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GIS-BASED ANALYSIS OF THE PRODUCTION OF BIOMASS AND ITS USE FOR COMPOSTING IN THE CZECH REPUBLIC

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Abstract: At present, various information systems including a sub-group of geographical information systems (GIS) are increasingly used in waste management (similarly as in other fields). Data are gradually standardized so that all levels of administration can use the unified data and individual systems are compatible. In this paper, GIS is used to analyze selected types of biomass suitable for composting in the Czech Republic. Based on statistical data from the Czech Statistical Office and data from other information systems, the issue is solved by GIS ArcView 9.1. Outputs are maps of intake areas of composting plants based on conditions pre-defined by user and the analysis of compostable biomass.

Key words*: information system, geographic information system, data, biomass, composting, analysis*

INTRODUCTION

Composting is currently one of the most frequently used processes to make high-quality humus outside the soil environment. It is an aerobic process of decomposition at which the original organic substances in composted raw materials and waste are to be degraded as rapidly and economically as possible and subsequently transformed into stable humus substances. These stable humus substances constitute a basis of soil fertility.

The issue of biologically degradable wastes as materials for composting plants has recently come to the fore of the interest of government authorities, primarily thanks to the Council Directive 1999/31/EC on the landfill of waste, which imposes an obligation

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on member countries to reduce the amount of stockpiled biodegradable waste and stipulates percentages by which the amount of disposed biologically degradable waste should be reduced in the given time intervals [1].

Agriculture and forestry are sectors in which the composting processes belong and similarly as other scientific branches, these sectors are currently using various information systems and technologies to assist in the solution of specific problems. This holds true also for the geographical information systems, which constitute one of the sub-groups of information systems [2].

GIS-supported works and projects arising in this area today in the Czech Republic are dealing with problems relating both to larger territorial units (Czech Republic, townships) or focus on a detailed study at the level of smaller regions and micro-regions.

As a concrete example of the first group of works we can mention the "Spatial analysis of climate change impacts on the growth and development of winter wheat" presenting an analysis of the effect of changing climatic conditions on individual characteristics of winter wheat growth in geographical conditions of the Czech Republic [3]. An example of the second group of works can be the "System of basic geobiocoenological data for landscape management" focused on the issue of using modern geoinformation methods in proposing a system of basic geobiocoenological data for landscape management and verification of their creation on selected localities of the Vysočina Region [4].

The work characterized in this paper belongs in the first group of the above-mentioned classification. It deals with the issue of biologically degradable wastes – concretely with the analysis of the potential of some biomass types suitable for composting in the Czech Republic, made by using geoinformation technologies.

This work applies GIS in the field, in which the geoinformation technologies have not been used so far for the purposes of a national-scale project. At the moment, there are only several information systems, which however provide only basic data about the location of the composting plant and its parameters (locality, amount of converted material). The data are not further processed and the systems do not use the data for any kind of analyses and conclusions since the data are not processed by some of geoinformation programmes (that would make it possible to work with the data and create concrete outputs) but only by the form of web applications.

This project eliminates the deficiencies of the hitherto developed web applications showing on concrete examples possibilities for the application of geoinformation systems in the field of biomass conversion in the Czech Republic.

MATERIAL AND METHODS

Generally, any (not only geographical) information system needs data in electronic form, which it can further work with. In this paper, the data is the information about the composting plants (geographical, attributive – concrete selected data like the amount of processed material, the amount of compost produced per year, machinery etc.), data on territorial units (townships, districts) and other [5].

Data gained from multiple sources were processed and used to create concrete outputs. The main source of information on individual composting plants was the company Agrointeg, s.r.o. residing in Brno. Other data were acquired from the database of the Zemědělská a ekologická regionální agentura, o.s. - ZERA (Agricultural and Ecological Regional Agency) residing in Náměšť nad Oslavou. These data were added information from web applications of the T.G.M. Research Institute of Water Management and some valuable data were supplied directly by operators of some composting plants.

In the following step, the data were processed so that they would be compatible with the used GIS software. This geoinformation system is ArcView GIS 9.1 by the American company ESRI, which makes it possible to create the required outputs from the project.

ARCDATA Praha s.r.o. provided the terrain layout for this work (ArcČR 500, Version 2.0a). The terrain layout comprised a database of files – so-called shape-files, forming in the terrain layout individual layers of objects and raster files (e.g. rasters representing the terrain model, colour relief etc.).

