NATURE-BASED SOLUTIONS AS A WAY TO ADAPT TO CLIMATE CHANGE IN THE STEPPE ZONE OF THE UKRAINIAN PART OF THE DANUBE RIVER BASIN

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Abstract. Today, the concept of nature-based solutions (NBS) is included in the main objectives of national development strategies of EU countries in the field of research and policy innovation. The aim of the study is to analyze the vulnerability of part of the Danube River basin, located in the steppe zone of Ukraine, to climate change and the possibility of adaptation to these changes through the implementation of nature-based solutions. The article shows the current characteristics of the temperature regime in the study area and their trends. There is a change in temperature conditions towards hotter and drier ones, which is clearly seen in the predominance of positive anomalies in mean monthly surface air temperature in recent decades, especially in the warm season. Heat waves have also become more frequent, with their frequency increasing sharply since the early 2000s. The main ways to reduce the risks caused by changes in climatic conditions towards hotter ones in urban areas, is the implementation by city authorities and local residents of the NBS, reducing the impact of heat stress, which will also have a positive impact on air quality and the aesthetics of the city, and will also contribute to improving public health and well-being. In rural areas, the implementation of the NBS, in addition to reducing greenhouse gas emissions and increasing sustainability in agriculture, will help mitigate damage associated with climate change.

Key words: nature-based solutions, Danube River, wetlands, surface air temperature anomalies, heat waves, land surface temperature

1. INTRODUCTION

In 2022, the UN Environment Assembly formally adopted the definition of “nature-based solutions” as “actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services, resilience and biodiversity benefits” (UNEP, 2022). The term “nature-based solutions” (NBS) covers various types of actions and levels of intervention in natural ecosystems aimed at solving environmental, social and economic problems on a regional and global scale.

Today, the concept of NBS is included in the main objectives of national development strategies of EU countries in the field of research and policy innovation, including problems related to the development of urbanization, adaptation to climate change and mitigation of its consequences, restoration of degraded ecosystems, biodiversity conservation, risk management and sustainability.

The aim of the study is to analyze the vulnerability of part of the Danube River basin, located in the steppe zone of Ukraine, to climate change and the possibility of adaptation to these changes through the implementation of nature-based solutions.

Review of previous studies

Today, there are a large number of studies aimed at developing various classifications of NBS (Eggermont *et al.*, 2015; IUCN, 2020), also, one of the main areas in the planning of the NBS is the issue of reducing the risks caused by climate change and its consequences (Raymond *et al.*, 2017). Along with the problem of global warming (Speak *et al.*, 2012) special attention is paid to the issues of implementation of the NBS in the process of coastal and river ecosystems restoration (Snoussi and Nibani, 2025), reducing risks associated with floods and water management (Dubovik *et al.*, 2022), as well as assessing the economic and social benefits (ECTP, 2022; Mikhailova *et al.*, 2025).

2. MATERIALS AND METHODS

Physical and geographical characteristics of the study area. The study area is the Danube River catchment area part, located in the steppe zone of Ukraine (Fig. 1), with a total area of 3533 km^2. This zone is located in the south of Odessa region and includes Izmail and part of Bolgrad administrative districts. The part of the study area located within the boundaries of the Bolgrad district is characterized by northern-steppe sloping flat landscapes of Eastern Europe. The Izmail District is characterized by medium-sloping, elevated steppe, plain, and lowland meadow landscapes; in the valleys of rivers and lakes, as well as the islands of the Danube Delta, there are floodplain landscapes: meadow-marsh and landscapes of floodplain meadows. In most of the territory, the area of natural elements in the total area of each type of landscape is 21-30 %. On the banks of the Danube and the southern part of the Ukrainian Danube lakes, as well as in the protected areas of the Kiliya part of the Danube Delta, the area of natural elements is more than 50 % of the total area of each type of landscape.

Climatic conditions. The study area is located in the steppe zone of the Danube Lowland. Based on data for 1986-2010 from World Maps of the Köppen-Geiger Climate Classification (2023) most of the area is in the Mediterranean climate zone (*Csc*). The climate is characterized by hot and dry conditions during the summer months, due to the prevalence of subtropical high-pressure systems. The average air temperature in July is 31-30 °C, the maximum 38-41 °C. Average monthly precipitation ranges from 57 mm in June to 36 mm in August. Atmospheric droughts are often observed (Slizhe M. *et al.*, 2023). It can continue throughout the spring-summer period (for example, in 2007, 2009, 2012), and also reach the character of severe and extreme droughts (Semenova, 2017). In winter, the area is predominantly in the zone of the polar front influence, which is accompanied by an increase in the frequency of cyclones. Therefore, this region is characterized by moderate air temperatures (from -1.2 to 1.7°C) and changeable rainy weather (28-37 mm) (Lipinsky *et al.*, 2003). The coastal zone of the study area, which includes the territory of the Danube Biosphere Reserve, is characterized by a cold semi-arid climate (BSk).

