PRACE GEOGRAFICZNE, zeszyt 115

Instytut Geografii i Gospodarki Przestrzennej UJ
Kraków 2005

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AN ASSESSMENT OF SOLAR CONDITIONS OF THE WIELICZKA FOOTHILLS WITH THE APPLICATION OF GIS (AS EXEMPLIFIED BY THE ENVIRONS OF GAIK-BRZEZOWA AND ŁAZY)

Abstract: The paper is an attempt at spatial representation of solar conditions of the chosen areas of the Wieliczka Foothills, varying in inclination and exposure. The source material is represented by measurement results of insolation from the station at Łazy and Gaik-Brzezowa over 1991-2000 and by the Numerical Model of Terrain for the stations. To carry out a digital map of insolation GIS was applied using the method by V. Stružka. As a result of the analysis it was found that – on account of the duration and the energy of sun's radiation – the solar conditions of the Wieliczka Foothills are favourable. Possibilities of their employment were also shown.

Key words: sunshine duration, insolation, solar conditions, GIS, foothill area

Introduction

Solar radiation coming to the active surface is a basic source of energy for the Earth and its atmosphere. Both the duration of the direct solar radiation and insolation i.e. the energy of total solar radiation reaching any inclined surface play an important role not only from the climatological-cognitive but also from the practical point of view. The role of solar radiation inflow is nowadays taken into consideration not only in agriculture but also in bioclimatology and in spatial planning on designing housing estates, streets, choosing the orientation of dwelling houses or in establishing recreation areas.

On account of insolation, an important discriminant of local climate especially in insolated areas becomes exposure. In moderate latitudes an annual increase in radiation on south-facing slopes with an angle of 20^{o} corresponds - according to P. R. Crowe (1987) – to an 8-9^{o} latitudinal shift to the south. Under the same conditions but on north-facing slope, a decrease in radiation corresponds to a 12-15^{o} latitudinal shift.

The aim of the present paper is an attempt at spatial presentation of solar conditions of the selected areas of the Wieliczka Foothills, varying in inclination and exposure, on applying the GIS as well as an assessment of the values of these areas for purposes of spatial planning in an aspect of sustainable development. Besides, the paper is a methodical study of the possibilities of employing GIS techniques in the field of climatology. Digital maps (Ustrnul, Czekierda 2003) give a very accurate picture of the diversification, incomparably better than the traditional one, drawn out manually; they make it possible an approximation and, further, a practically unlimited transformation. It is possible on their basis, on employing a map resolution, to read out the value of any given element in any chosen point.

Location of the study area, source materials and the method

According to the regional division of the Carpathians (Balon et el.) the investigated area lies in the sub-province of the Outer Western Carpathians, macroregion of the Carpathian Foothills, mesoregion of the Wieliczka Foothills. According to the regionalization of Poland by J. Kondracki (2001) the area in question is included in the West Beskid Foothills. There dominates the type of foothill relief with levelled hilltops, convex-concave slopes and flat-bottomed valleys. The absolute heights range between 180 and 425 m a.s.l. There prevail slopes inclined from 5 to 10^{o} with a slight predominance of north and west exposures (Fig.1)

The paper is based on meteorological sunshine duration data over 1991-2000 from research stations of the Institute of Geography and Spatial Managemnet of the Jagiellonian University at Gaik-Brzezowa (N 49^{o}51’ 20^{o}03’ E) and Łazy (N 49^{o}57’ 20^{o}29’ E). The duration of sunshine radiation was measured simultaneously at the two stations by a heliograph, type Cambell-Stokes, according to the instruction manual of the Institute of Meteorology and Water Management. Analysed were annual, monthly and 24-hour values of real sunshine duration.

The insolation of the terrain shown on the maps was determined using the method by V. Stružka (1959), which assumes that the annual course of the intensity of solar radiation is similar in particular years and the knowledge of solar radiation falling on horizontal surface makes it possible to calculate the insolation of the surface for any given inclination and exposure.

The value of total sun’s radiation reaching any exposed fragment of the Earth’s surface can be measured or estimated. The calculation methods consist in the designation of a relationships between potential and total radiation in the form of a function which includes sunshine duration or cloudiness.

It is possible to calculate sums of total radiation by employing the Black’s formula, established for Poland by J. Podogrocki (1978), or using the method worked out by A. Styszyńska (1995, 2002).

