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Assessment of aridization of climatic conditions on the Crimean Peninsula in summer using ground and satellite data

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SUMMARY

Climate vulnerability of the Crimean Peninsula is assessed based on the temperature and precipitation changes for the period 1991-2021 and satellite-derived drought index (VHI) variations for the period 2001-2021. There is an increase of temperature on average by 0.78±0.01 ºC per 10 years in summer, and a slight change in precipitation in June and July (within 2±1%). While in August there is a decrease of the precipitation amount by 10-12%. According to analysed data, the most severe drought condition manifestation on the Crimean Peninsula over the last twenty years was observed in 2007, 2017, 2018 and 2020. In the central part of the Crimean peninsula, which belongs to the climatic zone of Steppe Crimea, arid conditions had the greatest manifestation and distribution (zones with extreme and severe drought conditions are observed). Minor areas in the mountainous part of the Crimea also have signs of arid conditions, but for the most part the condition of vegetation is satisfactory in this area. In percentage terms, in 2007 VHI values of extreme and severe drought occupied 57% and 20% of the peninsula's area accordingly, as well 10% and 29% in 2017, 7% and 22% in 2018 and 11% and 26% in 2020.

Introduction

Modern climate change has the regional peculiarities and, in general, results in a decrease in the duration of the cold season and an increase in the duration of the vegetation season, as well as the tendency to anomalous high temperatures ≥30°C in summer (*IPCC, 2021; Barcikowska et al., 2020*). The area affected by droughts has been increased in the second half of the 20th century in Europe and droughts conditions depress the vegetation *(Bordi et al., 2009).* These regional features of climate change affect the vegetative activity of ecosystems, that can be confirmed by satellite remote sensing data. *(Karnieli et al., 2010; Baumbach et al., 2017).* An increase in arid conditions was revealed, which affects the productivity of ecosystems in the south of Europe, as well as, in the southern region of Ukraine, including Crimean Peninsula *(Bordi et al., 2009; Karamushka et al., 2022; Boychenko et al., 2022*).

According to the analysis presented in (*Boychenko and Kuchma, 2022*), on the plain part of the Crimean Peninsula of the average annual temperature has been increased by an average of 0.75° ± 0.12 °C per 10 years during the period 1991–2020 and the annual amount of precipitation has been decreased by an average of 27 ± 15 mm per 10 years (10–15%). There is a tendency in a decrease of precipitations throughout the year, especially in April, August–September, and November (up to 15%), with a slight increase in December–January, and July by 4–7% only.

The study aims to analyse the features of climate change in summer on the Crimean Peninsula for the period 1991–2021 by using meteodata and to assess the dynamics of drought severity index (VHI) for the period of 2001–2021 by using satellite data.

Method and Theory

In this study, empirical data from the meteostations Dzhankoy, Yevpatoria, Alushta, Kerch, Feodosia, Yalta and Simferopol, namely, averaged monthly surface air temperature, precipitations for the period 1991–2021 were used (after 2014, empirical data of (*CGO, 2021*), and for the period 2014–2021, data from the resource (*Weather and climate, 2022*)). The research results are based on the data processed according to the methods of statistical analysis of meteorological information. The calculations' statistical analysis and graphical design were performed using software packages MS Excel and XLSTAT.

To assess the climate aridity satellite-derived vegetation index was used to calculate the drought severity index, known as VHI (vegetation health index) based on the drought monitoring UN-Spider methodology *(Recommended Practice, 2022).* VHI was calculated as a combination of vegetation condition index (VCI) and temperature condition index (TCI). VCI index was calculated as the function of Normalized Difference Vegetation Index (NDVI) maximum and minimum over the long-term period, compared to NDVI value of the current month. Similar to VCI, TCI index was calculated as the comparison of minimum and maximum Land Surface Temperature (LST) to the LST of the current month. MODIS satellite imagery over the period of 2000–2021 was used as a data source for NDVI and LST data.

Results of investigations

Change in temperature and precipitation in summer on the Crimean Peninsula. The aridization of climatic conditions on the peninsula is especially enhanced during the warm period of the year. To assess the variability of climatic parameters, their anomalies were calculated, based the average value over 30 years for each weather station and averaged over the study territory. The anomalies of the average monthly temperature and precipitation amount in the summer months in Crimea for the period 1991–2021 are shown in Fig. 1. Against the background of temperature increase (on average by 0.78±0.01 °C per 10 years), there is a slight change in the amount of precipitation in June and July (within 2±1%), while in August the amount of precipitation decreased by 10-12%. However, high summer temperatures increase the evaporation of precipitation, which further exacerbates the situation with the aridization of climatic conditions.

