Geographia Polonica 2013, 86, 1, pp. 47-54

Geographia Polonica
Volume 86, Issue 1, pp. 47-54
http://dx.doi.org./10.7163/GPol.2013.6

INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION
POLISH ACADEMY OF SCIENCES
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APPLICATION OF THE UTCI TO THE LOCAL BIOCLIMATE OF POLAND'S ZIEMIA KŁODZKA REGION

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Abstract

This paper presents the spatial differentiation to biothermal conditions in the Ziemia Kłodzka region of Poland, the basis for the assessment being the Universal Thermal Climate Index (*UTCI*), with spatial analysis relating to maps made using a GIS application. The differentiation to *UTCI* values was defined for several types of weather.The greatest spatial differentiation to values for heat stress is to be observed in sunny, hot and dry weather in the presence of only gentle winds. Forests stand out from other types of landscape in the way they mitigate heat loads significantly.

Key words

UTCI • Ziemia Kłodzka • Poland • GIS • bioclimatic conditions • heat loads • heat stress

Introduction

The atmospheric environment is an important agent of human wellbeing, most especially where recreation and tourist activities are concerned. Important information for tourists thus entails an assessment of bioclimatic conditions in areas of recreational and touristic significance (Błażejczyk 2011a). However, local factors are seen to play a significant role in shaping climate as actually experienced by people (Kunert 2010), hence the need for the bioclimate for tourism to be evaluated on the local scale.

While various indices have been developed over the last hundred years with a view to assessing how people are influenced by the atmosphere, most made no direct reference to physiological reactions. It was in the 1990s that there at last appeared multi-node models of human heat balance capable of considering all the mechanisms of thermoregulation. On the basis of one of these models (the *UTCI*-Fiala multi-node model (Fiala et al. 2011)), a new index for the assessment of human heat loads known as the Universal Thermal Climate Index was developed (see articles in the current issue Bröde et al. 2013; Błażejczyk et al. 2013).

In the above regard, the aim of this paper is to present the spatial differentiation to biothermal conditions in Poland's Ziemia Kłodzka region, under various types of weather. The assessment in question made use of the Universal Thermal Climate Index (*UTCI*). The Ziemia Kłodzka region is frequently visited by tourists because of its attractive location in the Sudetic Mts. (Fig. 1), as well as the presence of several Polish health resorts.

Figure 1. Location of the study area within the territory of Poland (marked in grey).

Methods and data

The assessment of bioclimatic differentiation is based on spatial distribution maps for *UTCI*, which is expressed as an equivalent ambient temperature (°C) of a reference environment providing the same physiological response of a reference person as the actual environment (Błażejczyk et al. 2011). The reference condition is characterised by an activity level corresponding to walking 4 km/h, and by an environment determined by calm air (wind speed 0.5 $m \cdot s^{-1}$, 10 m above the ground, corresponding to approximately 0.3 $m \cdot s^{-1}$ at the level of the person), no additional thermal irradiation and 50% relative humidity, but vapour pressure capped at 20 hPa (Bröde et al. 2011).

