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Trends in the Environmental Conditions, Climate Change and Human Health in the Southern Region of Ukraine

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Abstract: The Kherson, Mykolaiv, Odesa, and Zaporizhzhia oblasts, being adjusted to the coasts of the Black and Azov Seas, are located in the steppe zone and constitute the southern region of Ukraine. The environmental parameters and health indicators of the population of the region are sensitive to the impact of natural (e.g., climate change) and anthropogenic processes. An analysis of satellite remote sensing data (NOAA NDVI time series) for the assessment of vegetation condition demonstrates an increase in frequency and duration of drought events in the region during the last few decades. It may have a relation to climate change processes. Data analysis of local meteorological observations over the past 100 years proved alterations of some bioclimatic indexes. The Equivalent Effective Temperature (I_{EET}) increases in winter and summer (due to the increasing repeatability of high anomalous temperatures) and remains stable in spring and autumn seasons. The increasing number and variability of climate anomalies can provoke an increase in cardiovascular and some other diseases in the local population. At the same time, an analysis of the statistical data of health indicators of the population (such as morbidity of digestion, breathing, and the endocrine and circulatory systems) shows a tendency to decrease morbidity (contrary to the indicators of the mountain regions' population, which have higher values of life expectancy). Interrelations between environmental, climate change, and population health indicators in the Black Sea region are being discussed.

Keywords: climate change; environment; NDVI index; human health; bioclimatic index

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Citation: Karamushka, V.; Boychenko, S.; Kuchma, T.; Zabarna, O. Trends in the Environmental Conditions, Climate Change and Human Health in the Southern Region of Ukraine. *Sustainability* **2022**, *14*, 5664. https://doi.org/10.3390/su14095664

Academic Editors: Madeleine Granvik and Aistė Balžekienė

Received: 13 April 2022
Accepted: 5 May 2022
Published: 7 May 2022

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1. Introduction

Regarding the conditions of modern global warming, considerable changes of different natural systems on Earth can potentially be seen in the very near future. Recent climate change, evidently, influences the ecological and socio-economic conditions of human well-being in different regions and can potentially result in considerable changes in geophysical, geochemical, and biological systems in the future [1,2].

The most vulnerable to climate change are coastal regions. Climate impact drivers include, but are not limited to, temperature increase, precipitation change, sea level rise, coastal erosion, storm surge, high-tide flooding, inland flooding, etc. [1,3]. Climate change affects marine and coastal ecosystems, human settlements, and human life.

Warming of air and seawater results in Mediterraniation of the Black Sea fauna, in particular, by increasing the diversity of benthic species in the Black Sea marine ecosystem due to the immigration of new species, with adverse effects. Alien species' invasions decline the abundance of, and cause the loss of, some native species [4].

The analysis of monitoring data and modelling of climate scenarios highlights a tendency of warming and drying over most of the Black Sea, as well as the Mediterranean and Caspian regions [5,6]. Due to a precipitation decrease, expansion of the areas with severe droughts are expected until the end of the 21st century [7]. In the nearest future, current climate change and human impact on the natural ecosystems (such as increased pollution, irrational land use, biodiversity decline, etc.) will significantly increase the risks to the vitally important domains for human settlements (water, ecosystems, food, health, and security) [6,8].

Among human settlements, cities, located in the coastal areas, are particularly vulnerable to climate change, as 70% of them are already facing the effects of climate impact drivers [2]. Coastal settlements are threatened, mainly, by flooding due to rising sea level, anomalous weather phenomena, etc.

The coastal areas of the Black and Azov Seas in the south of Ukraine are also subjected to these processes [9]. The southern region of Ukraine comprises the Kherson, Mykolaiv, Odesa, and Zaporizhzhia oblasts, being adjusted to the sea coast. The region is located in the Black Sea lowland. The spurs of the Podil Upland enter the north and northwest, including the Azov Upland in the eastern part and the Dnieper Upland in the southeast, meeting the Donetsk ridge in the east. Semi-arid climatic conditions, which are typical for the southern region of Ukraine, are exacerbated by climate changes [10].

Some of the most considerable consequences of climate change and their regional features are weather anomalies (heat waves, droughts, wind storms, heavy precipitation, river floods, etc.). Other consequences include an increase in the sea level, a spatiotemporal transformation of the steppe photosystem's structure, a reduction in the water content in the river basin, etc. [1,2]. In recent decades, extreme weather events have, increasingly, manifested in many regions. It is not only the frequency of extreme weather events that has been increased, but also the intensity and spatial distribution over the area [8,11,12].

However, ill-considered, irrational, and wasteful human activities contribute to and aggravate the negative consequences of climate change. Such activities include, but are not limited to, the violation of building requirements, intensive agriculture and water use, improperly maintained water pipelines and related littering, lack of systematic strengthening of slopes and river banks, etc. [2].

Global warming has 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 [13]. This affects the vegetative activity of ecosystems and can be confirmed by satellite remote sensing data, which, in addition to climatic records, provide important spatiotemporal information to identify global trends [14]. At the same time, drought conditions depress vegetation.

As shown in [12], in the second half of the 20th century in Europe, the area covered by droughts has increased, while in the following decade there was some decrease in the extent of drought. However, in the south of Europe, an increase in arid conditions was revealed, which affects the productivity of ecosystems. In particular, records on wheat and olive harvest as well as wine production show a large inter-annual variability, with statistically significant links to seasonal temperature and precipitation as well as a decrease in general ecosystem productivity in the Mediterranean region [15,16]. An increase in arid conditions has become a tendency, as well, in the southern region of Ukraine. The last decade was the driest, with especially noticeable droughts recorded in 2016, 2017, and 2020 [17].

Currently, heat waves are becoming more frequent and intense, especially in urban areas of Europe [18], which initiate spikes in excess heat-related deaths (for example, during the summer of 2003 in Europe) [19,20]. The increase in heat-wave days was observed in most of Europe over the past 30 years and is expected to continue during the cold season (winter) and summer until the end of this century [19].

Health indicators of the population and environmental parameters of such regions are sensitive to climate change as well as multiple natural and anthropogenic processes. Strategic sustainable development planning for the coastal regions' communities requires understanding the tendencies of the natural processes and human health [21].

Therefore, the objective of this study was to analyse environmental, climate change, and population health indicators in the southern region of Ukraine, in order to address possible tendencies and interrelations in climate change mitigation and adaptation strategies.

2. Materials and Method

In this study, empirical data from the meteostations Kherson, Mikolaiv, Odesa, and Zaporizhzhia (namely, averaged annual and monthly surface air temperature, precipitations, extreme weather events, and some other parameters) for the period 1900–2020 were used [22,23]. Moreover, the values of the meteorological norm for the above-mentioned parameters for the period 1991–2020 were calculated. For the period 1961–1990, the respective climatic norms were obtained from [24]. Location data and key climate indicators for regional meteostations are presented in the Table 1.

