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Research Paper

Agroclimatic characterization of Zamosc, Poland using hydrothermal coefficient (HTC)

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ABSTRACT

The hydrothermal coefficient (HTC), which is based on precipitation and temperature, is an important index used for characterizing the agroclimatic condition of a region. In the present study, 47 years (1976-2022) of data on air temperature and precipitation of Zamosc (Poland) were used to compute the hydrothermal coefficient (HTC) in different months of the growing season (April-October). Results revealed that temperature increased while precipitation decreased during the study period as a result the HTC also decreased. The average values of the HTC indicate deteriorating conditions for plant growth and development resulting from decreasing values of this coefficient. There was a clear increase in the number of months in which the value of the HTC≤1.3 coefficient corresponded to dry and extremely dry conditions. Particularly frequently dry and extremely dry conditions occurred in the second half of the growing season from July to October. Climate change is already causing a changing crop structure and the need to implement new technologies towards emerging threats. In order to ensure optimal plant yields, it is particularly important to rationally manage the available water resources.

Keywords: Climate change, hydrothermal coefficient (HTC), air temperature, precipitation, Poland

The climate changes observed since the end of the last century, characterized by rising air temperature and changes in the nature of precipitation, as well as more frequent than before occurrence of extreme phenomena such as storms, droughts, gusty hurricane winds, etc., have a significant impact on agricultural production. The uncertainty in precipitation supplemented by increased temperature condition may cause dry atmospheric condition which adversely affect the crop growth, development and ultimately production. Various indices viz standardized precipitation index (SPI), Palmer drought severity index (PDSI), moisture adequacy index (MAI), crop water stress index (CWSI), normalized difference vegetation index (NDVI), standardized precipitation evapotranspiration index (SPEI) etc. are used to monitor the drought conditions (Pandya *et al.,* 2022; Sridhara *et al.,* 2021). These indices are used not only to classify the climate of the region but also to monitor the drought condition and assessing agricultural condition during crop growing seasons.

The hydrothermal coefficient (HTC) developed by Selyaninov (1928) in Russian Federation and based on Russian Climate, uses temperature and precipitation values and is sensitive to dry conditions specific to the climate regime being monitored. It is flexible enough to be used in both monthly and decadal applications (Anonymous, 2024). This has been widely used in Bosnia and Herzegovina, Bulgaria, Kazakhstan, Lithuania, Ukraine and in many more countries including Russia (Evarte-Bundere and Evarts-Bunders, 2012; Gudko *et al.,* 2021; Rybashlykova *et al.,* 2023). Changes in the value of this coefficient in successive months of the growing season and in growing seasons in successive years may be the basis for the development of plant yield forecasts. In arid zones, the yields of soft winter wheat varieties are particularly affected by the variations of hydrothermal conditions, defined among others, by the hydrothermal coefficient (HTC). It is found that in 2019–2021, positive temperature shifts and drought resulted in an increase in the duration of the growing season of crop varieties, thinned plant density, and reduced productivity of drought-resistant varieties (Esaulko *et al.,* 2023). The climate change has further aggravated the pest and disease occurrence in the region (Samborski, 2013)

Therefore, an attempt has been made to analyze the hydrothermal coefficient (HTC) during the growing season (April-October) in Zamosc, Poland.

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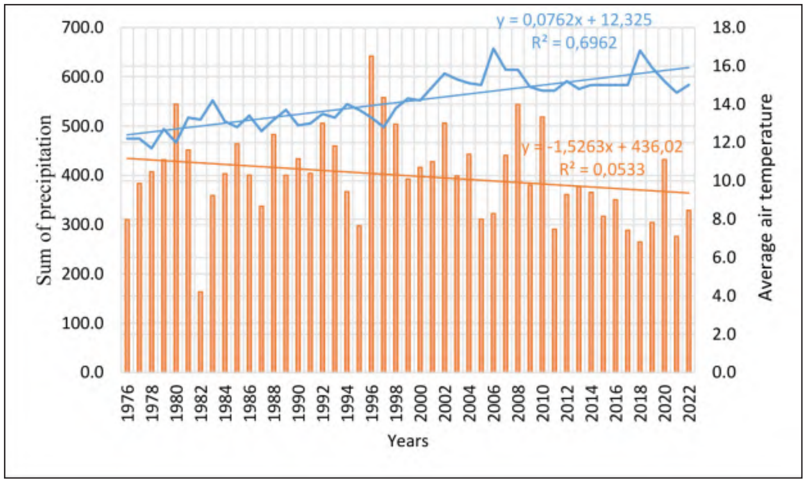

Fig. 1: Variation and trend in average air temperature and total precipitation during the growing season (April-October) in Zamosc.

