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Assessing Climate Aridity Trends in Southern Ukraine during 1991-2020

S. Boychenko *(S. Subbotin Institute of Geophysics of NAS of Ukraine; National University of Kyiv-Mohyla Academy)*, ***T. Kuchma*** *(Institute of Agroecology and Environmental Management; National University of Kyiv-Mohyla Academy)*, ****N. Maidanovych*** *(Leonid Pogorilyy UkrNDIPVT)*, ***T. Myronova*** *(National University of Kyiv-Mohyla Academy)*

SUMMARY

Assessment of Climate Aridity Trends in the Southern Region of Ukraine was conducted using data meteostations for the period 1991-2020. The analysis of climate aridization trends over the past 30 years in the study region has revealed a notable intensification of this process, especially in recent years. The hottest summer months occurred in 1992, 1999, 2001-2003, 2007, 2010, 2012, and 2017-2019. These periods were marked by anomaly high temperatures, dry winds, extended non-rainfall periods, and low air humidity, often reaching as low as 30%. Over the past 30 years, from March to October, the Southern Region experienced an average of 203±6 non-rainfall days, with a trend indicating an increase by an average of 0.4±0.1 days per 10 years. Conversely, the number of days with relative humidity up to 30% on the March–October time scale averaged 41±16 days, with a tendency to increase by 1.2±0.7 days per 10 years. The highest occurrence of days with relative humidity up to 30%, on average in the region, is typically observed in July and August (7 and 10 days per month, respectively). To assess climate aridity and calculate drought severity for vegetation were used a satellite-derived Vegetation Health Index (VHI). Drought indices derived from the summed VHI values in August for the years 2007, 2018, and 2020 in the Southern Region of Ukraine are presented.

Introduction

During the last few decades, climate warming in Europe, including Ukraine, has slightly exceeded the global rate (Baumbach et al., 2017; Boychenko and Kuchma, 2022; Semenova and Slizhe, 2020; Spinoni et al., 2016). Abnormally high temperatures, combined with a decrease in summer atmospheric precipitation, intensify the climate aridization process. Long droughts result in a range of negative consequences, including drying and death of plants in natural and agro-ecosystems, shallowing of rivers and lakes, dehydration, thermal discomfort, and risks to people's health and lives. In the Southern Region of Ukraine, the average annual temperature has increased by an average of 0.68°C per decade, and the annual amount of atmospheric precipitation has increased by 6-7%. However, a 15-25% decrease in monthly precipitation was recorded during the summer (Karamushka et al., 2022). The drought phenomena are defined as follows (Guidelines, 2019; The Climate of Ukraine, 2003): *non-rainfall period* – a time interval (up to 10 days or more) during which there is no precipitation, or its daily amount does not exceed 1 mm/day; *anomaly hot periods* – a deviation of the average daily temperature of a given area from the corresponding long-term value; *dry winds* – transfer of warm wind flow with a speed of 3-5 m/s, relative air humidity up to 30%, and temperature of 25°C and above; *low air humidity up to 30%* – relative air humidity 30% and less throughout the day. To assess the manifestation of arid conditions and their impact on vegetation it is advisable to apply satellite-driven indexes such as Vegetation Health Index (VHI) (Kogan, 1995).

The purpose of the work is to analyze the features of drought phenomena in the Southern Region of Ukraine during the warm season (March-October) from 1991 to 2020.

Method and Theory

For assessing trends of climate aridity in the Southern Region of Ukraine, meteorological data from Askania-Nova, Zaporizhzhia, Mykolaiv, Odesa, and Kherson for the period 1991-2020 (8-month time scale from March to October) were used (CGO, 2021). Specifically, the data contain non-rainfall days (including the days with precipitation amount less than 1 mm/day), days with low relative air humidity (30% or less), and anomaly hot months during the warm season. Anomaly-high monthly temperatures $\Delta T_k(m)$ were calculated using the formula ($\Delta T_k(m) = T_k(m) - (\langle T_{1991–2020}(m)\rangle + 2\sigma)$), where $T_k(m)$ is the average monthly temperature in the k-th year, $\langle T_{1991–2020}(m)\rangle$ is the long-term average for the given month, σ is the standard deviation, and *m* is the month number). The repeatability of meteorological variables' values (the frequency of occurrence of an indicator in the statistical distribution) is expressed in %. The Vegetation Health Index (VHI) was used to classify the severity of droughts and was calculated as a combination of the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI) using the UN-Spider drought monitoring methodology (Kogan, 1995; Recommended Practice, 2022). The VCI index was calculated as a function of the maximum and minimum Normalized Difference Vegetation Index (NDVI) and the TCI index was calculated by comparing the minimum and maximum Land Surface Temperature (LST) (Karnieli et al., 2010). The data for NDVI and LST were obtained from MODIS satellite images for some of the driest years of 2007, 2018, and 2020 in the summer month of August (Didan, 2021). The calculations' statistical analysis and graphical design regarding the repeatability of drought phenomena were performed by Excel and XLSTAT software packages.

