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Analysis of the potential evapotranspiration demands in the Czech Republic between 1961–1990

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Abstract: Dynamics of the evapotranspirational demands in the Czech Republic within three decades from 1961 to 1990 has been studied. The determination of the levels of influence of the respective natural components depends on the regionalized modelling techniques. The project of regionalized modelling is theoretically based on the potential evapotranspiration values (ET_0) calculated by FAO methodology (eqs. 1, 2) and the series of temperature and rainfall observations obtained by climatologic stations during a 30-year period from 1961 to 1990 and its relation to the absolute altimetric. The DMR-2 military digital elevation model of the Czech Republic relief consisting of a regular network of points with their altitudes specified in meters was used for the purpose of regionalized modelling. One step of the network in the S-42 coordinate system with the Gauss conforms cylindrical projection is equal to 100 meters; this implies that the smallest area for which the data can be processed is 1 hectare. The digital relief model can be linked to both direct (temperature, precipitation) and derived (evapotranspiration) quantities, which is one of the many novelties of regionalized modelling. The climatic data used in regionalized modelling records daily measurements were obtained by 85 climatologic and rainfall-monitoring stations from 1961 to 1990. Our results showed an appreciable decrease of the most drying area (ratio P/ET_0 up to 0.755) in the last decade 1981–90; half as less amounts compared with the previous decade 1971–80 (about 500,000 hectares). On the other hand, an apparent increase (more than 500,000 hectares in comparison with the previous decade 1971–80) of the wettest area (ratio P/ET_0 over 1.508) through the last decade was observed. Both first decades 1961–70 and 1971–80 look similar. The project mentioned in this article has made it possible to create models for the different time intervals which have showed higher reliability for heterogeneous application.

Key words: potential evapotranspiration, dynamics, regionalized modelling

Introduction

Geography is among the scientific disciplines which study both the complex interactions among the respective constituents of the natural sphere and the natural sphere as an integral whole. The similar aim of interest was focused on this subject by several authors in the Bohemian region, as Tomlain (1980), Kurpelová et al. (1975), and other regions Merta et al. (2001, 2006) etc. Regionalized modelling can significantly contribute to the knowledge and determination of the regularities manifesting in natural sphere. Regionalized modelling in the field of physical geography focusing on the relief, soil types, hydrology and climate is always more or less affected by the assessment of the remaining factors of the natural sphere. The determination of the levels of influence of the respective natural components depends on the regionalized modelling techniques, as geoinformation scientists would say, or on the development of methodological procedures in terms of conventional geography. In general, it is desirable to analyse numerous relationships presented in the bulk geographical data. Such an analysis forms the basis of regionalized modelling. The development of mathematics, geoinformation science, modern mathematics-based disciplines and systemic sciences not only provides for new instruments but also makes it possible to broaden or modify the contents and interpretation of regionalized modelling that may one day form the background for simulation of the future development, provided that is based on exact data analysis from the natural or social sphere.

The digital relief model can be linked to both direct (temperature, precipitation) and derived (evapotranspiration) quantities, which is one of the many novelties of regionalized modelling. All the geoinformation and cartographic processes described below were implemented within an unusually small processing area (100 m × 100 m). The project of regionalized modelling of climate has been originally initiated by the Ministry of Agriculture of the Czech Republic. The project comes out from the presumption of close relations of climatic and hydrologic values to shapes and configuration of ground, namely altitudes.

Material and methods

The project of regionalized modelling is theoretically based on the potential evapotranspiration values (ET_0) calculated using equations 1 and 2 by FAO methodology (Allen et al., 1998), and the series of temperature and rainfall observations obtained by climatologic stations during a 30-year period from 1961 to 1990 and its relation to the absolute altimetric. These interrelations were obtained by data processing applied to the specific unusual methods, considering both the amount of data (daily values of the air temperature, precipitation, air humidity, sunshine hours, wind speed and air pressure over a period of 30 years) and the necessity to apply all the physical and logical control methods so as to minimize the transmission of unreliable and inaccurate data into the further solution.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], $R_n = R_{ns} - R_{nl}$, where R_{ns} = net solar or short-wave radiation [MJ m^{-2} day^{-1}], R_{nl} = net outgoing long wave radiation [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], γ = psychrometric constant [kPa °C^{-1}], T = mean daily air temperature at 2 m height [°C], u_2 = wind speed at 2 m height [m s^{-1}], $e_s - e_a$ saturation vapor pressure deficit [kPa], Δ = slope of vapour pressure curve [kPa °C^{-1}],

$$\Delta = \frac{4098\left[0.6108\exp(\frac{17.27T}{T+237.3})\right]}{(T+237.3)^2} \qquad (2)$$

The climatic data used in the regionalized modelling records daily measurements obtained by 85 climatologic and rainfall-monitoring stations from 1961 to 1990. The measurements have been digitally recorded in a nationally adopted format since the 1960s, with the older measurements recorded on paper gradually converted into digital form.