Calculations of the *UTCI* were made using the Geographical Information System created for the Ziemia Kłodzka region using the *ArcMap 9.3* (ArcView license level) application. This system consists of two primary groups of data: basic information about the geographical environment (land use, types of relief, ground moisture) and basic topoclimatic information (global solar radiation, surface albedo, air temperature, wind velocity) (Błażejczyk 2001). Environmental information was archived in the raster mode at a resolution of 0.5 kmx0.5 km. It was derived from various sources. The land-use layer (Fig. 2) is based on Corine Land Cover 2006 data (GIOŚ 2011). These data were collected in regard to: forests, fields and wastelands, meadows, parks, rural settlement, urbanised areas and transport areas. Assigned to each raster was the environmental feature accounting for at least half of its area. The layer with types of relief (Fig. 2) was developed using the Digital Terrain Elevation Data (DTED) for level 2 (NGIA 2000). Forms of relief were categorized as: upland, valley, hill and peak, ridge, S slope, N slope and E or W slope as one category. The ground moisture layer (Fig. 2) was prepared by reclassification of the two previous layer (categories of ground moisture: dry, wet, watered) (Milewski 2011). Values for particular meteorological components (global solar radiation, air temperature, wind velocity) were not obtained by field measurement, but through reclassification of environmental layers. This procedure required averaged values for modifying coefficients of meteorological elements in different types of environment compared with standard conditions (at the local meteorological station) (Błażejczyk 2001; Kunert 2010). In this study, the values for meteorological components were calculated in relation to meteorological elements predicted for the station in Kłodzko (WMO-number: 12520; 50°26'N, 16°37'E; 356 m above mean sea level). Bioclimatic variables (*UTCI*, mean radiant temperature) were computed for various types of weather for the summer season, with the same resolution as for the environmental layers.

This paper addresses the following types of weather:

1. sunny (or cloudy), air temperature of 10°C, air humidity of 80%, wind velocity of 6 $m \cdot s^{-1}$,
2. sunny (or cloudy), air temperature of 20°C, air humidity of 50%, wind velocity of 4 $m \cdot s^{-1}$,
3. sunny, air temperature of 30°C, air humidity of 40%, wind velocity of 1 $m \cdot s^{-1}$.

Calculations of the *UTCI* made use of the following simplified equation:

$$UTCI = 3.21 + 0.872 \cdot t + 0.2459 \cdot Mrt + \\ -2.5078 \cdot v - 0.0176 \cdot RH \quad (1)$$

where:

t – air temperature (°C),
Mrt – mean radiant temperature (°C),
v – wind velocity at 10 m above ground ($m \cdot s^{-1}$),
RH – relative humidity of air (%) (Błażejczyk 2011a).

One input datum involved in the calculation of the *UTCI* is mean radiant temperature, a value that characterises the thermal impact of solar radiation and air temperature on human beings. It represents a uniform surface temperature of an

