MINISTRY OF FOREIGN AFFAIRS OF DENMARK

Mykolaiv
city on the wave

Assistance to the Development of the Mykolaiv Masterplan

Impacts of Climate Changes, Report

Final

September 2024

COWI

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Contents

List of Figures

List of Abbreviations

CMIP	Coupled Model Intercomparison Project Phase 6
CO2	Carbon Dioxide
EU	European Union
IPCC	Intergovernmental Panel on Climate Change
MFA	Ministry of Foreign Affairs
NASA	National Aeronautics and Space Administration
RCP	Representative Concentration Pathways
UN	United Nations

1 Introduction

This report has been developed within the framework of the project “Technical advice to the Danish Ministry of Foreign Affairs regarding Mykolaiv - Denmark partnership” financed by the Danish Ministry of Foreign Affairs (MFA). COWI has been entrusted the development of contributions to the masterplan regarding water, energy and solid waste. The masterplan concerns the Mykolaiv City and its development in the period till 2050 (throughout this report Mykolaiv City and Mykolaiv as well as City of Mykolaiv are used synonymously).

Mykolaiv Masterplan, which has been requested by the Mayor of Mykolaiv City, has a time horizon till 2050. It provides a compass for actions to be taken by the Mykolaiv City to ensure that it will develop into a thriving city attractive to its citizens and business community.

COWI and One Works assist Mykolaiv City Administration in developing the masterplan. In this work, COWI focuses on three sectors:

- Water and wastewater,
- Energy, including power, district heating and renewable energy sources.
- Solid waste management.

Mykolaiv City Administration meets every week with COWI and One Works to ensure proper coordination.

COWI has established a project organization consisting of a project management team and three sector teams of professionals, each headed by a Discipline Leader. Three sectoral Focal Points are responsible for monitoring cross-cutting activities, ensuring coordination between the parties and maintaining consistency in the deliverables.

To enhance transparency in the development of the Mykolaiv Masterplan, given its significant public interest and exposure, COWI has established three sector-specific Sounding Boards inviting all potentially interested parties to take part in these.

Figure 1-1: COWI’s contribution to the Mykolaiv Masterplan.

This report focuses on the impacts of climate changes in Mykolaiv Oblast and City.

It consists of 10 chapters, including the current introduction, namely:

- Chapter 2 provides an overview of the general climate characteristics of Mykolaiv, highlighting the region's unique seasonal patterns and how these have been historically influenced by various climatic factors.

- Chapter 3 examines temperature changes, presenting historical data and current trends that reveal the warming trajectory of the region. It also includes future temperature projections.

- Chapter 4 discusses precipitation changes, focusing on historical precipitation patterns and current trends. It also provides future projections.

- Chapter 5 addresses the critical issue of sea level rise, presenting both historical data and future projections.

- Chapter 6 explores flooding risks, providing an analysis of historical flood data and discussing the potential impacts of future floods on Mykolaiv.

- Chapter 7 assesses the impact of war on climate change in the region, recognizing the complex and often devastating interplay between conflict and environmental sustainability.

- Chapter 8 focuses on the sectoral impacts of climate change, analyzing how key sectors such as agriculture, water resources, infrastructure, and human health are affected.

- Chapter 9 offers strategic recommendations for climate change adaptation and mitigation, emphasizing the importance of international cooperation, governance reforms, and local measures.

- Chapter 10 concludes the report, summarizing the key findings and emphasizing the urgent need for action to ensure Mykolaiv's long-term sustainability and resilience.

Appendix A “References” includes references, providing a comprehensive list of sources and literature that have informed the analysis and recommendations presented in the report.

2 General climate characteristics of Mykolaiv region

2.1 Climate characteristics

In the southern part of Ukraine, within the basin of the lower reaches of the Southern Buh River, lies the Mykolaiv region, covering an area of over 24.6 thousand square kilometres. The region is bordered on three sides by other Ukrainian regions, while its southern territory stretches along several hundred kilometres of the Black Sea coast and its estuaries.

The climate is temperate continental, characterized by mild, low-snow winters and hot, dry summers.