Water resources. The study area has significant water reserves. The permanent watercourses of the Izmail and Bolgrad districts are distributed across the Danube River basin. The study area contains lakes such as: Yalpug (149 km^2), Kagul (the area varies seasonally from 82 to 93.5 km^2), Kugurluy (82 km^2), Katlabukh (68.5 km^2), Kitai (60 km^2), Kartal (14 km^2), Safyany (the area varies from 2.5 to 4.2 km^2), Dervent (1.35 km^2). In addition to the Danube River, the following small rivers flow through the district: Aliyaga, Drakulya, Yenika, Big and Small Katlabukh, Kyrgyz- Kitai, Nerushai, Yalpug.

Despite the fact that the study area is characterized by a semi-arid climate, the lack of water is compensated by its supply from the Danube River and the Danube Lakes through artificial canals, which allows for the widespread use of most of the area for agricultural needs. The area contains a large number of artificial ponds and reservoirs, used primarily for water supply, irrigation and fish farming.

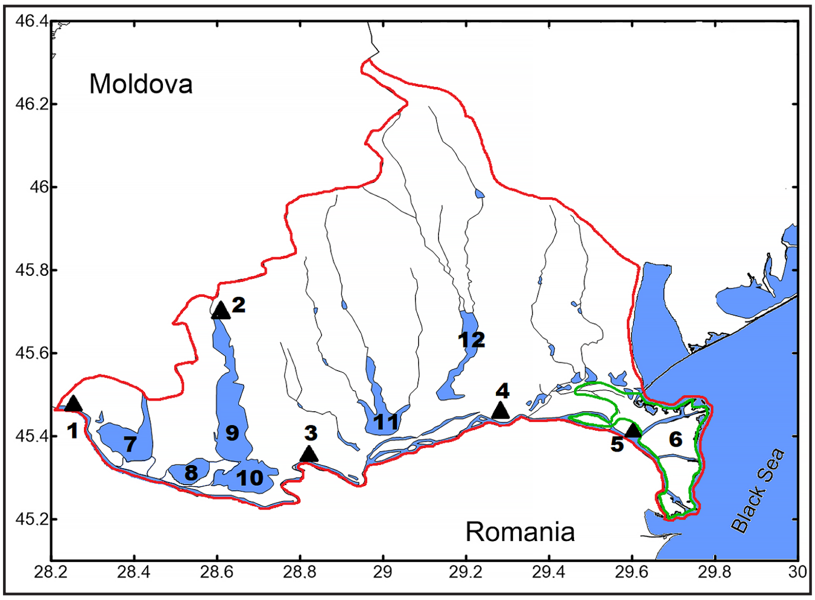

Fig. 1. Research area. Cities: (**1**) Reni, (**2**) Bolgrad, (**3**) Izmail, (**4**) Kiliya, (**5**) Vilkovo; (**6**) Danube Biosphere Reserve (green border); lakes: (**7**) Kagul, (**8**) Kartal, (**9**) Yalpug, (**10**) Kugurluy, (**11**) Katlabukh, (**12**) Kitai.

Water supply of the Izmail district is carried out from surface waters of the Danube basin and groundwater, artesian waters and mine wells. The amount of predicted reserves in the area is 123.81 thousand m^3/day (45.19 million m^3/year), of which 90.19 thousand m^3/day (32.92 million m^3/year) are explored and approved.

The Danube lakes are a true oasis of wildlife, home to valuable and endangered species of animals. Some of the lakes (Kugurluy) are of international importance.

Overall, four main factors influence the ecology of the Danube Delta: agriculture, flood protection, transport and climate change. The main pressures are the construction of agricultural and fish farming polders, as well as changes in the hydrological regime as a result of upstream land melioration, intensive agriculture, flood control and dam construction. Climate change is increasingly causing hydrological, chemical and thermal stressors. Rising air temperatures and reduced precipitation contribute to seasonal water shortages in the delta, despite increased river inflows into floodplain lakes through drainage channels (Freshwater, 2022).

Socio-economic characteristics. In the studied area, 235300 people (as for 2020) live (Decentralization, 2022). The largest settlements include Izmail (on 01.01.2022 the population was 69932 people), Bolgrad – 15479 people (Bolgrad, 2025), Reni – 19488 people (Reni, 2025), Kiliya – 19,064 people, Vilkovo – 8,201 people.

The main areas of economic activity are multi-sectoral agricultural production and processing of agricultural products, as well as production of building materials. The share of crop production in the gross output of the region is 58.6 %, livestock production – 41.4 %. The main products of plant growing are grain and leguminous crops. About 75 % of the total land fund of the district is agricultural land, of which 67 % is arable land, 1 % is hayfields, and 4 % is pastures. Also, the sphere of domestic and foreign trade, public catering and consumer services to the population is widely developed, playing a significant role in the formation of the general economic potential of the region. The enterprises of the region carry out foreign economic activity by exporting and importing goods, products of plant origin, leather, fur, products made from them, wine products. The structure of exports consists of: raw hides, peeled leather (66.2 %), and wood and wood products (27.6 %); products of plant origin (99.2 % of total imports) and pulp of wood or other fibrous cellulosic materials (0.6 %) are imported (Izmail, 2025).

The transport sector plays a significant role in the economic activity of the district. The following sea commercial ports are located on the territory of the district: Izmail, Reni, Kiliya, Ust-Dunaisk, the total cargo turnover of which in 2024 amounted to 17.3 million tons (Dunaets, 2025).