The layers (shape-files) can be as follows:

- dot patterns (municipality location, composting plant location etc.)
- linear patterns (communications, river pattern, geographical net)
- surface - polygon patterns (districts, regions, forest areas etc.)

Another needed step was to process the statistical data on the structure of land properties in the Czech Republic and to transform them into maps. Thus, it was later possible to establish yields of concrete biomass types suitable for composting in individual areas.

As to the structure of lands (distribution and individual types of agricultural and non-agricultural soil), the country's territory is relatively heterogeneous. Data on the division of individual agricultural and non-agricultural lands chosen as suitable for our work were data of the Czech Statistical Office (ČSÚ).

The ČSÚ data about the structure of lands were processed at several levels. The basic level is *The structure of lands in the Czech Republic by individual administrative regions (townships) - Czech Republic has 13 regions + capital city of Prague,* which is however too general, which would subsequently lead to high distortion of data and results of our work. This is why it is considered more adequate to stem from the statistical data for smaller territorial units.

A very detailed level of ČSÚ agrarian data is represented by *Selected statistical data for the municipality*. However, compared with the above basic level, this format is too detailed and inapt for multiple reasons of which one is the size of the territory. Cadastral areas of individual municipalities are often too small in respect of the size of area from which the given composting plant receives materials for the compost pile.

An adequate level for the processing of these data and further work with the project is *The structure of lands in the Czech Republic by individual districts – Czech republic has 78 districts*, which does away with the main disadvantages of the above-mentioned basic level. Sizes of areas at the level of districts as well as their number appear very adequate in respect of the studied issue. Districts in the Czech Republic are sized several hundreds of square kilometres and correspond well with the concerned areas of individual composting establishments (mostly from tens to hundreds of square kilometres). Therefore, these statistical data of ČSÚ were chosen for our analysis.

RESULTS AND DISCUSSION

Based on the chosen size of geographical units – districts, it was possible to establish and classify the shares of the respective soil categories in these territories. A map layer was plotted through the transformation of ČSÚ data, illustrating the percentage shares of agricultural lands in the Czech Republic. These were in the following step classified into arable land, gardens, orchards and permanent grasslands. For the non-agricultural land, a map layer was plotted based on the transformed data, illustrating the shares of forest stands in the total area of individual districts (Fig. 1).

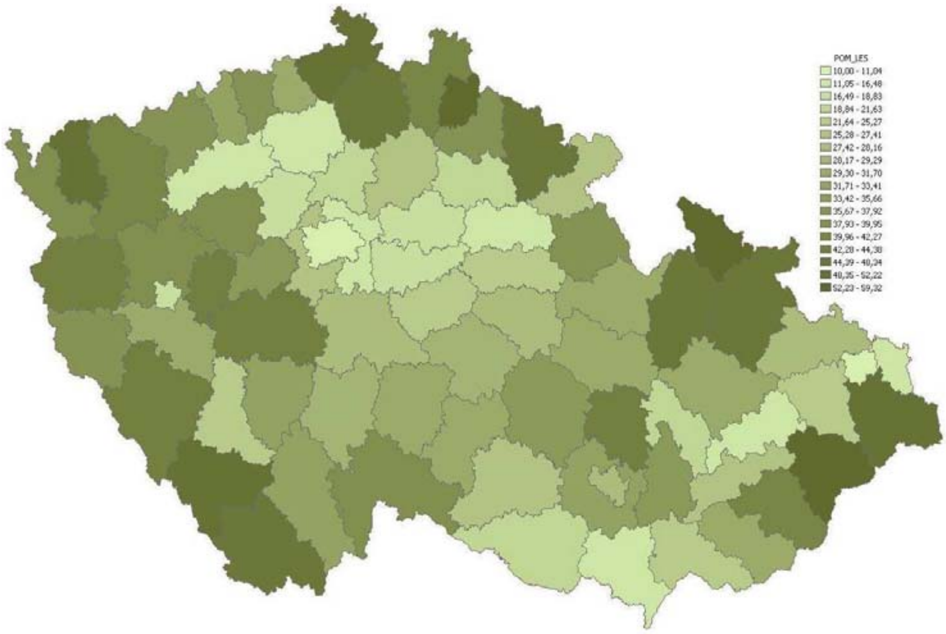

Figure 1. Percentage of forests in the individual districts of the Czech Republic

After having had established the percentage proportions of individual soil categories in terms of grown agricultural crops, we had to specify concrete raw materials (types of waste biomass) on them that would be suitable for composting and establish their yields (production).

