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Comparison of two different Local Climate Zone mapping methods

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1. Introduction

The Local Climate Zone (LCZ) classification (Stewart and Oke 2012) is an outstanding concept for the climate-related classification of urban areas in global scale. Although it was originally designed for meta data communication in observational urban heat island studies, its possible applications are numerous. One of the most important ones is the possibility to use these zones for the input of different climate or weather models in order to better represent urban areas. The use of this concept in these models is advantageous because this classification is based on the thermal characteristics of the urban areas, and it is connected to the most obvious alteration of the climate in urban areas, the urban heat island (Stewart 2011).

The LCZ system was initially designed for the classification of urban measurement sites (Stewart and Oke 2012), but meanwhile several methods for LCZ mapping have been proposed (Bechtel and Daneke 2012, Lelovics et al. 2014, Lehnert et al. 2015, Bechtel et al. 2015). The aim of this study is to present and compare two different LCZ mapping methods, Bechtel (Bechtel et al. 2015) and Lelovics-Gál (Lelovics et al. 2014) methods.

The first approach (Bechtel-method) is based on free multi-temporal remote sensing data and modern machine learning methods using classifiers like random forest. The entire workflow was implemented in the open source GIS SAGA (Bechtel et al. 2015).

The second method (Lelovics-Gál method) is a GIS based automatic software tool (Lelovics et al. 2014). As an input it uses different parameters of the urban structure (like building height, sky view factor, fraction of buildings, vegetation, built up areas, albedo) acquired from different sources (e.g. satellite and aerial images, 3D building databases, CORINE land cover dataset, road databases and maps). The basic elements of this GIS method are the building block and the lot area polygon around it. The approach consists of a fuzzy preliminary classification and a post-processing scheme. Initially, all lot area polygons are assigned to a most similar and a second most similar LCZ using the parameter ranges given by the LCZ fact sheets. Consequently, the polygons are aggregated to achieve at least the minimal size of 500 m x 500 m for a single LCZs using similarity rules.

The study area of this comparison is Szeged, Hungary, because in this city all of the needed input parameters are available for both methods. As a part of this comparison we analyze which are the most problematic built up types, spatial configurations, and also we try to find the advantages of the methods.

Finally, we aim the integration of both approaches combining the respective advantages. Therefore, we conduct the initial classification using the Bechtel method, since it needs only few and globally available input data. As the second step, the aggregation of the Lelovics-Gál method was implemented in a JAVA tool, in order to create LCZs of sufficient size.

2. Study area

Szeged (Hungary) is located in the Pannonian Plain in Central Europe (Fig. 1.). According to the climate classification system developed by Köppen it belongs to temperate warm climate with a rather uniform annual distribution of precipitation (Kottek 2006).

The city has 160,000 inhabitants and 281 km^2 administrative area, however the urbanized area is only about 30 km^2. River Tisza is the axis of the town and city has a regular avenue-boulevard structure (Fig. 1.). It is characterized by densely built up center, blocks of flats in the northern part, large area of family homes and warehouses mostly in western part (Unger 2004). In the study area several database and input material is available from earlier studies, eg. built-up parameters and Landsat images (Balázs et al. 2009), parameters used in the LCZ system and a set of other data (Rapideye satellite images, CORINE land cover, road database, etc.) (Lelovics et al. 2014).

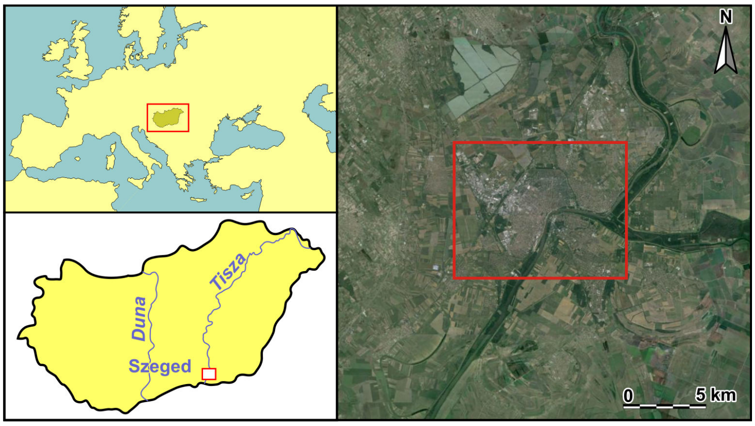

Fig. 1 Location of Hungary, Szeged and the study area (red lines)

3. Methods

3.1 Satellite image based (Bechtel) method

This method was designed to be universal, simple an objective to be part of a global protocol to derive information about form and function of cities. It applies free satellite images, free software and it can be handled without expert remote sensing knowledge. The methodology uses two software packages: Google Earth and SAGA-GIS. As an input data it applies globally available Landsat satellite images. The workflow consist two main steps (Bechtel et al. 2015).