There was no need in the present paper to use intermediate methods since actinometric measurements were taken at the station at Gaik-Brzezowa and Łazy. The spatial resolution (piksel size) of the model was in both cases 10 sq. m. By employment the GIS software (ArcGIS of the company ESRI) aspect mapn and an slope map were generated from the source model. Then in the process of reclassification the obtained pictures were transformed to obtain classes considered in the paper by V. Stružka (1959). Terrain exposures were divided into eight basic directions (N, NE, NW, E, W, S, SE, SW); also separated were 50 classes of slope inclinations- every 1 degree. The inclination map was overlaid on the map of exposures. For the obtained map values from the table included in the paper by V. Stružka (1959) were introduced.

Sunshine duration

Possible sunshine duration meant as a time from sunrise to sunset in a given day was designated from solar tables (1976) for the 50° of northern latitude. The shortest days in the Wieliczka Foothills occur between 19th and 25th December and last as little as 7 hours and 50 minutes. The longest days lasting 16 hours and 10 minutes occur between 18th and 25th June. The annual astronomical possible sunshine duration total amounts to 4,475 hours and changes from 255 hours in December to 495 hours in July. The amount of real sunshine duration is affected, apart from the astronomical factor, by cloudiness, fogs and atmospheric transparency. Mean annual real sunshine duration over 1991-2000 amounted to 1,544 hours for Gaik-Brzezowa and to 1,662 hours for Łazy.

Over the whole investigated period the course of sunshine duration at both stations is similar (correlation coefficient is 0.92) and the values are always higher at Łazy. The lower sunshine duration at Gaik is probably to be linked with a higher cloudiness of that station, this brought about by the vicinity of a water reservoir. The higher sunshine duration within the investigated decade (Fig.2) was recorded in 2000 and amounted to 1,825 hours at Łazy and 1,731 hours at Gaik, the lowest one occurred in 1996 and amounted to 1,469 and 1,359 hours respectively.

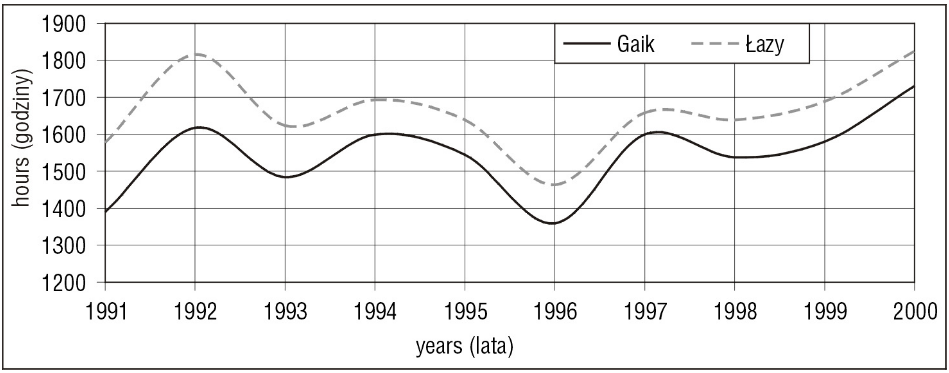

Fig. 2. The ten-year course of annual totals of effective sunshine duration at Gaik-Brzezowa and Łazy 1991-2000)

Ryc. 2. Przebieg dziesięcioletni sum rocznych usłonecznienia rzeczywistego w Gaiku Brzezowej i Łazach (1991-2000)

