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Changes in the Agroclimatic Areas of Slovakia in 1961–2020

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ABSTRACT

The World Meteorological Organisation predicts an increase in average annual temperature. As a result of climate change in Slovakia, one can expect changes in the distribution of precipitation and moisture availability, changes in the temperature availability of crop production, changes in wintering conditions, and many others. The aim of this work was the analysis of agroclimatic indicators for the period 1961–1990 and 1991–2020. The results showed an increase in the sums of temperatures in the growing season. Also, the increase in temperature resulted in a change in the zones of the agroclimatic indicator of moisture and the agroclimatic indicator of wintering. The zones have been shifting to higher altitudes throughout Slovakia.

Keywords: agroclimatic area, temperature indicator, moisture indicator, wintering indicator.

INTRODUCTION

The last eight years (2016–2022) were globally the warmest in the history of measurements. It was conditioned by constantly increasing concentrations of greenhouse gases as well as heat accumulated in the atmosphere and oceans (Markovič, 2023). The World Meteorological Organisation (WMO) predicts an increase in average annual temperature of between 1.1 °C and 1.7 °C (compared to the 1850–1900 average) for each of the years 2022–2026. The probability that at least one year in this period will be 1.5 °C warmer is 48%. Also, the probability that the five-year average (2022-2026) will be warmer than the last five years (2017–2021) is 93% (WMO, 2022a; Magde, 2022). The temperatures on the European continent have doubled compared to global temperatures over the last 30 years, the highest of any continent in the world. On average, this represents an increase of +0.5 °C per decade (WMO, 2022b). In Slovakia, the average annual temperature is rising about twice as fast as at the global level. Since the mid-20th century, the average annual air temperature has increased by about 2.0 °C. Over the next 15 to 20 years (to 2040), it is expected that air temperatures increase by 1.0–1.5 °C compared to the 1991-2020 climate normal. This means an even more extreme climate and weather pattern, greater and more widespread impacts due to more extreme droughts, heavier rainfall and storms, and the adverse impacts of high temperatures on population health, especially in summer, will become more pronounced (Pecho, Markovič, 2022).

Climate impacts are most extensive in natural ecosystems. As a result of climate change in Slovakia, one can expect, for example, changes in the distribution of precipitation and moisture availability, changes in the temperature availability of crop production, changes in phenological conditions, changes in agroclimatic production potential, changes in wintering conditions, prolongation of the main growing season, and many others (Horák, 2017).

Agriculture, land reclamation and water management are placing increasing demands on the precise characteristics of the environments in which the interests of their activities are concentrated. Such characteristics include studies describing landscape – agroclimatic studies (Šiška et al., 2005).

The aim of this work is the analysis of agroclimatic indicators (temperature indicator, humidity indicator and wintering indicator) for the period 1961–1990 and 1991–2020 to determine the changes in agricultural production areas in Slovakia.

MATERIAL AND METHODS

Study area

This study is focused on Slovakia. The country is situated in Central Europe (from 47° 44' 21'' up to 49° 36' 48'' of northern latitude and from 16° 50' 56'' up to 22° 33' 53'' of eastern longitude) with surface area 49,037 km^2. The territory belongs to Alpine-Himalayan belt system – the Carpathian Mountains are rimmed by plains of Pannonian Basin in the south (Záhorská Lowland, Danube Lowland, Východoslovenská Lowland). The location of Slovakia creates a transitional climate between maritime and continental, although the climate is mostly determined by altitude (SHMÚ, 2015). The most precipitation falls in the north (High Tatra Mountains – 2,000 mm/year) and the least in the lowlands (Danube Lowland – 550 mm/year). The average annual temperature varies from 9 °C to 11 °C, in the valleys and basins it reaches 6 °C to 8 °C. At an altitude of 1000 m the average annual temperature reaches values in the range of 4 to 5 °C, at an altitude of 2000 m around -1 °C, on the ridges of the High Tatras less than -3 °C (Bunčák et al., 2006; SHMÚ, 2023). Meteorological data from selected meteorological stations (Figure 1) were provided by the Slovak Hydrometeorological Institute.