Firstly, typical LCZ areas (training areas) have to be located in the study area; this part is carried out in Google Earth. The training areas are stored in a kml file containing a set of polygons for the different LCZ types and also a rectangle defining the border of the examined area. This kml file is used for the second part of the process which is carried out in SAGA-GIS.

Secondly, in SAGA-GIS the Landsat images and the vector file (containing the training areas) have to be preprocessed. The Landsat scene is cut with the border of study area in order to decrease the computation time, and the imagery is resampled to 100 m from the original 30 m to get a representation of the spectral signal of local scale urban structures rather than smaller objects. Finally, the classification is conducted with the built in random forest classifier based on the Landsat images and the training area polygons. The classifier calculates the most likely LCZ type and the probabilities for all LCZ classes for each pixel.

In urban environment the temperature value measured at a height of 1.5–2 m is influenced by its surroundings with a radius of a few hundred meters as a source area (Oke 2004, Unger 2009). The aim is to find homogenous LCZ areas with hundreds of meters to several kilometers characteristic dimension. In this light result of random forest classification is only a raw LCZ map, because theoretically each 100 m sized pixel can be different LCZ class and this case the expectation for the characteristic size of an LCZ area cannot be fulfilled. To reduce this noisy nature of the classification, aggregation and post-classification filtering are needed. In this study four different majority filter were used, each of it calculating the most specific LCZ category in a given radius around each pixel. The four filters had four different radii: 1, 2, 3 and 4 pixel corresponding to 100, 200, 300 and 400 m.

For this study area we used all spectral bands of 10 Landsat 7 images. The use of multiple images from different time (seasons) is advantageous thus using more spectral information the classification gives better results. The scenes obtained from USGS (earthexplorer.usgs.gov). All of the images are Worldwide Reference System (WRS) path 187 row 028, and taken at 2000-2003 in all seasons. The criteria of the selection of these images was to ensure the absence of clouds.

3.2 GIS based (Lelovics-Gál) method

The GIS method (Lelovics et al. 2014) follows an opposite logic than the satellite image based method. As a first step of the mapping process all of the parameters utilized for the definition of each LCZ class (Stewart and Oke 2012) are collected, for an elemental spatial unit called lot area polygons (Gál and Unger, 2009). As a next step, the method determines the first and second more likely LCZ category for each polygon. Finally, it aggregates these lot area polygons in order to achieve the adequate size areas what are comparable to the source area of the temperature measured at 2 m height (Oke 2004, Unger 2009). The method was implemented in FORTRAN language using Fortran GIS library, inputs are mainly text files and the final map is in ESRI shapefile format.

For the first part of the process in Szeged we applied data from different sources for the calculation of parameters inside each lot area polygon. The sky view factor (SVF) database with 5 m horizontal resolution originated from our earlier studies (Gál et al. 2009, Unger 2009). We calculated the building surface fraction and height of the roughness elements using the 3D building database of Szeged (Gál et al. 2009, Unger 2009). The pervious surface fraction was calculated from an RapidEye satellite image using the NDVI and corrected with a 1:25 000 topographic map, the Corine Land Cover database and a road dataset. Impervious and previous surface fractions were calculated from the building surface fraction. Terrain roughness class was evaluated with the Davenport roughness classification method (Davenport et al. 2000). Surface albedo was calculated from the RapidEye satellite image. Some parameters used in the LCZ definition were omitted due to lack of data (surface admittance and anthropogenic heat output).

The second part of the process is a rule-based classification. During this classification the method compares the value of a given parameter in a given polygon to the typical ranges given by Stewart and Oke (2012), and seven scores are assigned to the polygons based on the number of parameters that accords to the definition of an LCZ class. Finally the method stores the first and second most likely LCZ category if the sum of scores greater than 3, otherwise the lot polygon remaines as unclassified.