Based on the values of average production in selected types of biologically degradable waste [6], we constructed a table of the average production of the respective materials for the composting plants (Tab. 1). The table contains the name of the material, soil category and average yield.

The table below includes another compostable material – biologically degradable waste (BDW). Values of the average production of biologically degradable waste differ in dependence on the type of the built-up area (village/town); however, its average amount is 60 kg per capita and year in the Czech Republic. Based on this value, we created one of the map layers – production of biologically degradable waste for composting plants.

Table 1. Production of selected materials for the composting plants

Material	Soil category	Unit	Yield	Average
Straw	arable land	$kg{\cdot}m^{-2}$	0.6 - 0.8	0.70
Grass from the maintenance of gardens and parks	gardens	$kg{\cdot}m^{-2}$	0.2 - 0.4	0.30
Vegetable waste	gardens	$kg{\cdot}m^{-2}$	0.2 - 0.4	0.30
Waste wood from fruit plantations	orchards	$kg{\cdot}m^{-2}$	0.2 - 0.3	0.25
Grass from the maintenance of permanent grass stands	permanent grasslands	$kg{\cdot}m^{-2}$	0.3 - 0.6	0.45
BDW per capita villages / towns	-	$kg{\cdot}year^{-1}$	30-60 / 60-80	60.00

Thanks to the fact that the shares of individual raw materials are known as well as their average yields, it was possible to determine the total yield of these materials per unit area according to the following relation:

$$V_c = \sum_{i=1}^{n} v_i \cdot p_i \qquad (1)$$

Where:
V_c [$kg{\cdot}m^{-2}$] - total yield,
v_i [$kg{\cdot}m^{-2}$] - yield of the ith raw material for the composting plant,
p_i [-] - area share of the ith raw material in the given territory (district).

Tab. 2 exemplifies the calculation by using the-above relation by means of attributive data on the area shares of the respective raw materials and their yields. Abbreviation *PGL* means permanent grasslands.

Table 2. Example of establishing the total yields of selected raw materials in the respective soil categories (based on Tab. 1 and ČSÚ data on the structure of lands in the Czech Republic by individual districts)

District	Area size (ha)	Structure (%)			Yields of ind. materials (10^{-2} $kg{\cdot}m^{-2}$)			Total yield (10^{-2} $kg{\cdot}m^{-2}$)
		Gardens	Orchards	PGL	Gardens	Orchards	PGL	
Ústí nad Labem	40444	2.350	0.517	29.554	0.71	0.13	13.30	14.13
Česká Lípa	113708	1.400	0.256	15.775	0.42	0.06	7.10	7.58
Jablonec n.Nis.	40229	3.350	0.119	20.798	1.01	0.03	9.36	10.39
Liberec	92467	3.060	0.340	20.790	0.92	0.08	9.36	10.36
Semily	69893	2.510	1.040	25.201	0.75	0.26	11.34	12.35
Hradec Králové	87556	2.750	0.889	7.753	0.83	0.22	3.49	4.54
Jičín	88664	2.440	2.083	11.711	0.73	0.52	5.27	6.52
Náchod	85155	2.790	1.210	18.012	0.84	0.30	8.11	9.24

The identical procedure was used to determine total yields of all materials suitable for composting (BDW, dendromass etc.) in the individual districts.

It was also necessary to specify the size of the area (intake area of the composting plant) on which precisely an amount of raw materials exists, for which the given composting plant is designed in order to reach the value of a so-called maximum achievable yearly amount of the processed matter (k_p) in the given composting plant.

In the geoinformation software ArcView 9.1, this task can be resolved by creating *mantle zones*, representing graphically the smallest possible areas in which the required amounts of raw materials for the composting plants occur.

The creation of these mantle zones stems from the below relation:

$$P_{OZ} = \frac{k_p}{\sum_{i=1}^{n} v_i . p_i} = \frac{k_p}{V_c} \tag{2}$$

Where:

P_{OZ} [m^2] - mantle zone (intake area) size,
k_p [kg] - maximum achievable yearly amount of the processed matter,
v_i [$kg{\cdot}m^{-2}$] - yield of the i^{th} raw material,
p_i [-] - area share of the i^{th} raw material in the given territory,
V_c [$kg{\cdot}m^{-2}$] - total yield.