Growing season

Plant life is possible within a certain temperature range. The temperature range in which they can develop and grow depends on the individual plant species. Agricultural crops need certain amounts of temperature from sowing to harvesting, which is why the sum of active temperature has been implemented (Kurpelová et al., 1975). In order to determine the sum of active temperatures, it was necessary to calculate the onset and termination date of the main vegetation period (the period with the average daily temperature $T_d \geq 10$) for each meteorological station according to formulas (Šiška et al., 2005):

- onset of temperatures

$$r_v = R\frac{T_n - T_2}{T_1 - T_2} \text{ (days)} \quad (1)$$

- termination of temperatures:

$$r_p = R\frac{T_1 - T_u}{T_1 - T_2} \text{ (days)} \quad (2)$$

where: T_n – onset temperature (°C);
T_u – termination temperature (°C);
T_1 – the nearest average monthly temperature above the onset or termination of temp. (°C);

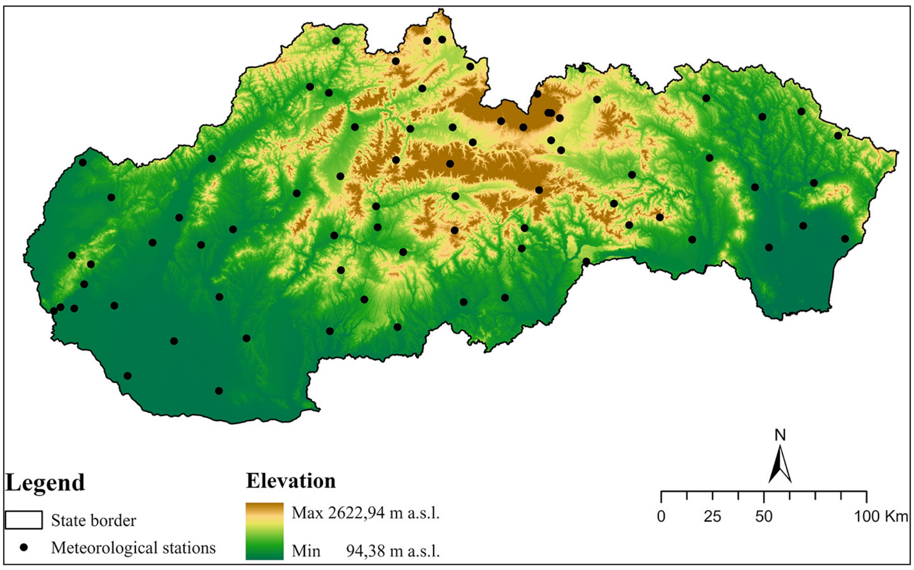

Figure 1. Location of meteorological stations

T_2 – the nearest average monthly temperature below the onset or termination of temp. (°C);
R – the difference in days between the middle of the months with the average temperature T_2 and the average temperature T_1, can be expressed as an average number $R = 30$;
r_v – difference in days between the middle of the month with temperature T_2 and the date of onset of temperature T_n;
r_p – difference in days between the middle of the month with temperature T_2 and the date of termination of temperature T_u.

Agroclimatic indicators

The basic factor that differentiates agriculture in Slovakia is temperature. Temperature during the growing season is the dominant criterion for the formation of the basic agroclimatic macro-areas and areas. The second important factor is moisture. On the basis of the climatic indicator of moisture in the summer period, agroclimatic subareas are divided. For fruit trees and winter crops, winter temperatures are the limiting factor. The average of the annual absolute minima helps to distinguish agroclimatic districts (Kurpelová et al., 1975).

Agroclimatic indicator of temperature is defined as the sum of the average daily air temperatures over the main growing season bounded by the onset and termination of the average daily temperature T ≥ 10 °C (TS10). According to TS10, the highest territorial units in Slovakia have been allocated (Kurpelová et al., 1975):

1) Agroclimatic macro-areas:
a) Warm macro-area with TS10 ≥ 2401 °C;
b) Slightly warm macro-area with TS10 2001 – 2400 °C;
c) Cold macro-area with TS10 1600 – 2000 °C.

