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Krzysztof Błażejczyk
University of Warsaw,
Faculty of Geography and Regional Studies,
Department of Climatology
00–927 Warszawa, ul. Krakowskie Przedmieście 30
e-mail: kblazejczyk@uw.edu.pl

MAPPING OF UTCI IN LOCAL SCALE (THE CASE OF WARSAW)

Kartowanie UTCI w skali lokalnej (na przykładzie Warszawy)

Streszczenie. W opracowaniu przedstawiono zróżnicowanie przestrzenne warunków biotermicznych w Warszawie. Jako miarę warunków biotermicznych zastosowano nowy wskaźnik obciążeń cieplnych człowieka UTCI. Do obliczenia wartości UTCI zastosowano uproszczoną formułę matematyczną:
$UTCI^* = 3{,}21 + 0{,}872 \cdot t + 0{,}2459 \cdot Mrt - 2{,}5078 \cdot v - 0{,}0176 \cdot RH$
gdzie: t oznacza temperaturę powietrza (°C), Mrt – średnią temperaturę promieniowania (°C), v – prędkość wiatru 10 m nad gruntem ($m \cdot s^{-1}$), a RH – wilgotność względną powietrza (%).
Do wygenerowania map i wykonania analiz przestrzennych zastosowano program IDRISI Tajga. Zróżnicowanie przestrzenne UTCI* określono dla kilku scenariuszy pogodowych:
– pochmurno (lub słonecznie), t = 10°C, RH = 50%, v = 8 $m \cdot s^{-1}$,
– pochmurno (lub słonecznie), t = 20°C, RH = 50%, v = 4 $m \cdot s^{-1}$,
– pochmurno (lub słonecznie), t = 30°C, RH = 80%, v = 2 $m \cdot s^{-1}$.
Stwierdzono wyraźny wpływ różnych typów użytkowania terenu na kształtowanie w ich obrębie warunków biotermicznych określonych za pomocą wskaźnika UTCI. Zróżnicowanie to jest szczególnie widoczne podczas pogody chłodnej i wietrznej oraz gorącej i wilgotnej. Wyróżniają się obszary leśno-parkowe, które łagodzą warunki chłodu oraz gorąca.

Key words: UTCI, Warsaw, GIS, recreational potential, bioclimatic conditions
Słowa kluczowe: UTCI, Warszawa, GIS, potencjał rekreacyjny, warunki bioklimatyczne

INTRODUCTION

The recent bioclimatic research should provide detail information regarded actual impacts of ambient environment on human organism. This issue is especially important for recreational and tourism purposes. Both activities should bring us satisfaction and relaxation. Meteorological conditions are important agents of well being in man (Blazejczyk 2007). They can support our mental-and-physical comfort or they can be limiting factors for outdoor activity (Scott, Dowson 2007). Local factors also play important role in creating climate felt by man (Kunert 2010).