The geographical location, developed transport network, favorable climatic conditions, wealth of natural and cultural objects create prerequisites for the development of a highly profitable tourism and recreation industry in the region. Eco-ethnic tourism, which has been developing in the last decade, includes tours of the Danube lakes of the Odessa region with visits to Ukrainian, Bulgarian, Moldavian ethnic farmsteads, acquaintance with national cuisine, customs, and culture.

Thus, this territory has a high potential for ecosystem services: resource (providing) services (water and food); regulating services (regulation of climate, floods, droughts, land degradation, etc.); supporting services (soil formation, nutrient cycling, photosynthesis, biodiversity); cultural and social services (cultural and recreational, spiritual, religious and other intangible benefits) that can ensure the well-being of local communities.

Databases. For the analysis of surface air temperature, the study used data on the average monthly surface air temperature anomalies for the period 1970-2020, from the Air and Marine Temperature Anomalies: HadCRUT4 dataset provided by the NOAA PSL, Boulder, Colorado, USA (NOAA PSL, 2025). Anomalies are calculated relative to the base period 1971-2000 and are provided as a data array with a spatial step of 5° on longitude and latitude (Morice *et al.*, 2012).

To analyze the number of hot days and tropical nights, meteorological observation data from the Izmail, Galați and Tulcea meteo stations for the period 1970-2024, obtained from the GSOD database (NOAA NCEI, 2025), were used.

For analysis of land surface temperature (LST), data of the Landsat Collection 2 Level-2, provided by Esri (2025a), were used. The data is a global imagery layer optimized for analysis, including Landsat 4, 5, 7, 8 and 9 Level 2 imagery processed by the Microsoft Planetary Computer and updated daily with the latest available imagery. Information about LST was obtained using a Thermal Infrared Sensor (TIRS) of Landsat 8 and 9 satellites, operating in two channels in the infrared range of 10.6-11.2 μm and 11.5-12.5 μm (USGS, 2025). TIRS receives data with a spatial resolution of 100 or 120 m, and then data is recalculated to 30 m (Esri, 2025b).

The wetland area was calculated using the QGIS software package based on Sentinel-2A satellite data. Sentinel-2 offers satellite imagery with a resolution of 10 to 60 m. Product data Sentinel-2 10 m land use/land cover time series, provided by the company Esri, was used in this study (Esri, 2025c). The product displays a global land use/land cover map for the period 2017-2024 obtained from ESA Sentinel-2 images with a resolution of 10 m. The Impact Observatory's artificial intelligence-based land classification model generates annual global land use/land cover estimates divided into 9 classes (Esri, 2025c). Each pixel in the image is assigned a specific land cover class (Karra *et al.*, 2021).

3. RESULTS

Surface air temperature anomalies. An analysis of mean monthly surface air temperature anomalies over the period 1970-2020 showed that positive anomalies have predominated since the 2000s (Fig. 2). In the summer period, the prevalence of positive temperature anomalies has been observed since the late 80s of the 20th century. It is possible to note the absence of abnormally cold winter temperatures since 2013. In general, increased average values of surface air temperature anomalies are observed in the period from January to March (0.84-1.07 °C) and from June to August (0.70-1.02 °C).

The maximum values of anomalies of mean monthly surface air temperature fall within the range of 3.59-6.86 °C. The highest positive anomalies are observed from January to March and in November. As can be seen from Table 1, in most cases the maximum mean monthly air temperature anomalies were observed since 2010.

Negative anomalies of the mean monthly surface air temperature cover the range from -1.52 to -7.82 °C. As can be seen from figure 2 and Table 1, the main period in which the air temperature in the study area was below its climatic norm was the 70s-80s of the 20th century, and the highest deviations were noted from November to March. In general, the most significant variations in air temperature anomalies are demonstrated in the cold half of the year (from November to March). The standard deviation (**SD**) in these months is 2.08-2.95 °C, which is approximately 2 times higher than the standard deviation in the warm half of the year.

An analysis of the linear regression coefficients (**a**) of surface air temperature anomalies showed that a statistically significant positive trend is observed in the period from March to November. The highest rates of air temperature growth are observed in the summer months and amount to 0.06-0.08 °C/year, which results in an increase in mean monthly air temperature anomalies by 2.4 °C over 30 years.

Repeatability of heat waves. A heat wave is a period of prolonged, abnormally high surface air temperatures relative to those normally observed in a given area. Heat waves can be characterized by low humidity, which exacerbates drought, and can also be accompanied by high humidity, which also increases the negative health effects associated with heat stress, dehydration and heatstroke. In Europe, there is a link between the occurrence of heat waves with an increase in morbidity and mortality during them (Dubovik *et al.*, 2022).