The last part of the mapping process is the aggregation of lot area polygons. The minimum recommendation for the process is to find a homogenous zone with at least 250 m radius. To fulfill this criteria is not straightforward, because the irregular heterogeneity of the urban forms. There is a simple case when a lot polygon has a given LCZ class and all of its neighbors have another one, in this case the LCZ class of the central polygon modified to the neighbors LCZ class. More often, at the edge of a homogenous set of polygons a different LCZ type polygon can be foundnd, in this case the second most likely category is examined, and if it is the same or similar to the others the cluster is merged. The unclassified lot area polygons are merged to the dominant neighboring polygons. This process is implemented iteratively and restartes until a circle with a radius of 250 m fits in the area of the set of lot area polygons (Lelovics et al. 2014).

3.3 Development of a combined method

Both of the methods have advantageous and disadvantageous parts. The satellite image based method is easy to use and needs only few and freely available input data, and it can be applied for any part of the world, but the last part (the majority filter) may need some improvement. The GIS method is very detailed, and it has an advanced area aggregation part, but it needs tremendous amount of input data, so it cannot be used worldwide. Therefore, we tried to integrate these two methods to keep all of the advantageous parts.

The combined method is similar to the satellite image based method until the post-classification filtering (Section 3.1). In this stage the majority filter is replaced the same area aggregation process what was used in GIS method (Section 3.2). Technically the algorithm is implemented in JAVA language, and it needs 100 m sized rectangles in ESRI shapefile format. The attribute table of the shapefile contains the two most probable LCZ types for each rectangle. The final aggregated LCZ map is stored in a new shapefile.

4. Results

The appearance of the obtained LCZ map highly depends on the applied post-classification filter (Fig. 2). The filter with 100 m radius does not seem to be adequate, several small (only few pixel sized) LCZ areas can be found (Fig. 2.A).

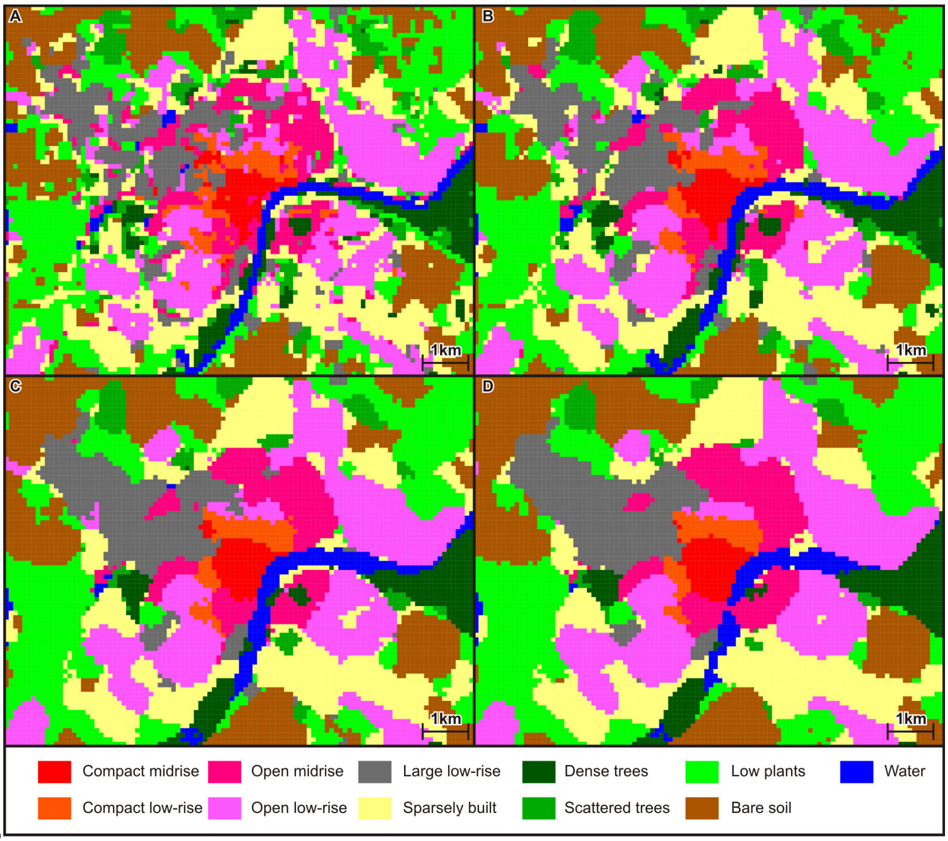

Fig. 2 Local Climate Zone maps evaluated by satellite image based method using different post-classification filters (A: 1 pixel filter, B: 2 pixel filter, C: 3 pixel filter, D: 4 pixel filter

The results of the larger filters are more acceptable, however with the increment of the size of the filter cause minor problems. The linear shaped areas, like the river Tisza disappears some places or it expands to an urban area in case of 400 m filter (Fig. 2.D). The separate parts of the city may be merged with the larger filters, as an example the open low-rise areas in the SW perimeter of the city are separate in case of 200 m filter, but not in the larger ones (Fig. 2.).