Table 1. Location of the meteostations * of the southern region of Ukraine and respective climatic norms of average temperature and precipitation for the periods 1961–1990 and 1991–2020.

Station	Latitude, Grad	Longitude, Grad	Altitude, m	Temperature, °C		Precipitation, mm/year	
				1961–1990	1991–2020	1961–1990	1991–2020
Kherson	46.63	32.61	54	9.8 ± 0.9	10.9 ± 0.9	441 ± 86	430 ± 109
Mikolaiv	47.03	31.96	50	10.0 ± 0.9	10.8 ± 0.9	410 ± 95	472 ± 89
Odesa	46.43	30.76	42	10.1 ± 0.8	11.3 ± 0.9	464 ± 106	463 ± 105
Zaporizhzhia	47.80	35.25	112	9.4 ± 1.0	10.4 ± 1.0	510 ± 103	449 ± 97

* The spelling of the name of the city is Mykolaiv; the corresponding meteostation is Mikolaiv.

NOAA AVHRR Surface Reflectance satellite imagery was used to calculate the Normalized Difference Vegetation Index (NDVI) to obtain the long-term datasets of vegetation condition and productivity over the period of 1982–2021 [25]. Satellite imagery was processed in Google Earth Engine, a large-scale web platform for cloud remote sensing data processing (https://earthengine.google.com, accessed on 6 May 2022).

In order to assess the climatic comfort for humans in a given region, the bioclimatic index Equivalent-Effective Temperature (I_{EET}) was used. It was calculated in accordance with the Missenard formula [26], using the daily empirical data (surface temperature, air humidity, and wind velocity) from regional meteostations for the period of 1991–2020 [17].

Data for the analysis of human health patterns and tendencies were obtained from the open sources of the State Statistics Service of Ukraine and the Ministry of Health Care of Ukraine [27,28]. The daily data on the confirmed cases of infection with the SARS-CoV-2 virus and the number of people who were suspected of being infected with the same virus in the Kherson, Mykolaiv, Odesa, and Zaporizhzhia oblasts in 2020–2021 were obtained from [29].

The research results are based on the data processed according to the standard methods of statistical analysis of meteorological information [30] and on an analytical review of published materials [10,31,32]. The calculations' statistical analysis and graphical design were performed using software packages MS Excel and StatSoft STATISTICA.

3. Results

3.1. Features of Climate Change in the Southern Region of Ukraine for 1900–2020

According to the analysis of meteorological data, the average annual temperature in the southern region of Ukraine for the period 1900–2020 was 9.9 ± 1.0 °C, while for the period 1990–2020, it was 10.7 ± 1.0 °C. At the same time, the climatic norm in the region for the period 1961–1990 was 9.8 ± 0.9 °C [24]. The annual amount of precipitation for 1900–2020 was 437 ± 85 mm/year; for 1990–2020, it was almost the same amount 440 ± 101 mm/year, while the climatic norm for the period 1961–1990 was higher (472 ± 96 mm/year [24]).

As it follows from Figure 1A, the temperature in the southern region was increasing by 1.1 ± 0.3 °C/100 years, for the period 1900–2020. The annual amount of precipitation in the region for the period 1900–2020 also increased (by ~10%, or about 40 mm/100 years) (Figure 1B).

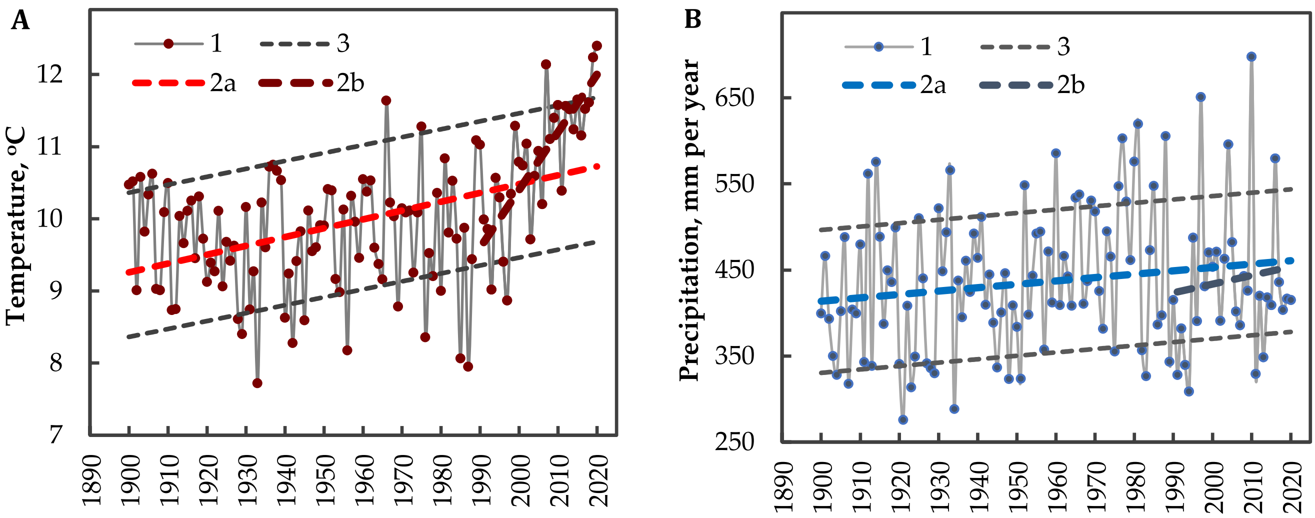


Figure 1. The annual average air temperature (**A**) and the annual amount of precipitation (**B**) for the southern region of Ukraine (1—empirical data, 2a—linear trend for the period 1900–2020, 2b—linear trend for the period 1991–2020, 3—±σ from trend).

However, climate change has greatly accelerated since the second half of the 20th century. Over the last 30 years, a more intense increase in temperature, by 0.77 ± 0.1 °C/10 years, was found (Figure 1A). The annual amount of precipitation for the period 1991–2020 has increased by 11 ± 4 mm/10 years (by 6–7% for the observation period) (Figure 1B).

In the conditions of modern climate changes, certain tendencies of changes in a seasonal course of temperature and precipitation were observed. The average monthly temperature for the period 1900–2020 increased more in the cold period (October–March, by 0.7–2.6 °C/100 years), while an increase in the warm period (April–September) was less intense (by 0.4–1.1 °C/100 years).

A comparison of the average monthly temperature (registered at the meteostations Kherson, Mikolaiv, Odesa, and Zaporizhzhia; estimated for the whole region) for the period 1991–2020 and the climatic norm for the period 1961–1990 are shown in Figure 2A. The change of the average monthly temperature for the period 1961–1990 was more intense in winter as well as in March and May (by 0.1–0.9 °C/100 years), while a decrease in April–December (by −0.4 ÷ −1.1 °C/10 years) was typical. However, for the period 1991–2020, the temperature was increasing during the whole year (0.1–1.4 °C/10 years) (Figure 2B).