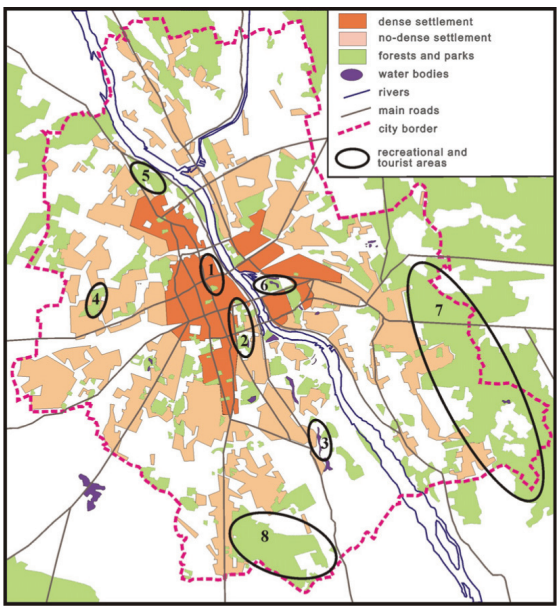


Fig. 1. Principal components of land use in Warsaw and main recreational and tourist areas: 1 – Old Town, 2 – Royal Parks, 3 – Wilanów Royal Residence, 4 – winter sport centre, 5 – forest park, 6 – football stadium (for Euro 2012), 7, 8 – protected forests
Ryc. 1. Podstawowe elementy zagospodarowania terenu w Warszawie oraz główne obszary aktywności rekreacyjnej i turystycznej: 1 – Stare Miasto, 2 – Łazienki, 3 – Wilanów, 4 – Szczęśliwice, 5 – Bielany, 6 – Park Skaryszewski i Stadion Narodowy, 7 – Mazowiecki Park Krajobrazowy, 8 – Las Kabacki

Thus, the evaluation of bioclimatic conditions in recreational and tourism areas, both temporal and spatial is very important in tourism information. The aim of the paper is to present spatial differentiation of biothermal conditions in Warsaw at various weather scenarios. The special attention will be paid for main recreational and tourist areas in Warsaw (Fig. 1). The places mostly visited by tourists are: Old Town, Royal Parks, Wilanów and football stadium where Euro

Cup 2012 will take place. Also, the residents of Warsaw practice their daily and weekend recreation in areas marked at figure 1.

The aim of the paper is to present the background and operational procedures used for creating local scale bioclimatic maps of Universal Thermal Climate Index (UTCI).

METHODS

For the assessment of biothermal conditions the new developed Universal Thermal Climate Index UTCI was used. The UTCI represents air temperature of the reference conditions (i.e. no solar and thermal radiation, no wind, relative humidity of 50%) with the same physiological response as the actual conditions (Blazejczyk et al., 2010). The UTCI is a new bioclimate index, developed in the frame of COST Action 730. It assesses heat stress in man outdoor during mild walking (4 $km \cdot h^{-1}$).

The calculations were made as a part of Geographical Information System created for Warsaw with the use of IDRISI Tajga software package (Kozłowska-Szczęsna et al. 1996). The system consists of three groups of layers: basic environmental layers (land use, types of relief, ground moisture, surface temperature), basic topoclimatic layers (global solar radiation, air temperature, wind speed, air humidity) and bioclimatic layers (mean radiant temperature, UTCI). Values of particular meteorological components were calculated by reclassification of environmental layers and reinterpretation of LANDSAT surface temperature. Bioclimatic variables were calculated for various weather scenarios for summer season. In the present paper the following weather scenarios are discussed:

- cloudy (or sunny), air temperature of 10°C, air humidity of 50%, wind speed of 8 $m \cdot s^{-1}$,
- cloudy (or sunny), air temperature of 20°C, air humidity of 50%, wind speed of 4 $m \cdot s^{-1}$,
- cloudy (or sunny), air temperature of 30°C, air humidity of 80%, wind speed of 2 $m \cdot s^{-1}$.

For the calculations of Universal Thermal Climate Index the following simplified equation (UTCI*) was applied:

$$UTCI^* = 3{,}21 + 0{,}872 \cdot t + 0{,}2459 \cdot Mrt - 2{,}5078 \cdot v - 0{,}0176 \cdot RH \qquad (1)$$

where: t is air temperature (°C), Mrt is mean radiant temperature (°C), v is wind speed at 10 m above ground ($m \cdot s^{-1}$), RH is relative humidity of air (%).

Simulated UTCI* values were also compared with UTCI calculated on the base of observed meteorological data.

RESULTS

Warsaw is a city with an area of about 500 km^2 and with significant differentiation of land use (Fig. 2).