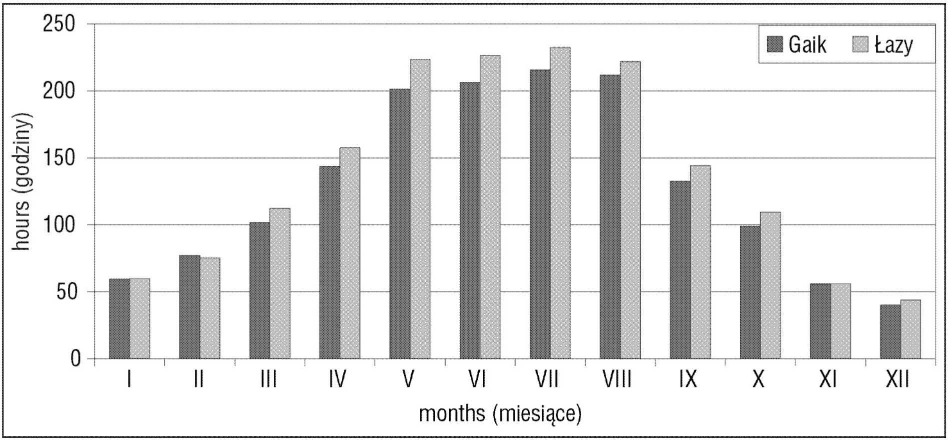

Fig. 3. The annual course of real monthly effective sunshine duration at Gaik-Brzezowa and Łazy (1991-2000)

Ryc. 3. Przebieg roczny sum miesięcznych usłonecznienia rzeczywistego w Gaiku Brzezowej i Łazach (1991-2000)

The most sunny month in a year (Fig.3) and at the same time very changeable on account of cloudiness is July. In some years (1994, 1995) the monthly totals of sunshine duration in July exceeded 300 hours, while in others (2000) they were as low as 136 hours. The high values of sunshine duration (above 200 hours) are to be observed also in May, June and August. It is worthwhile to note that August is marked by the highest values of sunshine duration between 10 a.m. and 4 p.m. as compared to other months.

The least sunny month, on astronomical reasons as well as on account of the highest annual cloudiness, is December. Mean monthly sunshine duration amounts to only 44 hours at Łazy and 41 hours at Gaik. Minimum monthly sunshine duration was recorded in December 1995 and amounted to as little as 18 hours at Gaik.

The daily course of sunshine duration in the Wieliczka Foothills is contained between 4 and 20 with only May, June and July display sunshine duration of 16 hours. Sunshine duration of December, January and November is only half that value (eight hours) The main daily sunshine duration in December does not frequently achieve 1,5 hour and only sporadically it exceeds 6,5 hours. In the swing of summer the average sunshine duration ranges between 6,0 and 6,6 hours while the maximum daily totals amount to 14-15 hours.

In the relevant period the most sunny day was June 10th, 2000 The maximum recorded sunshine duration at both stations amounted to 15.5 hours at Łazy and 15.4 hours at Gaik. The highest sunshine duration occurs between 10 a.m. and 2 p.m. More sunny are afternoon rather than morning hours which is probably due to morning mistiness and higher cloudiness as compared with the afternoon.

Insolation

On characterizing radiation conditions of the areas with varied relief it is total insolation that plays the most significant role. Apart from direct radiation it also includes dispersed radiation the share of which changes depending on optical features of the atmosphere, cloudiness, inclination and slope aspect. According to Z. Olecki (1989) the sufficiently accurate values of total radiation with a simultaneous simplification of calculations can be obtained by using not the direct values of total radiation but its relative value which is the ratio of that radiation falling on a given surface to the amount of energy received by a horizontal surface. That value indicates by how much total radiation of an inclined surface differs from its value on a horizontal surface. Therefore, knowing the sums of total radiation for a horizontal surface (Tab. 1) it is possible to designate (Stružka, 1959) approximate values of total solar radiation on

Tab. 1. Mean rate of total solar radiation ($W{\cdot}m^{-2}$) during cloudless weather and under conditions of real cloudiness in the afternoon hours at Gaik-Brzezowa over 1971-1997 (Olecki, 2002)

Tab. 1. Średnia intensywność całkowitego promieniowania słonecznego ($W{\cdot}m^{-2}$) przy bezchmurnej pogodzie i w warunkach realnego zachmurzenia w godzinach południowych w Gaiku Brzezowej w latach 1971-1997 (Olecki, 2002)

Weather conditions	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
cloudless	300	433	642	782	865	879	859	795	663	475	328	258	606,5
mean cloudiness	167	251	391	454	502	516	530	537	419	272	167	133	361,6

a given inclined and orientated surfaces i.e. to determine their sunshine duration. (Fig.4, 5). Areas of the highest insolation (130-140%) cover as little as 4 ha of the surface of the whole area. The highest share (some 10 thousand ha) constitute surfaces with solar radiation totals amounting from 100 to 110%, then horizontal surfaces (some 2,600 ha), and areas (some 2,300 ha) with insolation from 110 to 120%. The area with the lowest insolation (below 100%) covers an area of some 1,800 ha.

