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LARGE SCALE URBAN HEAT ISLANDS MAPPING BASED ON SPATIAL INFORMATION PROVIDED BY YOUNG VOLUNTEERS

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Abstract: The base of large scale mapping of urban heat islands (UHI) is a large amount of spatial information which can be highly expensive to collect. Our Department has also experimented with using wireless sensor networks; however, it is more efficient and cheaper to collect data provided by volunteers. Young volunteers (primary and secondary school students) are relatively easy to motivate, and direct contact can be built up between project managers and volunteers through teachers. Volunteered geographic information (VGI), created by young volunteers, was collected with the help of Web 2.0 technology. It was complemented by traditional scientific geographic information collected by wireless sensors developed for air temperature measurement. Geospatial analysis of recorded VGI for urban heat islands was used for a better understanding of spatial relationship between urban land cover and UHI, and of the rapid change of UHI due to changing meteorological conditions. Large scale UHI maps were generated using VGI to uncover hidden structures in UHI. These maps were compared to the medium scale UHI maps, which were created by impervious surface maps derived from spectral mixture analysis of a Landsat TM image.

Keywords: young volunteers, large scale UHI mapping, remote sensing, urban environment

1. INTRODUCTION

At the beginning of the 19th century, geography became a discrete academic discipline. However, its scientific approach has been different from that of other natural sciences. It is primarily the lack of axiomatic structure that causes confusion. Based on scientific and mathematical knowledge, some laws of geography were formulated in the 1970s, the best known of which is perhaps Tobler's first law of geography (Tobler, 1970). It says that "everything is related to everything else, but near things are more related than distant things". In spite of the fact that in his apparently simple law Tobler used strict mathematical relations (for example differential equations) in order to simulate urban growth, the law itself cannot be regarded as a scientific one.

At the end of the 20th century, based on the systematic handling and analysis of spatial data, geoinformatics as a discipline created a scientific structure by which geographical thinking became analogous to the rigorous approach of other areas of science. Geoinformatics has not only made it possible to process large amounts of spatial information, but it has also strengthened the role of geography as the bridge between human and physical sciences.

A professional GIS software and open source applications have been broadly adopted in geographical research and on various levels of geography education for the construction of spatial concepts and spatial cognition. Beside the sometimes expensive data sources, data preparation by researchers and lecturers limit the ability of environmental awareness and human-environment interaction (Wu, 2013).

The World Wide Web (WWW) has evolved significantly from its early stages in the 1990s to become a sophisticated source of information. At the beginning of the 21st century, the term "Web 2.0" was first introduced by O'Reilly in 2005 on web (O'Reilly, 2007). In fact, the term Web 2.0 relates to a "new platform where users can customize their own applications on the WWW to meet their own design, ideas, and functionality and most importantly, can create their own data or edit existing data” (Neis & Zipf, 2012). This technology has made it possible to add geographically determined records to databases (e.g. Wikimapia, OpenStreetMap, Flickr, etc.) and to disseminate user-generated spatial data. Pieces of volunteered geographic information (Goodchild, 2007) “have profound impacts on geographic information systems and more generally on the discipline of geography and its relationship to the general public”.

In geography education, with the spreading of the internet and web applications, spatial information can be incorporated into the curriculum, which can enhance understanding of complex spatial processes. Furthermore, the concept of Web2.0 provides a new perspective for students to share their observations on a web-based platform. Experimentation and instrumental measurements are less and less widely applied in geography education due to the decreasing number of lessons and costly materials and equipment. The Hungarian National Curriculum (HNC, 2012), which was adopted in 2012, discusses the concept of digital competence in detail. The use of information and communications technology (ICT) is based on the following skills and activities: recognition (identification), retrieval, analysis, storing, generation, presentation and exchange of information, digital content creation and sharing, as well as communicative cooperation via the internet. In the teaching and learning process in the field of geography, it is particularly important to lay a considerable emphasis on developing the skill of obtaining and processing information by direct experience (partly field experience), observations and use of opportunities offered by the digital world.

One of the advantages of voluntary data collection is that numerous volunteers can take part in the project; however, the quality of the resulting data is still questionable. Therefore, in scientific projects relying on voluntary data collection it is necessary to train the volunteers and present the method of measurement. Motivation of volunteers is also important so that they execute spatial data collection precisely. What makes the volunteer create VGI content in his free time and collect data in a way that they are sufficiently accurate for scientific purposes? Volunteers can be motivated not only by belonging to a particular target group or by the idea of protecting our own environment (local patriotism), but also by experiencing scientific recognition and discoveries, which are important methods of science education.

For our short-term project in the city of Szeged we chose local primary and secondary school students who had already received some geography education. The call was spread via the internet as well as by the assistance of teachers, but the teachers did not assign any other tasks to the students and they did not reward them for this activity. Students measured the temperatures twice a day, in the morning and in the evening, using their own thermometer and sent the measurement results to the project managers via a web application. They gave the geographic coordinates of the given measurement point by using a web application. This so-called sensor network was completed with a network of 16 static wireless sensors to record air temperature in urban environment. Geospatial analysis of recorded VGI for urban heat islands was used for a better understanding of spatial relationship between urban land cover and UHI, and the rapid change of UHI due to changing meteorological conditions. Large scale UHI maps were generated using VGI to uncover hidden structures in UHI. These maps were compared to the medium scale UHI maps, which were created by impervious surface maps derived from spectral mixture analysis of a Landsat TM image.

2. METHODOLOGY AND DATA

Three data sources were used for large scale mapping of urban heat islands: air temperature data (VGI) collected by students, data provided by wireless sensor network, and medium resolution satellite images.

2.1. Collection of VGI

A short, one-week campaign was planned to collect the VGI. In local curricula, which are based on the National Curriculum, teaching about meteorological phenomena occurs in the autumn semester. Therefore, for practical reasons, the campaign was timed to take place after the students had acquired the necessary theoretical and practical knowledge and we also attempted to find a few days’ period free of other school obligations in order that they can collect data uninterruptedly. The most appropriate period for this seemed to be the one week long autumn break (29th October – 4th November 2012), when students could perform air temperature measurement at home, in their own neighbourhood.

The campaign was announced through two information channels. A detailed description of the project was published on the website of the University of Szeged, Department of Physical

Geography and Geoinformatics, and printed handouts were distributed in some selected schools. The electronic advertisement described the purpose of the project:

Dear Young Volunteers, Our Data Collecting Friends,

One of the most important parts of scientific research is accurate data collection, which is based on clearly defined methods. In our research to be presented below students who take part in the simple measurement and data collection process could give us valuable help.