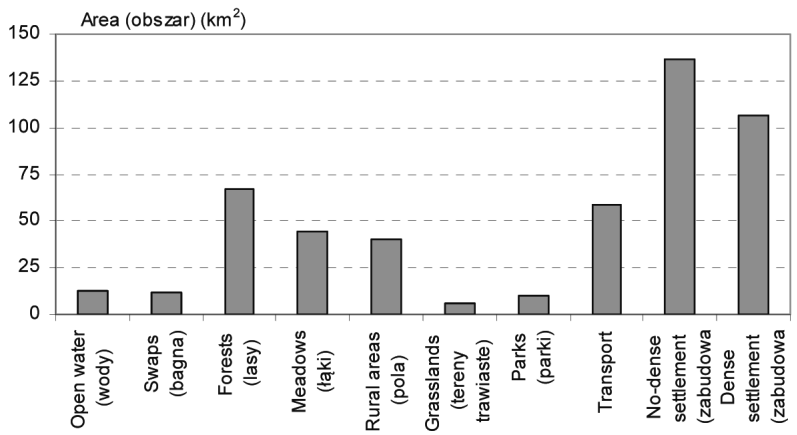


Fig. 2. Area of various land use types in Warsaw
Ryc. 2. Powierzchnia zajmowana przez różne typy użytkowania terenu w Warszawie

About 243 km^2 is a built-up area (28% no-dense and 22% dense settlements). Forests cover about 13% of city area. 85 km^2 is still used for agriculture as meadows and fields. Relatively great area (about 60 km^2, i.e. 12%) is used for transport system (roads and railways). For tourism and recreational purposes the forests and city parks are mainly used. Tourists are concentrated in the centre of the city (dense settlement) where Old Town, museums and theatres are located. The another tourist place, the Wilanów Royal Residence, is located in the south part of the city with no-dense settlements. Daily recreational activity of Warsaw's citizens is practice in parks and forests.

When comparing biothermal conditions in selected types of land use in various weather scenarios we can notice that the greatest spatial differentiation of UTCI* is observed during low air temperature and strong winds. The mean UTCI* value for whole city area is about 2°C in cloudy and 4°C in sunny weather. In particular recreationally used types of landscape UTCI* is significantly higher, especially inside forests (Fig. 3). On the other hand during high air temperature forests reduce sensible temperature of about 5–6°C in comparison to city centre. Hot, sunny and humid weather is mostly stressed for tourists in the city centre. During weather with moderate temperature, humidity and wind speed there are not significant differences between tourist and recreation areas in Warsaw.

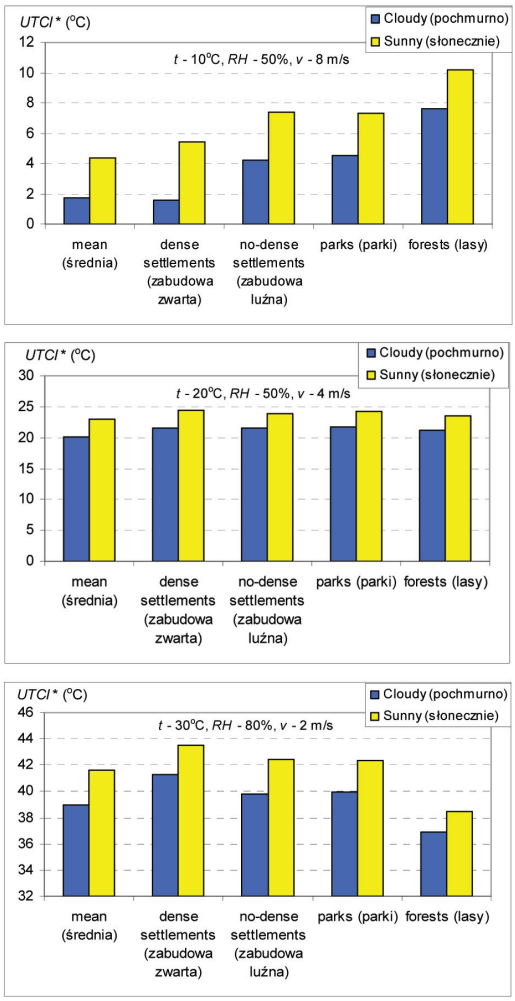


Fig. 3. Mean values of UTCI* in selected types of land use in various weather scenarios
Ryc. 3. Średnie wartości UTCI* w wybranych typach użytkowania terenu w różnych scenariuszach pogody