Results

The repeatability of the number of non-rainfall days in the Southern Region of Ukraine during 1990-2021. The non-rainfall periods in Ukraine are caused by the anticyclonic nature of synoptic processes and the orographic features of the area (The Climate of Ukraine, 2003). According to spatial distribution, rainless periods are divided into western origin (with an average duration of 15-16 days per month) and northern, eastern, and southern origin (with an average duration of 17-25 days per month) (The Climate of Ukraine, 2003). Non-rainfall periods in Ukraine are mainly fixed from April to October, but in the Southern Region – from March to October. The maximum repeatability of the

phenomenon is typical in July-August. The number of non-rainfall days in the Southern Region over the past 30 years during March to October is on average 203±6 days, with a trend to increase on average by 0.4±0.1 days (from 3 to 5 days) per 10 years (see Figure 1a). The spatial distribution of average number of non-rainfall days has slight differences, namely in Askania-Nova – 205±8, Kherson – 203±8, Mykolaiv – 204±7, Odesa – 206±6, Zaporizhzhia – 197±7 days per 8-months were fixed.

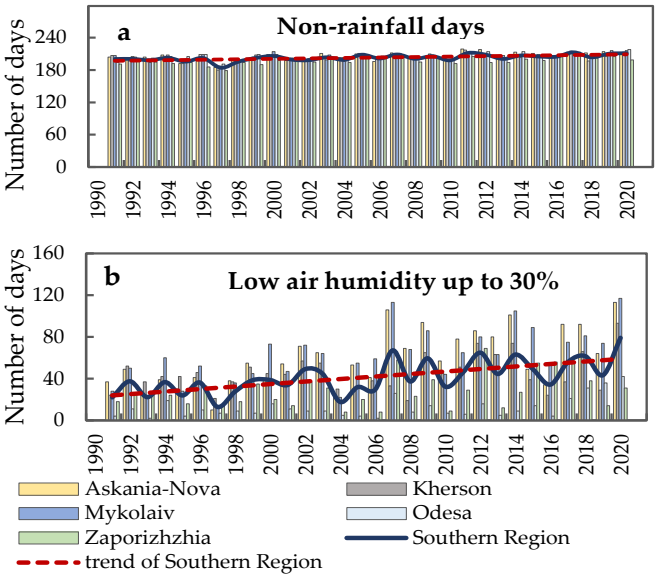

Figure 1 *The time course of the number of non-rainfall days* ***(a)*** *and number of days with low air humidity up to 30%* ***(b),*** *which were recorded at meteorological stations and average in the Southern Region of Ukraine on a time scale of 8 months (March-October) during 1991-2020*

However, in some years, the number of days with this phenomenon can be much higher, for example, in Askania-Nova (219 days in 2011, and 218 days in 2012), Kherson (217 days in 2011, and 215 days in 2017), Mykolaiv (216 days in 2020), Odesa (216 days in 2019, and 218 days in 2020) and Zaporizhzhia (213 days in 2017). While the least number of days is ~185-197 days per 8 months (March-October). In the warm period of the year, on average, it is recorded up to 25-27 non-rainfall days per month, with a maximum in August up to 30-31 days. Generally, in the Southern Region of Ukraine, there is a trend towards an increase in the number of non-rainfall days from 0.2 to 1.3 days/month per 10 years, except for July, there is a decrease of –0.1 days per 10 years (see Figure 2a).