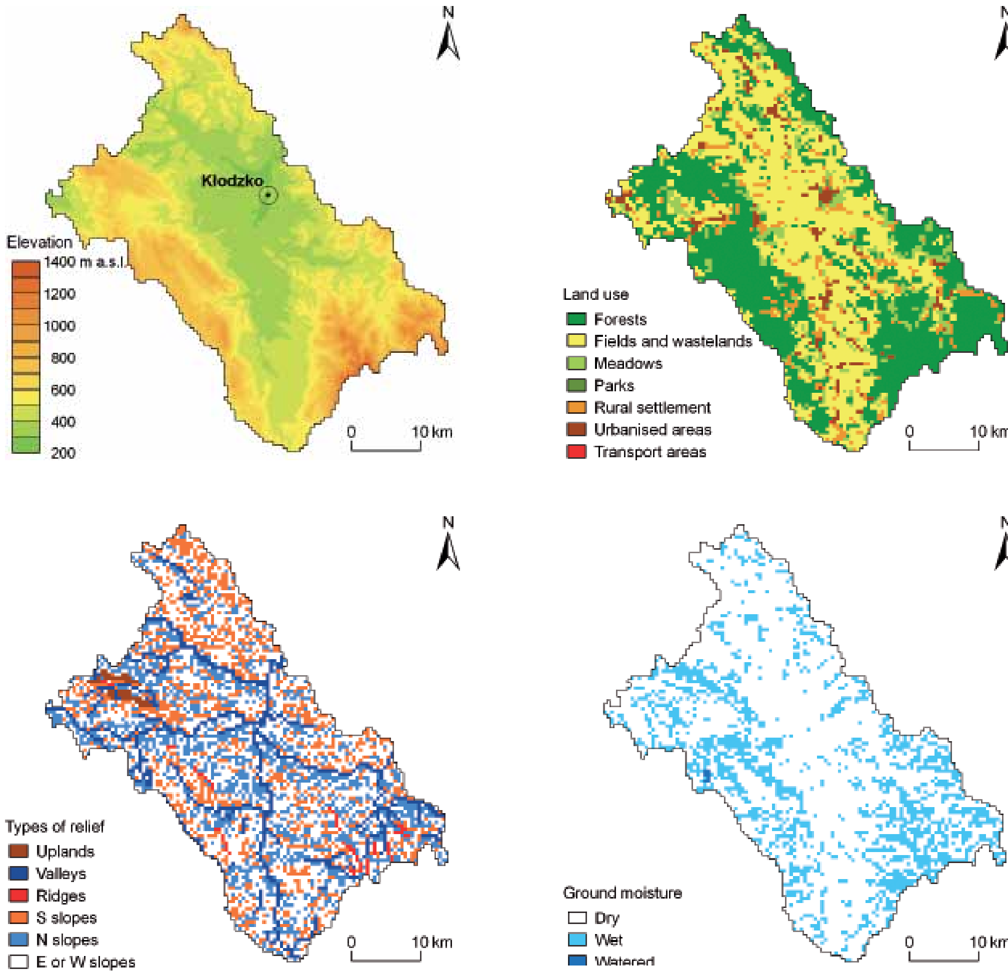

Figure 2. Elevation, land use, types of relief and ground moisture in the Ziemia Kłodzka region.

imaginary enclosure surrounding the person. *Mrt* was calculated in line with the equation:

$$Mrt = [(R' + 0.5 \cdot Lg + 0.5 \cdot La) / (s_h \cdot s)]^{0.25} + -273 \quad (2)$$

where:

- R' – solar radiation absorbed by a nude man ($W \cdot m^{-2}$),
- Lg – ground radiation ($W \cdot m^{-2}$),
- La – back radiation ($W \cdot m^{-2}$),
- s_h – the emissivity coefficient for the human body (=0.95),
- s – the Stefan-Boltzmann constant ($=5.667 \cdot 10^{-8}$, $W \cdot m^{-2} \cdot K^{-4}$) (Błażejczyk 2011b).

A detailed description of the *Mrt* calculations can be found in Błażejczyk (2004).

To calculate *Mrt*, global solar radiation intensity was set at 800 $W \cdot m^{-2}$ for a sunny day and 200 $W \cdot m^{-2}$ for a cloudy day. This study takes into account changes in air temperature due to altitude (vertical temperature gradient $\gamma = 0.6°C \cdot 100\ m^{-1}$), while proceeding on the assumption that relative humidity does not change with altitude over the area as a whole. This assumption reflects what is known to be a very limited influence of relative humidity on the *UTCI*.

Results

The Ziemia Kłodzka region is represented by full square rasters within the border of Kłodzko poviat ('county'). Ziemia Kłodzka is taken to have an area of about 1,570 km², of which forests cover 44%.

An equally extensive area is put to agricultural use as fields and meadows. About 160 km^2 is built-up, 107 km^2 of that in villages and the rest in towns (Fig. 3). In the Ziemia Kłodzka region, most of the tourist trails are located in mountain areas covered by forest, so for tourism purposes it is mainly forests that are used. Further important further areas of tourist activity are towns, and most especially those enjoying the status of health resort (i.e. Długopole-Zdrój, Duszniki-Zdrój, Kudowa-Zdrój, Lądek-Zdrój and Polanica-Zdrój) (Kozłowska-Szczęsna et al. 2002).