More than 60% of the world population lives in cities, which cover less than 5% of the Earth's surface. This shows that these urban areas are greatly affected by environmental changes carried out by man.

In densely built-up urban areas, the phenomenon of urban heat islands can often be observed under certain weather conditions. It means that the air temperature can be several degrees higher in the city than in the outskirts. The urban air temperature measurements can provide researchers with more detailed information on the extent of temperature differences, and the location of warmer and cooler parts of the city.

Using the collected large amount of data and modern computer processing, a map showing the extent of urban heat islands can be generated. Relying on this information, city planners can reduce environmental impacts on urban dwellers.

Please, take part in the measurement process and contribute to the success of the research.

Join an academic research project based on voluntary GIS data collection!

We placed a link in the aforementioned website, where, by applying Web 2.0 technology, the young volunteers could upload their measurement data.

On this simple form young volunteers had to indicate text data about the measurement point (street and number), as well as (due to didactic reasons and to the checking of data accuracy) provide its spatial and geographical coordinates by using another web application.

Teachers were given handouts providing similar information to that of the above-presented text. We could only hope that there would be a great number of volunteers who measure and record temperature data both in the mornings and in the evenings during a week, and upload them through the web interface.

The project description included that the results of data analysis would not only be published in the web interface, but the academic researchers carrying out the research would also present the results in the schools and consult the students having taken part in the research. The number of volunteers could be estimated from demographic data of Szeged (Table 1).

The number of the students who are learning or who have already learnt environmental studies and geography is approximately 5000 in primary education and 6000 in secondary education in city of Szeged. From the nine primary and secondary schools visited, about 1000-1500 students could be involved in the research. After the short, one-week preliminary campaign 484 people visited the website from 23rd October to 8th November 2012. The project homepage was connected to Google Analytics as an account, for measuring the number of visitors and generating audience overview and map overlay of spatial distribution of visitors (Fig. 1).

The visitors mainly came from Hungary (95%), but there were visitors from other European countries (Czech Republic, France, Germany, Romania, Serbia, etc.) and from Algeria, Egypt and India. It is obvious that foreigners and the Hungarian visitors of the website who do not live in Szeged could get all information about the project solely from the website. The majority (173 visitors) of the Hungarian visitors (356 persons) living in Szeged were from among the students who visited the web interface of the project due to the information given them by their teachers. Consequently, in case of projects based on voluntary data collection, initial preparation and attracting attention are extremely important, and direct feedback should be given to the volunteers about the utilisation of their collected data.

Table 1. Number of students in primary and secondary education in Szeged (KSH − Hungarian Central Statistical Office; ITV)

	2001	2005	2012*
Number of students in full time primary education (head)	14923	13020	12000
Number of secondary school students (head)	14144	15968	16500

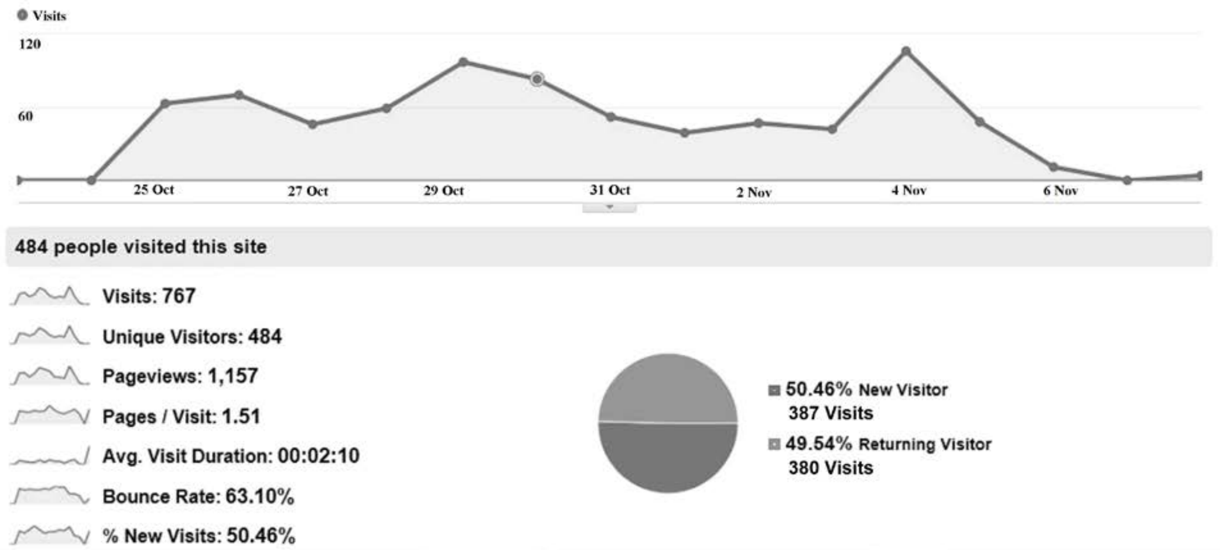

Figure 1. Number of project homepage visitors from 23rd October to 8th November 2012

2.2. Wireless sensor network

UC Mote Mini low power wireless sensor module was used for our measurements. This device promotes IEEE 802.15.4/ZigBee wireless communication protocol in order to realize low data rate. The radio module is able to operate at a data rate of 250Kbps in ISM 2.4Ghz band. The control is regulated by a 16 MHz Atmel ATmega128RFA1 microprocessor with 128kB RAM. Several types of sensors are integrated into this device (Fig. 2):

1. light sensor
2. pressure sensor
3. temperature sensor
4. humidity sensor

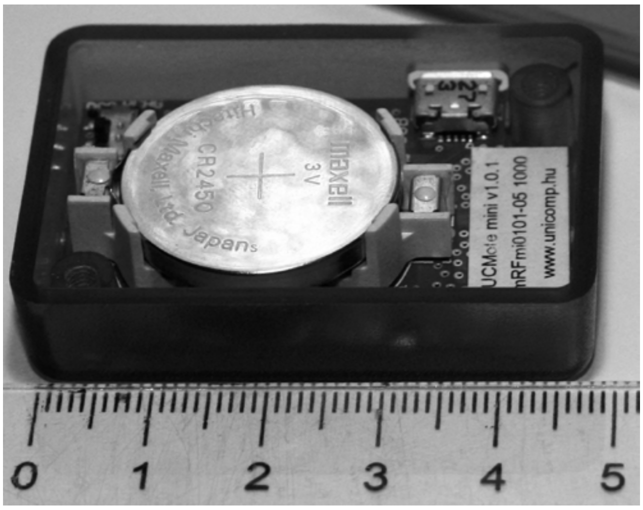

Figure 2. UC Mote Mini low power wireless sensor module

The used equipments were bought in the frame of the TÁMOP-4.2.2/08/1/2008-0008 program of the Hungarian National Development Agency.