2) Agroclimatic areas:
a) Very warm area with TS10 ≥ 3001°C;
b) Predominantly warm area with TS10 2801 – 3000 °C;
c) Sufficiently warm area with TS10 2601 – 2800 °C;
d) Relatively warm area with TS10 2401 – 2600 °C;
e) Relatively moderately warm area with TS10 2201 – 2400 °C;
f) Slightly moderately warm area with TS10 2001 – 2200 °C;
g) Moderately cold area with TS10 1801 – 2000 °C;
h) Predominantly cold area with TS10 1600 – 1800 °C.

Agroclimatic indicator of moisture is given by the difference between potential evaporation (E_O) and precipitation (Z) in the summer months of June-August ($K_{VI-VIII}$). According to the climatic indicator $K_{VI-VIII}$, seven subareas are divided in Slovakia (Kurpelová et al., 1975):

1) Very dry subarea with $K_{VI–VIII}$ ≥ 151 mm;
2) Mostly dry subarea with $K_{VI–VIII}$ 101 – 150 mm;
3) Slightly dry subarea with $K_{VI–VIII}$ 51 – 100 mm;
4) Slightly wet subarea with $K_{VI–VIII}$ 1 – 50 mm;
5) Mostly wet subarea with $K_{VI–VIII}$ -50 – 0 mm;
6) Wet subarea with $K_{VI–VIII}$ -100 – -51 mm;
7) Very wet subarea with $K_{VI–VIII}$ ≤ -101 mm.

Agroclimatic indicator of wintering represents the long-term average of annual absolute minimum temperatures (T_{min}). According to the indicator of wintering, 5 districts are divided (Kurpelová et al., 1975):

1) Mostly mild winter district with T_{min} ≥ -18.1 °C;
2) Relatively mild winter district with T_{min} -18.1 to -20.0 °C;
3) Moderately cold winter district with T_{min} -20.1 to -22.0 °C;
4) Mostly cold winter district with T_{min} -22.1 to -24.0 °C;
5) Cold winter district with T_{min} ≤ -24.1 °C.

Data processing in GIS

The coordinates of the meteorological stations were uploaded into the Geographic Information System (GIS) program. The observed values of each agroclimatic indicator were assigned to the stations. From the point data, surface values were created by Raster Interpolation tool. Among several interpolation methods, the Topo to Raster tool was chosen. This interpolation method, developed by ESRI, is designed to generate hydrologically correct digital elevation models (DEMs). It is based on the ANUDEM program created by Michael Hutchinson in 1988 and it is optimised to have the computational efficiency of local interpolation methods, as Inverse Distance Weighted interpolation, without losing the surface continuity of global interpolation methods, as Kriging and Spline (Šinka et al., 2015; Igaz et al., 2021; ESRI, 2023). The resulting maps were categorised according to the Agroclimatic indicator of temperature, the Agroclimatic indicator of moisture as well as the Agroclimatic indicator of wintering for periods 1961–1990 and 1991–2020.

RESULTS AND DISCUSSION

When analysing the agroclimatic indicator of temperature (TS10), it can be clearly stated that the zonation of Slovakia has been significantly influenced primarily by the change in temperature regime. The individual analyses presented in Figures 2a and 2b clearly show a significant change in the warm macro-area (TS10 ≥ 2401 °C) in comparison with the years 1961–1990 and 1991–2020, where a shift of this macro-area to higher altitudes is presented. In turn, in 1961–1990 the agroclimatic warm macro-area was located solely in the Danube Lowland and Východoslovenská Lowland, for 1991–2020 this region shifts to the Danube Upland in the west of the country and the Východoslovenská Upland in the east of Slovakia. A similar scenario applies to the slightly warm macro-area (TS10 2001–2400 °C) and the cold macro-area (TS10 1600–2000 °C), where there is a significant shift to higher altitudes.

