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Monitoring of climate changes and the state of natural complexes of the Cheremsky Nature Reserve

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SUMMARY

In recent decades, global climate changes have resulted in a range of regional climatic processes and phenomena, exerting significant impacts on the natural complexes within nature conservation areas, protected objects, and elements of the ecological network. The study of these effects is highly pertinent to the territories and natural systems encompassed by the Cheremsky Nature Reserve, a particularly valuable nature conservation complex in Northwestern Polissya. Our analysis was based on meteorological data from the nearest weather station, complemented by remote sensing techniques examining vegetation and water indices over the 5-year period. This examination revealed several notable deviations from climatic norms, including: an increase in annual and maximum air temperatures by 2.0°C and minimum temperatures by 1.0-1.5°C, an increase in annual precipitation by 5-6%, a drastic reduction in snow cover duration by 2-2.5 times, a decrease in the number of days with precipitation by 10-17%, a substantial increase in the number of days with thunderstorms. These findings suggest a negative impact on natural complexes, primarily due to an increase in evaporation from the active surface and a corresponding decrease in the humidity coefficient by 20-25%. Additionally, our study revealed the interrelation between vegetation processes and the dynamics of climatic indicators.

Introduction

Monitoring the ecological condition of landscape complexes within Ukraine's Nature Reserve Fund (NRF) in the context of climate change constitutes a significant theoretical and practical challenge. It necessitates the utilization of contemporary methods for analysis and assessment, along with forecasting the future trajectories of natural processes within these complexes. This holds particular relevance for the Cheremsky Nature Reserve (Cheremsky NR), among the most precious reference natural landscapes found in Northwestern Polissia. The hydrobiological equilibrium of wetlands, forested areas, and lakes within the reserve is intricately tied to the fluctuations of various climatic parameters, including air temperature and humidity patterns (precipitation levels, air moisture, and active surface evaporation), among others. These dependencies underscore the importance of our research, which is conducted through the application of statistical and graphical techniques, complemented by remote sensing (RS) methods.

Method and/or Theory

The purpose of this work is to study the recent regional dynamics of climatic indicators in Cheremsky NR in the context of global climate changes and their impact on natural complexes, utilizing data from multispectral satellite images. *The tasks* include: 1) Statistically assessing and graphically analyzing the dynamics of climatic indicators within the region concerning regional climate changes. 2) Analyzing available space images for the study area. 3) Identifying specific features of the reserve's natural complexes using high-resolution optical images at various points in time. 4) Evaluating differences in the moisture level in the surface layer of the territory based on normalized water indices derived from multispectral space images. 5) Analyzing the dynamics of vegetation and water indices for the 5-year period from 2016 to 2020. *Materials and methods:* The analysis was conducted through manual and semi-automatic decoding of sets of space images. The chosen analysis period spans five years, from 2016 to 2020. The assessment of vegetation indices was also compared with corresponding climatic indicators using weather station observation data from Manevychi, the station closest to Cheremsky NR's territory. Previous studies have addressed the impact of climate change on the ecological state of protected areas in Ukrainian Polissia by researchers such as Boichenko S. et.al. (2010), Konishchuk V.V. (2007), Fedoniuk V.V. et al. (2016), Fedoniuk V., Khrystetska M. et al. (2020), Kovalchuk I.P. et al. (2013). They noted significant impacts on the hydrological regime of water bodies and emphasized the need to expand hydrobiological monitoring programs in this context (Klymenko M.O. et al. (2020). Similar research is conducted globally, with notable works by Tamm O., Maasikmäe S., Tamm T. (2018), Janse, J. H. et al (2019). The current state of natural complexes in Cheremsky NR has been assessed by Konishchuk V.V. (2007), Boyarin M.V., Savchyk L.A. (2017), Lakyda P.I., Hotsyk O.S. (2019). Researchers like Myrka V.V. et al. (2022) have begun assessing the impact of climate change on these complexes. Many of these modern studies employ remote sensing (RS) methods, similar to approaches used by Darrah S. et al. (2019), Chen B. et al. (2018). Therefore, this study combines traditional statistical and graphical analysis with results obtained through RS methods, in line with contemporary research trends.