The accuracy of SHT21 temperature sensor is ± 0.3°C and its scale is 0.01°C, whereas the accuracy of SHT21 humidity sensor is ±0.2% RH and its scale is 0.04 % RH. Data collection can be realized with 2MB external flash TinyOS, which is a small, open-source, energy-efficient software operating system which supports large scale, self-configuring sensor networks. The device is powered by a LIR2450 battery. In course of our study, data were recorded every 10 minutes. The sensors could be used for more than 3 months without battery replacement.

2.3. Satellite image

The satellite images were downloaded from the GLOVIS internet database of U.S. Geological Survey (USGS). We found 8 pieces of Landsat 5 TM images for the location of Szeged, Hungary in the year of 1986 (16 April, 2 and 18 May, 19 June, 5 July, 22 August, 7 September, 25 October) which fit to all the conditions described below. Each of the images was transformed into the UTM projection system (WGS84 ellipsoid, zone 34). From the following years we could not download records in such a big amount or in such a good quality (i.e. free from cloud cover).

A Landsat 5 TM satellite image recorded on 16 October 2006 was used in the study, which had been downloaded from the online repository of the U.S. Geological Survey (USGS). In data selection it was important to choose an image which was free from clouds and was recorded in the heating period i.e. between 16 October and 15 April. The above mentioned Landsat 5 TM satellite image met the stringent selection criteria. The image had a 30 meter geometric resolution and was available in UTM projection system (WGS84 N34), which was later converted to Unified National Projection (EOV).

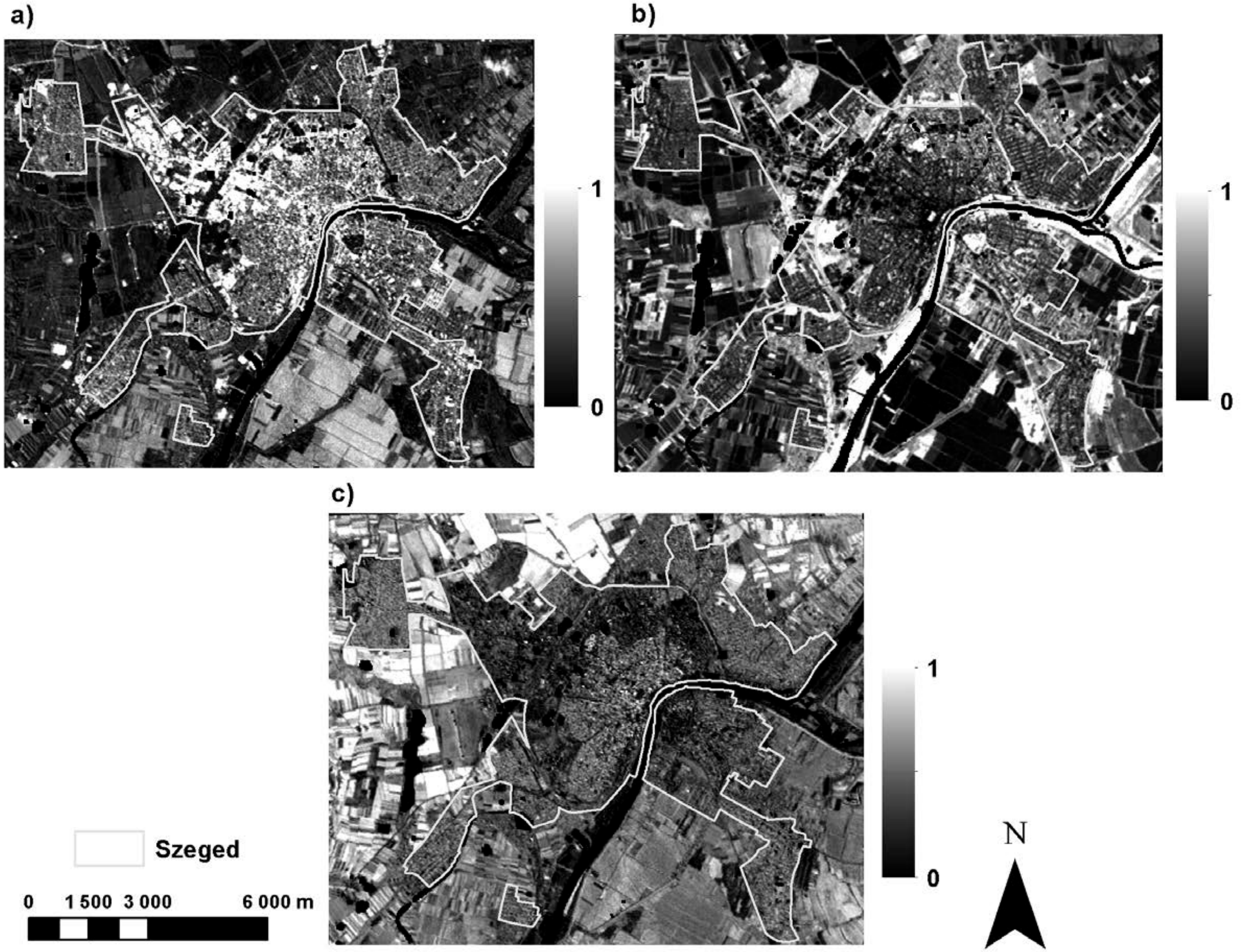

Figure 3. Fraction rate map of (a) impervious surface, (b) vegetation and (c) soil taken from the spectral partition of a Landsat TM satellite image (16 October 2006)

Radiometric and atmospheric corrections were carried out using the ACTOR2 module of ERDAS Imagine software.

On the Landsat TM image a ratio map was created with the method of Spectral Mixture Analysis (SMA). This map shows the rate of vegetation, soil and impervious surface inside the pixel (Weng, 2012). The aim of SMA is to define the ratio of land cover types with homogeneous spectrum, the so-called endmembers inside the pixel (Roberts et al., 1998). The linear partition model has the following equation (1):

$$R_b = \sum_{i=1}^{j} f_i \cdot R_{i,b} + \varepsilon_b \quad (1)$$

R_b: reflectance value of the image in band 'b',
j: number of endmembers,
f_i: rate coefficient of endmember 'i',
R_{ib}: reflectance value of the 'i'-th endmember in band 'b',
ε_b: remainder error value.