The repeatability of the number of days with low air humidity up to 30% in the Southern Region of Ukraine during 1991-2020. The frequency of days with a relative air humidity of 30% or less in Ukraine was recorded from several times to several dozen from April to October (in the Southern Region from March to October) (The Climate of Ukraine, 2003). A decrease in relative humidity to 30% and below is the cause of the "atmospheric drought" phenomenon. In the Southern Region, the number of days with relative humidity up to 30% on the March-October time scale is 41±16 days, with a tendency to increase by 1.3±0.7 days (from 6 to 20 days) per 10 years (see Figure 1b). At the same time, the spatial distribution of the number of days with low humidity has certain differences, in particular: Askania-Nova – 60±27, Kherson – 45±17, Mykolaiv – 61±26, Odesa – 12±10, Zaporizhzhia – 29±16 days per 8 months.

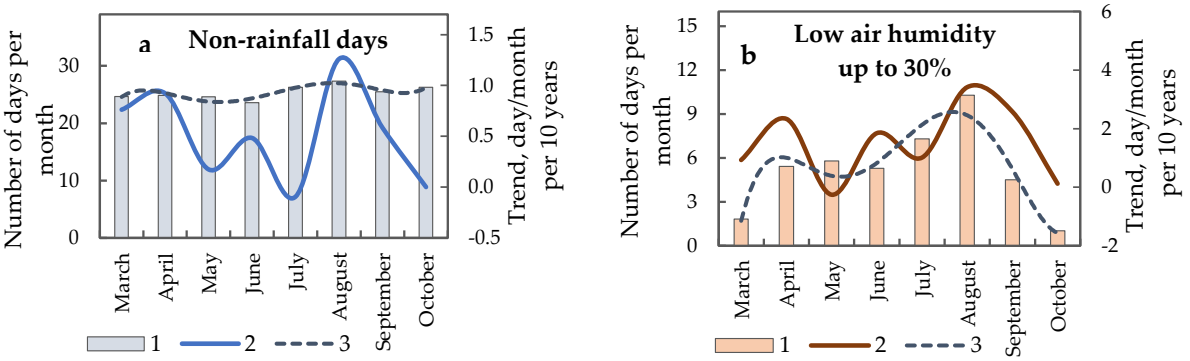

Figure 2 *Comparison of seasonal variations in the frequency of the number of non-rainfall days* ***(a)*** *and days with air humidity up to 30% (****b****) in the Southern Region of Ukraine during the warm part of the year for 1991-2020 (1 – empirical data, 2 – trends, 3 – 5th-degree polynomial spline regression)*

But in some years (2007, 2009, 2012, 2014, 2017, 2018, and 2020), a significantly higher number of days with relative humidity up to 30% was recorded. For example, in Askania-Nova (106 days in 2007 and 113 days in 2020), Kherson (93 days in 2020), Mykolaiv (113 days in 2007, 105 days in 2014, and 117 days in 2020), Odesa (42 days in 2020), Zaporizhzhia (58 days in 2007 and 69 days in 2012), which in some places almost doubles the regional average. The manifestations of periods with relative air humidity of 30% and less are analyzed for the warm period of the year and have a certain seasonal course with a maximum in summer (see Figure 2b). The highest repeatability of the number of days with relative humidity up to 30%, on average in the region, is typical for July and August (7 and 10 days per month, respectively). In the Southern Region, there is a tendency to increase the frequency of days with relative humidity up to 30% from 1 to 3 days/month per 10 years, except May, where a decrease of –0.3 days/month per 10 years.

Anomaly hot months during the warm season in the Southern Region of Ukraine during 1991-2020. Abnormally high air temperatures in Ukraine are set in the anticyclonic weather regime (The Climate of Ukraine, 2003).

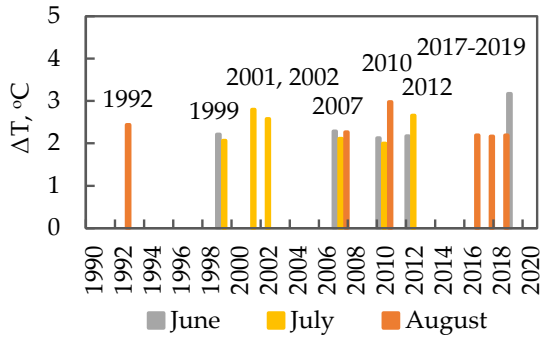

Figure 3 *Anomaly hot months (June-August) during the warm season 1991-2020 in the Southern Region of Ukraine*

Dry continental air of moderate latitudes or tropical air from the southeast, especially in the warm period of the year, brings hot dry weather with frequent dry and non-rainfall periods. The frequency of abnormally high air temperatures ΔT (in May-August in the Southern Region of Ukraine during the period 1991-2020 clearly increased. So, the hottest summer months were set in 1992, 1999, 2001, 2002, 2007, 2010, 2012, and 2017-2019 (see Figure 3). The analysis showed that these periods were accompanied by abnormally high temperatures, dry winds, non-rainfall periods, and low air humidity up to 30%.