The frequency distribution of precipitation in summer months by gradations (<25; 26-50; 51-75; 76-100; >101 mm per month) recorded at meteostations of Crimea for the period 1991-2021 is shown in

Fig.2. The abnormally low precipitation has the highest frequency by 0.31-0.48, and the amount of precipitation in the range by 26-50 (which is about the average climatic norm) has a frequency by 0.28-0.29. An anomalously high amount of precipitation of more than 100 mm/month has a frequency by 0.05-0.08 in June-July, and 0.11 ±0.06 in August. August is the most arid month in the Crimea and at the same time, as a result of heavy rain in some years it can fall up to 200 mm per month or more (for example, in 2004 in Simferopol and Dzhankoy).

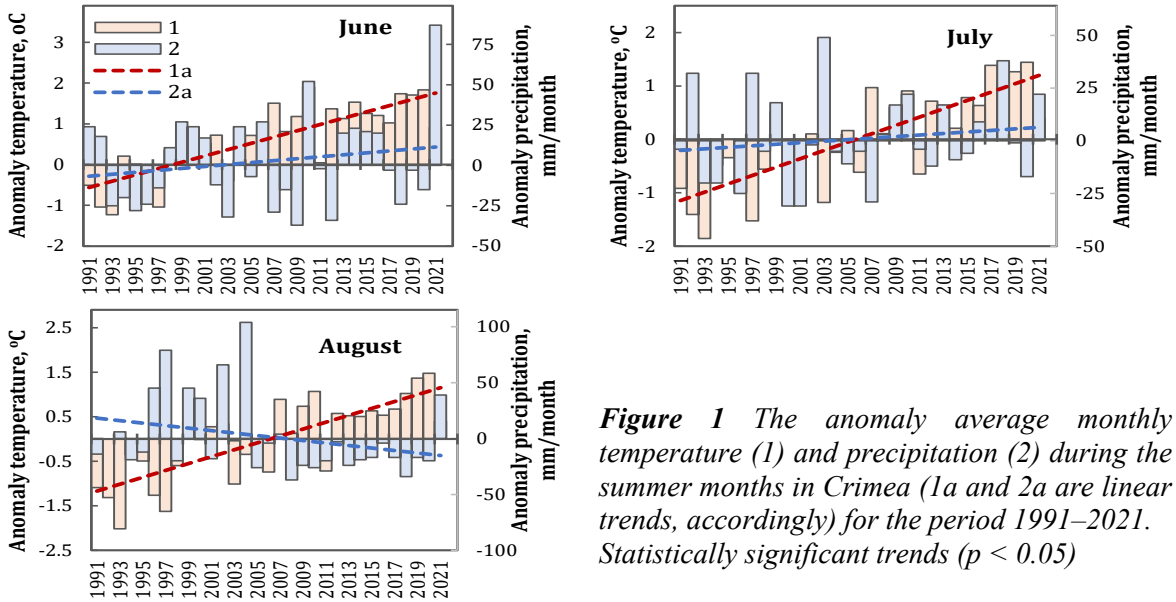

Figure 1 *The anomaly average monthly temperature (1) and precipitation (2) during the summer months in Crimea (1a and 2a are linear trends, accordingly) for the period 1991–2021. Statistically significant trends ($p < 0.05$)*

However, due to the dry soil, the precipitation is not assimilated by ecosystems and most often lead to flooding. The productivity of ecosystems responding to such climatic conditions was analysed using satellite data.