The DMR-2 military digital elevation model of the Czech Republic relief consisting of a regular network of points with their altitudes specified in meters (rounded off to one meter, with absolute accuracy of 2 to 3 meters) was used for the purpose of regionalized modelling. One step of the network in the S-42 coordinate system with the Gauss conform cylindrical projection is equal to 100 meters; this implies that the smallest area for which the data can be processed is 1 hectare. The digital model consists of a set of files specifying the following data: the x coordinate, the y coordinate and the corresponding height above sea level (Baltic vertical Datum after adjustment). Every file contains 10,000 points located in an area of 10 km × 10 km.

The following basic tasks had to be performed to transform the digital relief model using the S-42 coordinate system into a seamless digital relief model using the JTSK (Krovak's uniform trigonometrical network), civil coordinate system applying the Krovak's conform conical projection:

– zone to zone transformation of the 34 longitude zone into the 33 longitude zone with the central meridian being 15° of the geodetic longitude in the S-42 coordinate system

– transformation of all the regular network points from the S-42 coordinate system into the JTSK coordinate system

– spatial interpolation and homogenisation of the altimetric values so as to obtain integer multiples of hundreds of meters (y and x coordinates in the JTSK system)

– creation of an import file for the Grid sub-system of an Arc/Info geographic information system.

For the purpose of regionalized modelling, the data regarding the maximum, minimum and mean daily air temperatures and daily precipitation totals were extracted from a wide range of measurements taken by the climatologic stations during the 30-year period. The evapotranspiration was calculated by FAO (Penman-Monteith algorithm) methodology.

After the initial analysis of the amount of data for the expected regionalized modelling had been done, it turned out that it would be effective to apply some of the available geographic information systems, like Arc/Info system (8.0.2 workstation version). The Arc/Info geographic information system provides numerous parametrically variable functions of spatial interpolation that had to be analyzed for the purpose of regionalized modelling. The initial conditions were set by the number of interpolation points (ca 8, 000,000), about 100 usable locations of climatologic stations and the need to transform the initial layer into a regular grid with the distance equal to 100 meters. Carrying out the appropriate analysis, the interpolation function was chosen. Its principle consists in the calculation of the weighted arithmetic mean, with the weights being the inverted values of the powers of the distances between the initial points and the point of interpolation. The ability of Arc/Info to integrate database systems and modules developed in programming languages played a significant role. Nevertheless, significant parts of the regionalized modelling were implemented using programs developed in the C/C++ languages as the appropriate functions were missing in the Arc/Info system.

After establishing the station ASCII file, with every record containing data items (location specifying the geodetic longitude and latitude and the JTSK system coordinates, indicative, station name, median of annual precipitation, temperature and potential evapotranspiration, values analogous to mean values and, in particular, the respective station height above sea level) the probability distribution and its parameters were analyzed. The regression program determines the existence of a correlative relationship between the independent variables – station heights – and the gradually dependent variables – medians of annual rainfall, potential evapotranspiration and its mutual ratio. Besides that, the program calculates the coefficient of the quadratic regression function, determines deviations of all types of medians for the respective stations by applying the least squares method of adjustment, and provides for the visualization of the correlation field with regression curve.

The partial and final results of regionalized modelling (either as an integral whole or as detailed cut-out) were always visualized on the working terminal using the appropriate functions of Arcplot, Grid and Arc subsystems. Their importance for identifying the correct regionalization procedure was significant. Visualizations at a scale of 1:200,000

Table 1. Results of the quadratic regression between altitude (independent variable) and P/ET_0 ratio in 85 localities through the individual decades.

decade	*a*	*b*	*c*	avg	var	st.d.	covar	cc
61–70	0.694905	0.000913	0.134E-08	1.154	0.265	0.515	74.525	0.556644
71–80	0.626722	0.001085	6.670E-08	1.147	0.278	0.528	79.703	0.580924
81–90	0.421300	0.001987	−0.280E-08	1.260	0.363	0.602	107.516	0.686571

Table 2. Final results of the estimation of particular scale range areas (ha) of the P/Epot ratio through the single decades over the Czech Republic.