The monthly precipitation for 1900–2020 increased more in the cold period (November–March, by 6–12 mm/month per 100 years, on average ~23%/month per 100 years, except October), while a precipitation decrease in the warm period (April–September, by 2–7 mm/month per 100 years, on average ~8%/month per 100 years, except May and September) was typical.

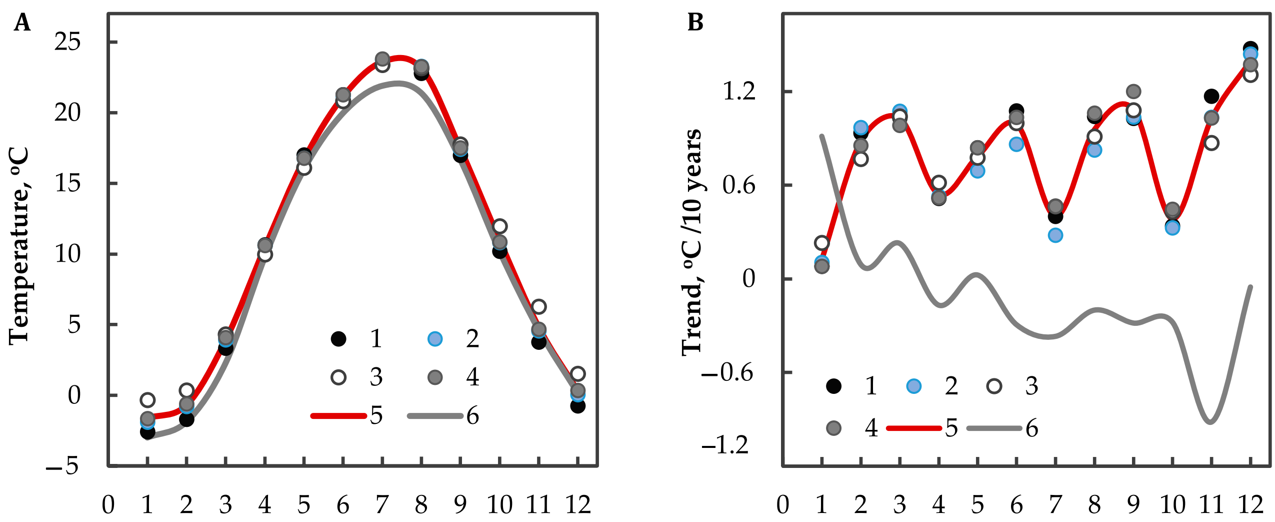


Figure 2. Seasonal variation of temperature (**A**) and corresponding trends (**B**): average monthly values for meteostations Zaporizhzhia (1), Mikolaiv (2), Odesa (3), and Kherson (4) as well as the values of the climatic norm estimated for the whole region, for the periods 1991–2020 (5) and 1961–1990 (6).

Comparison of the monthly precipitation amount for the period 1991–2020 and the climatic norm for the period 1961–1990 are shown in Figure 3A. As one can see, the maximum amount of precipitation has shifted from July to June. The amount of monthly precipitation for the period 1961–1990 decreased in the cold period of the year (November–March) and May (on average ~13%/month per 10 years), while an increase in the warm period of the year (April–September, on average ~18%/month per 10 years) was typical. However, for the period 1991–2020, the monthly precipitation was increasing (on average ~11%/month per 10 years), except in June, July, October, and November, when it was decreasing (on average ~12%/month per 10 years) (Figure 3B).

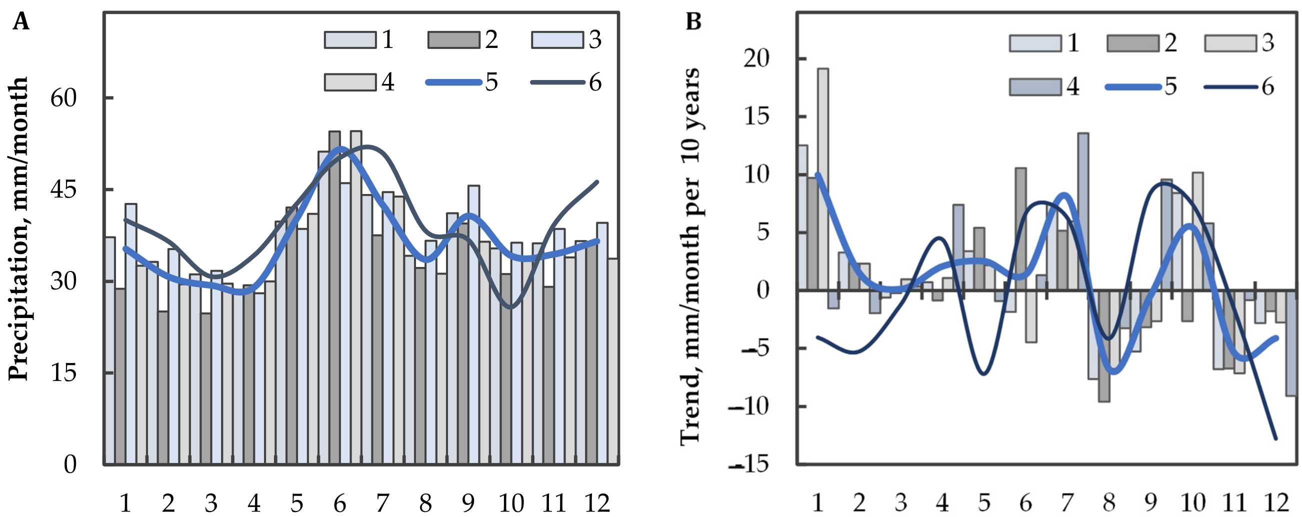


Figure 3. Seasonal variation of precipitation (**A**) and corresponding trends (**B**): monthly precipitation values for meteostations Zaporizhzhia (1), Mikolaiv (2), Odesa (3), and Kherson (4) as well as for the whole region (5), for the period 1991–2020; 6—values of the climatic norm for the period 1961–1990.

New maximum temperature records have been repeatedly registered in the southern region, as well as over the whole territory of Ukraine, during the last decades. It was determined that the repetition and duration of the summer heat (temperatures above 30 °C) increased. Furthermore, droughts take place more often and embrace larger territories [12].

For the development of possible climate change scenarios in the territory of the southern region, global scenarios of temperature changes RCP4.5 and RCP8.5 until the end of 21st century [1,2], the semi-empirical scenarios for Ukraine (Scenario 1 and Scenario 2) [33–35] and the tendencies of climate change in the region, since the end of the 19th century and at the beginning of the 21st century were taken into account. Consequently, climatic scenarios for this climatic zone are as follows (scenarios have a countdown from 1900): optimistic scenario (RCP4.5) is $\Delta T_{2050} \approx 1.4 \pm 0.3$ °C; pessimistic scenario (RCP8.5) is $\Delta T_{2050} \approx 2.2 \pm 0.3$ °C.