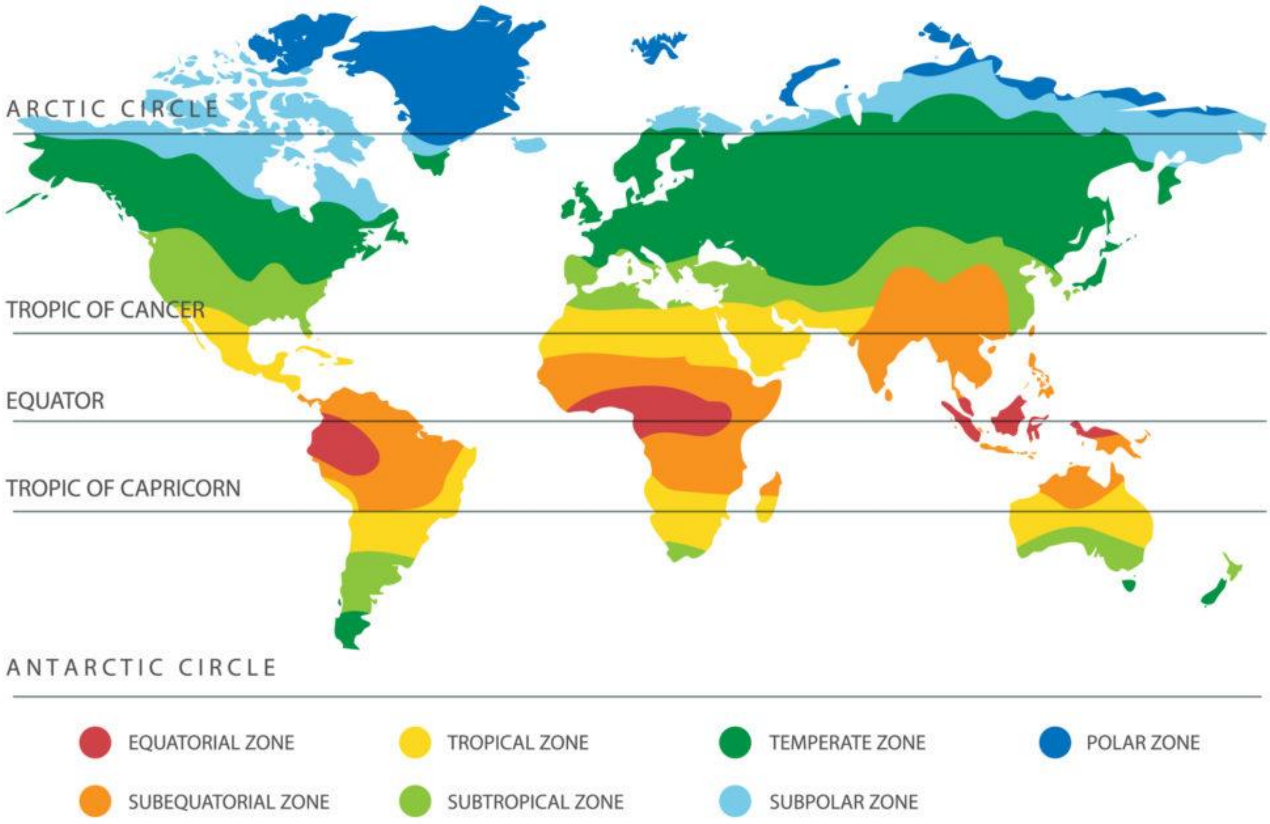

Figure 2-1: World climate zones.

The region is situated in the steppe zone, based on its natural conditions.