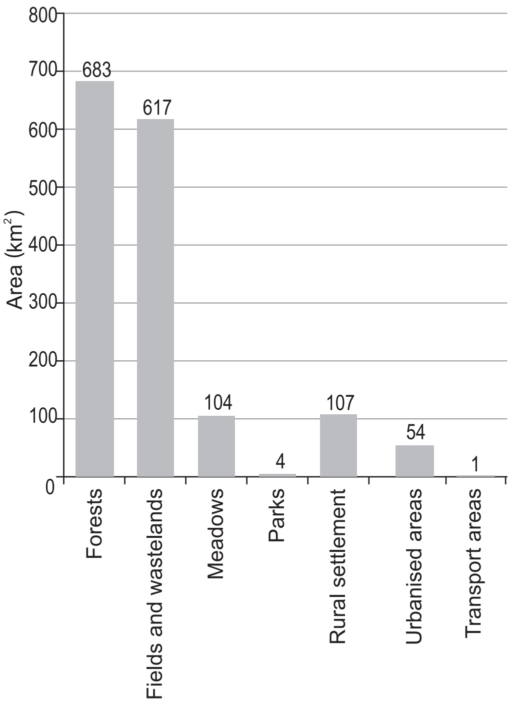

Figure 3. Area accounted for by various types of land use in the Ziemia Kłodzka region.

The comparison of *UTCI* values in relation to different types of land use under various weather conditions reveals that the greatest spatial differentiation to the *UTCI* is observed when air temperatures are high and winds weak (Tab. 1). Average *UTCI* values range from about 29°C in forests to 47°C in urbanised areas. Forests are thus the least stressful places for tourists on hot, sunny and dry days. On the other hand, at times of low air temperature, forests step the sensible temperature up by about 4°C on a sunny day and 10°C on a cloudy day, as compared with the meadows that are mostly cold-stressed irrespective of cloudiness. In cool and windy weather, biothermal conditions are least stressful in urbanised areas and parks (only on sunny days), this being a favourable feature for health-resort visitors. Urbanised areas are not favourable to tourist activity on hot and sunny days with only gentle winds. In turn, under weather that entails moderate temperatures and wind velocities, there are no significant differences noted between individual land-use types. Only urbanised areas stand out on account of values for the *UTCI* that are higher than with other types of land use.

When comparing the average *UTCI* values associated with different types of land use under three weather scenarios, sunny days are found to be associated with the greatest difference between the third and first scenarios in the case of rural settlement (Fig. 4). This exceeds 36°C, thereby demonstrating that it is these areas that

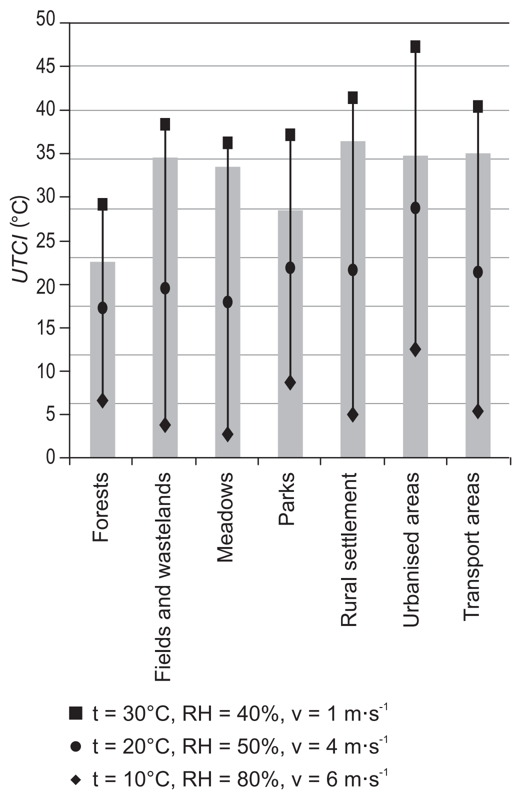

Figure 4. Average values for the *UTCI* under various types of land use and different weather conditions with a cloudless sky, and the difference between *UTCI* values for scenarios with an air temperature of 30°C or of 10°C (marked by grey bars).

Table 1. Minimum, maximum and average values for the *UTCI* under various types of land use and in different weather conditions.