The agroclimatic indicator of moisture ($K_{VI-VIII}$) is also very important and characterises the excess or lack of moisture. Within this assessment

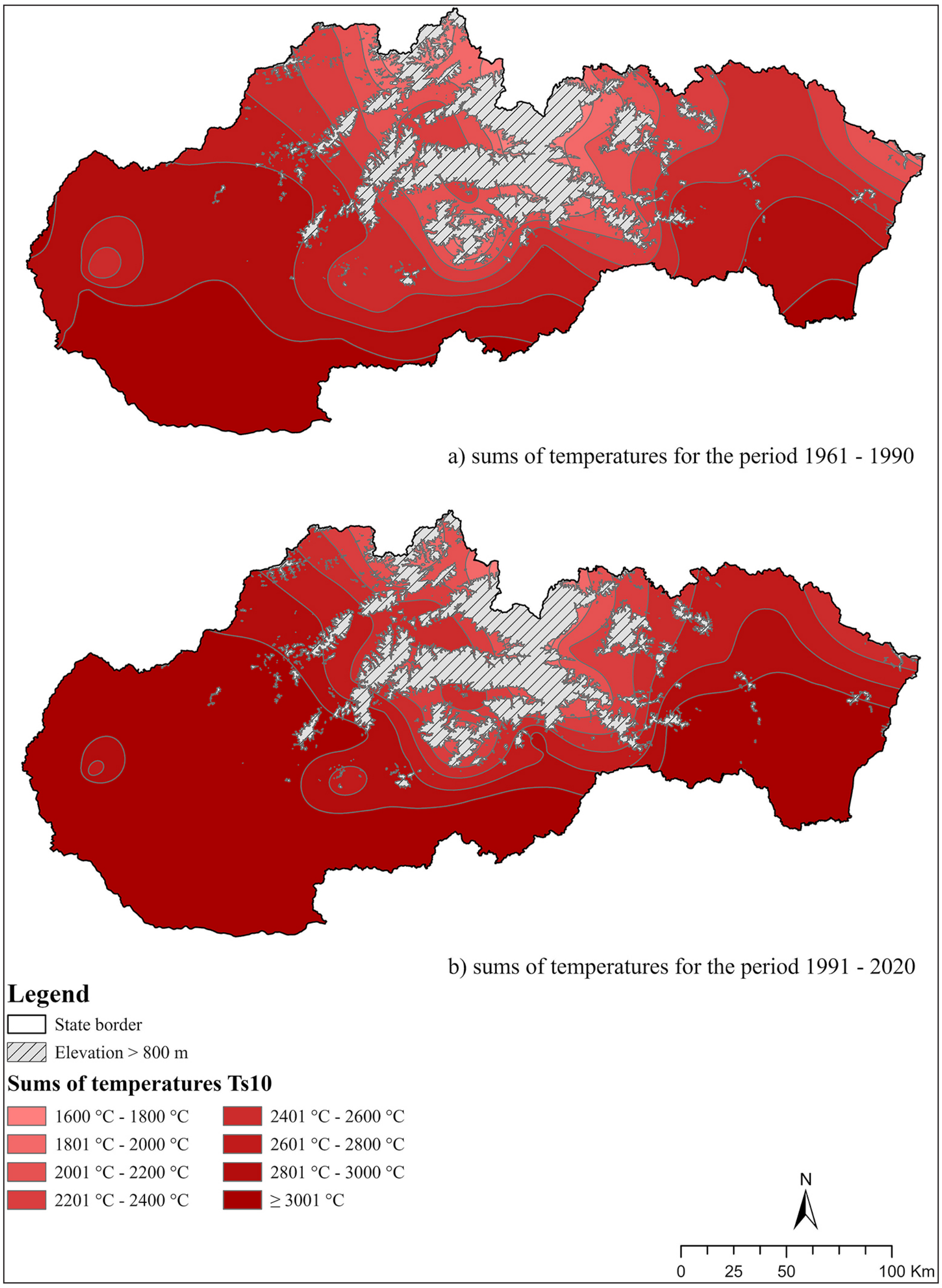

Figure 2. Agroclimatic indicator of temperature (TS10) for (a) 1961–1990 and (b) 1991–2020