The spatial distribution of UTCI* categories are presented on figure 4. The smallest differentiation of heat stress is observed at moderate temperature (20°C), humidity (50%) and wind speed (4 $m \cdot s^{-1}$). Independent on cloudiness UTCI* values are at majority of city area within the range of "no thermal stress" (9–26°C). In sunny summer days moderate heat stress (26–32°C) can be found only inside industrial and very dense settlement areas. During extreme weather conditions complicated city structure create great spatial differentiation of biothermal conditions. At cloudy, cool and windy weather UTCI* in the city downtown can fall down to moderate cold stress range. On the other hand dur-

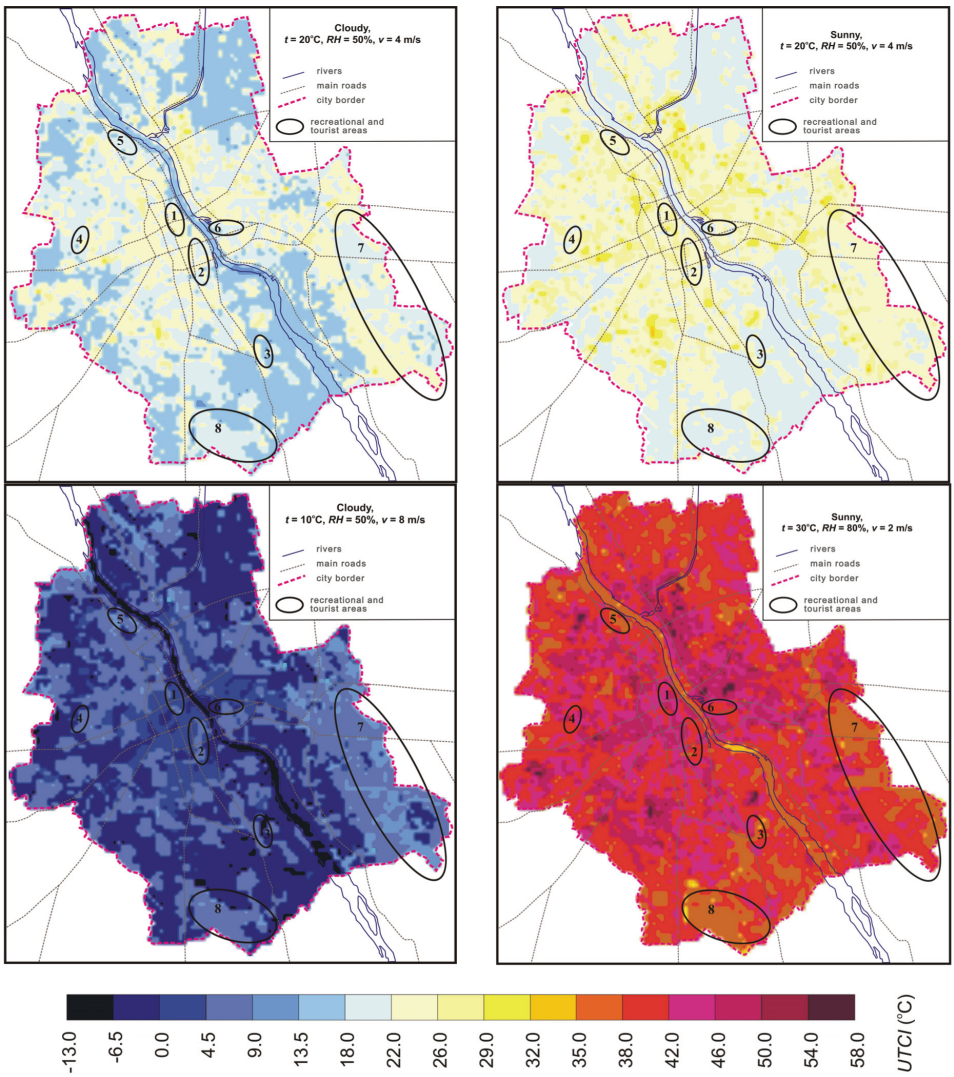


Fig. 4. Spatial distribution of UTCI* in Warsaw in selected weather scenarios
Ryc. 4. Rozkład UTCI* w Warszawie w różnych warunkach pogodowych

ing sunny, hot, humid and calm weather several hot spells with extreme heat stress are found in the city centre.