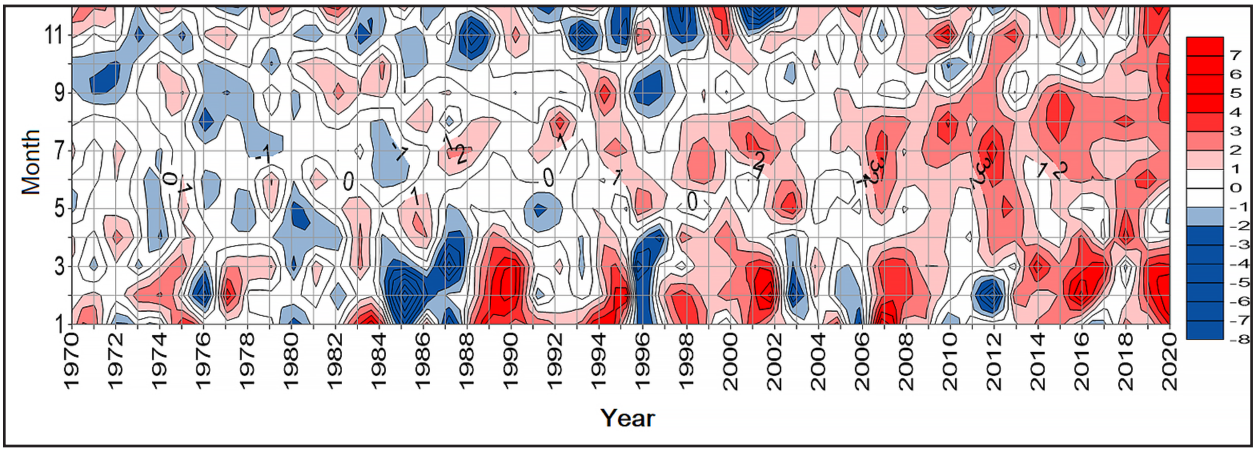

Fig. 2. Interannual and seasonal variations of the mean monthly surface air temperature anomalies in the study area, according to CRU data.

Table 1. Statistical indicators of the series of anomalies of mean monthly surface air temperature (°C) in 1970-2020.

Indicators	Months												Average for the year
	1	2	3	4	5	6	7	8	9	10	11	12	
AT_{avr}	1.07	0.84	0.94	0.40	0.42	0.70	0.97	1.02	0.29	0.19	0.02	0.24	0.59
AT_{max} / year	6.86 2007	6.38 2016	5.06 1990	4.61 2018	4.08 2003	3.98 2019	4.69 2012	4.29 2010	4.00 1994	3.94 2020	5.23 2010	3.59 2019	2.66 2020
AT_{min} / year	-4.18 1987	-7.82 1985	-5.57 1987	-3.43 1987	-2.55 1980	-1.52 1984	-1.80 1970	-2.89 1976	-2.86 1996	-2.26 1972	-6.09 1993	-5.12 2001	-1.28 1985
SD	2.29	2.95	2.34	1.64	1.47	1.32	1.43	1.54	1.58	1.38	2.24	2.08	0.92
a / per year	0.02	0.04	**0.05**	**0.04**	**0.03**	**<u>0.06</u>**	**<u>0.06</u>**	**<u>0.08</u>**	**<u>0.05</u>**	**0.04**	**0.05**	0.02	**<u>0.04</u>**

* ***a***, statistically significant at the 0.05 level are highlighted in bold font; ***a***, statistically significant at the 0.01 level are highlighted underlining

An indicator of the area's susceptibility to heat waves is the number of combined tropical nights (minimum daily air temperature >20 °C) and hot days (maximum daily air temperature >35 °C) per year.

An analysis of surface air temperature at Izmail station in 1970-2020 showed that the number of combined tropical nights and hot days increases from decade to decade (Table 2). Similar indicators are noted at Galați and Tulcea stations located in the Lower Danube basin in Romania.

Differences in the value of the indicator at different stations are due to local physical and geographical conditions that affect the temperature and humidity regime, as well as the distance from the Black Sea.

Land surface temperature (LST). Land surface temperature describes how warm or cold the Earth's surface is and also describes related processes such as the exchange of energy and moisture between the land surface and the Earth's atmosphere. LST affects the rate and timing of plant growth and is dependent on the albedo of the underlying surface. LST data can improve decision-making on water use and irrigation strategies and serve as an indicator of crop health and water stress (Earthdata, 2025). Numerous studies have shown the existence of a negative correlation between LST and Normalized Difference Vegetation Index - NDVI (Xian and Crane, 2006; Bokaie *et al.*, 2016; Ünsal *et al.*, 2023), a negative relationship between LST and distance to highways, distance to city center, altitude, northward direction, forest and marshland density, as well as a positive relationship between the density of the built environment and the density of unused areas (Li *et al.*, 2010). Also, a high correlation of LST with topographic parameters was found (Gao *et al.*, 2020) and even a negative correlation was found between LST and socio-economic level of development (Huang *et al.*, 2011).

For analysis of the spatial distribution of LST across the city of Izmail, points, located in different city areas with different greenery density, were selected (Fig. 3a).

Points 1, 2, 3 are located in areas occupied by single-storey manor-type buildings. Point 4 is located in the central part of the city, on the central avenue of the city. The avenue is 115 m wide and is planted with tall trees. Point 5 is located in the central part of the city, in an area with high-rise buildings, where the space between the houses is planted with tall trees and bushes. Point 6 is located in the eastern part of the city, in a forest park area on the territory of the memorial park-museum "Fortress". Point 7 is also located on the territory of the park-museum "Fortress", but in an area with meadow and steppe vegetation. Point 8 is located on the Danube embankment, in a park area between the river and Lake Lebyazhye.