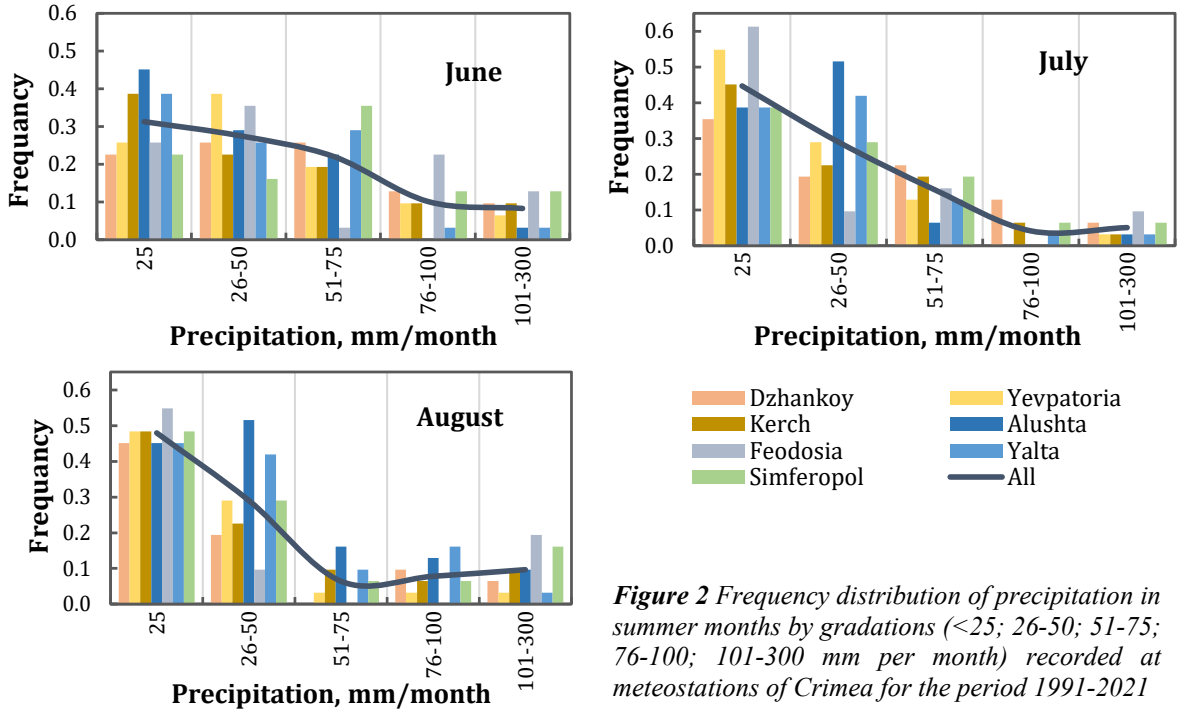

Figure 2 *Frequency distribution of precipitation in summer months by gradations (<25; 26-50; 51-75; 76-100; 101-300 mm per month) recorded at meteostations of Crimea for the period 1991-2021*

Climate Aridity Analysis Using Drought Severity Index of the Crimean Peninsula. To assess the manifestation of arid climatic conditions and their impact on vegetation as well as to define the areas, which are more prone to drought conditions, the satellite-driven monthly drought severity index (VHI) was analysed over the period of 2001–2021 (*Recommended Practice, 2022, Karnieli, et.al., 2010)* (see Figure 3A). Drought severity classification was made according to the recommended VHI threshold's values (<10-extreme drought, 11–20-severe drought, 21–30-moderate drought, 31–40-mild drought, >40-no drought) (*Recommended Practice, 2022)*.