Climate aridity analysis in the Southern Region of Ukraine using Vegetation Health Index. To assess the manifestation of arid climatic conditions and their impact on vegetation, as well as identifying areas more susceptible to drought conditions, we analyzed a satellite-driven monthly drought severity index known as the VHI for the selected driest years. The VHI was used to classify the severity of droughts based on specific threshold values (Kogan, 1995). The classification was as follows: values of VHI < 10 are "Extreme drought"; VHI 11-20 is "Severe drought"; VHI 21-30 is "Moderate drought"; VHI 31-40 is "Mild drought"; VHI > 40 is "No drought". Drought indices from VHI in August 2007, 2018, and 2020 in the Southern regions of Ukraine are shown in Figure 4. As you can see, in 2007, a drought in August covered a significant part of Ukraine, and the values of the drought index (VHI) were classified as "Extreme drought" and "Severe drought". However, in 2018 and 2020, the index mostly had VHI values of "Mild drought", with only sporadic instances of "Severe drought" and "Moderate drought".

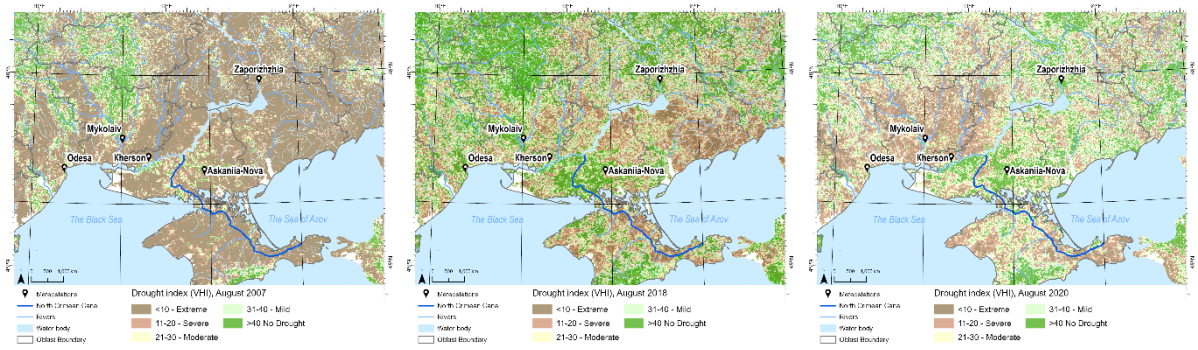

Figure 4 *Drought index from summed Vegetation Health Index (VHI) in August 2007, 2018, and 2020 in the Southern Region of Ukraine (Didan, 2021)*

Conclusions

Analysis of climate aridization trends over the past 30 years in the Southern Region of Ukraine has proven the intensification of this process, especially in recent years. The hottest summer months were in 1992, 1999, 2001, 2002, 2007, 2010, 2012 and 2017-2019. These periods were accompanied by abnormally high temperatures, dry winds, non-rainfall periods, and low air humidity up to 30%. The number of non-rainfall days in the Southern Region over the past 30 years from March to October is on average 203±6 days, with a trend to increase on average by 0.4±0.1 days (from 3 to 5 days) per 10 years. The number of days with relative humidity up to 30% on the March-October time scale is 41±16 days, with a tendency to increase by 1.3±0.7 days (from 6 to 20 days) per 10 years. The highest repeatability of the number of days with relative humidity up to 30%, on average in the region, is typical for July and August (7 and 10 days per month, respectively). A satellite-derived vegetation index VHI was used to classify the severity of droughts based on specific threshold values in August 2007, 2018, and 2020 in the Southern Region of Ukraine. The index values made it possible to assess drought phenomena in 2007 as "Extreme drought" and "Severe drought", while in 2018 and 2020 – mostly as "Mild drought".

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