For the LST analysis, images from the 2021-2025 period of Landsat 8 and 9 satellites were selected, obtained in July under similar conditions of exposure of the underlying surface and cloudiness. Additionally, the NDVI values calculated from the image data are provided.

Table 2. Average annual number of combined tropical nights and hot days.

Station	Period					
	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	2020-2024
Izmail	0.1	0.6	0.8	2.7[1]	2.0[2]	n/d
Galați	n/d	n/d	1.6	5.6	7.2	7.0
Tulcea	n/d	n/d	1.0	1.9	1.4	2.0

* n/d – no data, [1] – period 2000-2003, [2] – period 2013-2015

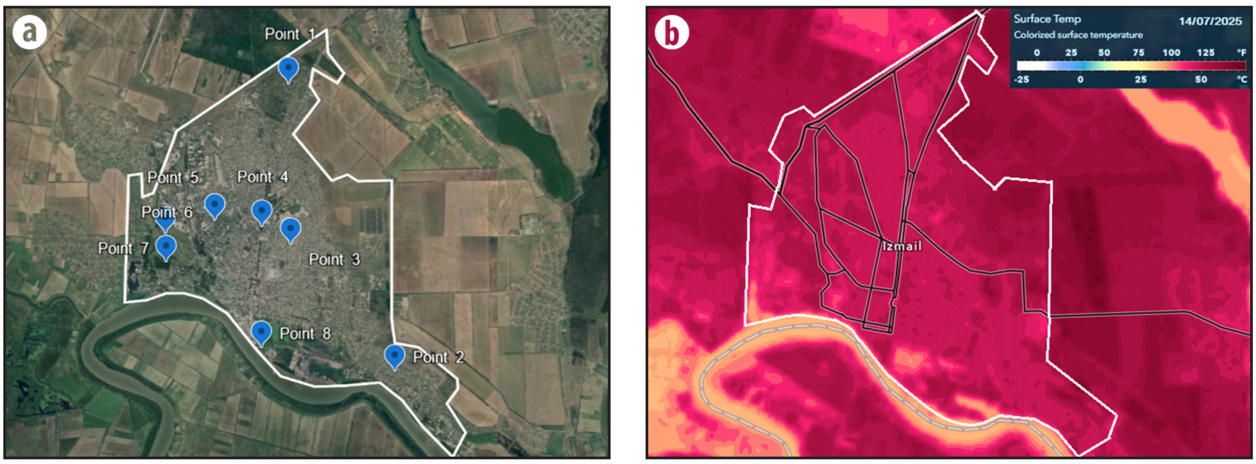

Fig. 3. Map of Izmail: (**a**) point placement scheme; (**b**) LST (°C) distribution on 14.07.2025 according to the TIRS sensor data of the Landsat 9 satellite.

The calculation of the correlation coefficient between LST and NDVI showed the presence of a moderate inverse linear relationship (**rxy** = -0.7). LST analysis showed that in conditions of single-storey manor-type buildings (points 1-3) LST is within 41-49 °C with NDVI values from 0.624 to 0.296 (Table 3, Fig. 3b).

In conditions of greening with medium and tall trees located between multi-storey buildings (point 5), as well as on the central avenue of the city (point 4), LST is within 42-47°C, with NDVI values of 0.806-0.669.

In park and forest park zones (points 6 and 8) LST has the lowest values of 36-42 °C with NDVI of 0.835-0.424. The lower LST at these points is due not only to the presence of well-developed vegetation, but also to the immediate proximity of the points to the Danube River and water bodies, which affect the temperature and humidity conditions in this area, softening the conditions on hot summer days.

In the zone characterized by meadow and steppe vegetation (point 7), the highest LST values (40-54 °C) are noted with the lowest NDVI values (0.471-0.185).

As can be seen from Table 3, at points 4, 8, located in the conditions of a forest park zone close to water bodies, LST is on average lower: by 6 °C, than at points 1-3, located in the conditions of single-story buildings; by 5 °C than at points 4 and 5, located in conditions of greenery with medium and tall trees, located inside single-storey and multi-storey buildings; by 10 °C than in steppe vegetation conditions. It should be added that in the areas around the city of Izmail occupied by arable land, the LST value reaches up to 66 °C (Fig. 3b). At the same time, large areas occupied by wetlands are characterized by LST values of 31-32 °C. This distribution of LST over the area occupied by different types of underlying surface forms the thermal balance of this territory, and the wetlands of the Danube Delta play a key role in mitigating the negative impact of hot conditions in this region.

The area occupied by wetlands in the Izmail district. Wetlands are unique ecosystems that occur in places where the groundwater level is close to ground level or where the land is covered by water, seasonally or permanently. The wetland area was assessed using raster images of land use obtained from Sentinel-2 images with a resolution of 10 m. The processing was carried out using the QGIS software package, which allows you to calculate and study areas on satellite images.