3.2. Extreme Weather Events

Key negative factors of the climate change impact on the environment, urban infrastructure, and human health are the intensification of extreme weather events and disturbed weather conditions. In the region, the real threat is posed by thunderstorms, hailstorms, heavy rains, dry winds, waterspout, flooding due to downpours; squally wind, drought, sawtooth storm, hot weather and disturbed weather [10].

According to the analysis of meteorological data, over the past few decades there has been some increase in the frequency and severity of the events observed [10,31,32]. There was a decrease in the number of days with minimum temperatures below 0 °C (in spring and winter), while an increase in warm-temperature events has occurred during the annual cycle, and an increasing tendency of anomalous high temperatures ≥30 °C has been observed in summer. Especially in urbanized territories, the situation is deteriorated due to pervasive phenomena of "heat waves".

In addition, there is a tendency to increase the intensity of heavy rains, when monthly climatic norms or even more fall during a few hours. In particular, on 4 August 2019, about 120–125 mm of precipitation fell in Zaporizhzhia, which exceeded two monthly norms. On 13 July 2020, the city received almost its monthly precipitation in less than three hours. Torrential rains led to flooding in the city of Zaporizhzhia on 1, 13, and 30 June 2021.

The annual numbers of days with extreme weather events, registered at the meteostations of the region as well as calculated for the whole region for different periods, are presented in Figure 4. As can be seen, only hailstorms are rare, while all other extreme weather events are typical for the region.

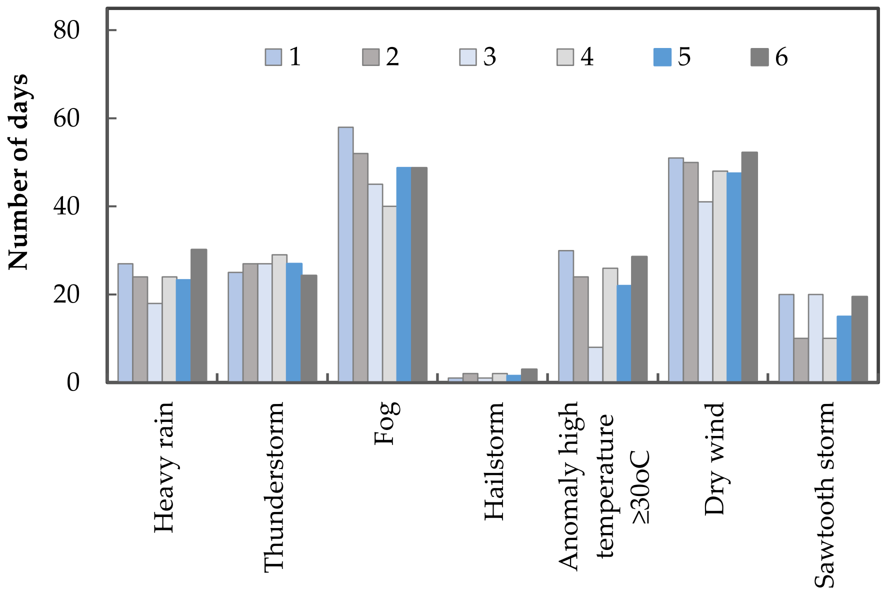


Figure 4. Annual average number of days with extreme weather events for meteostations Zaporizhzhia (1), Mikolaiv (2), Odesa (3), and Kherson (4), as well as the whole region (5), for the climatic norm period (1961–1990), and for the whole region, for the period 1986–2005 (6).

A comparison of the number of extreme weather events, registered during the climatic norm period 1961–1990 [24] and the period 1986–2005 [32], shows that the situation with fog remains unchanged, while the number of thunderstorms slightly decreased; however, the average numbers of days with heavy rains, hailstorms, abnormally high temperature, dry winds, and sawtooth storms increased.

3.3. Regional Trends in the Normalized Difference Vegetation Index Dynamic

Climate changes are resulting in regional seasonality changes of temperature and precipitation: the duration of the cold season has been decreasing, whereas the duration of the vegetation season has been increasing. This affects the vegetative activity of ecosystems, and can be confirmed by satellite remote sensing data, which, in addition to climatic records, provide important spatiotemporal information to identify global trends. Vegetation indexes, in particular the Normalized Difference Vegetation Index (NDVI), are derived from satellite imagery and are widely used for the monitoring of vegetation photosynthetic capacity, carbon assimilation, evapotranspiration, vegetation phenology, and primary productivity. Data about the impact of disturbances such as drought, fire, flood, and frost [25,36] justified that the NDVI has a strong correlation with maximum temperature, potential evapotranspiration, and aridity. The positive NDVI trend was evident in most parts of Ukraine [37,38].

The NDVI dynamic per oblast for the periods of 1982–2021 is shown in Figure 5.

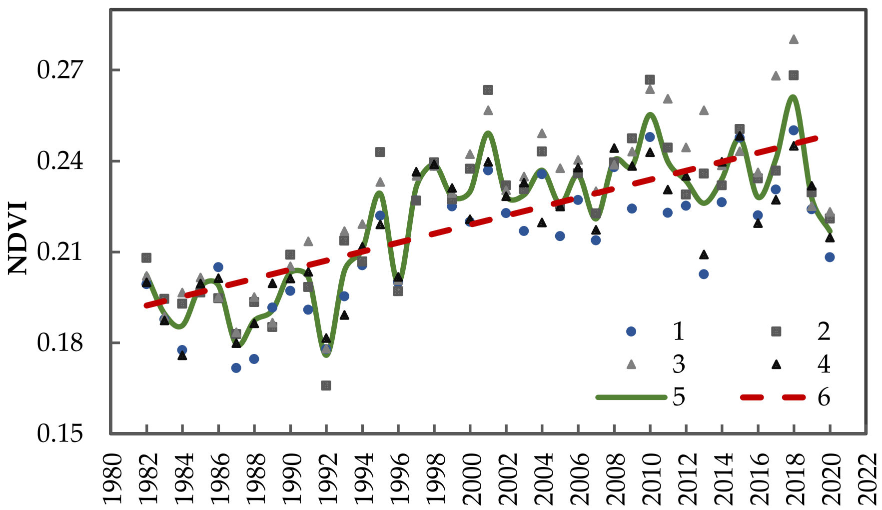
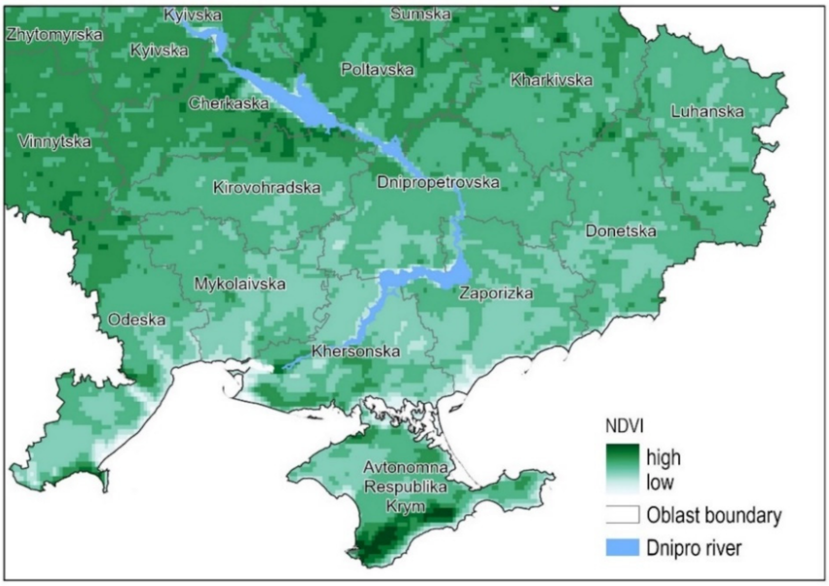