ratio P/Epot	period 61–70 (ha)	period 71–80 (ha)]	period 81–90 (ha)
up 0.755	870863	1007650	507955
0.755–0.850	780328	798487	476094
0.850–0.937	754470	799390	650394
0.937–1.001	659437	762547	529016
1.001–1.051	836691	731480	560569
1.051–1.120	817924	704206	599878
1.120–1.203	876814	777845	933334
1.203–1.331	752205	775411	1177146
1.331–1.508	660312	632449	1080997
over 1.508	875451	895030	1369112

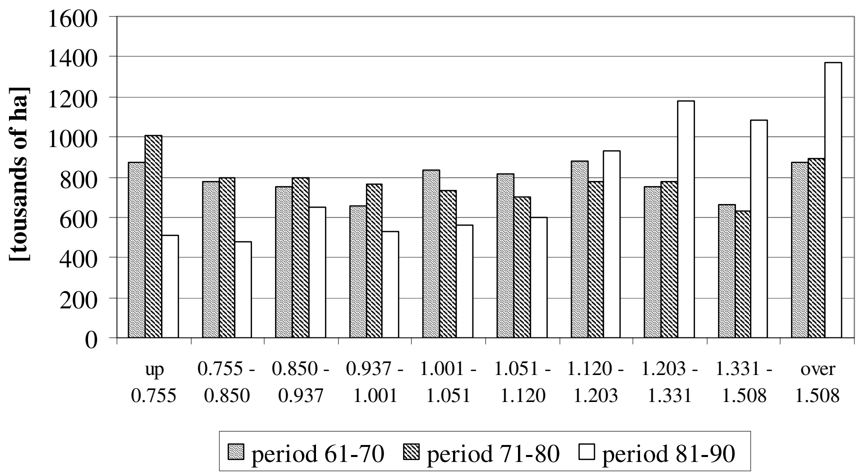

Fig. 1. Graph of individual scale range development through the single decades.

were preceded by constructing coverage with polygons defining the respective sheets of the applicable basic maps based on the known division into sheets in the JTSK coordinate system. The required final colour visualizations in the format of basic maps of the Czech Republic at a scale of 1:200,000 were generated with a sufficient resolution.

Results

The results of quadratic regression $y = a + bx + cx^2$ between altitude (independent variable) and P/ET_0 ratio through the individual decades (Tab. 1) indicated the increase of ratio through the last decade 1981–90 on average.

The detailed development is shown in the Tab. 2 and Fig. 1 where we can see an appreciable decrease of the most drying area (ratio P/ET_0 up to 0.755); half as less amounts compared with the previous decade 1971–80 (about 500,000 hectares). On the other hand, an apparent increase (more than 500,000 hectares in comparison with the previous decade 1971–80) of the wettest area (ratio P/ET_0 over 1.508) through the last decade was observed. Both first decades 1961–70 and 1971–80 look similar, the second of them was a bit drier (the driest area extended by more than 100,000 hectares), and a bit wetter as well (the wettest area extended by 25,000 hectares). The same conclusion indicates the average value of P/ET_0 ratio (Tab. 1).

From the coloured maps in the Fig. 2–4 we can see the changes in the locations of the individual scale range areas. Comparing the second decade 1971–80 with the first one 1961–70 there was a slight increase of the driest area in the Southern Moravia and a slight increase of the wettest area in the northern hilly Moravian re-