Land use	Sunny			Cloudy		
	min	max	avg	min	max	avg
	t=10°C, RH=80%, v=6 m·s^{-1}					
Forests	2.6	9.0	6.6	2.6	9.0	6.6
Fields and wastelands	-1.7	6.8	3.8	-7.5	0.9	-2.0
Meadows	-2.3	6.1	2.7	-8.1	0.2	-3.1
Parks	7.8	9.1	8.7	2.7	4.1	3.6
Rural settlement	1.6	7.9	5.0	-4.2	2.1	-0.7
Urbanised areas	10.0	13.6	12.5	4.6	8.3	7.2
Transport areas	3.7	7.3	5.4	-1.7	1.5	-0.4
$avg_{max} - avg_{min}$	-	-	9.8	-	-	10.3
	t=20°C, RH=50%, v=4 m·s^{-1}					
Forests	13.3	19.6	17.3	13.3	19.6	17.3
Fields and wastelands	15.0	21.9	19.5	9.1	16.0	13.7
Meadows	13.9	20.7	17.9	8.1	14.8	12.1
Parks	21.0	22.3	21.9	15.9	17.2	16.8
Rural settlement	18.3	24.1	21.6	12.7	18.2	15.9
Urbanised areas	26.3	29.8	28.7	20.8	24.4	23.3
Transport areas	19.9	22.9	21.4	14.4	17.1	15.6
$avg_{max} - avg_{min}$	-	-	11.5	-	-	11.3
	t=30°C, RH=40%, v=1 m·s^{-1}					
Forests	25.3	31.5	29.1	situation not considered		
Fields and wastelands	35.1	39.9	38.3			
Meadows	33.3	38.1	36.2			
Parks	36.2	37.5	37.1			
Rural settlement	38.2	43.1	41.4			
Urbanised areas	44.8	48.3	47.3			
Transport areas	39.3	41.4	40.4			
$avg_{max} - avg_{min}$	-	-	18.1			

respond most intensively to changes in weather. The most stable biothermal conditions are in turn to be observed in forests. For these areas, the difference between the scenarios discussed amounts to some 22°C. With other types of land use, the differences are similar, with only parks being characterised by relatively low *UTCI* values.

The spatial distribution to *UTCI* categories is presented in Figures 5-9. Independently of cloudiness, the most limited differentiation of heat stress is observed where temperature (20°C), humidity (50%), and wind velocity (4 m·s^{-1}) are all moderate. In the main, the *UTCI* values fall within the 'no thermal stress' range (i.e. 9-26°C, and thus encompassing the 'thermal comfort zone' of 18-26°C). On sunny summer days, moderate heat stress (26-32°C) is to be noted within urban areas only (Tab. 2). Slight cold stress (0-9°C) can only be found to a limited degree on meadows, during cloudy weather. Equally limited differentiation as regards heat stress is to be observed in sunny, cool and windy weather conditions. Almost the whole area is characterised by slight cold stress. The spatial distribution to *UTCI* values displays diversification on cloudy days. Heat stress then ranges from 'slight cold stress' to 'moderate cold stress'. Areas of the greatest tourist activity (i.e. forests, parks and areas of urban settlement) are classified within the 'slight cold stress' category. On the other hand, during sunny, hot, dry and

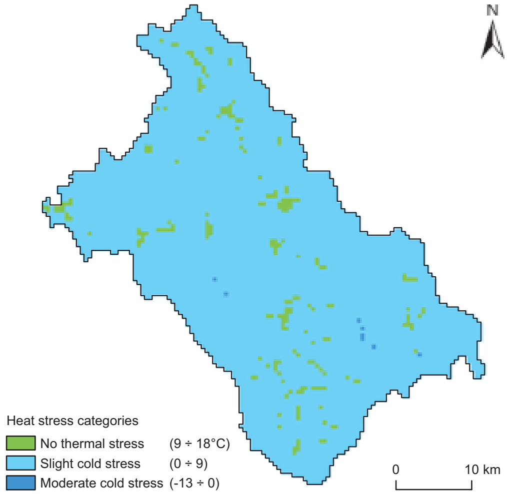

Figure 5. Spatial distribution to heat-stress categories in the Ziemia Kłodzka region on a sunny day with an air temperature of 10°C, air humidity of 80% and a wind velocity of 8 $m \cdot s^{-1}$.