In case of the GIS based method only the built up types can be examined, because this method is not suitable to use the non-urban land cover types. In the urban area the identified LCZ types and their spatial pattern are the same, however there are few minor differences (Fig. 3). The edges of LCZ polygons are sharper, and in this case there are more linear shaped areas (Fig. 3).

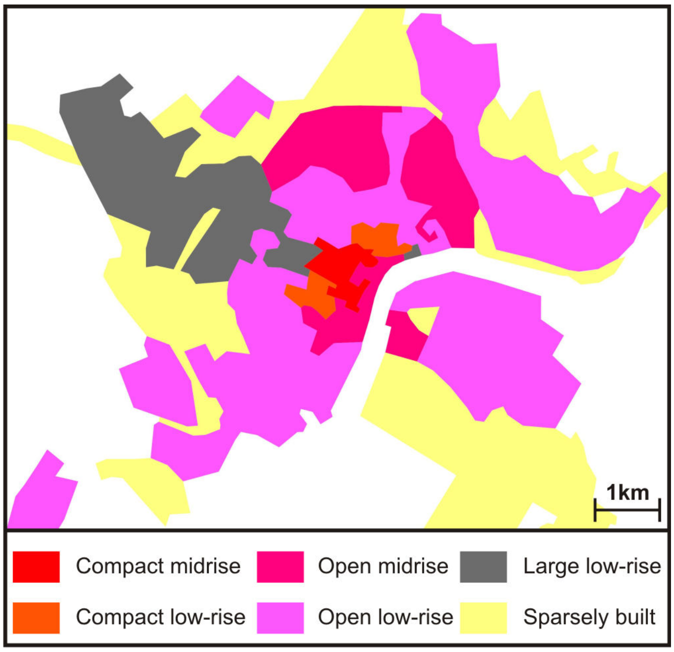

Fig. 3 Map of Local Climate Zone evaluated by GIS method

When comparing the results of the two methods we found that the ratio of the 100 m pixels identified as a different LCZ in urban areas are the following: 30% for 100 m filter, 26% for 200 m filter, 22% for 300 m filter and 21% for 400 m filter. In the following, we concentrate on the problematic areas and try to find some typical areas with significant differences. Some places the surface materials may cause differences, as an example a railroad station is identified as open low-rise by the satellite based method (Fig. 4.A), but it is identified as large low-rise by GIS method. Area B in Fig. 4 is a good example of the problematic properties of filtering, GIS method identified it as open midrise, but thanks to the surrounding large low-rise areas the filtered LCZ maps of the satellite based method identified this area also as large low-rise. Near the center of Szeged in the bank of Tisza a large area (Fig. 4.C) is located what is clearly open midrise, GIS method identified it as we except, but the filtering also erase this area from the LCZ map produced by satellite image based method. The area in Fig. 4.D is a good example for border case situation, it was identified as open low-rise by GIS method, open midrise by the other, but this area is so complex that the best decision is not obvious.

Fig. 4 Typical differently identified areas.

If we compare the results of the combined method to the GIS method we found that the ratio of the 100 m pixels identified as a different LCZ is only 15%, additionally in the problematic areas the combined method are much more closer to the GIS method. If we take into consideration than the GIS method uses much more data and it calculates almost all of the parameters of the LCZ scheme and this combined method can produce an almost similar result using only a set of satellite images than this 15% difference may be acceptable. The map produced by the combined method is presented in Fig. 5. The linear shaped LCZ areas are preserved, and the edges of the different LCZ areas are sharp as can be expected, since the different built up styles change over short ranges in cities.

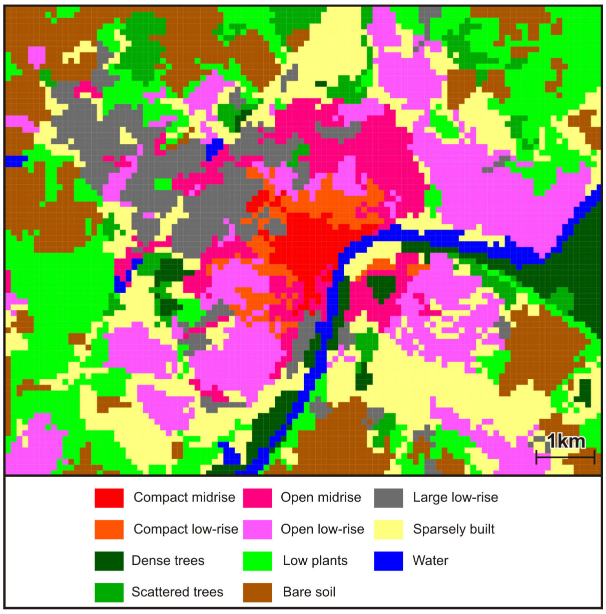

Fig. 5 LCZ map generated by the combined method.