Analysis of the area occupied by different classes of land use/land cover in the Izmail district of Odessa region (Table 4) showed that wetlands characterized by class 4 "Flooded vegetation" occupy an average of 166.4 km^2, which is 5 % of the total area of the district.

Table 3. LST (°C), NDVI and satellite survey information.

Date		14.07.2025	11.07.2024	17.07.2023	06.07.2022	27.07.2021
Satellite		Landsat 9	Landsat 9	Landsat 8	Landsat 9	Landsat 8
Sun Elevation, °		61.573	61.887	61.193	61.752	59.383
Sun Azimuth, °		137.350	136.810	137.658	139.151	139.763
Cloud Cover, %		1	1	3	1	1
Point 1	T, °C	49	45	45	46	41
	NDVI	0.378	0.526	0.439	0.509	0.624
Point 2	T, °C	48	45	43	45	41
	NDVI	0.414	0.491	0.470	0.447	0.605
Point 3	T, °C	49	46	43	45	44
	NDVI	0.296	0.505	0.533	0.412	0.423
Point 4	T, °C	46	44	42	43	43
	NDVI	0.734	0.723	0.794	0.727	0.767
Point 5	T, °C	47	46	43	44	42
	NDVI	0.669	0.674	0.806	0.715	0.721
Point 6	T, °C	40	36	39	38	36
	NDVI	0.814	0.812	0.835	0.814	0.828
Point 7	T, °C	51	54	48	50	40
	NDVI	0.275	0.185	0.262	0.357	0.471
Point 8	T, °C	42	40	39	40	37
	NDVI	0.424	0.478	0.564	0.475	0.623

Table 4. Area **S** (km^2) occupied by different classes of land use/land cover in the Izmail district of Odessa region.

Class 2020		S, km^2						% of total area
		2021	2022	2023	2024	average in 2020-2025		
1	Water	569.4	570.6	567.7	565.0	562.5	567.0	16
2	Trees	85.1	126.4	101.7	115.0	135.5	112.7	3
4	Flooded vegetation	138.4	179.7	142.3	185.4	186.1	166.4	5
5	Crops	2118.0	2125.5	2144.6	2108.9	2133.1	2126.0	61
7	Built Area	195.1	188.8	189.8	193.1	194.7	192.3	5
8	Bare ground	0.5	0.1	1.6	0.4	0.1	0.5	≈ 0
11	Rangeland	392.2	307.6	350.9	330.9	286.6	333.6	10

This class includes areas of any type of vegetation with obvious intermixing of water throughout a majority of the year. This class also includes the seasonally flooded area that is a mix of grass and/or shrub and/or trees and/or bare ground.

The largest wetlands by area on the territory of the district are:

1. Wetlands of the Danube Biosphere Reserve. The total area is 328 km^2 (Marushevsky and Zharuk, 2006). According to the Ramsar classification system, these wetlands are classified as types "F" (estuarine waters; permanent water of estuaries and estuarine systems of deltas) and "L" (permanent inland deltas). This territory is entirely included in the protected areas of Ukraine. The lands are the delta of the Chilia Branch of the Danube. Within its boundaries are swampy areas, floodplain forests, straits, canals, alluvial islands, freshwater lakes, sand ridges, and in the coastal part - low sand spits that separate the bays from the sea. The area includes a 1 km wide strip of the Black Sea surrounding the delta from the east. According to Sentinel-2 satellite images in 2020-2024, the area occupied by class 4 "Flooded vegetation" within the boundaries of the reserve and Ermakov Island averages 92.3 km^2, which is about 55 % of the total area of class 4 "Flooded vegetation" (166.4 km^2) located in the Ukrainian part of the Danube Delta.

2. Wetland of Lake Kugurluy (area 65 km^2). Lake Kugurlui is located in the Danube floodplain and is connected to it by several canals, and to the nearby lakes Yalpug and Kartal by small straits. The area of the lake varies from 60 to 80 km^2, the average depth is 1.04 m, and the maximum is 3 m, dry periods – up to 1.5 m. In some years the depth of the lake does not exceed 0.6-0.9 m (Marushevsky and Zharuk, 2006). These wetlands are of the type "O" (permanent freshwater lakes (over 8 ha); includes large oxbow lakes). According to Sentinel-2 data, the area of class 4 "Flooded vegetation" within Lake Kugurluy averages 48.9 km^2, which corresponds to about 29 % of the area occupied by "Flooded vegetation" in the study area.

3. Wetland of Lake Kartal (area 5 km^2). Lake Kartal belongs to the western group of Danube reservoirs. The lake is connected to the Danube and other bodies of water in this group (lakes Kagul, Yalpug, and Kugurluy) through artificial canals (Orlovsky, Skunda, Repida, etc.). The lake's water surface area is 14 km^2. The average depth is 1.04 m, the maximum is about 3 m. During dry periods, the lake's depth does not exceed 1.5 m (Marushevsky and Zharuk, 2006). These wetlands are of the type "K" (coastal freshwater lagoons; includes freshwater delta lagoons) and "Ts" (seasonal/intermittent freshwater marshes/pools on inorganic soil; includes sloughs, potholes, seasonally flooded meadows, sedge marshes). According to Sentinel-2 data, the area of class 4 "Flooded Vegetation" within Lake Kartal in 2020-2024 was 7.8 km^2, which is slightly less than 5 % of the area occupied by "Flooded Vegetation" in the study area.