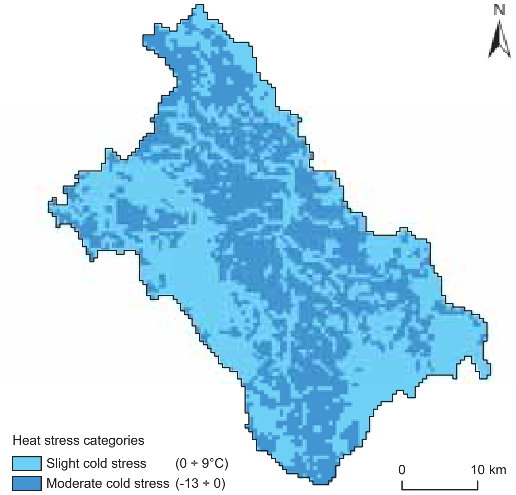

Figure 6. Spatial distribution to heat-stress categories in the Ziemia Kłodzka region on a cloudy day with an air temperature of 10°C, air humidity of 80% and a wind velocity of 8 $m \cdot s^{-1}$.

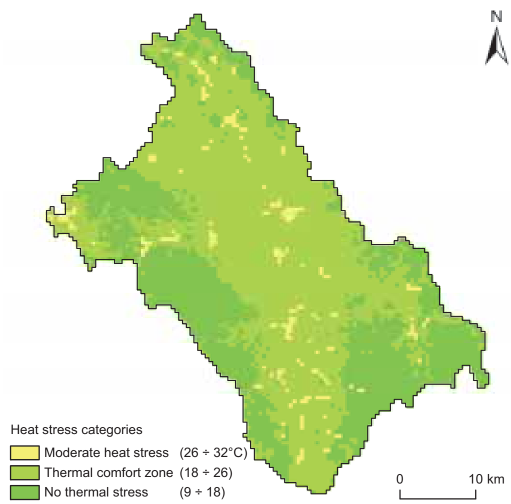

Figure 7. Spatial distribution to heat-stress categories in the Ziemia Kłodzka region on a sunny day with an air temperature of 20°C, air humidity of 50% and a wind velocity of 4 $m \cdot s^{-1}$.

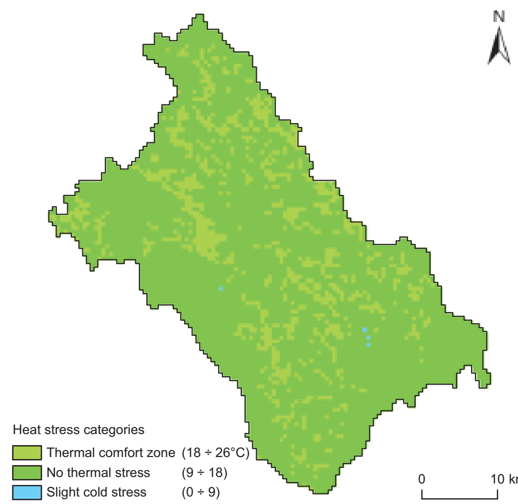

Figure 8. Spatial distribution to heat-stress categories in the Ziemia Kłodzka region on a cloudy day with an air temperature of 20°C, air humidity of 50% and a wind velocity of 4 $m \cdot s^{-1}$.

calm weather several hot spaces characterised by extreme heat stress are to be found in urbanised areas. It is under these circumstances that the spatial differentiation to heat stress is greatest. Categories of heat stress range from 'no thermal stress' in forested highest parts of mountains to 'extreme heat stress' in almost all urban areas. The category of 'moderate heat stress' only extends to the forests that are areas of most-limited heat stress. On hot days, parks are characterised by moderate heat stress, though resort to shaded places allows limited activity to be continued with.