5. Conclusion and outlook

In this paper we presented the preliminary results of combination of two LCZ mapping method with completely different approaches. As the results show, the highly data-intensive GIS method and globally applicable satellite method produce slightly different LCZ maps. We identified few typical cases where the two methods produce different results. These differences are mostly caused by the post-classification filtering, thus we applied the aggregation process of the GIS method in the raw output of the satellite based process. The difference of the LCZ map of this combined method from the map of the GIS method is decreased, and also the typical differences disappeared. The result is promising, although the combined method needs improvement by technical and conceptual reasons. In particullar, it can use only a specific resolution (100 m rectangles), the preparation of the inputs is time consuming, and the size criteria for an LCZ area is not fulfilled in several cases.

The combination of these methods may be useful and helps to improve the satellite based method. Since it does not require any additional input data, the main advantage of the process is remained and it can be applied globally in any urban area without remote sensing and GIS expert knowledge. The combination of these methods can be useful for the WUDAPT project (Bechtel et al. 2015) also, and it may help to evaluate the effect of the climate change for urban areas (Zuvela-Aloise et al. 2015).

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References

Balázs B., Unger J., Gál T., Sümeghy Z., Geiger J., Szegedi S., 2009: Simulation of the mean urban heat island using 2D surface parameters: empirical modeling, verification and extension. *Meteorological Applications* **16**, 275–287

Bechtel B., Daneke C., 2012: Classification of local climate zones based on multiple earth observation data. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal* **5(4)**, 1191–1202

Bechtel B., Alexander P.J., Böhner J., Ching J., Conrad O., Feddema J., Mills G., See L., Stewart I., 2015: Mapping local climate zones for a worldwide database of the form and function of cities. *ISPRS International Journal of Geo-Information* **4(1)**, 199–219

Davenport A.G., Grimmond C.S.B., Oke T.R., Wieringa J., 2000: Estimating the roughness of cities and sheltered country. *Proceedings 12th Conference on Applied Climatology, Asheville, NC*, 96–99

Gál T., Unger J., 2009: Detection of ventilation paths using high-resolution roughness parameter mapping in a large urban area. *Building and Environment* **44**, 198–206

Gál T., Lindberg F., Unger J., 2009: Computing continuous sky view factor using 3D urban raster and vector data bases: comparison and application to urban climate. *Theoretical and Applied Climatology* **95**, 111–123

Kottek M., Grieser J., Beck C., Rudolf B., Rubel F., 2006: World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift* **15(3)**, 259–263

Lehnert M., Geletič J., Husák J., Vysoudil M., 2015: Urban field classification by “local climate zones” in a medium-sized Central European city: the case of Olomouc (Czech Republic). *Theoretical and Applied Climatology* 10.1007/s00704-014-1309-6

Lelovics E., Unger J., Gál T., Gál C.V., 2014: Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling. *Climate Research* **61(1)**, 51–62

Zuvela-Aloise M., Bokwa A., Dobrovolny P., Gal T., Geletic J., Gulyas Á., Hajto M., Hollosi B., Kielar R., Lehnert M., Skarbit N., Stastny P., Svec M., Unger J., Vysoudil M., Walawender J.P., 2015: Modelling urban climate under global climate change in Central European cities. *Geophysical Research Abstracts* **17**, EGU2015-1594

Oke T.R., 2004: *Initial guidance to obtain representative meteorological observation sites*. WMO/TD No. 1250, Geneva

Stewart I.D., 2011: A systematic review and scientific critique of methodology in modern urban heat island literature. *International Journal of Climatology* **31**, 200–217

Stewart I.D., Oke T.R., 2012: Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society* **93**, 1879–1900

Unger J., 2004: Intra-urban relationship between surface geometry and urban heat island: review and new approach. *Climate Research* **27**, 253–264

Unger J., 2009: Connection between urban heat island and sky view factor approximated by a software tool on a 3D urban database. *International Journal of Environment and Pollution* **36**, 59-80