Figure 5. Dynamic of the NDVI, averaged by vegetation season (April–October) using satellite imagery of the southern region of Ukraine, for the period 1982–2020 (Zaporizhzhia (1), Mykolaiv (2), Odesa (3), Kherson (4) oblasts, the whole region (5), liner trend (6)).

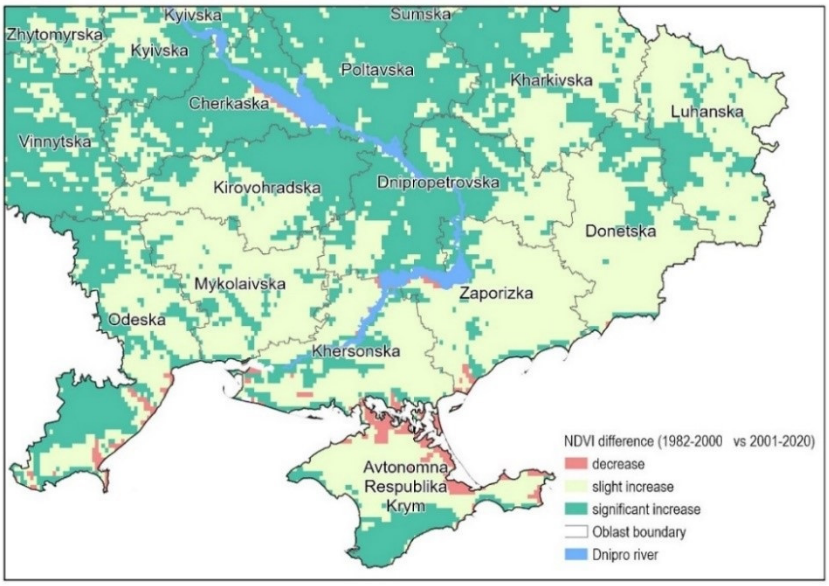
In general, there is a positive trend of the NDVI in all studied oblasts, for the period 1982–2020. The NDVI appears to be sharply increasing until 2000, which may indicate a positive effect of increasing temperature on the productivity of ecosystems [25]. The integral growth of the NDVI values has two possible reasons: the extension of the vegetation period and the creation of more comfortable minds for vegetation (e.g., temperature increase and growth of precipitations).

Following the period of the 2000s, the positive trend has been slowing down, and a slight negative tendency is observed in the Mykolaiv oblast.

A comparison of the long-term averaged NDVI values for the periods 1982–2000 and 2001–2020 revealed the areas with a negative NDVI tendency, for instance, the Odesa oblast coastal areas and Azov Sea coastal areas in Crimea (Figure 6). However, in general the southern region territory tends to show a slight NDVI increase.



(**A**)



(**B**)

Figure 6. The spatial-temporal distribution of the NDVI, averaged for vegetation period (April–October) in the southern region of Ukraine for the period 1982–2020 (**A**), and the difference of the NDVI values for the periods 1982–2000 and 2001–2020 (**B**).

These are areas near water bodies (estuaries), where in recent years there has been a decrease in water levels and water surface area as well as signs of desertification, which may be the cause of a significant decrease in the NDVI in the surrounding areas [39].

3.4. The Tendency of Thermal Bioclimatic Conditions Changes

As far as some changes in comfortable thermal conditions for humans are caused by regional climate change [26,40–43], we have analyzed such conditions for the population of the southern region. For this study, the equivalent-effective temperature was used [26]. For temperate latitudes, including the territory of Ukraine, comfortable thermal conditions for humans have I_{EET} values of 16 ÷ 23 °C. Thermal conditions with values 12 ÷ 16 °C can also be considered as comfortable, if persons are active [42,43].

It was estimated that weather conditions in the region, with an apparent temperature of very cold–cold–cool–slightly cool, compose about 264 ± 8 (73%) days annually [42]. Thus, the population of the southern region experience conditions of physiological cold stress (extreme cold–strong cold–moderate cold–slight cold stress) during the prevalent time of the year. The "slightly warm" and "warm" apparent temperatures are observed on average 101 ± 7 (~27%) days per year in the region, and such apparent temperature is considered as subcomfortable and comfortable for humans. I_{EET} values that fall into the gradation "hot" (23 ÷ 30 °C) are observed during a few days (~1). However, in certain years, over 10 days with strong heat stress for humans were observed.

The number of days during the year for each gradation of I_{EET} and the corresponding trends for the cities of Odesa, Mykolaiv, Kherson, and Zaporizhzhia, for the period 1991–2020, are shown in Figure 7.