Results

The assessment of Cheremsky NR's natural complexes utilized multispectral imagery from Landsat-8 and Sentinel-2 satellites, known for their multispectral capabilities and frequent updates. Analysis was conducted using the Sentinel-HUB and EOS LandViewer services. Given the operational period of the Sentinel-2 satellite starting in 2015, the analysis focused on the 5-year span from 2016 to 2020, resulting in the identification of approximately 500 images of the target area, with over 100 meeting the quality criteria. During the selected period of 2016–2020, a comprehensive analysis of meteorological indicators and phenomena was conducted, encompassing average, minimum, and maximum air temperatures; relative humidity; precipitation amounts including annual, daily, and maximum values; average wind speed; minimum and maximum wind speed; atmospheric pressure including average, minimum, and maximum readings; sky cloudiness; snow cover and its duration, including maximum height; and various weather phenomena like rain, snow, fog, blizzards, and thunderstorms (quantified by their frequency throughout the year). For all these indicators, the data underwent rigorous statistical processing, climatological analysis, and graphical interpretation of their dynamics. Standard statistical and mathematical methods were employed, and graphical representations were generated using the Excel program. To assess the moisture conditions of the territory and their impact on the reserve's wetland complexes, which hold particular ecological significance, the study calculated evaporation rates and the wetting coefficient based on the established methodology by N. Ivanov. Table 1 provides an overview of integrated average annual and 5-year average indicators for the 2016–2020 period. Let's now delve into the key findings derived from this analysis.

Table 1 *Indicators characterizing the regime of temperature and humidity for the period 2016–2020 (according to the data of the Manevychi station)*

Indicator	Year					Climatic norm	Average values for 2016-20
	2016	2017	2018	2019	2020		
T average (°C)	+9,0	+8,8	+9,4	+10,0	+9,9	+7,0	+9,4
Relative humidity, %	80	78	76	75	77	80	77,2
Precipitation amount, year, mm	559	804	581	639	733	660	663
Evaporation, mm	499	544	613	661	610	443	588
Coefficient of hydration	1,12	1,5	0,95	0,97	1,2	1,5	1,13

The assessment of meteorological indicators in the Cheremsky NR territory revealed the following results: 1) The average annual air temperature during 2016–20 was +9.4°C, nearly 2°C higher than the climatic norm, calculated based on the 1961–1991 period according to WMO recommendations. This significant temperature increase highlights the region's pronounced global warming trends. Notably, 2019 was a historic year, recording an average annual temperature exceeding 10.0°C for the first time in the observed historical period. 2) The average minimum air temperature ranged between +4.9°C and +5.9°C, with the highest value of +5.9°C also occurring in 2019. This exceeded the climatic norm by 1–1.5°C. 3) The average maximum air temperature fluctuated between +11.8°C and +14.8°C, which is 2°C higher than the climatic norm. Once again, the warm and dry year of 2019 recorded the highest value (+14.8°C). 4) Absolute minimum and maximum temperatures remained within the climatic norm. 5) Relative air humidity levels averaged 75-80%, falling 2-5% below the climatic norm. 6) Wind speed averaged close to 2 m/s, which is lower than the climatic norm. 7) Atmospheric pressure readings remained within the climatic norm. Notably, maximum atmospheric pressure values reached 1042-1043 hPa, compared to the climatic norm of 1040 hPa. 8) Overall sky cloudiness also adhered to the climatic norm, varying from 5.7 to 6.5 points. However, lower cloudiness indices were unusually low (2.7-2.0 points) in certain years (2016-2017), resulting in an average of 3.7 points, 0.4 points below the climatic norm. In 2018–2020, the lower cloudiness index returned to the climatic norm. 9) Annual precipitation ranged from 559 to 804 mm during the study period, with a 5-year average of 663 mm surpassing the long-term average for Manevychi station. 10) The maximum daily precipitation amount remained within the climatic norm, although it exhibited atypical patterns in the autumn months of 2016 and 2020. 11) Snow cover duration fluctuated from 6 to 7 days to 64 days, considerably lower than the climatic norm in most study years, averaging 2.5 times less. 12) The average snow cover height observed typical values or exceeded climatic norm indicators, ranging from 12 to 30 cm with an average of 19 cm. 13) The frequency of weather phenomena, including rain, snow, fog, blizzards, and thunderstorms, was examined separately. Findings indicated a variable annual count of days with precipitation (rain and snow) ranging from 168 to 116 days. This trend showed a decrease, with the 5-year average (142 days with precipitation) falling below the climatic norm (152 days) for both rain and snowfall. 14) The annual average of days