Sum of endmember rate coefficients is 1 in case of all pixels, and $f_i \geq 0$ is true as well (2).

$$\sum_{k=1}^{j} f_{i,k} = 1 \quad (2)$$

We applied the method of Normalized Spectral Mixture Analysis (NSMA) (Small, 2003;Wu, 2004)], in which we selected 3 endmembers: artificial surface, vegetation and soil (3, 4).

$$\overline{R}_b = \frac{R_b}{\mu} \times 100 \quad (3)$$

where

$$\mu = \frac{1}{N} \sum_{b=1}^{N} R_b \quad (4)$$

and $\overline{R}_b$ is the normalized reflectance of band 'b' per pixel; R_b is the original reflectance of band 'b'; μ is the mean of reflectance values in the pixel; and N is the number of bands (6 at TM images).

The result of NSMA is a map that shows the rate of land cover types inside the pixel. These maps illustrate the spatial distribution of certain land cover types. Pixel values are between 0 and 1. In case of 1, the rate of the land cover type is 100 % inside the pixel (Fig. 3).

3. RESULTS

3.1. Processing of received VGI

The reliability evaluation of VGI data does not differ from that of spatial data collected in other ways. It covers both the spatial and the descriptive data.

The spatial feature of the VGI can be provided by specifying the location of measurement in multiple ways. For instance, in addition to GPS coordinates, giving geographical coordinates and, in case of measurements carried out in the city, indication of street and number can reveal whether the volunteer has given the location of the measuring point accurately. In some cases, giving the direction and distance of the detected phenomenon can support localisation. For example, the path of a meteor which was observed from three different locations can be quite well defined; moreover, it can be even more precisely defined if the phenomenon was filmed.

The attribute accuracy of spatial phenomenon depends on its spatial variability. In case of a discrete phenomenon the observer can easily decide whether the given phenomenon has occurred or not, e.g. the bird has appeared in its nest, the lake has frozen, lightning has flashed, etc. Such a phenomenon can be added to the database using logical variables (true or false; yes or no; 1 or 0).

In case of a constantly changing phenomenon, types of variables can be ordinal, interval, or ratio. If using ordinal and interval variables, the volunteer can assess whether his measured data is in the given interval (e.g. temperatures are above zero; while hiking in the mountains the observation was made at a higher or lower altitude than that of the mountain shelter, etc.)

Measuring a constantly changing phenomenon (e.g. temperature, altitude, distance, etc.) and recording it as a ratio variable implies considerable uncertainty, even in case of a standard scientific observation. In case of VGI data collection, uncertainty is greater, as the exact way of measurement and the exact type of thermometer used are not always known. The only way to filter out incorrect data is the statistical analysis of the large dataset. However, correct data describing the extreme variability of the phenomenon may also be marked as “very likely incorrect” during the statistical analysis due to the significant deviation from the mean value.

3.1.1. Attribute accuracy of recorded air temperature data

A total of 115 volunteers submitted their dataset until the end of the measurement period (4 November 2012). We have also received data recorded in settlements located farther away from Szeged. Nevertheless, we used these data only to gain information, and, as a matter of course, they have not been included in the urban heat island intensity map of Szeged.

The volunteers were asked to carry out the measurements in the mornings and in the evenings.

Data were generally sent between 8 to 10 a.m. and 6 to 8 p.m. In late October, early November, the daily range of temperature can be maximum 10°C on overcast, windy, and rainy days, while it can be 20°C on cloudless, bright, and windless days. Resulting from the fact that, on the one hand, temperature range can be maximum 1-2°C in a 2-hour period and, on the other hand, error tolerance can also be at least ±1-2°C depending on reading and accuracy of instrument, we did not correct temperature data for a given time.

It was a characteristic feature of measurements that on overcast, windy, and rainy days the trendline of data sent by volunteers was horizontal, and values hardly changed on average during the measurement period. However, on cloudless, bright, and windless days the trendline was slightly rising in the morning period, which indicates an actual rise in temperature, but the difference between the minimum and maximum values of the trendline never exceeded 2°C.

One of the reasons for uncertainties of VGI based projects is the attribute accuracy of recorded data. It is extremely difficult to notice if someone deliberately provided incorrect data.

All volunteers used their own thermometer for measuring; therefore their precision and accuracy are unknown for the data processor. It is also unknown how accurate the volunteers were in reading their thermometers. In present study, parallax error can occur while reading the liquid thermometers, since the average height of 10-12 year old children is 130-140 cm and we asked them to place their thermometers in a 1.5-2 m high position.

In order to filter out incorrect data from the dataset, the following method was applied. 16 calibrated wireless sensors were placed in different parts of the city with different land cover types and land use. For instance, sensors were placed in sparsely built-in, suburban areas in the outskirts of the city, as well as in the densely built-in city centre. The sensors recorded the air temperature in ten-minute intervals. In a given *t* point of time, the minimum ($T_t$min) and the maximum ($T_t$max) values of the recorded data define a temperature interval. When recorded data of the volunteer fell in the ($T_t$max+2, $T_t$min-2) interval, they were kept in the database; however, when they were outside this interval, they were not included in UHI mapping.

3.1.2. Accuracy of spatial information

Young volunteers attending some of the schools visited in Szeged were asked to give the street and number of their house or flat. In addition, they had to give the geographical coordinates of the measurement point by copying it out from the aforementioned Google Maps website. Orientation based on a digital map is not a problem for 10-12 year old children nowadays, as they not only have the necessary minimum knowledge of cartography, but due to digital technology they are also accustomed to orientate in both the real and the virtual world.

According to Kerski, (2003) “GIS appears to improve learning of geographic content, not just skills. Furthermore, GIS fostered higher-order analytical and synthetic thinking, and increased students' knowledge of absolute and relative locations of places across the globe”.

As a result, marking the measurement point on the map was very likely to be correct. Otherwise, large-scale mapping can deal with even a 10-20 m horizontal inaccuracy. We have not dealt with vertical accuracy, since the city lies on both banks of the river Tisza, and the relative differences in altitude were not more than 3 m, i.e. in case of placing the thermometers at places with a 1.5-2 m relative height, they were almost at the same elevation above sea level.

Geocoding of Google Maps had a significant 30-100 m inaccuracy earlier. In case of Szeged and its surroundings, maps can be replaced by GeoEye satellite images recorded in 2012, the geometric resolution of which makes it possible to easily recognise the place of measurement, and the tag is assigned to the correct building. In the present project, the geographical coordinates of the measuring point had to be given on the form. Therefore, the question arises whether Google Maps assigns accurate geographic coordinates to the buildings found on the basis of street and number.