The relation (2) was used to establish the area size of mantle zones for individual composting plants. Based on the obtained values and through their conversion into attributive tables, ArcView was able to plot the mantle zones (intake areas) of the composting plants using all above-mentioned biomass sources from the surroundings (Tab. 1).

The described situation assumes the use of material occurring within the intake area at 100%. In practical operation, however, the value cannot be achieved since actual material recovery in the given region is affected by many factors. Some places may be inaccessible for machines. Losses may occur during handling the material and its transport into the composting plant. Moreover, there may be some competitive relationships in the region and more operators of composting plants or even other establishments (e.g. biogas stations) may be interested in the given commodity.

To be able to tell the actual size of the mantle zone around a concrete composting plant, we need to add *yield coefficient* to the relation (2), expressing in percent the total amount of material gained from the given territory as compared with the amount theoretically possible:

$$P_{OZ} = (\frac{100}{v}) \frac{k_p}{\sum_{i=1}^{n} v_i . p_i} = (\frac{100}{v}) \frac{k_p}{V_c} \tag{3}$$

Where:

v [%] - yield coefficient, caused by the limited access to all raw materials in the given territory, by losses at transportation, handling etc. The value of this coefficient is specific for each individual composting plant and is established by the composting plant operator.

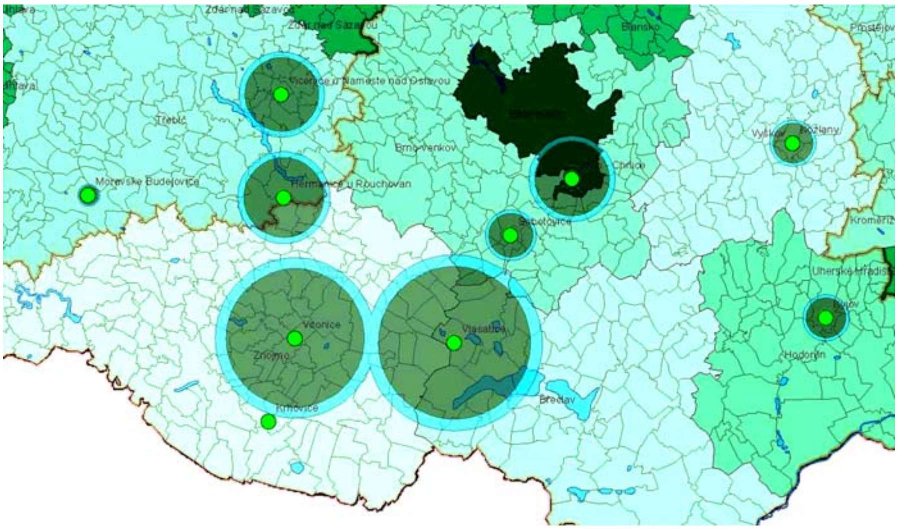

Figure 2. Change in the size of the original mantle zone (inner brown circle) to larger one (blue concentric circle) after taking into account the yield coefficient

Fig. 2 shows a model situation of mantle zone change by taking into consideration the yield coefficient. The original mantle zone (established according to [2]) delineates the area size at 100% gain of all available selected raw materials for the composting plant. The larger concentric blue circle defines the mantle zone of the intake area (calculated according to [3], which includes the area that will guarantee full utilization of the composting plant k_p while taking into account the yield coefficient of 75%.

Example of intake areas of composting plants processed at the level of municipal cadastres

As to the basic size for individual soil categories, this paper is worked out at the level of districts as mentioned and reasoned above. Therefore, certain discrepancies must necessarily occur between the average amount of matter in the district, which was used to determine the mantle zone size, and the actual average amount of matter in the area. Supposedly, the deviation will be smaller in large mantle zones and bigger in small mantle zones.

The quantification of deviations confirmed the assumption. In very small intake areas of composting plants, which occupy only several cadastres of municipalities, the deviation usually does not exceed 10%. Medium-sized and large intake areas of composting plants – like the composting plant Kutná Hora – Neškaredice mentioned as an example in this paper (Fig. 3 and Tab. 3) – normally exhibit a deviation below 4%.