MATERIALS AND METHODS

The daily precipitation and air temperature data of Zamosc (Lat. 50°42'N, Long. 23°15'E, Altitude 212 m) from 1976 to 2022 period were obtained from the Academy of Zamosc, Poland. The monthly average values of air temperature and precipitation totals for vegetation periods (April-October) were calculated and its trends were analysed using 47 years data. The direction of changes in the values of selected meteorological elements was determined using basic statistical characteristics calculated on the basis of an Excel spreadsheet and the PQStat v.1.8.6 program.

The hydrothermal coefficient of Selyaninov (Selyaninov, 1928), which is a measure of the effectiveness of precipitation in successive months of the growing season (April-October), was used to assess the conditions for plants growth and development. It is the coefficient of securing plants in water, also referred to as the conventional moisture balance in the form:

$$HTC = R \cdot 10/\Sigma t$$

where: R – monthly the sum of precipitation in millimeters; Σt – monthly sum of daily air temperature values.

The value of hydrothermal coefficient (HTC) in the range of $1.3 \leq HTC \leq 1.6$ are considered as optimal, ensuring adequate temperature and precipitation. The conditions when the values of the HTC are lower than 0.7, it is considered as very dry and extremely dry conditions and above 2.5, is very humid and extremely humid conditions (Skowera and Puła 2004). This means that both excess moisture and drought reduce the resistance of crop plants to infections, contribute to the development of a wide variety of diseases and affect the yield obtained. Conditions with extreme values of the hydrothermal coefficient (HTC <0.7 and HTC >2.5) are particularly unfavorable for plants. The frequency of occurrence of optimal conditions was determined as the ratio of the number of observations having the property $1.3 \leq HTC \leq 1.6$ to the size of the entire statistical sample.

RESULTS AND DISCUSSION

In Zamosc, between 1976 and 2022, the average air temperature during the growing season varied from 11.7°C in 1978 to 16.9°C in 2006. Over 47 years, its average value increased from 12.5°C to 15.8°C. The temperature changes recorded in this period are described by the equation: Y= 0.076x+12.325, which means that from 1976 to 2022, there was an average temperature increase of 0.076°C per year in each successive growing season. At the same time, a decrease in total precipitation of about 70mm was recorded. This phenomenon is described by the equation: Y=-1.526+436.02. Thus, statistically, each year during the growing season, a decrease in the value of total precipitation of about 1.5 mm was observed (Fig. 1).

During 1976-2022, the average value of hydrothermal coefficient (HTC) was 1.43 and varied from 0.71 in 2018 to 2.54 in 1980 (Fig.2). In 47 years, the average value of the coefficient during the growing season was below the value of 1.30: 16 times, meaning that the conditions were quite dry to very dry, and 13 times it was above 1.60, meaning that the conditions were quite humid to very humid. Optimal vegetation conditions for plants in the period from April to October ($1.3 \leq K \leq 1.6$) in the years studied occurred in 18 growing seasons (Fig. 2).

The value of the hydrothermal coefficient (HTC) in the growing season (April-October) was influenced by the average values of this coefficient in subsequent months of the period. Of the 329 months analyzed, optimal conditions ($1.3 \leq HTC \leq 1.6$) occurred in only 39 months, accounting for 11.8% of all months. In the rest, the HTC >1.6 occurred in 121 months, or 36.8%, and HTC <1.3 in 169 months, or 51.4% of all months (Table 1).

Thus, conditions ranging from fairly dry to extremely dry (HTC<1.3) were far more frequent in the second half of the growing season (July-October), compared to the April-June period, when the hydrothermal coefficient (HTC) values were greater than 1.6 (Fig. 3). The number of months with HTC<1.3 has increased markedly in the current century (since 2000). The increase in the number of months with fairly dry and dry conditions in this period was the result of a decrease in the number of months with optimal

Table 1: Frequency of the hydrothermal coefficient (HTC) in Zamosc during the growing season in three size classes.

Hydrothermal coefficient	HTC - frequency in months:							
	April	May	June	July	August	September	October	Seasonal total
HTC<1.3	6 (12.8%)	19 (40.4%)	18 (38.3%)	37 (78.7%)	31 (66.0%)	33 (70.2%)	25 (53.2%)	169 (51.4)
HTC >1.6	39 (83.0%)	22 (46.8%)	20 (42.6%)	6 (12.8%)	8 (17.0%)	9 (19.1)	17 (36.2%)	121 (36.8)
1.3≤ HTC ≤1.6	2 (4.2%)	6 (12.8%)	9 (19.1%)	4 (8.5%)	8 (17.0%)	5 (10.6%)	5 (10.6%)	39 (11.8)

Table 2: Values of the correlation coefficient R between the hydrothermal coefficient (HTC), air temperature (x_1) and total precipitation (x_2) during the growing season.