The remaining approximately 10 % of the wetland area classified as flooded vegetation according to Sentinel-2 data includes the wetlands of the lakes Kagul, Yalpug, Katlabukh, Kitai, as well as the river islands Velikii Daller, Malyi Daller and Malyi Tataru, located in the Chilia branch of the Danube. The islands are part of the Regional Landscape Park "Izmail islands". Bogatyansko-Staronekrasovsky floodplains, located between Lake Katlabukh and the Danube, are a floodplain massif combined with a wide water surface (Lake Lung), and are a landscape reserve of local importance.

As can be seen from Table 4, the area occupied by class 4 "Flooded vegetation" has interannual variations. In recent years, there has been an increase in the area of wetlands (up to 186.1 km^2 in 2024), which is due to a decrease in the area of pastures located in the Kiliya Delta of the Danube Biosphere Reserve. Thus, in 2024, the area occupied by "Flooded vegetation" in the Danube Biosphere Reserve was 74. km^2, and in 2024 it increased by 48 % to 110.2 km^2. At the same time, the area occupied by class 11 "Rangeland", which in the Izmail district is mainly concentrated within the boundaries of the Danube Biosphere Reserve, decreased from 392.2 km^2 in 2020 to 286.6 km^2 in 2024.

It is necessary to pay attention to Class 2 "Trees", which is any significant accumulation of tall (4.5 m and above), dense vegetation, usually with a closed or dense canopy. As a rule, areas with high vegetation are thickets of trees extending along the banks of the Danube, some sections of the banks of the Danube lakes, river valleys, slopes and bottoms of ravines and beams, as well as artificially created forest belts. Despite the small area, on average 112.7 km^2, which is close to 3 % of the total area of the study area, this class of territory has great ecological significance in terms of biodiversity conservation, since such objects act as biocorridors through which organisms migrate between biocenters, which are the wetlands of the Danube Lakes and the Danube Delta. Preservation of a dense network of biocorridors contributes to increased connectivity (Udovychenko, 2017) of the entire biocentric-network landscape structure of the Danube Delta.

NBS in the urban environment. Based on the fact that one of the main challenges associated with climate change in the study area is the increase in air temperature, which is most pronounced in the summer months, when temperatures reach their maximum in the annual course, one way to mitigate this challenge is to implement NBSs aimed at reducing the impact of heat stress, reducing air temperature (cooling effect), and managing heat and greenhouse gases. Direct benefits from the use of such NBS include thermal comfort, as well as improved public health and well-being due to the reduction of risk factors caused by increased air temperature.

To identify possible NBS, it is necessary to take into account the ecosystem services provided by urban ecosystems aimed at regulating temperature (*e.g.* cooling). In this case, the leading role in solving the problem is given to such natural processes as evaporation, evapotranspiration and shading. After Dubovik *et al.* (2022), the most effective NBS are the creation of green spaces (urban parks and gardens, green schoolyards and sports grounds, meadows, green strips, "multifunctional" dry detention ponds or vegetated drainage basins), increasing the area occupied by trees and shrubs (forest (including afforestation), orchard, vineyard, hedges/shrubs/green fences, street tree(s)), as well as the creation of an green built environment (green roof, green wall / facade, green streets, alleys and parking lots, temporary and/or small-scale green structures).

Green space is a multifunctional open space characterized by natural vegetation and permeable surfaces. It may include (freestanding) trees or woody vegetation in addition to open space. Creating shallow depressions in the underlying soil can trap precipitation, increase infiltration and evapotranspiration, and provide temporary storage of water. This type of NBS can also help improve air quality and reduce the urban heat island effect.

Street trees affect the temperature of the city through the shade they provide and the evapotranspiration effect. Trees can provide better thermal comfort for pedestrians and reduce the cooling needs of nearby buildings (Wang and Akbari, 2016). Combining street trees with overall street design and configuration can provide optimal strategies for reducing heat stress in the city. Parks larger than 10 hectares create the most long-range and intense cooling effect in urban areas (Aram *et al.*, 2019). Choosing the right plant species can also improve the efficiency of urban cooling (Feyisa *et al.*, 2014).

Natural or semi-natural vegetation systems (especially perennial woody vegetation) provide regulating ecosystem services such as shade provision, precipitation interception, increased evapotranspiration, slope stabilization and erosion control, air purification by absorbing pollutant gases, CO_2 capture and storage, and dust particle interception. Trees and shrubs can influence on the distribution of gases in the urban atmosphere, improving air quality and positively affecting on human comfort.

Green spaces have the potential to provide ecosystem services such as food provision (*e.g.* from community gardens), genetic resources (creation or restoration of habitat, improved habitat connectivity), freshwater (infiltration, retention, storage and/or reuse of water); to regulate air quality (pollutant deposition, pollutant absorption and sequestration/transformation), climate (evapotranspiration, shading), water quantity and quality and erosion (water drainage, infiltration, retention, storage and/or reuse, soil stabilization, water filtration), pollination (habitat creation or restoration, improving habitat connectivity); to provide cultural ecosystem services related to spiritual, religious, aesthetic value, as well as recreation and tourism (Dubovik *et al.*, 2022).