The original mantle zone that was established before by using the mentioned method is delineated by the red circular line. Cadastres of municipalities from which material can be obtained from the selected biomass types for the composting plant $k_p = 1.13 \cdot 10^7$ kg are depicted in the individual shades of green colour, representing the amount of selected compostable raw materials per unit area (values from $11\text{-}165 \cdot 10^3$ $kg \cdot km^{-2}$). The actual value k_p of the composting plant is $1.20 \cdot 10^7$ kg. Tab. 3 presents parameters of the composting plants including a comparison with the calculated mantle zone.

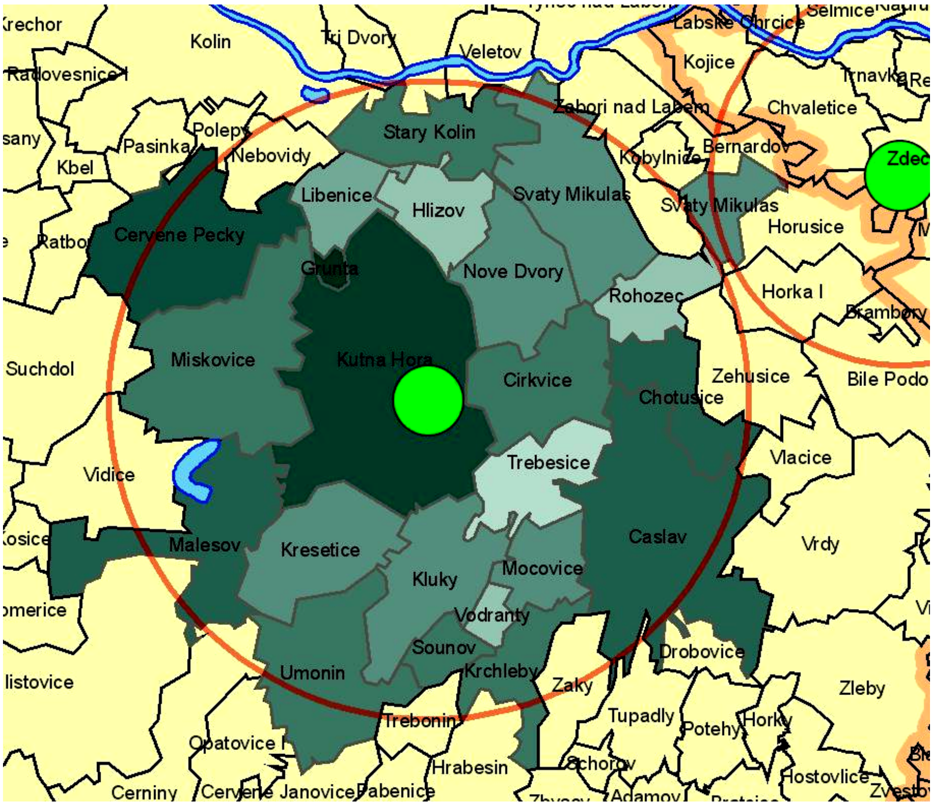

Figure 3. The composting plant Kutná Hora – Neškaredice, plotted at the level of municipal cadastres

Table 3. Parameters of selected composting plants

Attribute	*Value*	*Unit*
Size of the delineated area (green)	*236.43*	*km^2*
Mantle zone area (red circular line)	*240.29*	*km^2*
Total amount of matter in the delineated area	*1.13*	*10^7 kg*
Actual k_p of the composting plant	*1.20*	*10^7 kg*
Calculated average amount of matter in the district	*49.95*	*10^3 kg·km^{-2}*
Actual average amount of matter occurring in the area	*48.20*	*10^3 kg·km^{-2}*
Deviation of the average amount of matter in the district from the actual amount of matter in the area	*3.63*	*%*

Analysis of selected biomass types for composting in the Czech Republic

After the database had been created and from it the above-mentioned map outputs from the project, we analyzed the results.

Tab. 4 presents average yields of selected raw materials (Tab. 1) per unit area that are added dendromass. Dendromass is understood to be waste product from the cultivation of forest soil and conversion of timber (its average amount in the Czech Republic is 513 kg per 1 ha forest).

Based on the knowledge of average yields of compostable raw materials in the individual townships of the Czech Republic (see Tab. 4), Tab. 5 was created - *Yearly potential of selected raw materials in individual townships of the Czech Republic*. The table was used to plot a diagram presented in Fig. 4. Similarly as the Tab. 4, this Tab. 5 contains in last column values including dendromass.