Hydrothermal coefficient (HTC)	April	May	June	July	August	September	October	IV-X
$(x_1) + (x_2)$	0.969	0.992	0.994	0.992	0.997	0.992	0.986	0.952
(x_1)	0.394	0.339	0.212*	0.333	0.004*	0.019*	0.287	0.574
(x_2)	0.866	0.946	0.980	0.976	0.979	0.976	0.941	0.879

* values are insignificant

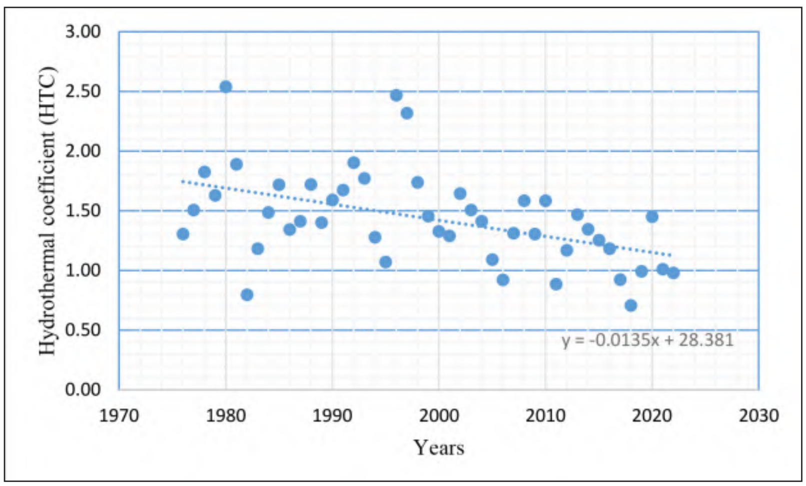

Fig. 2: Variation and trend of the hydrothermal coefficient (HTC) during the growing season

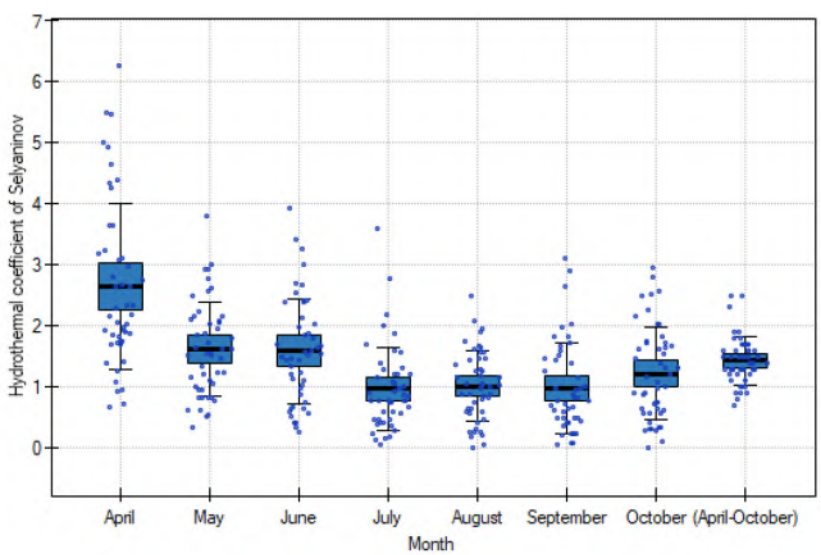

Fig. 3: Direction and magnitude of trends HTC in Zamosc in NE Poland (1976-2022). The box plot designates confidence interval 95% and standard deviation.

conditions ($1.3 \leq HTC \leq 1.6$) and months with fairly wet to extremely wet conditions HTC>1.6.

Regression analysis of the equation: $HTC = a + b_1x_1 + b_2x_2$ indicates that in each of the months of the growing season there is a statistically significant relationship of $p<0.05$ between the value of the HTC and total precipitation (x_2), while for air temperature (x_1) in June, August and September the relationship was below the assumed threshold of $p<0.05$ (Table 2).

The presented results of the study indicate that in the growing season over the past 47 years there has been a marked increase in air temperature and significant changes in the distribution of precipitation. The result is a progressive drought process, as indicated by the decreasing values of the hydrothermal coefficient (Fig. 2). The observed climate changes confirm the results of research and analyses by other authors, according to which the dry climate zone B is expanding in Europe and is compensating by the simultaneous decrease in the area covered by tropical climate A, and especially by the temperate climate C (Beck *et al.,* 2005). The effect of the progressive increase in air temperature is not only an increase in soil temperature (Górniak, 2023), but also a decrease in soil moisture, which has a significant impact on the conditions for the growth and development of crop plants. Temperature and water supply are crucial for seed germination, and thus affect the species composition and diversity of communities (Walck *et al.,* 2011).

CONCLUSION

The study revealed that at Zamosc in the eastern part of Poland, air temperature was found to increase while precipitation had the decreasing trend during past 47 years, resulting in the declining trend in the hydrothermal coefficient (HTC). This confirm the threat resulting from the observed climate changes, the consequence of which is the progressive steppe formation of this area. In order to ensure the right conditions for the growth and development of plants, it is extremely important to rationally manage water resources in order to obtain the best possible yields and preserve the natural values of this region.

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