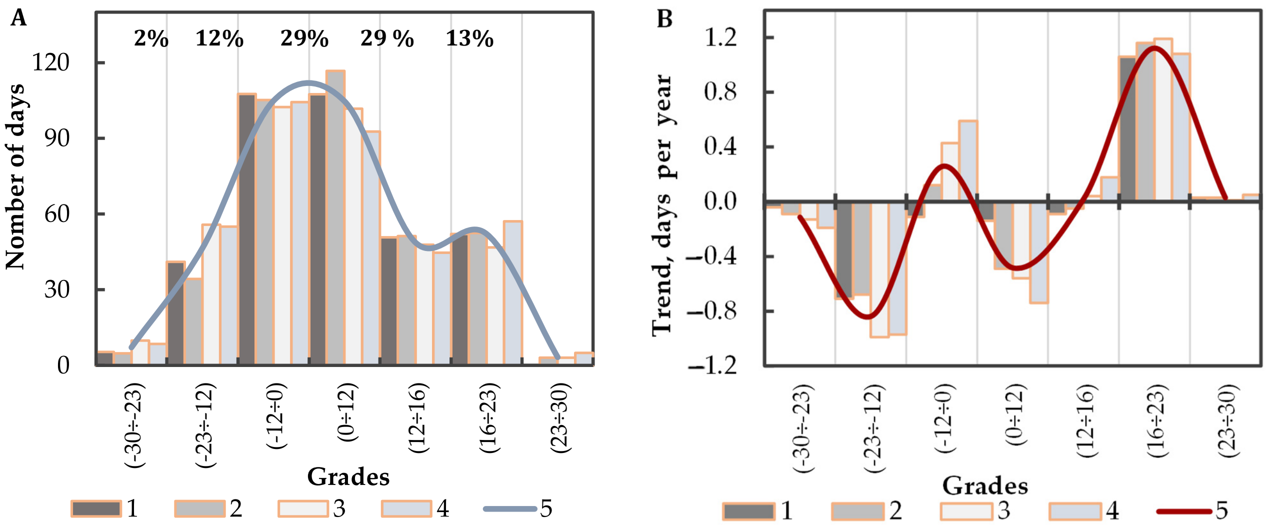


Figure 7. Distribution of the number of days with thermal conditions for humans, due to I_{EET} gradations (**A**) and corresponding trends (**B**), based on the data of the meteostations Zaporizhzhia (1), Mykolaiv (2), Odesa (3), and Kherson (4) as well as for the southern region as a whole (5), for the period 1991–2020.

Determined tendencies in the redistribution of weather conditions, according to the I_{EET} gradations for this period, are as follows (Figure 7B): a decrease in the number of days falling into gradations "very cold" (−30 ÷ −23 °C), "cold" (−23 ÷ −12 °C) and "slightly cool" (0 ÷ 12 °C), by −0.1, −0.8, and −0.5 days per year, respectively, and an increase in the number of days corresponding to the gradations "cool" (−12 ÷ 0 °C), "slightly warm" (12 ÷ 16 °C), "warm" (16 ÷ 23 °C), and "hot" (23 ÷ 30 °C), by 0.3, 0.02, 1.1, and 0.03 days per year, respectively. The similar tendencies in the regional redistribution of bioclimatic conditions were described earlier in [42].

Thus, climate change causes more comfortable temperature conditions for people during the cold season and somewhat complicates such conditions in the warm season, by increasing the frequency and duration of abnormally high temperatures.

3.5. Dynamic of the Health and Well-being Indicators of the Region

Climate-dependent changes of the bioclimatic conditions in the southern region definitely influence mental and physical human health and, consequently, the well-being of the population. There is, as well, clear evidence of the effect of climate impact drivers on public health (for example, see [19,20]). Such influence can be direct (e.g., mediated through bioclimatic conditions) and indirect (e.g., mediated through increasing the risk of environmentally dependent decreases).

Presented below, the results describe the dynamic of the health indicators of the southern region's population for the last decades and create the basis for the assessment of the risk caused by climate impact drivers on human health.

Using demographic data of the National Statistic Service [27,28], we have analyzed, among others, such integrated health and well-being indicators as life expectancy, for the time frame 2000–2020. The value of this indicator for the population of the southern region is lower than for the population of the EU countries, but it has been growing non-monotonically in all oblasts, at least since 2000 (Figure 8A). At the same time, the overall mortality rates of the population in the region remain relatively high and are not decreasing (Figure 8B). On the contrary, we saw a sharp increase in the indicator in 2020, which may be the result of the SARS-CoV-2 pandemic.

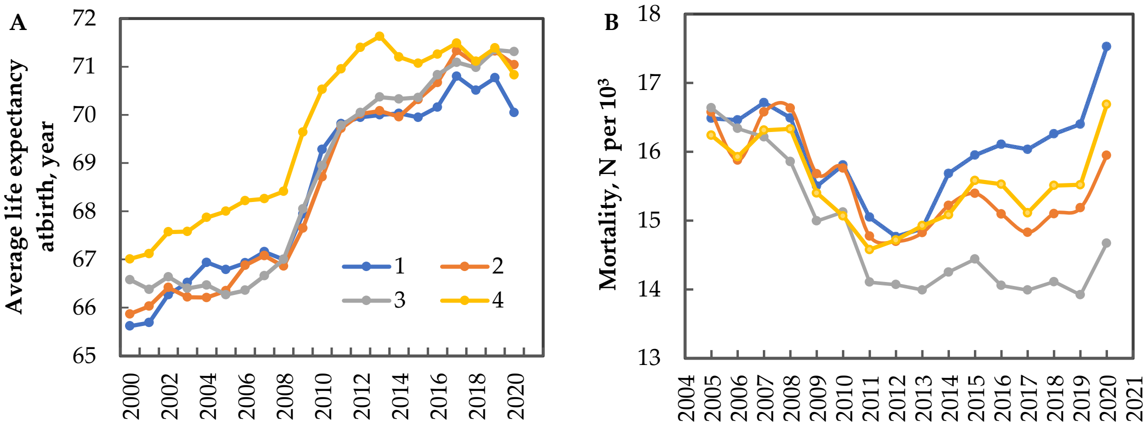


Figure 8. Average life expectancy at birth (**A**) and mortality dynamic of the population (**B**) of the Kherson (1), Mykolaiv (2), Odesa (3), and Zaporizhzhia (3) regions in 2000–2020.

However, the analysis of the dynamics of mortality rates by their causes from various diseases resulted in the establishment of a certain trend (Figure 9). In particular, there are pronounced downward trends in the dynamics of mortality from some environmentally dependent diseases. Figure 9A represents the results of statistical estimates and shows the dynamics of mortality caused by parasitic and infectious diseases. As we can see, these indicators are declining in all parts of the southern region. In 2005, the mortality rates from these diseases in the Odesa oblast were twice as high as in the Zaporizhzhia oblast, but both decreased markedly and converged in 2020.

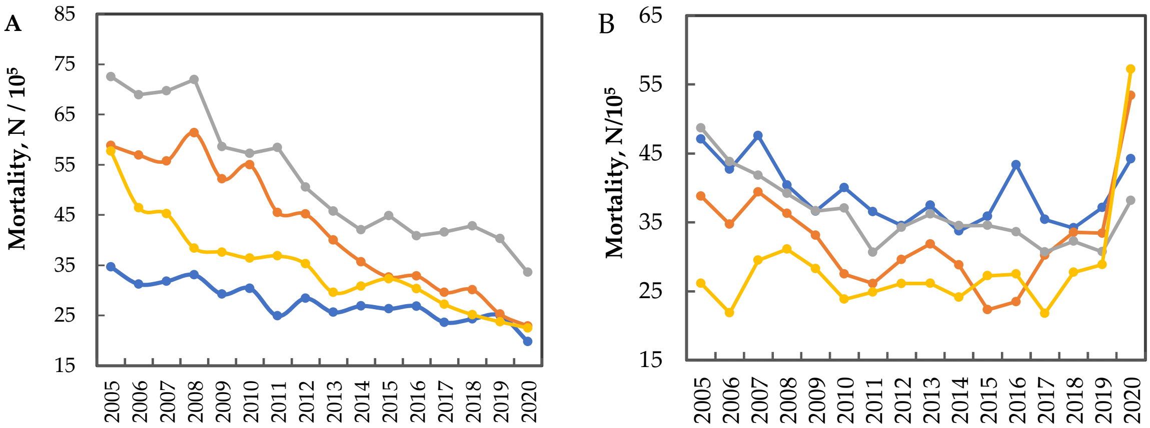


Figure 9. Dynamics of the number of deaths caused by parasitic and infectious diseases (A00–B99) (**A**) and respiratory diseases (J00–J98) (**B**) in the Kherson (1), Mykolaiv (2), Odesa (3), and Zaporizhzhia (3) regions in 2005–2020.