(Figures 3a and 3b), it can be noted that there are also changes in zones. In particular, the areas where the risk of drought is expected to increase (the very dry subarea – $K_{VI-VIII} \geq 151$ mm and the mostly dry subarea – $K_{VI–VIII}$ 150–100 mm) areas are increasing. These changes are in close context with increasing average temperature and with uneven distribution of rainfall.

The methodology mentions that two climatic normals were compared in the analyses of the agroclimatic indicator of wintering. Specifically, the climatic normal for 1961–1990 and the climatic normal for 1991–2020. The presented map outputs clearly show that the agroclimatic region of mostly mild winter district ($T_{min} \geq$ -18.1 °C) is shifting to higher altitudes, especially in the southern part of central Slovakia (Figures 4a and 4b). These shifts are noticeable throughout Slovakia. It is similar with the relatively mild winter district (T_{min} -18.1 to -20.0 °C), the moderately cold winter district (T_{min} -20.1 to -22.0 °C) and the mostly cold winter district (T_{min} -22.1 to -24.0 °C). In these districts, over the last thirty-year normal period (1991–2020), mainly due to global

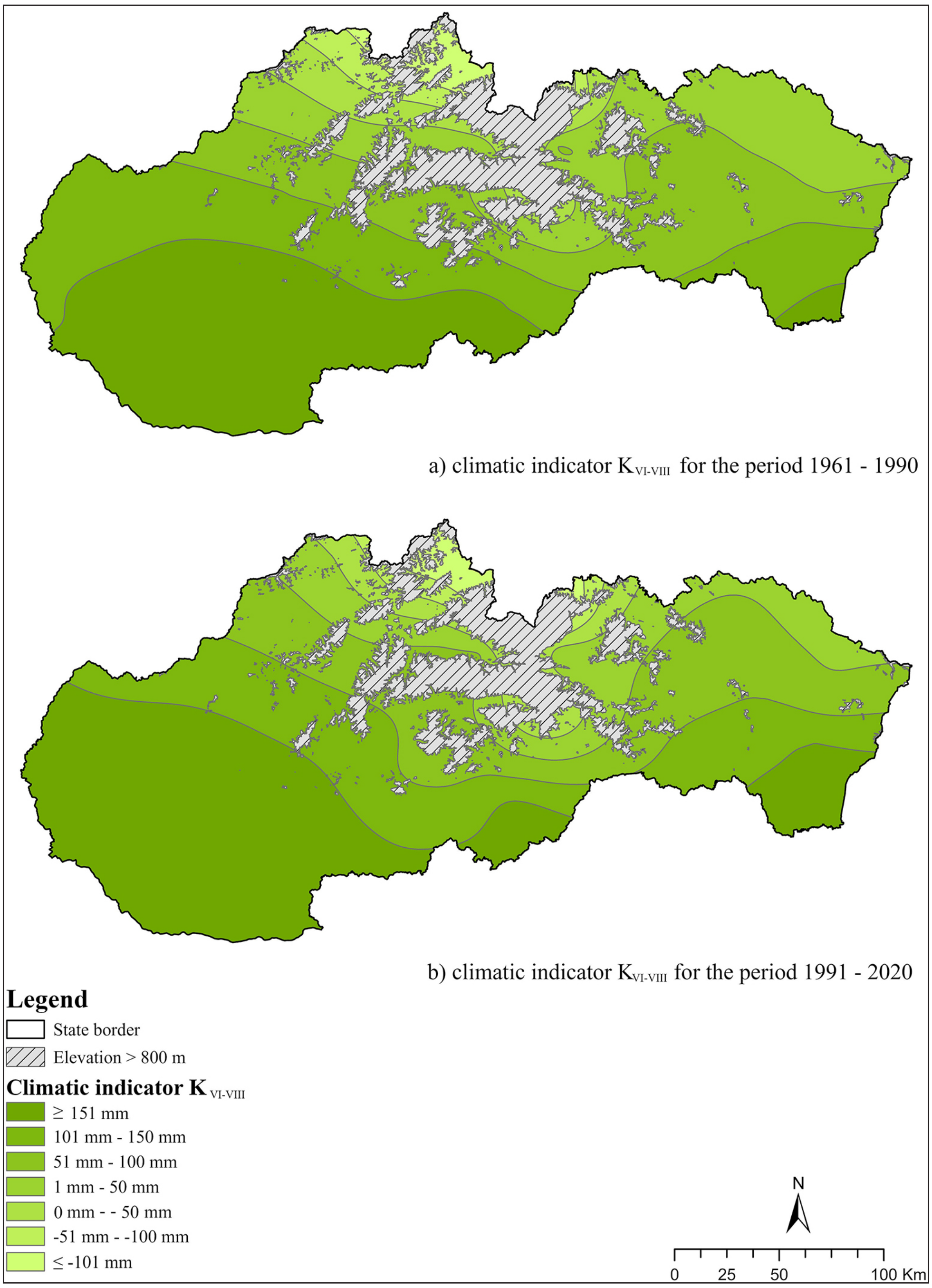

Figure 3. Agroclimatic indicator of moisture ($K_{VI-VIII}$) for (a) 1961–1990 and (b) 1991–2020

warming, the zones have been shifting to higher altitudes throughout Slovakia. At the highest altitudes (areas not used for agricultural activities or in limited quantities), where is the mostly cold winter district ($T_{min} \leq$ -24.0 °C), refers significant changes in absolute minima have been recorded (e.g., Oravská Lesná - T_{min} -27.2 °C in 1961–1990 and T_{min} -24.7 °C in 1991–2020). However, these changes were not significantly reflected in the changes on zones of the area.

Increasing average temperatures in Slovakia leads to an earlier onset and later termination of the period with an average temperature ≥ 10 °C, which potentially extends the growing season of crops. Several authors have dealt with this issue in Slovakia. Valšíková-Frey et al. (2011) predicted an earlier planting by 20 to 25 days and a later harvest by 10 to 15 days by 2075 in the southern regions of Slovakia. An extension of the growing season until 2100 for selected crops (tomato, white cabbage, carrot, watermelon) is also predicted in several publications by Čimo et al. (2020a; 2020b). The extension of the growing season also occurs in Poland by 1–3 days per