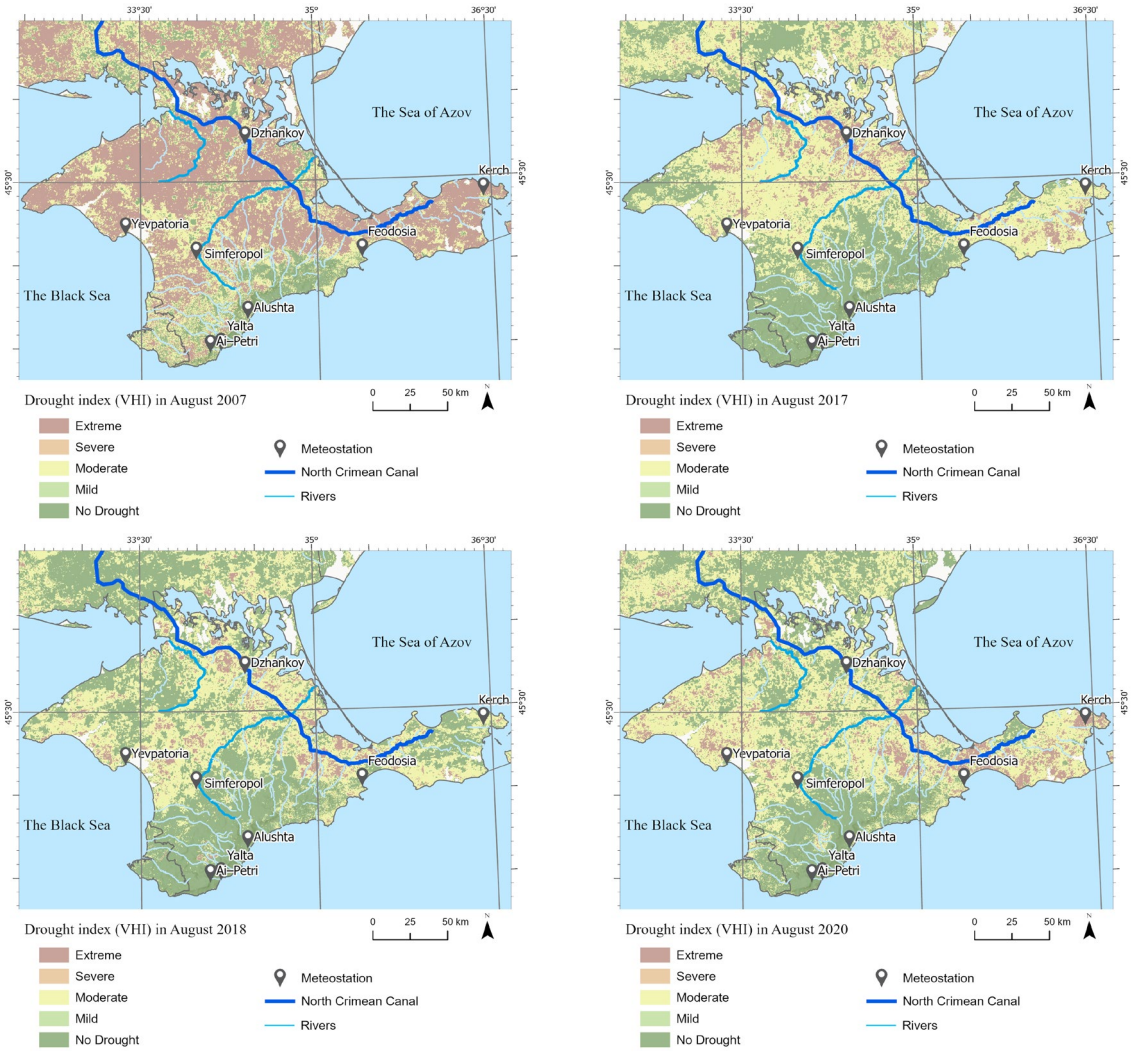

Figure 3 *Drought index from summed vegetation health index (VHI) in summer (in August 2007, 2017, 2018 and 2020) on the Crimean Peninsula*

According to analysed data, the most severe drought condition manifestation on the Crimean Peninsula over the last twenty years were observed in 2007, 20017, 2018 and 2020 as shown on Figure 3. In the central part of the Crimean Peninsula, which belongs to the Steppe Crimea climatic zone, arid conditions had the greatest manifestation and distribution (zones with extreme and severe drought conditions are observed) in these years. While most of the agricultural lands are located in the central part of the Peninsula. Areas of extreme drought conditions are also observed in the Northern coastline area of the Crimean Peninsula. Minor areas in the mountainous part of the Crimea also have signs of arid conditions, but for the most part the condition of vegetation in this area is satisfactory. In percentage terms, in 2007 VHI values of extreme and severe drought occupied 57% and 20% of the

peninsula's area accordingly, as well 10% and 29% in 2017, 7% and 22% in 2018 and 11% and 26% in 2020

Conclusions

There is an increase of temperature on average by 0.78±0.01 ºC per 10 years on the Crimean Peninsula in summer, and a slight change in precipitation in June and July (within 2±1%). While in August there is a decrease of the precipitation amount by 10-12%. However, high summer temperatures increase the evaporation of precipitation, which further exacerbates the situation with the aridization of climatic conditions. The frequency distribution of precipitation in summer months by gradations for the period 1991-2021 has abnormally low values with the highest frequency of 0.31-0.48, and the amount of precipitation in the range of 26-50 has a frequency of 0.28-0.29. According to analysed data, the most severe drought condition manifestation on the Crimean Peninsula over the last twenty years was observed in 2007, 20017, 2018 and 2020. In the central part of the Crimean Peninsula, which belongs to the Steppe Crimea climatic zone, arid conditions had the greatest manifestation and distribution (zones with extreme and severe drought conditions are observed) in these years. Minor areas in the mountainous part of the Crimea also have signs of arid conditions, but for the most part the condition of vegetation in this area is satisfactory. In percentage terms, in 2007 VHI values of extreme and severe drought occupied 57% and 20% of the peninsula's area accordingly, as well 10% and 29% in 2017, 7% and 22% in 2018 and 11% and 26% in 2020.

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