Similar trends are also observed in the rates of mortality from respiratory diseases during 2005–2017 (Figure 9B), the spread of which is directly related to the quality of the environment [44]. However, since 2019, the number of deaths caused by respiratory diseases has increased sharply, and this increase is, most probably, connected with the SARS-CoV-2 pandemic.

In 2019–2021, the world faced the challenge of the SARS-CoV-2 pandemic outbreak, which reached Ukraine in early 2020 [29,45]. In temperate latitudes, the spread of respiratory viruses is mainly seasonal, as their onset occurs in the first half of October and the end of March, but an atypical spread of diseases caused by the SARS-CoV-2 virus was also recorded in the warm periods of 2020 and 2021. The main factors that can affect the spread and development of the influenza virus, in addition to strain-specific characteristics, social, and behavioral aspects of the population, the immune status of an individuals, and the level of economy and medical care in the country, are also related to the environmental conditions [27,28].

According to the data [29], by April 2022, over $4975.8 \cdot 10^3$ confirmed cases of SARS-CoV-2 infection and more than 108.0×10^3 fatal cases were recorded in the south of Ukraine. The percentage of confirmed cases of infection for the number of people living in the region is 4–6%, and for deaths is $0.2 \pm 0.05\%$. For some oblasts, these parameters are as follows (in 10^3 cases): the Zaporizhzhia oblast is 227.2 and 6.1, the Mykolaiv oblast is 152.5 and 3.6, the Odesa oblast is 331.3 and 6.1, and the Kherson oblast is 110.0 and 2.9. It was confirmed that seasonal climatic variability and extreme weather conditions affected the spread of viruses [46,47].

The recorded peculiarities of the indicators of health and well-being of the population of the southern region depend on climate impact drivers, however, socio-economic and other factors also contributed to these patterns.

4. Discussion

The data presented above indicate that climatic indicators in the southern region of Ukraine show a steady trend towards change. This picture is not unique for the region and is observed at least throughout the territory of Ukraine, as well as other coastal areas. In particular, for the last 120 years, climate changes were characterized by an increase in surface temperature by 1.2 ± 0.2 °C/100 years [48–50]. At the same time, climate change in Ukraine has spatial differences. In the northern regions, warming was more intense (by 1.7 ± 0.4 °C/100 years) with some decrease in the amount of precipitation during the year, especially in summer, while in the southern region, the temperature demonstrated a less intense increase (by 0.8 ± 0.3 °C/100 years), with a slight increase in precipitation by ~10% for the cold period and a significant decrease in summer by ~20–30% [33,50]. An intensification of temperature increase and a decrease in precipitation, at the same time as an increase in the frequency of heat waves and heavy precipitation events during recent decades in other parts of the country, have all been recorded.

Similar trends are observed in other regions of Europe [7,51–53]. In the Black Sea coastal area, a significant temperature increase has been observed for the period 1982–2014 [51]. Meteorological observation in Georgia during 1981–2010 has shown a significant warming in summer time, at the rate of 0.84 °C/10 years, which is almost twice as fast as the annual trend of temperature (0.47 °C/10 years) [52].

Increasing heat extremes during the summer and fall seasons have been registered since the 1960s [52,53]. Trends toward an increase in the frequency and intensity of extreme precipitation for the period 1961–2008 have been identified in the western coast of the Black Sea, covering the Bulgarian, Romanian, and (partly) Ukrainian coasts [53].

Such changes are affecting the state of local terrestrial ecosystems. According to the presented and described results (Figures 5 and 6), the NDVI, as an integral indicator of photosynthetic activity of the territory, is increasing synchronously with temperature and total precipitation. However, an increase in surface temperature can cause droughts, therefore, in some southern localities, a downward trend in the NDVI has been observed in recent years [25,39]. Therefore, registered changes in vegetation activity in the region can be considered as one of the multiple consequences of climate change.

Based on the described results, as well as taking into account published scientific data, it can be argued that climate change in the southern region of Ukraine has caused some other adverse effects on the environment.

A noticeable spatiotemporal transformation of the steppe phytosystem structure under the influence of climate was registered in some protected areas within the natural reserve "Elanetskyj steppe", Black Sea, and "Askania-Nova" Biosphere Reserves. Monitoring data and an analysis of the main typological varieties of steppes became the basis for identifying trends towards the decreasing xeromorphic component of photosystem (by $30 \pm 10\%$), along with the increasing of mesomorphic (by $10 \pm 5\%$) and ligneous (by $20 \pm 10\%$) components, during the monitoring period since the 1950s [54,55].

The level of the Black and Azov Seas is increasing by 20 ± 3 sm/100 years [9,56,57]. During the last 120 years, it corresponds to the increase in the global sea level [1,2]. This process, as well as increasing the human-caused load on the environment, became the reason for the acceleration of some negative phenomena in the coastal ecosystem, namely an intensification of the processes of abrasion and erosion, the flooding of the coast and maritime spits, the changing characteristics of sea water (a decrease of water transparency, fluctuations in water salinity and expansion of hypoxia zones), and the degradations of biodiversity resulting, in particular, from the intervention of alien species.

Changes in the river deltas of the region are mainly unfavorable. Increasing water temperature and salinity, decreasing depths due to silting, reducing volume of freshwater flow from rivers, and intensifying seawater outcrops from the seas, through the raising sea level and the high content of nutrients (ammonia and nitrate, mineral phosphorus, etc.) have been detected in the Dnipro–Bug, Dniester, and Danube estuaries and deltas [58,59]. This has led to the degradation of native biodiversity in estuaries and causes increasing marine species intervention.

Seasonal reductions of water content in the river basins (South Bug, Dnipro, Dniester, etc.) and reservoirs are mainly caused by the increased water consumption and climate change (in particular, in summer, since the surface temperature rises, precipitation decreases, and water evaporates intensively). The intensive water pollution by wastewater from the municipal sector as well as industrial and agricultural enterprises, and the exploitation of water transport, makes the situation even more complicated [59–61].

The increasing frequency and intensity of extreme weather events, as well, can be considered as consequences of climate change and local/regional conditions [10,31,32,48]. Heat waves, droughts, wind storms, heavy precipitation, river floods, etc., are happening more and more often. During the annual cycle, a visible decrease in the number of frosty days is observed, while an increase in warm days has occurred over the year. The number of days with a maximum temperature above 30 °C is increasing. Precipitation extremes (the number of days with precipitation > 10 mm) are most frequent in summer and are strongly associated with flooding and waterlogging.