The difference between the geographical coordinates of the point of reference given with geodesic accuracy and the geographical coordinates given by Google Maps is not more than 0.00003 degree in any direction, which means that the horizontal error is less than 4 m. It means that if Google Maps finds the plot or building of the measuring point on the basis of street and number, giving the geographical coordinates of a point located inside the plot provides sufficient accuracy for generating large-scale maps (Fig. 4).

3.2. Creation of UHI maps based on VGI and wireless sensor data

3.2.1. The studied city, its urban structure, and land use

The temperature-increasing effect of cities caused by urbanisation (the so-called urban heat island - UHI) is one of the most deeply examined fields of climatology. Features of UHIs are well documented from different cities, mainly from the temperate zone (e.g. Oke, 1997; Kuttler, 1998). One of the most difficult aspects of this phenomenon is studying its peak development during the diurnal cycle. UHI intensity is in strong connection with urban land use, and mainly with the ratio of impervious materials which cover the surface. UHI mapping, on the one hand, well demonstrates the spatial variations in the urban microclimate, and, on the other hand, proves the strong impact of human activities on the environment.

The study area was the city of Szeged and its environment. Szeged is the third most populated city in Hungary (circa 170 000 inhabitants), which is located in the south-eastern part of Hungary on the Great Hungarian Plain (46°N, 20°E) at 79m above sea level, not far from the Hungarian-Serbian border.

The terrain of the city and its countryside is a large flat floodplain. The river Tisza flows through the city, however, apart from this river there are no large water bodies nearby. This geographical situation (no orographic climate influences) makes Szeged a good choice for studying a relatively undisturbed urban climate. According to Köppen's classification, the area belongs to the climatic region Cf, which means a temperate warm climate with a rather uniform annual distribution of precipitation (Péczely, 1979). After the great flood of 1879 the city had to be entirely rebuilt. The planned inner-city area was surrounded by a 12km long round dam (Körtöltés) and it was filled up, thus it became 4-6m higher than it previously had been. The new, planned structure of the city is characterised by a network of avenues and boulevards. Small settlements located outside the round dam later were annexed to the city (Fig. 5).

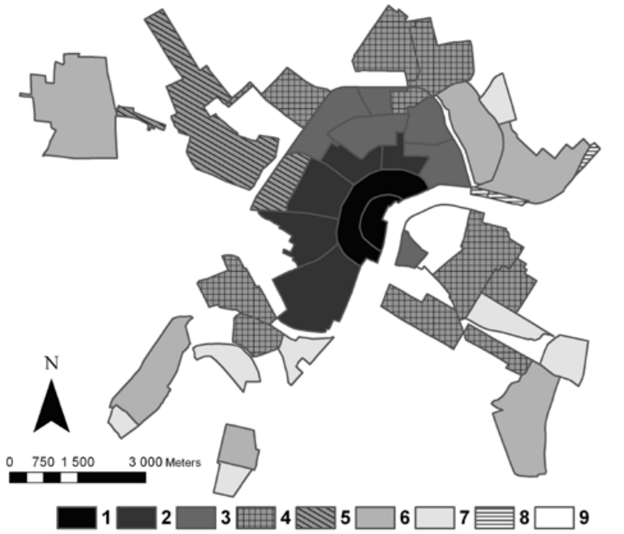

Figure 5. Inner functional districts of Szeged (Hungarian Central Statistical Office, 2003). 1 – Downtown; 2 - Inner residential area; 3 - Housing estates; 4 - Suburban residential area; 5 - Industrial area 6 - Rural residential area 7 - Weekend house area 8 - Inner resort area; 9 - Garden suburb

3.2.2. Climatological conditions before and during the data collection period

According to the Daily Weather Report of the Hungarian Meteorological Service, early winter weather characterised most of Europe on 28 October 2012. An arctic air mass was moving towards Eastern and South-Eastern Europe, and in front of it, a warm air mass was moving towards the Black Sea and the southern part of the East European Plain.

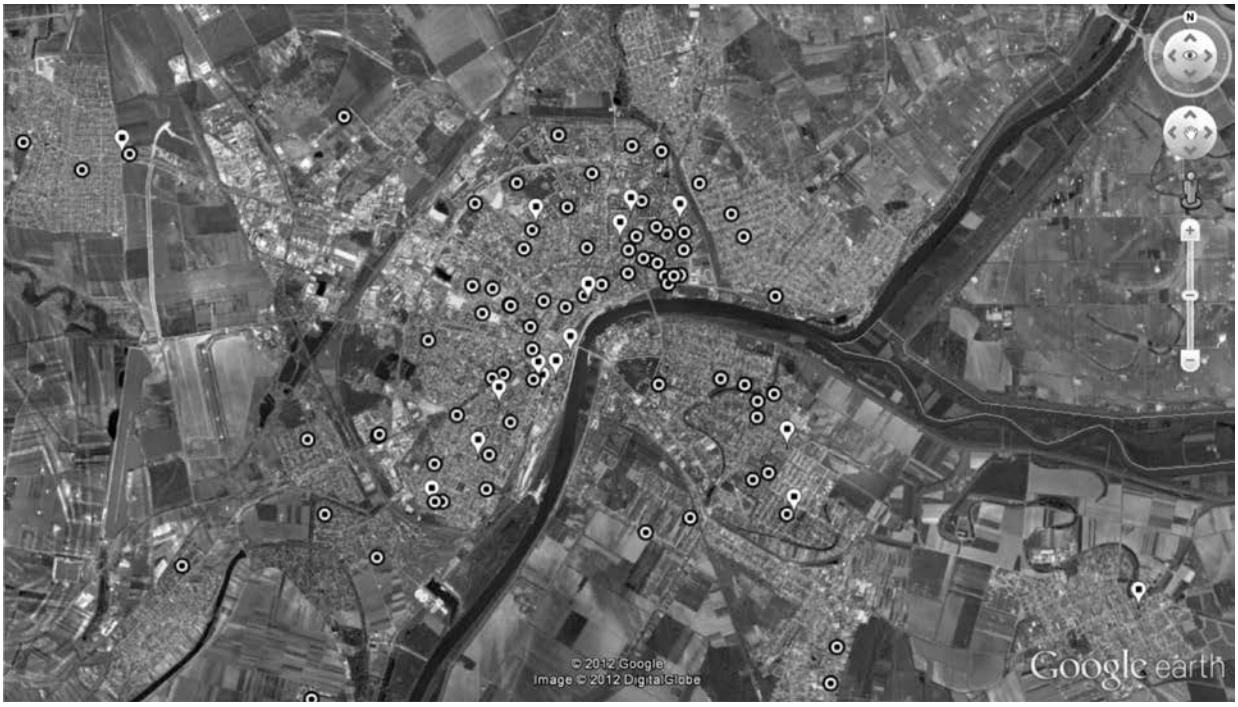

Figure 4. Location of volunteers and wireless sensors in Szeged

Along the surging frontal zone separating the two air masses, the sky was overcast and it was raining in many places. Moreover, it was snowing in Central Europe, and even in the lowland areas of the Carpathian Basin. The air temperature was only 1.8°C in early afternoon. Along the fronts connected to the cyclones, also in the central part of the Carpathian Basin, the sky was heavily overcast and it was raining in many places.