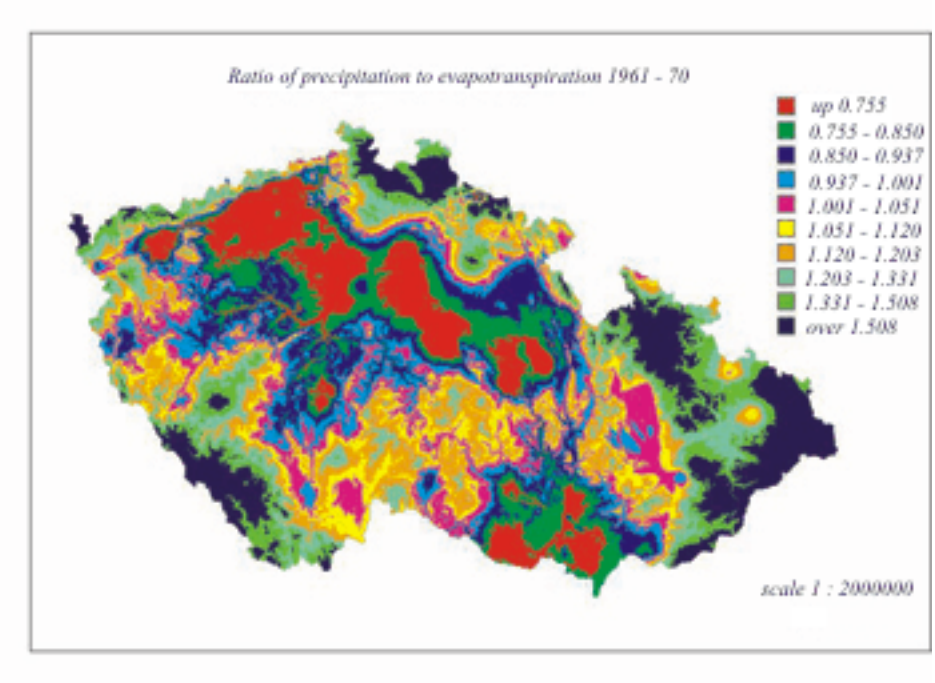

Fig. 2. The final plot of the individual scale range areas through the first decade of 1961–1990 period over the Czech Republic.

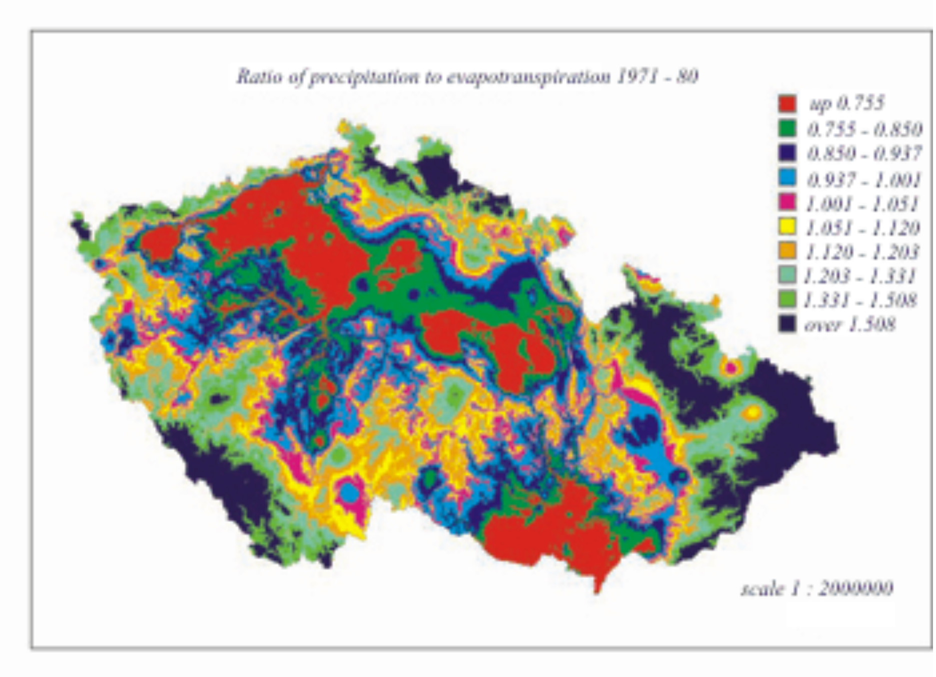

Fig. 3. The final plot of the individual scale range areas through the second decade of 1961–1990 period over the Czech Republic.

gion and Šumava Mountains. During the last decade 1981–90 a huge growth of the wettest area was observed in Šumava Mountains, Bohemian Highlands, the Ore Mountains as well as in Giant Mountains and Eagle Mountains, while the hilly countryside of Northern Moravia recorded a significant decrease of wet areas. The area of the driest region in the southern part of the North Bohemia district considerably retreated as well, namely in the eastern part of the landscape.

Discussion

Unlike the data processing based on incomplete 50-year series of observation data collected from 1901 to 1950, the regionalized modelling described above was based on a 30-year series of observation data collected by cli-