The specificity of bioclimatic conditions in Warsaw is also well seen when considering what kind of heat stress predominates in various types of land use in different weather conditions. During cool and windy weather in dense settlements moderate cold stress can occur at about 40% of their area. At the same weather at no-dense settlement and in the parks only at 21–24% of their areas

moderate cold stress is observed. However, slight cold stress predominates at 70–74% of those landscapes. In the forests, moderate cold stress is very rare. However, we can experience no thermal stress at more then 36% of forested. During the weather of moderate temperature, humidity and wind speed UTCI* represented thermoneutral zone (18–26°C) predominate in all studied types of land use; depending on solar radiation at 80–93% of considered areas have optimal conditions for tourism and active recreation areas (Tab. 1).

Table 1. Percentage of areas with specific UTCI* range in selected types of land use in Warsaw

Tabela 1. Procentowy udział obszarów reprezentujących różne zakresy UTCI* w wybranych typach użytkowania terenu w Warszawie

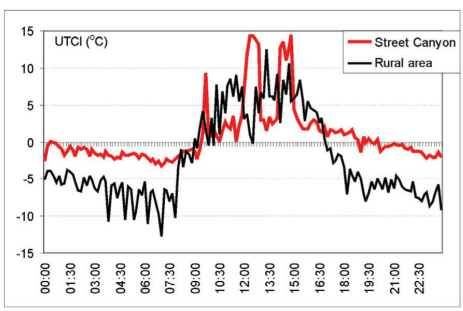
Weather scenario	UTCI* range (°C)	Cloudy					Sunny				
		mean	dense settlements	no-dense settlements	parks	forests	mean	dense settlements	no-dense settlements	parks	forests
t – 10°C, RH – 50%, v – 8 m·s^{-1}	–13 ÷ –6.5	4.3	1.0	1.4	0.6	1.3	0.1	0.1	×	×	0.3
	–6.5 ÷ 0	**42.6**	**38.3**	23.0	20.0	5.2	33.7	6.5	16.9	5.2	4.9
	0 ÷ 4.5	9.1	27.6	4.1	11.6	1.2	16.2	**38.5**	8.7	21.3	1.6
	4.5 ÷ 9	35.9	32.0	**66.9**	**59.4**	**56.0**	12.5	30.1	15.4	29.7	5.5
	9 ÷ 13.5	8.0	1.2	4.5	8.4	36.0	**36.4**	24.7	**57.5**	**41.9**	**84.9**
	13.5 ÷ 18	0.1	×	×	×	0.2	1.1	0.1	1.4	1.9	2.8
t – 20°C, RH – 50%, v – 4 m·s^{-1}	9 ÷ 13.5	0.6	0.2	0.1	×	1.0	×	×	×	×	×
	13.5 ÷ 18	**33.2**	9.5	17.2	6.5	5.3	×	×	×	×	×
	18 ÷ 22	32.2	44.1	27.0	**48.4**	**54.3**	38.9	13.1	21.8	14.8	17.2
	22 ÷ 26	32.0	**44.7**	**54.4**	40.6	38.7	**45.7**	**63.2**	**57.7**	**65.8**	**76.2**
	26 ÷ 29	1.8	1.5	1.3	4.5	0.5	13.0	20.4	19.2	14.8	5.9
	29 ÷ 32	0.1	×	×	×	0.2	2.3	3.3	1.3	4.5	0.5
	32 ÷ 35	×	×	×	×	×	0.1	×	×	×	0.2
t – 30°C, RH – 80%, v – 2 m·s^{-1}	26 ÷ 29	0.0	0.1	×	×	0.1	×	×	×	×	×
	29 ÷ 32	0.6	0.3	×	×	0.9	0.1	×	×	×	0.5
	32 ÷ 35	13.9	3.9	4.5	8.4	14.1	0.7	0.2	0.1	×	0.9
	35 ÷ 38	**34.4**	17.9	23.8	23.9	**66.0**	17.8	3.7	2.1	9.0	**51.6**
	38 ÷ 42	29.0	26.8	**55.8**	**46.5**	14.9	**43.3**	30.1	**48.6**	**52.3**	39.5
	42 ÷ 46	17.3	**47.5**	8.7	11.0	3.2	22.5	**41.3**	36.1	19.4	6.0
	46 ÷ 50	4.3	3.3	7.2	9.0	0.7	13.5	23.6	11.7	12.3	1.1
	50 ÷ 54	0.6	0.2	0.1	1.3	0.1	1.7	1.0	1.3	6.5	0.4
	54 ÷ 58	×	×	×	×	×	0.4	×	0.1	0.6	×