with blizzards (0.8 days) was lower than the climatic norm. This correlated with the general decline in snow days and snow cover duration. 15) The average annual number of days with thunderstorms (27 days) exceeded the climatic norm by 40%, indicating an intensification of convective weather phenomena. This change could negatively impact Cheremsky NR's natural complexes, potentially leading to a 30–35% increase in evaporation from the active surface and a 20–25% decrease in the humidity coefficient.
The assessment of the reserve's natural complexes using remote sensing (RS) methods involved the utilization of vegetation indices and a normalized water content index, with the most common vegetation index being the NDVI (Normalized Difference Vegetation Index). For the Cheremsky NR territory, a total of 523 Sentinel-2 images were available from December 2016. Among these, 120 images from 2017 to 2020, characterized by a cloud cover of less than 15%, were selected. NDVI values were subsequently computed from these selected images, and graphical representations depicting the NDVI changes based on average and maximum values were generated (see Fig. 1). Additionally, separate cartograms were created to illustrate these variations.

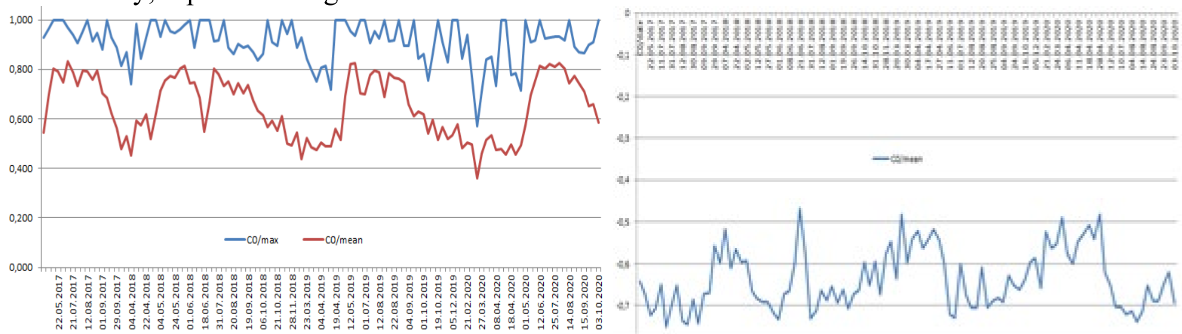

Figure 1 *Estimated change in the NDVI index and distribution of mean water index values from 2017 to 2020*

The graph analysis reveals distinct seasonal patterns in vegetation development each year. However, noteworthy variations exist between individual years, closely correlated with meteorological dynamics. The period of lowest vegetation levels occurred between February and April 2020, primarily due to a snowless winter compounded by dry weather conditions in March and April. It wasn't until mid-May, following rainfalls, that vegetation growth resumed. Besides this period, the lowest vegetation levels are generally anticipated during the winter months. The longest vegetation season was observed in 2018. These features are also evident in separate images, which facilitate the evaluation of areas with differing index values. Lakes and wetlands typically exhibit the lowest index values, while forested regions in the northwest section of the reserve tend to have the highest values. Seasonal development is influenced by various meteorological factors, particularly humidity levels. The Normalized Water Index (NWI or NDWI) serves as an indicator characterizing soil moisture and water exchange in the upper layer of the territory. As illustrated in Fig. 1, the dynamics of this index are less consistent, reflecting fluctuations in precipitation. Extended dry periods are associated with reduced water content in the area, while prolonged rainfall leads to increased moisture levels. Overall, these assessments enable the identification of both general and localized patterns and trends in the dynamics of several physical parameters of the territory, along with the development of biocenoses-associated indicators.

Conclusions

1. Landsat-8 and Sentinel-2 multispectral imagery enable the tracking of various water content indices within the Cheremsky NR territory, along with the development of vegetation. This capability proves invaluable for scrutinizing seasonal and annual fluctuations within the natural complexes of Cheremsky NR. 2. Through an analysis of multispectral imagery spanning the years 2016 to 2020, distinct periods characterized by the highest and lowest values of vegetation and moisture indices

were identified. These findings align closely with the analysis of climatic factors conducted independently. 3. Given the considerable geographical distance between the Manevychi meteorological station and the reserve's territory, it is advisable to consider the installation of an automated meteorological station within the reserve in the future. This strategic step would enable the precise characterization of microclimatic indicator variations within the hydro-ecological systems and complexes of Cheremsky NR, including the Cheremske marsh and the reserve's lakes. 4. In subsequent endeavors, it is prudent to maintain ongoing remote monitoring of the territory, accompanied by the selection of representative test areas for more detailed analysis. This approach will facilitate the meaningful comparison of satellite-derived data with real-world measurements of microclimatic and hydrobiological parameters.

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