Table 4. Average yields of selected raw materials in individual townships of the Czech Republic

1.	*2.*	*3.*
Township	*Average yields of selected raw materials (10^3 kg·km^{-2})*	*Average yields of selected raw materials including dendromass (10^3 kg·km^{-2})*
South Bohemia	*87.46*	*124.88*
Plzeň	*79.55*	*119.09*
Karlovy Vary	*105.67*	*148.93*
Ústí nad Labem	*83.72*	*113.54*
Liberec	*116.04*	*160.31*
Hradec Králové	*90.78*	*121.75*
Pardubice	*82.07*	*111.55*
Prague + Central Bohemia	*54.40*	*81.35*
Vysočina	*68.25*	*98.02*
South Moravia	*41.86*	*70.34*
Zlín	*89.15*	*128.82*
Olomouc	*70.66*	*106.16*
Moravian Silesia	*100.17*	*134.99*
Czech Republic	*77.52*	*111.12*

Based on values of the total designed k_p of composting plants in individual townships and on the maximum potential of selected biomass types suitable for composting (P_{max}; P_{dmax}), we constructed the below table. Table 6 is to express what percentage share from the available potential l of selected raw materials would be consumed by the composting plants if they would use only the sources of these raw materials for reaching the k_p value.

Values in the table were calculated according to the following relation:

$$V_P = \frac{\sum_{i=1}^{n} k_p}{P_{\max}} \left(\frac{100}{v}\right) \tag{4}$$

Where:

V_p [%] - consumption share of composting plants from the max. potential of selected raw materials in the township,

$\sum_{i=1}^{n} k_p$ [kg] - sum of the k_p of all composting plants in the township,

P_{max} [kg] - maximum potential of selected raw materials in the township (P_{dmax} value is incorporated in values including dendromass)

v [%] - yield coefficient

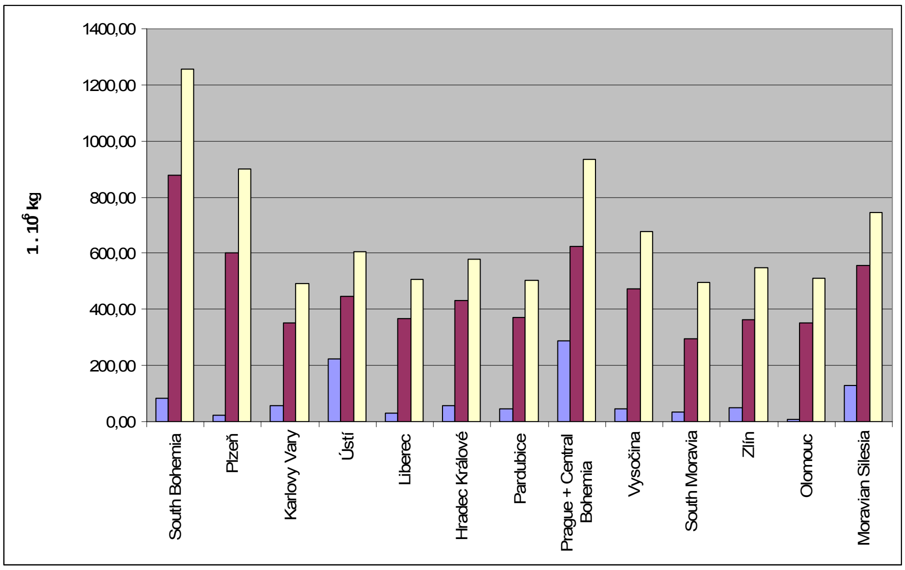

Figure 4. Diagram of the potential of selected raw materials in individual townships of the Czech Republic (blue column = designed k_p value of composting plants in the township, purple column = P_{max}, yellow column = P_{dmax}) Diagram is made from values in Table 5.

The table is divided into three sections. The first section contains shares expressed in percent under theoretical assumption that 100% of selected raw materials occurring in the territory of interest is gained (column 2). The other two sections (columns 3 and 4) picture the values at yields of 75% and 60%, i.e. each of sections splits into two columns of which the left one shows the percentage shares of the use of selected raw materials without dendromass and the right one shows the percentage shares of the use of selected raw materials including dendromass.