Changes in the temperature and other characteristics of the region affect bioclimatic conditions, having a direct and indirect impact on the health and well-being of the local population. In the cold period of the year, the number of days with uncomfortable conditions ("very cold", "cold", and "slightly cool") is decreasing, while the number of days with comfortable conditions in the warm season is increasing (Figure 7). At the same time, the shift towards less comfortable climate conditions has been fixed in summer—probably, due to the repeatability of the high anomalous temperature and aridization. According to the results of some studies [42], human mortality rates in summer are increasing, when I_{EET} exceeds 26 °C. Increased death numbers associated with hypothermia can be registered, when the daily minimum I_{EET} is less than -14 °C.

To some extent, this can also affect the integrated indicators of the health and well-being of the population. An increase in temperature and more frequent periods of extreme heat correlate with a significant increase in the number of diseases and the mortality rate, especially among the elderly, as was observed in Europe in 2003 [19,20].

The dynamics of changes of some health indicators can be clearly seen in Figures 8 and 9, but it is premature to state, unequivocally, that these changes are caused by climate impact drivers only. Further analysis is needed to determine the role of climate factors in changing health and well-being indicators, and, in particular, in the expansion of the SARS-CoV-2 pandemic [46,47].

However, there is no doubt that heat waves, extreme weather events, and other climate impact drivers increase the risk of the spread of infectious diseases, allergic reactions, and adverse health and environmental effects. Assessing such risks is an important prerequisite for the elaboration of the strategies for the development of local communities and regions. Table 2 presents the results of the risk assessment for the health and environmental sectors, based on an analysis of the long-term meteorological data for the southern region, while applying practical methodological approaches [62,63]. As can be seen, the risk of deterioration of human health and the state of the environment (water, soil, biodiversity) by climate impact drivers is mainly assessed as high. It means that corresponding provisions to manage such risks have to be integrated into operational management plans and development strategies at the local and regional levels.

Table 2. Risks associated with climate change for environmental and health sectors in the southern region of Ukraine.

Sector of Impact	Expected Impact Driver	Probability	Expected Level of Risk	Timeframe	Impact Indicators
Environment and biodiversity	Warming	High	Moderate	Medium- and long-term	Expansion of the habitats of thermophilic species to the north. Increasing plant productivity.
	Dry weather	High	High	Short- and medium-term	Depletion of soils and water resources. Changes in biodiversity. Reduced plant productivity. Fires. Pests' expansion. Costs of elimination of consequences.
	Extremely hot weather	High	High	Short- and medium-term	Depletion of soils and water resources. Changes in biodiversity. Reduced plant productivity. Fires. Pests' expansion. Costs of elimination of consequences.
	Heavy rain	High	High	Short- and medium-term	Flooding, pollution of water bodies, damage to trees. Costs of elimination of consequences.
	Thunderstorm, hailstorm, squall	Moderate	Moderate	Short- and medium-term	Damage. Fires. Costs of elimination of consequences.
	Dry wind, sawtooth storm	Moderate	High	Medium- and long-term	Depletion of soils and water resources. Changes in biodiversity. Reduced plant productivity. Fires. Pests' expansion. Costs of elimination of consequences.
Health	Warming	High	Moderate	Medium- and long-term	Improving the comfort of climatic conditions.
	Disturbed weather conditions	High	High	Short- and medium-term	Deteriorating health of the population. Increasing costs of medical care.
	Anomalous high temperature	High	High	Short- and medium-term	Deteriorating health of the population with possible fatalities. Vulnerability to infections and viruses. Increasing costs of medical care.
	Heavy rain	High	High	Short- and medium-term	Deteriorating health of the population with possible fatalities. Vulnerability to infections and viruses. Increasing costs of medical care.
	Thunderstorm, hailstorm, squall	Moderate	Moderate	Short- and medium-term	Injuries and deteriorating health. Increasing costs of medical care.
	Dry wind, sawtooth storm	Moderate	High	Short- and medium-term	Injuries and deteriorating health. Increasing costs of medical care.

5. Conclusions

The recent tendencies of climate change and the change in environment of the southern region of Ukraine have drawn certain consequences for the environment, local economy, and the well-being and health of the population. Since the end of the 19th century until the beginning of the 21st century, in the territory of the southern region of Ukraine, there was an increasing temperature, by 1.1 ± 0.3 °C/100 years, with a maximum of warming in the cold period of the year, and there was a slight increase in the amount of precipitation, up to

~10% per 100 years. Moreover, the tendency of climate change has increased much higher over the last 30 years.

Climate change and regional features of their manifestations are considered to be one of the main causes of weather anomalies. The main potential adverse environmental effects of climate change in the southern region of Ukraine include, among others, the spatiotemporal transformation of the steppe phytosystem structure, the increase in the sea level, unfavorable changes in the deltas of rivers, and the reduction of the water content in the basins of rivers (South-Bug, Dnipro, Dniester etc.) and reservoirs, increasing the frequency and intensity of extreme weather events.

The duration of the vegetation season has shown a noticeable increasing trend, associated with the starting date (temperature near 10 °C), which is coming earlier, and the ending date, which is later. The positive NDVI trend has been observed in the region at least since 1980; however, since 2000, the sharp increasing tendency of the NDVI has slowed down, and a downward trend has been observed in some areas.

Change of climate conditions (temperature increasing and more frequent periods of extreme heat) has led to some changes in the bioclimatic indexes for humans. There are shifts towards a more comfortable climate in winter, due to warming, and in summer, due to the increasing repeatability of anomalous high temperatures. Population in the region is decreasing, however, which demonstrates stable growth of the average life expectancy. Respiratory diseases are the most common diseases in the region. Statistic data of population morbidity (in particular, environmentally sensitive respiratory diseases) demonstrate specific regional dynamics and have tended to increase during the last years. Such a dynamic may have, among others, causes related to climate change.

Unfortunately, the new realities caused by the war in the southern region of Ukraine have had a horrible impact on human life, making significant negative adjustments in the course of environmental processes and leading to a terrible deterioration of the natural and human-made environment.

Author Contributions: Conceptualization, V.K. and S.B.; data curation, S.B., T.K. and O.Z.; formal analysis, S.B., T.K. and O.Z.; funding acquisition, V.K.; investigation, V.K. and T.K.; methodology, V.K., S.B. and T.K.; project administration, V.K.; resources, S.B. and T.K.; software, S.B. and T.K.; validation, T.K.; visualization, S.B. and T.K.; writing–original draft, S.B.; writing–review and editing, V.K. and S.B. All authors have read and agreed to the published version of the manuscript.

Funding: APC was funded by the National University of Kyiv-Mohyla Academy (Ukraine).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The results presented in this study are based on the data available in the open sources, which are described in the section Methods and Materials and are listed in the References section.

Conflicts of Interest: The authors declare no conflict of interest.

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