The rate of total solar radiation per horizontal surface in the Wieliczka Foothills changes over a year (Tab. 1), with average cloudiness ranging from 133 $W{\cdot}m^{-2}$ in December to 537 $W{\cdot}m^{-2}$ in August while during cloudless weather in December it is 258 $W{\cdot}m^{-2}$ and reaches its maximum of 879 $W{\cdot}m^{-2}$ in June.

Summary and conclusions

The Wieliczka Foothills reveal very good solar conditions, both on account of its duration as well as of the energy of solar radiation reaching any given inclined surface. The real insolation in that area exceeds by more than 100 hours the mean annual insolation total for the entire Poland (1,526 hours) as given by M. Kuczmarski (1990).

Owing to varied relief more than 70% of the surface of the investigated area shows higher sums of solar radiation totals as compared with horizontal surfaces.

Especially privileged areas are the southern slopes of the environs of the Dobczyce Reservoir where insolation is by more than 60% higher than on northern slopes. The analyses performed of solar conditions of the Wieliczka Foothills, by employing the GIS technique, make it possible to formulate practical conclusions to be of significance in various fields of life e.g. in bioclimatology or spatial planning.

In a bioclimatic aspect the results obtained predispose the area to heliotherapy. According to S. Tyczka (1964) the annual number of hours with sunshine for health resorts should exceed 1,500 hours, hence the area of the Wieliczka Foothills does fulfill that criterion. The most favourable conditions for heliotherapy occur there from May to August, between 10 a.m. and 4 p.m.

When designing housing development, on account of favourable solar conditions, the dwelling houses should be located on south-facing slopes. It is important for the houses to have extended roofs, which would sufficiently shade southern walls in summer but make it possible at the same time to be fully sun-exposed in winter. The north-facing wall would be coolest, so the number of openings letting in cool air should be lessened. Instead south-facing walls can be used as a source of heat, especially in winter when the sun stands low above the horizon.

Terrain inclination favours the inflow of solar radiation, but with high slopes it can present a difficulty in carrying out building works. Small gradients (up to 5^{o}) facilitate the development. Land slope above 13^{o} enforces development parallel to contours.

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Ocena warunków solarnych Pogórza Wielickigo z wykorzystaniem GIS (na przykładzie okolic Gaika-Brzezowej i Łazów)

Streszczenie

Celem niniejszego opracowania jest próba przestrzennego przedstawienia warunków solarnych wybranych terenów Pogórza Wielickiego, o różnym nachyleniu i ekspozycji z zastosowaniem GIS oraz ocena walorów tego obszaru dla potrzeb planowania przestrzennego w aspekcie zrównoważonego rozwoju. Praca ta, stanowi ponadto studium metodyczne możliwości wykorzystania technik GIS-u w dziedzinie klimatologii.

W opracowaniu wykorzystano dane meteorologiczne dotyczące usłonecznienia z lat 1991–2000 ze stacji naukowych Instytutu Geografii i Gospodarki Przestrzennej Uniwersytetu Jagiellońskiego w Gaiku–Brzezowej i Łazach.

Nasłonecznienie terenu na mapie zostało określone metodą V. Stružki (1959), która zakłada, że roczny przebieg natężenia promieniowania słonecznego jest w poszczególnych latach podobny i znajomość promieniowania słonecznego na powierzchnię poziomą pozwala obliczyć nasłonecznienie powierzchni o danym nachyleniu i ekspozycji.

W wyniku przeprowadzonej analizy stwierdzono, że Pogórze Wielickie posiada bardzo dobre warunki solarne, zarówno ze względu na czas trwania, jak i energię promieniowania słonecznego docierającego na dowolnie nachylone powierzchnie. Usłonecznienie rzeczywiste na tym obszarze przekracza o ponad 100 godzin rocznie średnią sumę usłonecznienia dla Polski., a ponad 70% powierzchni badanego terenu wykazuje wyższe sumy całkowitego promieniowania słonecznego niż na powierzchnię poziomą. Szczególnie uprzywilejowane są południowe stoki okolic Zbiornika Dobczyckiego, gdzie nasłonecznienie jest o ponad 60% wyższe niż na stokach północnych.

W opracowaniu zawarto wnioski praktyczne, które mogą mieć zastosowanie w różnych dziedzinach życia, np. w bioklimatologii czy planowaniu przestrzennym.

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