile	Mean	Median	Upper quartile	Maximum	Std. deviation
MSW (kg/cap.)	10.0	197.3	275.8	273.3	351.6	770.6	131.4
HHS (person)	1.3	2.4	2.6	2.6	2.7	3.7	0.2
TER (%)	0	6.0	8.8	8.0	11.0	35.0	4.4
IMA (no)	48.4	95.2	101.7	100.0	105.8	369.8	11.2

scedasticity and/or nonstationarity. Based on the results of Koenker's statistics, we proceeded to computation of GWR. If we assume that the relation between dependent and independent variables varies spatially, we can use GWR to explore local relation by moving spatial kernel through study area. Kernel functions are used to calculate weights that represent spatial dependence between observations. So, unlike OLS, GWR gives us so called local coefficients β that are specific to each areal unit (Keser, 2012). For each model calibration location, i = 1..., n, the GWR model is

$$Y_i = \beta_{i0} + \sum_{k=1}^{p-1} \beta_{ik} X_{ik} + \varepsilon_i \quad (2)$$

where Y_i is the dependent variable value at location i, X_{ik} is the value of the kth covariate at location i, β_{i0} is the intercept, β_{ik} is the regression coefficient for the kth covariate, p is the number of regression terms, and ε_i is the random error at location i (Wheeler and Paez, 2010).

The GWR model was computed using ArcGIS.

3. RESULTS AND DISCUSSION

3.1 Non-spatial data analysis

The results of OLS are statistically significant but the model explains only 2.9% of the variation of MSW between municipalities (Table 2), which is relatively low compared to other studies. The results indicate that the household size has the highest relative impact, followed by sex ratio and the share of tertiary educated people. Household size and sex ratio have negative impact on MSW generation, while education has positive impact. That means that bigger households produce in average per capita less MSW than smaller households and men produce in average less MSW than women. In the case of education, in municipalities with higher share of tertiary educated people is higher MSW generation.

3.2 Spatial data analysis

In second step, in order to analyse spatial stability of the influence of the three selected socio-demographic variables we computed the Koenker's studentized Breusch-Pagan statistic. The results of this test were statistically significant, which indicates heteroscedasticity and/or nonstationarity. Therefore, the application of GWR is in this case justified.

The GWR model explains 73% of intermunicipal variation in MSW generation. The local R^2 distribution for analysed municipalities is visualized in Figure 2, the values range from almost zero to 85%. We detected significant spatial non-stationarity regarding influence of independent variables on MSW, the relation to MSW changes spatially, but we can also detect regions with similar patterns of MSW generation. It is interesting that the local R^2 does not correlate with population size of municipalities, demographic variables therefore do not explain situation in smaller cities better than in bigger citiesand vice versa.

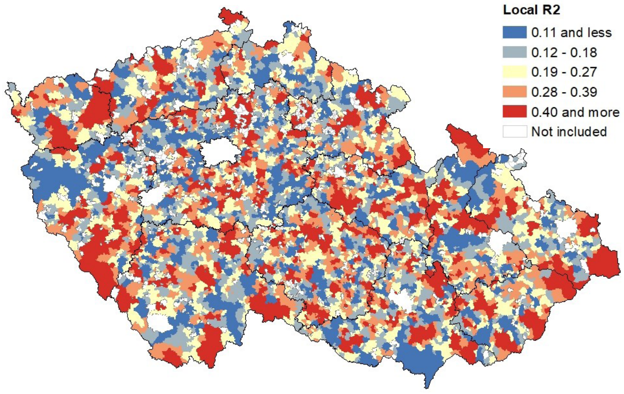

FIGURE 2: The local R^2 distribution for GWR model, CR, 2011.

The local regression coefficients show variation over the study area and moreover, all three variables incur negative as well as positive coefficients in different municipalities as shown in Figure 3. This result indicates that effect of independent variables does not only vary, but can have even opposite influence in different municipalities.

Regarding household size, it is generally assumed that there is a negative relation (e.g. Beigl et al., 2004; Beigl et al.; 2008). That means that the average generation of MSW per person decreases depending on the growing number of household members. Some products are still bought by households regardless of their size. We confirmed this relation on the global level using OLS, but on the local level there are also municipalities with opposite relation. On the local level, 60% of analysed municipalities show negative coefficient estimates, on the contrary, in 27% of municipalities the coefficient is positive.

Situation regarding sex ratio and its influence on MSW generation is similar. On the global level, there is also negative effect. This supports the conclusion of Talalaj and Walery (2015) that men produce less MSW than women. On the local level, we found the same direction of relation in 51% of municipalities, in 35% of units the relation is op-

TABLE 2: OLS model for MSW generation, CR, 2011 (Source: Authors).