Green roofs are interesting as a means of providing natural heat supply (Kabisch and van den Bosch, 2017), and help solve a number of environmental and socio-economic problems associated with urban sprawl and climate change (Calheiros and Stefanakis, 2021). They represent artificial ecosystems that can mitigate problems such as urban heat islands because they have a higher albedo than dark roofs (Susca *et al.*, 2022). Green roofs reduce the load on the cooling system (up to 70 %), as a result of which the indoor air temperature can decrease by 15 °C, which significantly improves thermal comfort conditions. Green roofs, like natural reservoirs, can hold rainwater, delay runoff and promote evapotranspiration, which helps reduce the load on the city's sewer system during heavy rainfall. The possibility of combining green roofs with blue-green roof rainwater harvesting systems to conserve drinking water or manage stormwater runoff can further reduce the risk of flooding in urban settings (Mihalakakou *et al.*, 2023). Research shows that properly designed blue-green roofs provide minimal trade-offs and maximum ecosystem services over time (Droz *et al.*, 2021), as well as native or drought-tolerant flora (Wang *et al.*, 2022).

It should be noted that the municipal authorities of the cities of Izmail and Bolgrad districts almost every year carry out campaigns aimed at increasing the greening of urban areas, planting green spaces, and also take steps to create new park areas (Reni-Odessa, 2021). However, countering such a serious challenge as climate change requires a systematic approach and the development of measures and an action plan at the state level.

NBS in a rural environment. Using renewable energy sources in farms can reduce CO_2 emissions, which will ultimately help preserve the climate. Thus, biogas, solar and wind installations can be used for processing and storing products on farms, for example, for cooling milk and other food products.

Implementation of climate-smart agriculture principles – an approach that helps guide the actions needed to transform and reorient agricultural systems to effectively support development and food security in a climate change conditions– to increase agricultural productivity and incomes; help local communities adapt and build resilience to climate change, and will also contribute, where possible, to the reduction and/or complete elimination of greenhouse gas emissions (Lipper *et al.*, 2014).

Significant benefits can be achieved by introducing agroforestry – land-use systems in which perennial woody plants are intentionally integrated into land use, as are crops and/or animals. In agroforestry systems there are ecological and socio-economic interactions between the different components. Agroforestry is particularly important for smallholder farmers and rural communities as it can diversify their crops, improve food security and make farms more resilient to climate change (FAO, 2018).

The concepts of organic farming and multi-level farming are aimed at preserving natural ecosystems in connection with increasing crop yields (Access Agriculture, 2025; OFRF, 2025).

However, it should be noted that there are also a number of skeptical opinions on the effectiveness of the implementation of the NBS in rural areas. They point out that in this case, NBS is not a panacea for social problems caused by both human activity and climate change (Mikhailova *et al.*, 2025). On the scale of the vast territories required for allocation for the NBS implementation, it will require, if not a renunciation of economic development or food production, then a reduction in the volumes of production, which ultimately will not be able to mitigate the damage caused by climate change (Griscom *et al.*, 2017).

4. CONCLUSIONS

In the study area, there is a change in temperature conditions towards hotter and drier ones, which is clearly seen in the predominance of positive anomalies in mean monthly surface air temperature in recent decades, especially in the warm season. Heat waves have also become more frequent, with their frequency increasing sharply since the early 2000s. Reduced LST values in the city of Izmail and its suburbs are observed in areas covered with dense vegetation (trees and bushes), as well as in areas occupied by wetlands. The LST value in areas located in conditions of greenery with medium and tall trees is 5-10 °C lower than in urban areas and park areas with grassy vegetation. In arable land areas, LST can reach temperatures of 66 °C and higher, which, as a result of heat exchange between the air and the underlying surface, leads to its intensive heating. The proximity of wetlands to populated areas in the study area can be considered a factor that has a positive effect on the local formation of temperature conditions, which occurs against the background of an increase in the value of temperature indicators in the region as a whole.

The wetlands of the study area, together with the tree stands that extend along the banks of the Danube, are an important provider of ecosystem services, supplying local communities with food and other materials, participating in the regulation of the climate in the area, and also contributing to the conservation of biodiversity. Despite the fact that their total area does not exceed 10 % of the total zone of the study area, in recent years, a positive growth trend has been observed, which is due to a decrease in the area of land allocated to pastures. The main ways to reduce the risks caused by changes in climatic conditions towards hotter ones in urban areas, is the implementation by city authorities and local residents of the NBS, reducing the impact of heat stress, which will also have a positive impact on air quality and the aesthetics of the city, and will also contribute to improving public health and well-being. In rural areas, the implementation of the NBS, in addition to reducing greenhouse gas emissions and increasing sustainability in agriculture, will help mitigate damage associated with climate change (for example, an increase in the frequency of droughts in the study area) and will ultimately contribute to food security and sustainability in the socio-economic sphere in the region.

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