It is possible to conclude from values in Tab. 6 that the amount of compostable matter from the selected raw materials is sufficiently high in the Czech Republic. We have to point out however that due to competitive relationships, the availability of raw materials is affected by the location of the composting plant in the region. If this factor is neglected, a mutual competition may occur of two and even more composting plants. Then it may happen that a given composting plant would not have access to the given raw materials and would not meet its k_p value or would have to bring the material from a larger distance, which would increase the operating costs.

Table 5. Yearly potential of selected raw materials in individual townships of the Czech Republic

1.	2.	3.	4.
Township	Total achievable annual amount of processed matter (k_p) in composting plants of the township (10^6 kg)	Maximal potential of selected raw materials (P_{max}) in the township (10^6 kg)	Maximal potential of selected raw materials incl. dendromass (P_{dmax}) in the township (10^6 kg)
South Bohemia	84.85	879.60	1255.89
Plzeň	21.70	601.49	900.42
Karlovy Vary	58.00	350.33	493.70
Ústí nad Labem	221.90	446.64	605.74
Liberec	29.20	367.04	507.06
Hradec Králové	56.24	431.94	579.27
Pardubice	43.90	370.09	504.09
Prague + Central Bohemia	285.99	626.18	936.46
Vysočina	46.60	472.67	678.88
South Moravia	32.17	295.83	497.13
Zlín	48.60	364.58	547.68
Olomouc	8.35	353.40	510.65
Moravian Silesia	130.34	554.42	747.15
Czech Republic	1067.84	6114.21	8764.12

Table 6. Percentage shares of the use of selected raw materials for composting plants at various yields in individual 3townships of the Czech Republic

1.	2.		3.		4.	
	100 % yield		75 % yield		60 % yield	
Township	Without dendro-mass	With dendro-mass	Without dendro-mass	With dendro-mass	Without dendro-mass	With dendro-mass
South Bohemia	9.65	6.76	12.86	9.01	16.08	11.26
Plzeň	3.61	2.41	4.81	3.21	6.01	4.02
Karlovy Vary	16.56	11.75	22.07	15.66	27.59	19.58
Ústí	49.58	36.63	66.24	48.84	82.80	61.05
Liberec	7.96	5.76	10.61	7.68	13.26	9.60
Hradec Králové	13.02	9.71	17.36	12.95	21.70	16.18
Pardubice	11.86	8.71	15.82	11.61	19.77	14.51
Prague + Central Bohemia	45.67	30.54	60.90	40.72	76.12	50.90
Vysočina	9.86	6.86	13.15	9.15	16.43	11.44
South Moravia	10.87	6.47	14.50	8.63	18.12	10.79
Zlín	13.33	8.87	17.77	11.83	22.22	14.79
Olomouc	2.36	1.64	3.15	2.18	3.94	2.73
Moravian Silesia	23.51	17.44	31.35	23.26	39.18	29.07
Czech Republic	17.46	12.18	23.29	16.25	29.11	20.31

Fig. 5 shows localities in which a competition may occur between the individual composting plants. This situation applies namely to the composting plants near larger cities (Prague, Ostrava industrial agglomeration in Moravian Silesia). Different shades of green in map shows the total potential of selected types of biomass. Lightest shade is $40 \cdot 10^3$ kg·km^{-2} and darkest is $200 \cdot 10^3$ kg·km^{-2}.