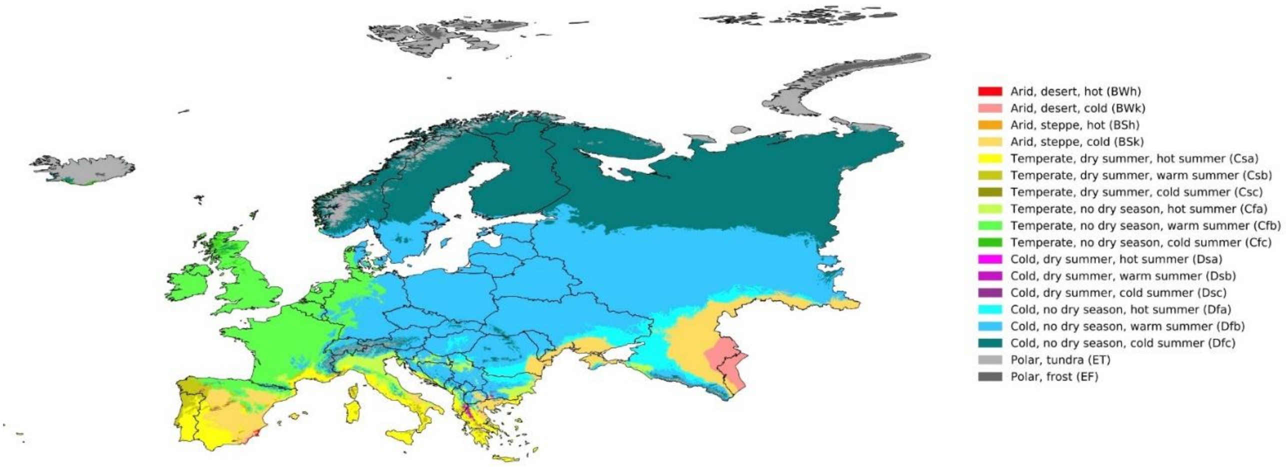

Figure 2-2: Climate classification map for Europe.

The average annual air temperature is 8-10°C, with July averaging between 21.2-22.9°C, and January averaging between -3.2 to -5°C. The absolute maximum temperature reaches 38-39°C, while the absolute minimum falls to -29-33°C. The frost-free period lasts 160-205 days, and the vegetation period extends for 215-225 days.

Most precipitation (65-70%) falls during the warm season in the form of showers, occasionally accompanied by hail, with daily precipitation amounts reaching up to 60-70 mm. The annual precipitation ranges between 380-500 mm.

The average annual relative humidity is 60-70%, but in summer months it drops to 40-60%, often falling below 30% during the daytime, and in dry wind conditions, it can drop to 10-20%, with such days occurring 11-17 times, and in August, they may occur every other day. The hydrothermal coefficient does not exceed 0.8-0.9, indicating the aridity of the climate. Rainless periods can last for 2.5-3 months.

2.2 Seasonal climate patterns

Mykolaiv Region is characterized by distinct seasonal changes typical of a temperate continental climate. Each season presents specific features that influence temperature fluctuations, precipitation, and overall weather conditions.

- *Winter:* Winter in the region is typically mild and short. Average January temperatures range from -2°C to -5°C. Severe frosts are rare but possible. Precipitation occurs mainly in the form of snow, although a significant part of the winter can be dry with minimal snowfall.

- *Spring:* Spring arrives early, marked by a gradual increase in temperature. March and April are transitional months, with temperatures rising to +8°C...+15°C. Precipitation is more frequent in early spring, creating favorable conditions for agricultural activities.

- *Summer:* The summer period is long, hot, and dry. Average July temperatures reach +22°C...+24°C, but during heatwaves, temperatures can exceed +30°C. Summer precipitation is usually brief and accompanied by thunderstorms, often with strong winds.

- *Autumn:* Autumn in Mykolaiv is warm and extended. September and October are often characterized by comfortable temperatures ranging from +10°C to +18°C. Precipitation gradually increases during this period, although much of the autumn remains dry. November marks the onset of temperature decline and preparation for the winter season.

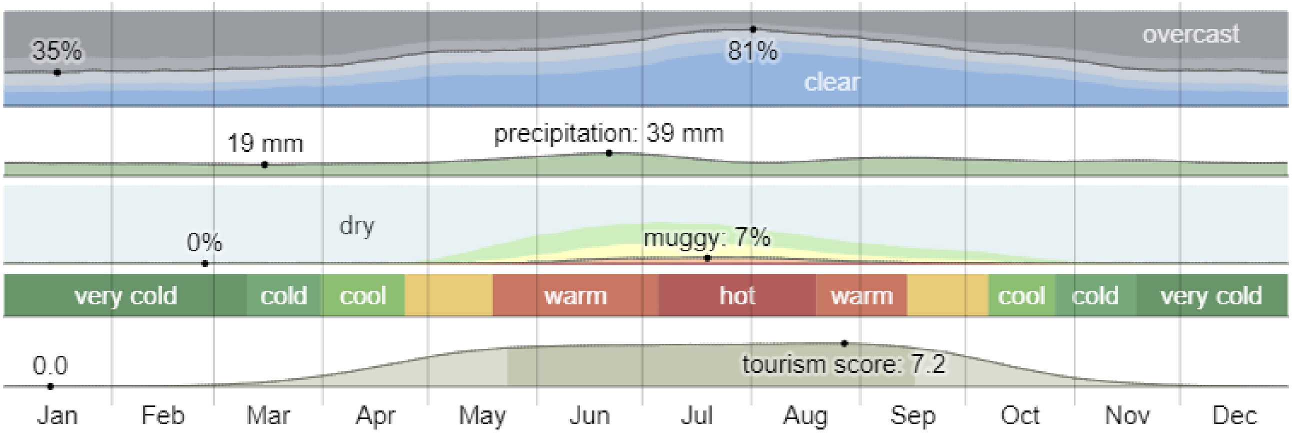

Figure 2-3: Climate in Mykolaiv.