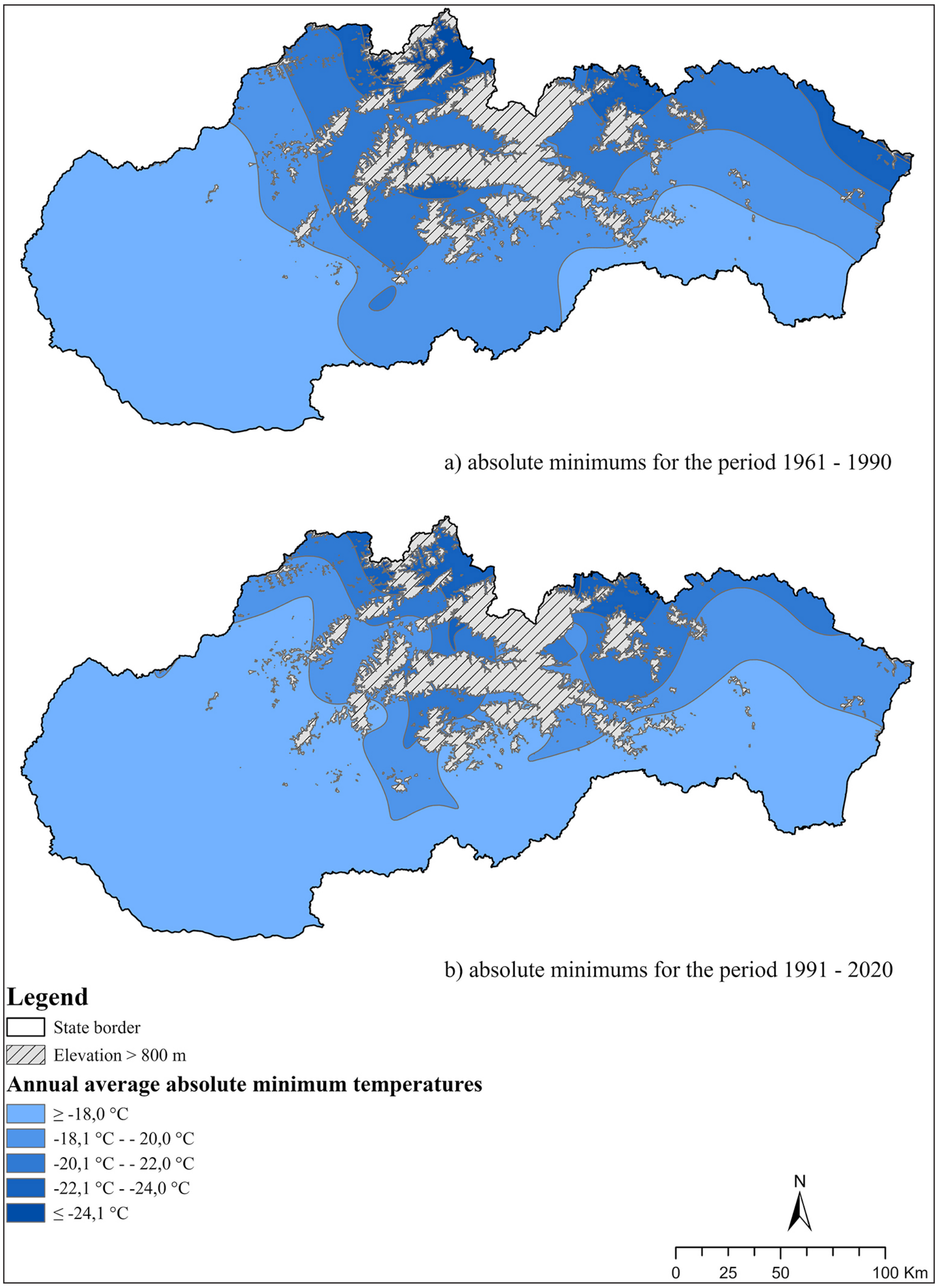

Figure 4. Agroclimatic indicator of wintering for (a) 1961–1990 and (b) 1991–2020

decade (Olszewski, Żmudzka, 2000). With higher temperatures, there is a visible increase in the number of hot days, what they claim in Montenegro (Burić et al., 2014) or in Serbia (Unkašević et al., 2013). Agricultural production is sensitive to high temperatures and lack of precipitation. In recent years, prolonged periods without rainfall alternating with extreme rainfall have become increasingly common, causing floods, destroying crops, and eroding agricultural land (USDA, 2013). Increasing temperatures also affect winters. In recent years in Slovakia, there has been almost no snow cover in winter in the southern regions. Also, Popov et al. (2017) in Bosnia and Herzegovina found from the analysis a decrease in frosty days since 1990.

CONCLUSIONS

Climate change affects everyday life around the world. In Europe, climate change is the most pronounced of all continents, which also affects agriculture the most. Therefore, the aim of this paper was the evaluation of agroclimatic indicators. The results showed a prolongation of the onset and termination of temperatures ≥ 10 °C, which also increased the sums of temperatures in the growing season. The increase in temperature affected the values of evaporation and precipitation, which resulted in a change in the zones of the agroclimatic indicator of moisture; There are higher temperatures, moderate winters and absolute minimum temperatures, which is seen especially in the southern regions of Slovakia. With climate change, it is necessary to change the strategy of agricultural production, and owing to such outputs, the options for agricultural producers can be proposed.

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