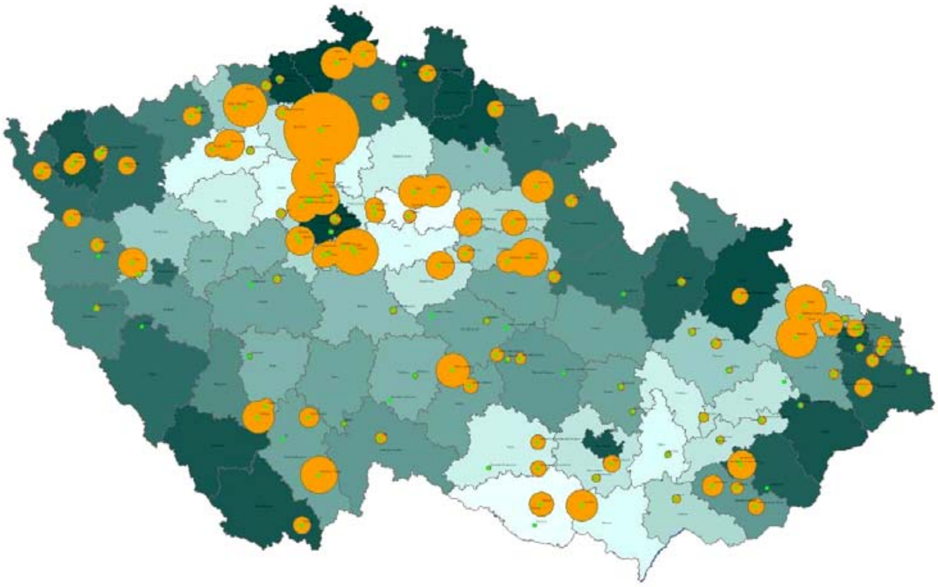

Figure 5. Map of the production of selected biomass types with delineated mantle zones of individual composting plants

By contrast, localities clearly show in the map, which appear suitable for building a new composting establishment. This map output (Fig. 5) can help a prospective developer find an adequate locality for building a composting plant with the sufficient amount of raw materials and without severe conflicts with competitors.

We can mention the example of a composting plant in the Ústí Township (the largest mantle zone on the map in Fig. 5 - north of Prague). The k_p value of this composting plant is $8 \cdot 10^7$ kg. The amount of actually processed matter in 2009 was only $1.2 \cdot 10^7$ kg. Upon consulting the composting plant operator, we found out that the establishment had been oversized due to the amount of material occurring in the region and the intake area size was corresponding. The fact can be seen also in the size of the mantle zone whose radius is ca. 20 km and area ca. 1150 km^2. This is only one example of using this project in practice when inadequate adjustment of the value of the maximum amount of matter processed in the composting plant can be prevented.

Possible directions of project use and development

The project offers multiple possibilities for use. One of them is to develop an application (accessible via web) that would make the database available to users, especially expert public. An extension is expected with a database of biogas stations so that a more complete general view of biomass-processing operators in the Czech Republic is acquired. Thanks to this expansion, the application might be used to offer a "biomass exchange" to users. Biomass producers would offer individual commodities to interested customers such as composting plant operators (or operators of biogas stations).

Based on topical data in the given area and after plotting the mantle zones, it would be clear which operators of composting plants have vacant capacities in the given moment and how big the capacities are. The biomass producer would choose a concrete plant (e.g. based on transport distance if more operations with vacant capacities occur in the surroundings) to which they would direct their material and thus, the composting plant operator would be freed of the necessity to search biomass for their establishment in the surroundings.

This web application could be used also by government authorities, which co-decide upon the allocation of subsidies in the field of biomass management, possibly also by the public as an information on the localization of the nearest biomass processing plant (e.g. in the case of interest in the produced compost).

CONCLUSIONS

The work discussed in this paper aimed at the development of a practically utilizable GIS of biomass management in the Czech Republic on the basis of currently offered geographical information systems (ArcView GIS 9.1).

The main output of the project is a general analysis of the potential of selected biomass types suitable for composting in the Czech Republic. The project is designed as an open version into which data on other commodities (e.g. waste from urban greenery maintenance etc.) can be introduced. This open version of the project can be also used for the introduction of other databases (e.g. network of biogas stations) to extend possible outputs to the other sector of waste management.

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GIS ANALIZA PROIZVODNJE BIOMASE I NJENE UPOTREBE ZA KOMPOSTIRANJE U REPUBLICI ČEŠKOJ

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Sažetak: Danas se različiti informacioni sistemi, uključujući i geografske informacione sisteme (GIS), sve više koriste u upravljanju otpadom (slično kao i u drugim oblastima). Podaci su postepeno standardizovani tako da svi nivoi administracije mogu da koriste ujednačene podatke, a individualni sistemi su kompatibilni. U ovom radu GIS je upotrebljen za analizu odabranih tipova biomase pogodne za kompostiranje u Republici Češkoj. Na osnovu statističkih podataka Češkog Statističkog Zavoda i podataka iz drugih informacionih sistema, zadatak je rešen pomoću GIS programskog paketa ArcView 9.1. Rezultati su mape oblasti nastanka biljne mase za kompostiranje, zasnovane na uslovima koje su prethodno definisali korisnici i analizi biomase pogodne za kompostiranje.

Ključne reči*: informacioni sistem, geografski informacioni sistem, podaci, biomasa, kompostiranje, analiza*

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