Table 2. Percentage of areas with specific *UTCI* range under various types of land use in the Ziemia Kłodzka region.

UTCI (°C)	Forests	Fields and wastelands	Meadows	Parks	Rural settlement	Urbanised areas	Transport areas	Forests	Fields and wastelands	Meadows	Parks	Rural settlement	Urbanised areas	Transport areas
	sunny							cloudy						
	t=10°C, RH=80%, v=6 m·s^{-1}													
9-18	0.0	0.0	0.0	14.3	0.0	100.0	0.0	-	-	-	-	-	-	-
0-9	100.0	100.0	98.3	85.7	100.0	0.0	100.0	100.0	5.5	1.7	100.0	25.1	100.0	33.3
-13-0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	94.5	98.3	0.0	74.9	0.0	66.7
	t=20°C, RH=50%, v=4 m·s^{-1}													
26-32	0.0	0.0	0.0	0.0	0.0	100.0	0.0	-	-	-	-	-	-	-
18-26	27.3	95.3	51.8	100.0	100.0	0.0	100.0	27.3	0.0	0.0	0.0	5.9	100.0	0.0
9-18	72.7	4.7	48.2	0.0	0.0	0.0	0.0	72.7	100.0	99.0	100.0	94.1	0.0	100.0
0-9	-	-	-	-	-	-	-	0.0	0.0	1.0	0.0	0.0	0.0	0.0
	t=30°C, RH=40%, v=1 m·s^{-1}													
>46	0.0	0.0	0.0	0.0	0.0	97.7	0.0	situation not considered						
38-46	0.0	71.8	1.2	0.0	100.0	2.3	100.0							
32-38	0.0	28.2	98.8	100.0	0.0	0.0	0.0							
26-32	99.6	0.0	0.0	0.0	0.0	0.0	0.0							
18-26	0.4	0.0	0.0	0.0	0.0	0.0	0.0							

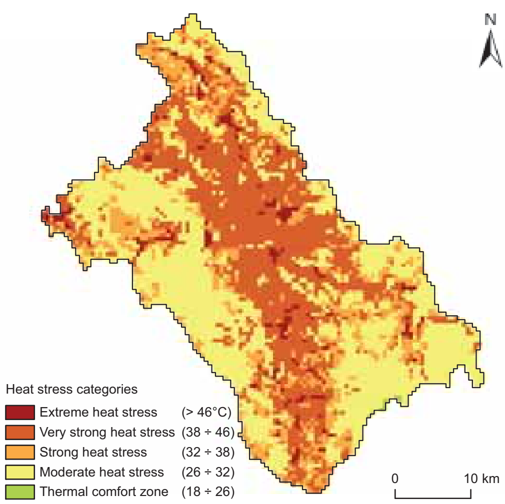

Figure 9. Spatial distribution to heat-stress categories in the Ziemia Kłodzka region on a sunny day with an air temperature of 30°C, air humidity of 40% and a wind velocity of 1 m·s^{-1}.

Conclusions

The *UTCI* simulations made for Poland's Ziemia Kłodzka region reveal marked spatial differentiation of biothermal conditions under various types of weather. This is especially well seen under hot, dry and calm weather conditions. The research confirms that the most marked differences are to be observed between forests and urbanised areas. Forests mitigate cold stress at times of low air temperature and strong winds, while also mitigating heat stress considerably on hot, dry days featuring nothing more than gentle breezes. The influence of various types of land use in shaping biothermal conditions is thus strong.

GIS simulations of the *UTCI* correlate well with *UTCI* values calculated on the basis of observed meteorological data (Błażejczyk 2011a). The resulting differentiation of biotopoclimates shows that the methods under discussion may prove useful in studies of local bioclimate for the purposes of tourism or other uses.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the author(s), on the basis of their own research.

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Article first received • March 2012
Article accepted • July 2012