Overall, the climatic conditions of the Mykolaiv Region exhibit sharply defined seasonal changes, with long, hot summers and short, mild winters, which significantly impact the region's water balance and agricultural practices.

3 Temperature Changes

3.1 Historical temperature data and current situation

Historical temperature data indicate significant climate changes in the Mykolaiv region, reflecting global warming trends. Temperature observations in the region have been recorded since the early 20th century, and these data serve as crucial indicators of climate change.

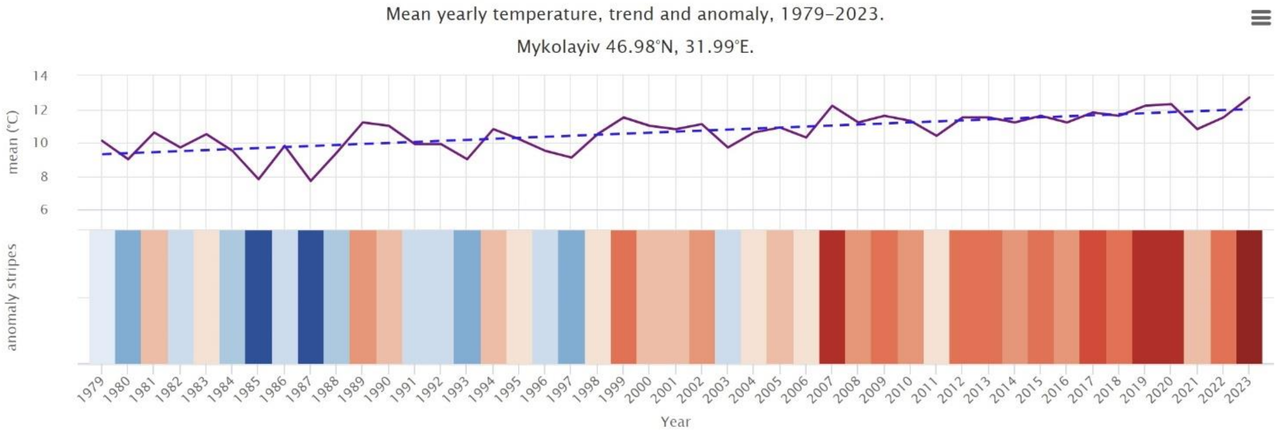

Figure 3-1: Yearly temperature changes in Mykolaiv

The top graph shows an estimate of the mean annual temperature for the larger region of Mykolaiv. The dashed blue line is the linear climate change trend. If the trend line is going up from left to right, the temperature trend is positive and it is getting warmer in Mykolaiv due to climate change. If it is horizontal, no clear trend is seen, and if it is going down, conditions in Mykolaiv are becoming colder over time.

In the lower part the graph shows the so-called warming stripes. Each coloured stripe represents the average temperature for a year - blue for colder and red for warmer years.

20th century: During the first part of the 20th century, the average annual temperature in the Mykolaiv Region ranged from +8°C to +10°C. January has traditionally been the coldest month, with average temperatures ranging from -2°C to -5°C, while July remains the warmest month, with average temperatures of +22°C to +24°C. Temperature data from this period confirm that the region's climate was stable but exhibited significant seasonal fluctuations.

Second half of the 20th century: Data from 1961 to 1990 show a gradual increase in average air temperatures. The average annual temperature in the region increased by 0.5°C during this period. This rise can be attributed to both natural variability and the enhanced anthropogenic impact that intensified in the latter half of the century.

Late 20th century - early 21st century: From 1991 to 2010, a further increase in temperature was observed. The average annual temperature rose by 1.2°C, indicating an acceleration in climate change. The increased frequency of abnormally warm winters and prolonged heatwaves during summer became a typical feature of this period. The data recorded an increase in the number of days with temperatures above +30°C and a reduction in the duration of winter. According to the Mykolaiv meteorological station, average winter temperatures have risen by 1.8°C compared to the early 20th century.