Several waves of rain coming from South and South-Western Europe were passing through the country. In the morning it was snowing in some places in the north-western part of Hungary, while in other places it was raining and sleeting. The maximum temperatures varied between 3°C and 7°C.

The weather gradually improved in the period October 29-31. At the beginning of the measurement period the sky was overcast, but the clouds had cleared up by Wednesday (31 October), therefore temperatures had fallen to -4°C and +2°C by dawn on Wednesday.

It was sunny with 7-10 hours of sunshine in much of the country on Wednesday and, as a result, maximum temperatures were between 8°C and 14°C.

The warm front brought about very cloudy or overcast skies, scattered showers and rain in much of the country again on 1 November. The clouds cleared up only in some places in the southern part of the country. The south-easterly winds increased in several places and it was stormy in the Southern Great Plain. Maximum temperatures were generally between 9°C and 15°C. The weather remained predominantly overcast and humid with a relatively high maximum daily temperature of 18°C-20°C until the end of the measurement period (4 November).

3.2.3. Analysis of wireless sensor data

Sixteen sensors were placed in different parts of the city, e.g. in the courtyards of primary and secondary schools in the densely built-in central parts of the city and in the garden suburb located at the outer part of the built-up urban area. Data were automatically collected every ten minutes. Data processing was carried out in the Department of Physical Geography and Geoinformatics at the end of the measurement period. Wireless sensor data (Fig. 6.) also reveals that at the beginning of the measurement period (29 October 2012) air temperatures varied between 2°C and 5°C in the city as a result of cold air masses, precipitation and strong winds. This weather condition is not favourable for the development of the urban heat island. Due to the calm, sunny, and windless weather, daytime temperatures rose by 3°C-5°C, but there was an increase in temperature drop at night, and in some places temperatures fell below zero on 30 and 31 October. Especially the temperature values measured in the early hours on 1 November show considerable spatial differences. The minimum temperatures were 5°C-6°C in the city centre, while they were around 1°C in the garden suburb of Baktó.

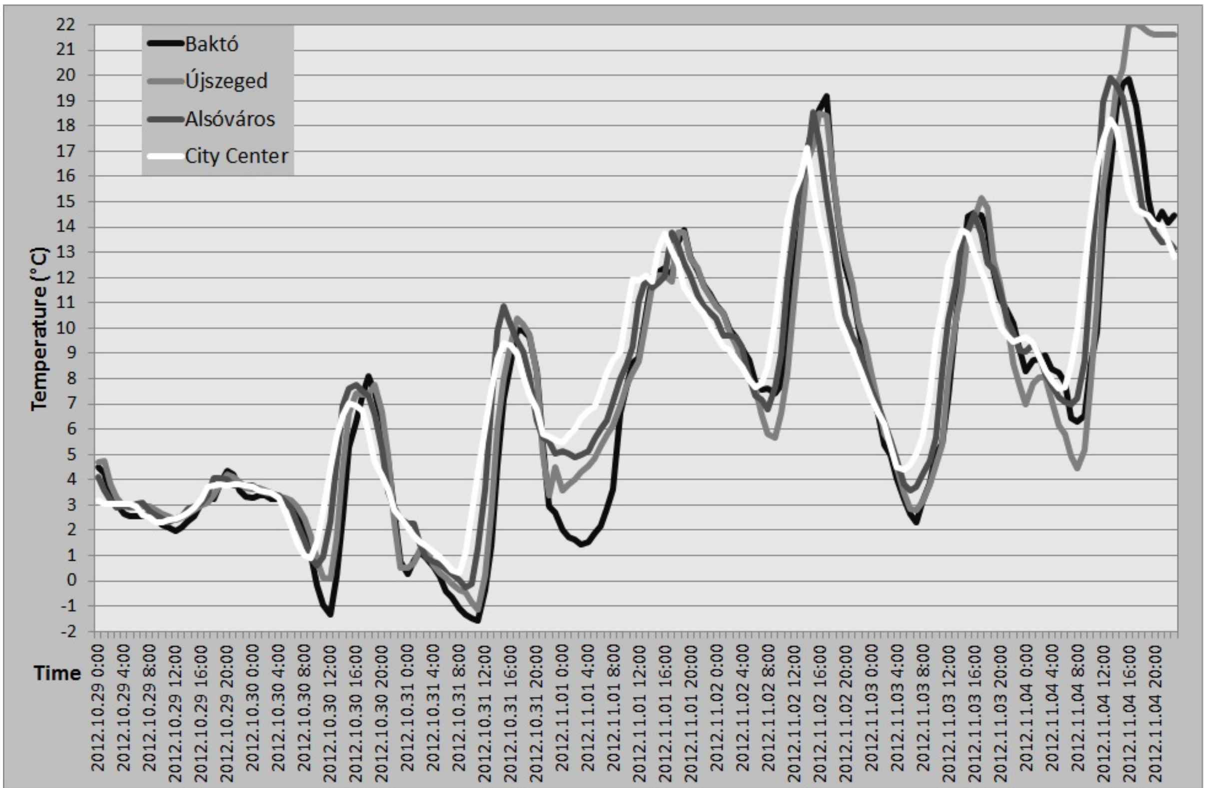

Figure 6. Weekly air temperatures recorded by wireless sensors (29th October-4th November 2012)

As it can be seen from the data of the other two sensors shown in figure 6, air temperatures gradually drop towards the outskirts of the city, in accordance with the decrease in the built-up ratio. The maximum UHI intensity was 5°C. Two days were enough for the development of the urban heat island. The developed UHI decreased due to the effect of a new warm front and the maximum UHI intensity was around 2°C during night-time and daytime.

3.2.4. Large scale UHI mapping based on VGI

Based on the weather conditions and the wireless sensor data analysed above, we have generated UHI maps for two different points in time. Permanent meteorological stations can only be found in the city centre, and at the airport located to the west of the city; therefore the UHI calculated from their data can be relevant only to a small area.

The wireless sensor network made up of 16 sensors well complemented the continuous dataset; however, it is still not enough for generating a detailed UHI map for the large inner-city area of Szeged (35 km^2). By adding the circa 100 periodic data measured by volunteers to the database, a fairly accurate map can be generated.