	Coefficients	Standardized Coefficients	t Value	Significance
Constant	541.01		23.89	0.000
HHS	-92.21	-0.16	-11.56	0.000
TER	1.15	0.04	2.86	0.000
IMA	-0.38	-0.07	-5.21	0.000
Number of observations				5445
R^2				0.029
Adjusted R^2				0.029

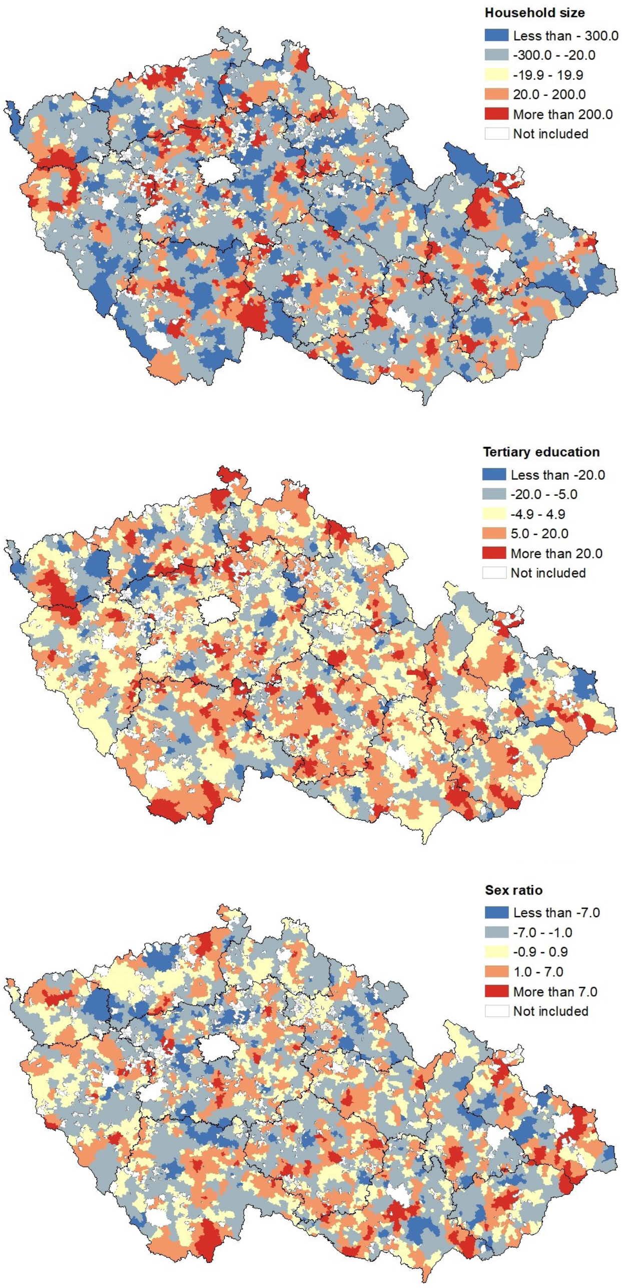

FIGURE 3: GWR coefficient estimates, CR, 2011.

posite, and the rest shows no impact of sex ratio on MSW generation.

As in the global model, share of population with tertiary education is the only predominantly positively correlated independent variable. The coefficient estimates are positive in 50% of municipalities and negative in 37% of units. Education as independent variable was also used in the study of Keser et al. (2012). On the global level this variable was not statistically significant, but on the local level the authors discovered in some provinces positive relation. It is interesting that they did not find any provinces with negative relation as is the case in our paper.

Because the spatial analysis is not a widely used method in explaining MSW generation so far and based on the used data it is hard to explain the differences in particular factors. There are probably other variables (such as environmental values, situational characteristics incl. socio-demographics, and psychological factors incl. social norms, Barr, 2007) that are influencing the behaviour of the inhabitants in the regions. An important role could play also the location of the municipality regarding metropolises or periphery regions (including the so called inner periphery that is in the Czech conditions influencing many social aspect, Musil and Müller, 2008). Further studies should consider more spatial information such as population density, characteristics of housing or average income of the households.

4. CONCLUSIONS

The results of GWR show that to understand MSW generation on municipal level, we cannot use only standard global statistical methods (such as OLS). As concluded, spatial effects matter. Based on the GWR method, the socio-demographic characteristics have significant influence on MSW generation, but this influence varies spatially and has even opposite signs in different municipalities. This situation can diminish the detected variability explained by OLS and can lead to neglecting of socio-demographic aspect in decision making. Our conclusion is important for waste management planning as well, because it supports application of the subsidiarity principle in the practice. Even though objectives of the waste management policy are given at national level, many decisions are made at the local level (Lazarevic et al., 2012)

Further important benefit of the GWR method is a fact that it allows to define areas with a similar character of the examined relation, which may serve as the basis for follow-up analyses carried out directly in the chosen regions.

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