Current Trends: Recent data indicate that the warming trend continues. Since 2010, the average annual temperature has been rising by 0.2°C per decade.

To better understand the current climatic conditions in the Mykolaiv region, table with average monthly temperatures for the last year 2023 is provided. These data will help identify the most recent trends in temperature changes in the region and compare them with long-term historical data.

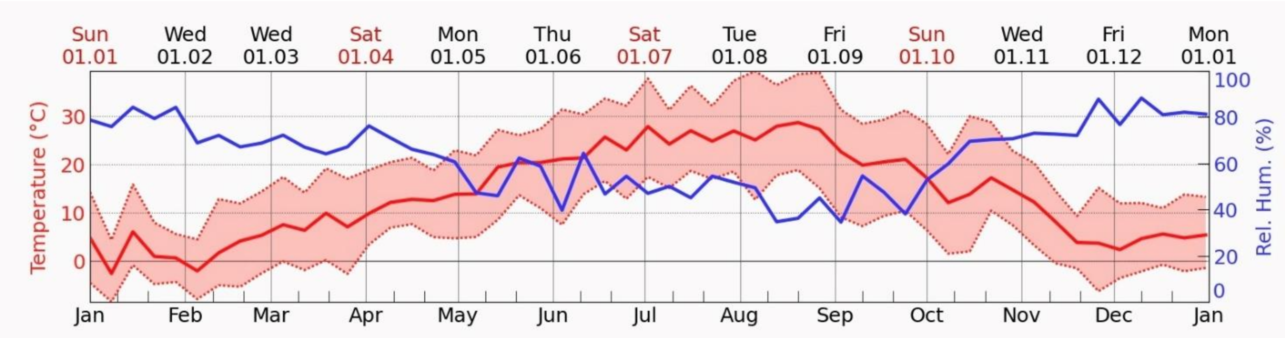

Figure 3-2: Temperature model for 2023 in Mykolaiv

The graph presents the temperature (red line) and relative humidity (blue line) throughout the year. It includes data on the minimum, maximum, and mean temperatures for each month.

3.2 Future temperature projections

The increase of the yearly average temperature is projected to continue consistently, with an acceleration at the end of the century. Both winters and summers is projected to become warmer. Both for the RCP 8.5 and RCP 4.5 scenarios, the temperature increase for the near (2021-2040), mid (2041-2060) and far (2081-2100) future exceeds the observed changes during the 1991-2010 baseline. Both the daily minimum (at night) and maximum temperatures are expected to increase.

The average of the maximum temperature for July is projected to reach more than 34 degrees in the far future. In general, increasing temperatures is expected to cause heat waves during summer. In the end of the century almost all cities will experience a temperature increase of 5 degrees for each of the months.

c		Baseline	ssp126	ssp245	ssp370	ssp585
Daily mean temperature °C	1991-2020	10.91				
	2020-2039		11.3	11.3	11.2	11.5
	2040-2059		11.9	12.0	12.3	12.7
Yearly maximum of daily maximum temperature (°C)	1991-2020	15				
	2020-2039		16	16	16	16
	2040-2059		16	16	17	17
Number of days with temperature > 30 °C anomaly (days)	2020-2039		15	15	15	18
	2040-2059		23	25	28	35

Figure 3-3: Projected climate change for different scenarios derived from CMIP6 at the location of Mykolaiv. The data is obtained from the World Banks Climate Knowledge Portal. The anomaly is against the period 1995-2014. The values shown are the median of the model ensemble.

In the Sixth Assessment Report of the IPCC, Representative Concentration Pathways (RCPs) are still used to assess the impacts of climate change. These scenarios are associated with time series of greenhouse gas emissions, aerosols, and chemically active gases in the atmosphere, as well as changes in land use. The RCPs include one low concentration scenario (RCP2.6), two moderate/medium scenarios (RCP4.5 and RCP6.0), and one very high greenhouse gas concentration scenario (RCP8.5). The scenarios are named based on the change in energy consumption by 2100 compared to the pre-industrial period and correspond to a radiative forcing of 2.6, 4.5, 6.0, and 8.5 W/m², respectively.