In present study our objectives are (1) to reveal whether there is a relationship between the UHI and the different climatic conditions using VGI based UHI maps, and (2) to find whether there is a relationship between the UHI and the built-up ratio.

Firstly, we stored data sent via the Web 2.0 application in a relational database, and after the detection of incorrect data, we generated daily UHI maps from point data using the Topo to Raster tool of ArcMap10. The Topo to Raster tool is an interpolation method specifically designed for the creation of hydrologically correct digital elevation models (DEMs). It is based on the ANUDEM program developed by Hutchinson (1989).

On the first day of the measurement period (29 October) the weather conditions were unfavourable for UHI development. The temperatures measured varied between 2°C-7°C and the highest temperatures were measured in the city centre, and in the more densely populated parts of the city (Fig. 7). The UHI intensity was just 1-2°C.

The urban heat island, which can be divided into three parts (Upper-town, City centre, and Lower-town), can be clearly seen on figure 7, on the right bank of the river Tisza, from north to south. The UHI intensity was 1°C-2°C, i.e. air temperatures in the densely built-in parts of the city hardly differed from those in the outer, suburban parts. At the same time depressions can be observed between the separate urban heat islands where air temperatures in the inner city are similar to those in the outskirts.

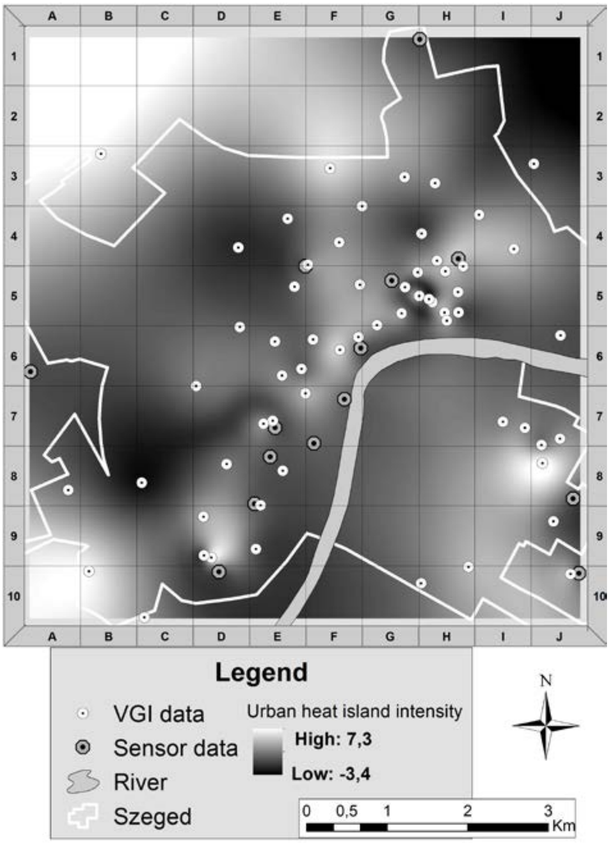

Figure 7. Spatial distribution of UHI on 29th October 2012 at 8 AM

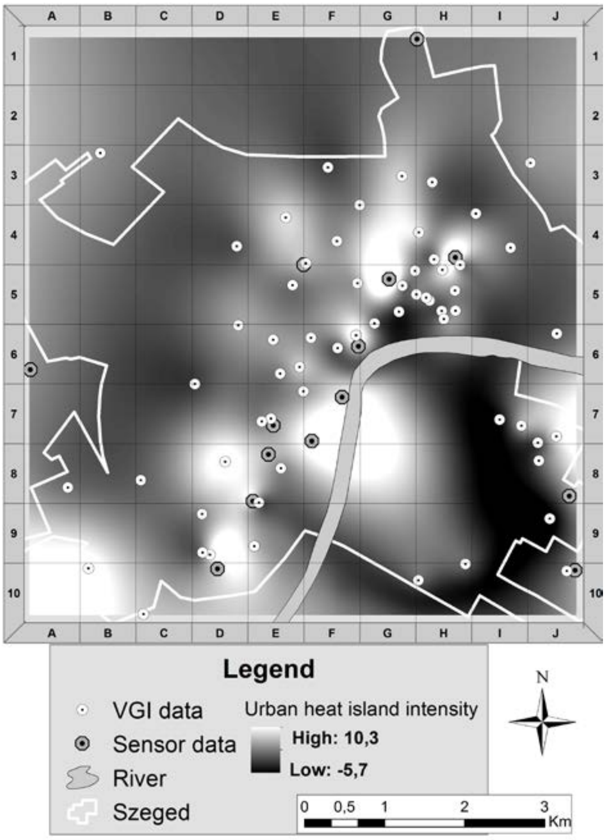

Figure 8. Spatial distribution of UHI on 31st October 2012 at 8 AM

The greatest depression developed over the largest urban green area, the Szeged Zoo. Other depressions are related to areas with low building heights, where cold air from the surrounding areas can easily flow into the city.

The UHI map based on VGI data for 31 October shows several urban heat islands (Fig. 8). They are more extended than two days before and the intensity values are also higher. The maximum urban heat island intensity values are around 7°C in the city centre.

Based on the above map it can be stated that maximum UHI intensity maps generated from VGI data can be considered reliable. They clearly show, on the one hand, the effects of weather conditions favourable or unfavourable for UHI development, and, on the other hand, the relationship between the areas with different built-up ratios and maximum UHI intensity.

3.3. Comparing UHI intensity maps and the mean UHI intensity map

Modelling mean urban heat island intensity has been going on for many years in Szeged (Unger, 1999; Unger et al, 2001), where the relationship between the urban land cover and the UHI was described with numerical models for heating (16 October-15 April) and non-heating seasons.

Besides fieldwork, we obtained built-up ratio data by sub-pixel based classification of medium and large scale satellite images. The daily mean UHI intensity can be modelled on the basis of the determined linear regression relationship between the built-up ratio (%) and the measured UHI intensity values in the heating season (Bottyán & Unger, 2000) using the following model equation (5):

$$\Delta T = 0.012 \cdot B + 0.439 \quad (5)$$

ΔT: urban heat island intensity,
B: built-up ratio (%).

The ratio map of artificial surfaces (Fig.3a) clearly shows a densely built in (70%-100%) zone between the city centre and the industrial part of the city, running in NW-SE direction.

Similarly, high values were detected along the boulevards, avenues, and building complexes with commercial, service and supply function. The ratios of artificial surfaces inside the pixels were around 30%-60% in case of the inner residential areas. In case of riparian forests and smaller or larger parks and forests located in the city the ratios varied between 0%-10%.