Categories of UTCI* observed in present studies: from –13 to 0 – moderate cold stress, 0–9 – slight cold stress, 9–18 – no thermal stress, 18–26 – no thermal stress (thermoneutral zone), 26–32 – moderate heat stress, 32–38 – strong heat stress, 38–46 – very strong heat stress, > 46°C – extreme heat stress

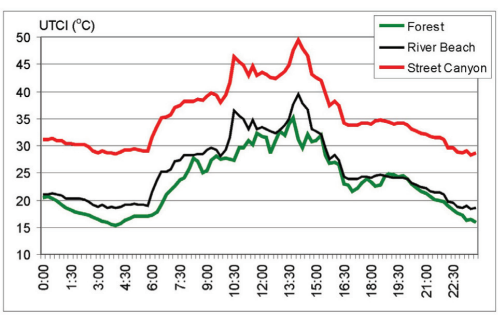
At the weather with weak winds and high air temperature and humidity bioclimatic conditions are most stressful for tourism and active recreation. In settled areas as well as in parks located in the city centres very strong heat stress predominates. Only inside the forests bioclimatic conditions are relatively milder and strong heat stress is the most frequent range of UTCI*.

The simulated values of UTCI* were validated with the use of experimental data taken from field experiments carried out in Warsaw. For this data full version of UTCI was calculated with the use of BioKlima©2.6 software package. Four types of landscapes were chosen: street canyon in downtown, rural area, forest and river beach. Figure 5 gives two examples of field research. Data from street canyon and rural area represent sunny day in autumn (October). There is well seen higher UTCI in the city centre then in its vicinity, especially in the night hours. During the day UTCI in street canyon is periodically lower then at open area. It is due to low Sun altitude that cause great shadows in the street bottoms. This is the phenomenon that was found in UTCI* simulations for cool, windy weather (Fig. 4).

The second example represents sunny summer day (July) with relatively high temperature as well as moderate humidity and weak wind. In such condi-



October



July

Fig. 5. Daily courses of UTCI in selected types of land use in Warsaw
Ryc. 5. Przebieg dobowy UTCI w wybranych dniach października i lipca w niektórych typach zagospodarowania terenu

tions street canyon, forest and river beach were examined. The highest UTCI was observed in street canyon. At river beach and in forest its values were significantly lower. An interested founding was that forest was the coolest type of landscape, of about 3–5°C cooler then river bank. Also this experimental data well fit to simulations made for hot, humid weather (see Fig. 4).

CONCLUSIONS

The use of Geographical Information System gives great possibility to provide spatial distribution of biothermal conditions, expressed by UTCI* index, in various scales and types of land use. The UTCI* simulations made for Warsaw show great spatial differentiation of heat stress in various weather scenarios. It is especially well seen during cool and windy weather as well as at hot, humid and calm conditions. The greatest differences are observed between city centre and forests. While in cool weather forests are significantly warmer then the city centre then in hot weather they are cooler that other types of city landscape.

GIS simulations of UTCI are well correlated with its values calculated on the base of observed meteorological data. It is especially seen in street canyons and forests.

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