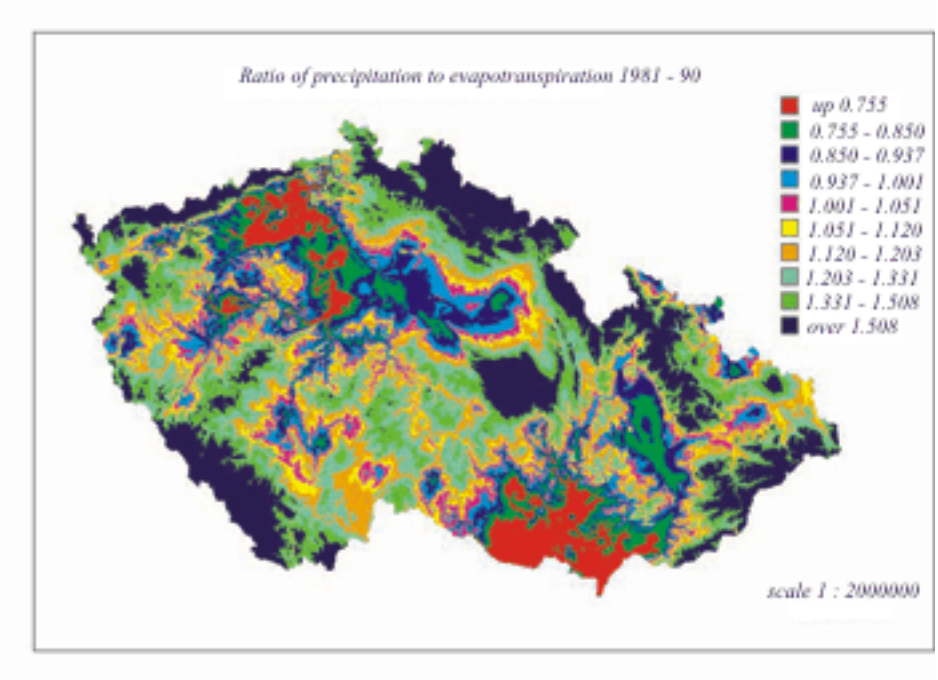

Fig. 4. The final plot of the individual scale range areas through the third decade of 1961–1990 period over the Czech Republic.

matologic stations. In addition to this, the development of dry-wet area shape in the Czech Republic through the individual decades of the 30-year epoch was determined. A huge growth of the wettest area was observed in the last decade 1981–90.

The influence of morphogenetic characteristics – inclination, exposition, convex and concave configuration of square areas of variable dimensions or solar irradiation – was reflected in the correction of absolute heights. The inclination and exposition values are to be found in the individual grids, while the geodetic latitude and bearings have to be determined by calculating from the y and x coordinates. These represents the input of the program provides for converting coordinates into geodetic latitude and calculating the solar irradiation values according to the following formula:

$$z = \cos(90° - B)\cos(s) + \sin(90° - B)\sin(s)\cos(a) \quad (3)$$

where $z =$ non-dimensional solar radiation, $a =$ exposition bearing, $s =$ inclination and $B =$ geodetic latitude. The statistic analysis of the elevation and solar radiation (equation 3) grids resulted in a regression of the determinative correction of the elevation model. Both the final corrected elevation grid and the absolute elevation model are used for the further solutions of regionalised modelling.

The regionalized modelling was based on a technological tool, the Arc/Info geographic information system run by the Irix operating system. When it was not possible or effective to use Arc/Info, new programs were designed and developed in the C, C++ languages according to the original theoretical basis.

The models created by regionalized modelling are flexible and visualisation-invariant (MORAVEC, 1986). Different categorization and scale range adjustment in the summarised quantities does not constitute a significant problem. Requirements of this kind are likely to be specified by the users.

The creation of the localisation component of the landscape appears to be the most demanding part of the work from both the theoretical and practical points-of-view. The regionalized modelling databases are seamless and homogenous in the space, containing grids, layers and individual points in the JTSK coordinate system with a step of 100 metres and coordinates defined in hundreds of meters.

The regionalized modelling appears to be a necessary precondition for determining those regions with less favourable conditions for agriculture, as well as potential modifications of the landscape characteristics in general. Climatic and hydrological conditions modelling for the purpose of landscape care project is based on the idea of independent view as a solution which has not a superior purpose. The project should solve a technology and structure of models from point source of known temporal (daily) and position climatic and hydrologic data to global space (areal) units within the optional time interval. On the basis of history and today models it is possible to form models which extrapolate the future and even regard global warming parameters. In this sense this models can give marked contribution to the purpose modification of landscape care, agriculture, forestry and water management.

The contribution of the work is mainly in the level of methodology, which is unique in the field of application. On the basis of history and today models it is possible to form models which extrapolate the future, even as regards global warming parameters. In this sense these models can give marked contribution to the purpose modification of landscape care, agriculture, forestry and water management.

In spite of the fact that many authors (e.g. TOMLAIN, 1980; KURPELOVÁ et al., 1975; PIVEC et al., 2005) have focused on the landscape water consumption, the dynamics of development has not been investigated yet. The project mentioned in this article has made it possible to create models for different time intervals, e.g. a day, several days, a dozen of days and a year which have showed higher reliability for heterogeneous application.

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