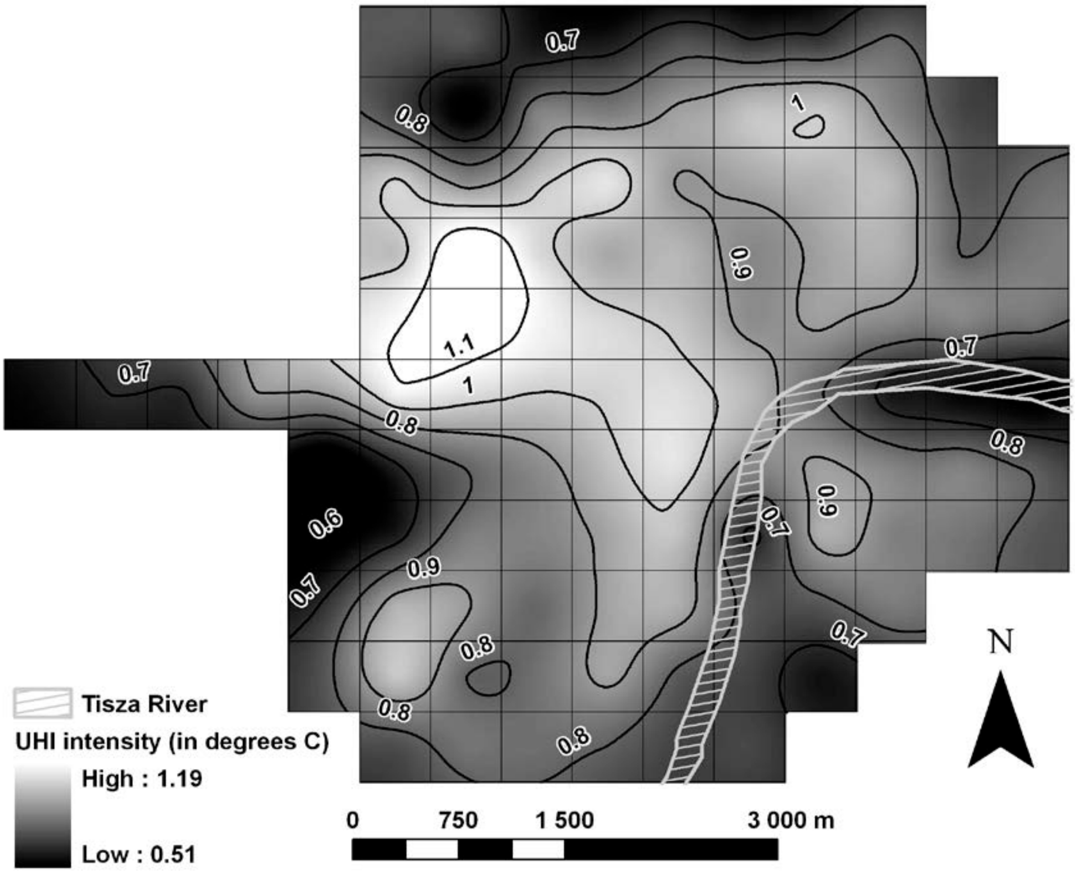

Figure 9. Map showing the spatial distribution of UHI intensity, derived from the ratio map of impervious surfaces (LTM image acquired on 16th October 2006)

A grid network comprising of 107 cells (500m x 500m in size each) was placed on the ratio map of artificial surfaces. In case of each cell, the mean built-up ratio within the given cell was assigned to its centre and the estimated daily mean UHI intensity value was calculated using the linear regression method. Using these points and the Topo to Raster interpolation method, we generated the map showing the spatial distribution of UHI intensity for the total area in Szeged (Fig. 9).

A maximum intensity zone (1-1.1°C) running from NW to SE direction, reaching the city centre, and limited only by the river Tisza in the east can be observed on the UHI intensity map. Due to the linear relationship between the built-up ratio (%) and the UHI intensity, these high intensity values developed over the aforementioned densely built-in industrial area, and the city centre.

In addition, there were higher UHI intensity values (0.9-1°C) over a housing estate zone located in the north-eastern part of the city. Lower UHI intensity values (0.6-0.7°C) characterised the Szeged Zoo area located in the west, and the northern, north-eastern rural, suburban parts of the city. The mean UHI intensity map and the maximum UHI intensity map generated from the VGI data show a strong correlation. The three urban heat islands, located in the northern, central and southern parts of the city, can be clearly identified on both maps. The reliability of VGI data is also proved by the fact that on the mean UHI intensity map maximum values are related to the central heat island; similarly, maximum intensity values appear in the city centre on the map generated from the VGI data.

3.4. Presentation of results for volunteers in classroom

One of the most important parts of a scientific project based on volunteered geographic information is the feedback, in course of which the volunteers can get more information about the results of the project. Through the feedback the volunteers can themselves feel that they are part of a bigger group sharing a common field of interest. Due to the visible results (like maps) their activity does not reduce, and their motivation survives. Primary and secondary school pupils were involved in our project. Besides the necessary geographical experience they do not have more knowledge about complex GIS models (like surface modelling from point sources), so the analysis of the recorded VGI and UHI mapping were prepared by the authors.

After the mapping and spatial analysis the scientific results were presented to the participating volunteers in the primary and secondary schools, and the authors met the volunteers personally. The researchers highlighted the importance of the volunteers' activity in the project. In course of these discussions they emphasized the effects of human-environment interaction, the relationship between urban and local climate, as well as the connection between urban land cover and the development of urban heat islands, this way strengthening the importance of protecting our environment.

4. CONCLUSIONS

Young volunteers (primary and secondary school students) were motivated and involved in our research study and a direct contact was built up between project managers and volunteers through teachers. Volunteered geographic information (VGI), created by young volunteers, was collected with the help of Web 2.0 technology and it was complemented by wireless sensors developed for air temperature measurement. Detailed daily UHI maps were generated from the collected data and these maps were compared to the medium scale UHI maps, which were created by impervious surface maps derived from the spectral mixture analysis of a Landsat TM image. Very strong connection could be recognized between the urban land cover and the spatial distribution and size of the urban heat islands.

Volunteer geographic information derived from the Web 2.0 highlighted the importance of volunteers' activity as citizen sensors. The combination of VGI, conventional and web-based GIS applications, and remote sensing are useful in and contribute to geography education. The participation in a VGI-based research project encouraged pupils to record spatial data, and to develop spatial knowledge by observing their environment. The preparation and analysis of self-measured spatial information will inspire pupils' interests in learning further geographic and environmental issues.

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