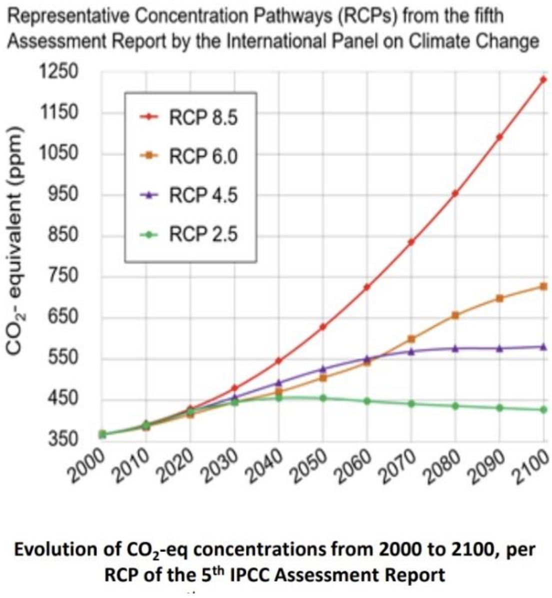

Figure 3-4: IPCC AR5 Greenhouse Gas Concentration Pathways

RCP 4.5 scenario assumes that reforestation programs will be implemented and traditional land-use practices will change. Under this scenario, a general reduction in energy consumption and the use of fossil fuels is expected, with an increase in the use of renewable energy sources and nuclear energy.

RCP 8.5, on the other hand, is characterized by increasing greenhouse gas emissions, leading to high levels of greenhouse gas concentrations. This scenario reflects a future situation in which greenhouse gas emission reduction policies are not implemented.

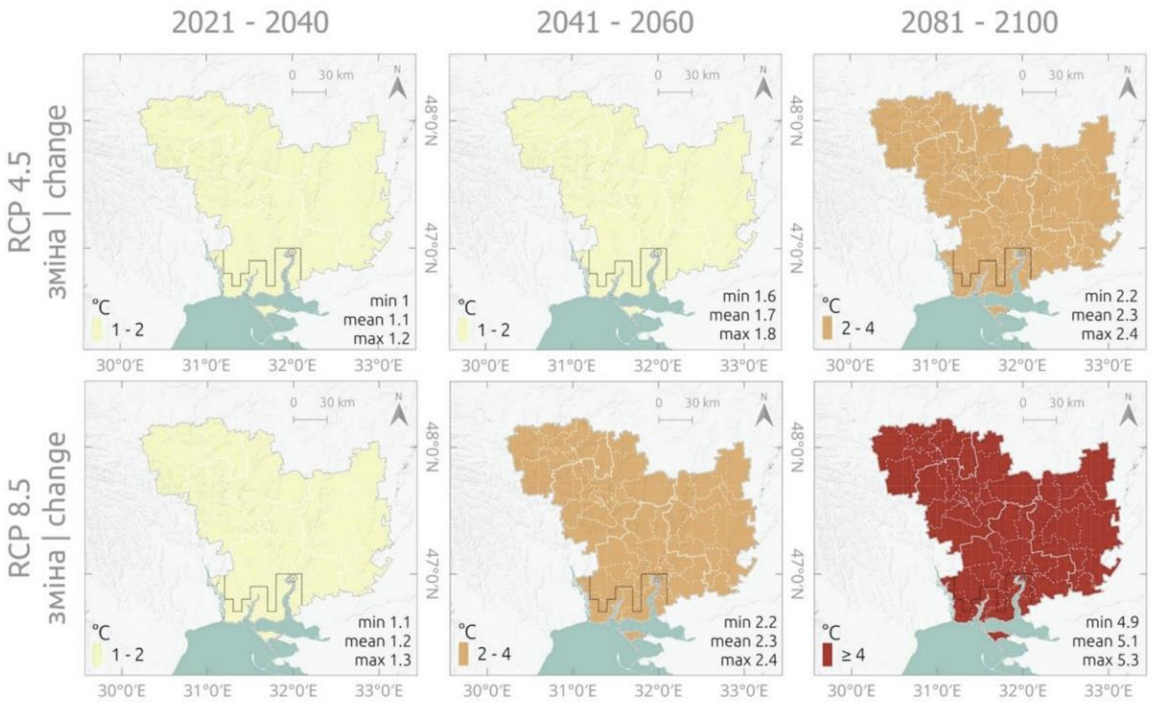

Figure 3-5: Annual mean air temperature in Mykolaiv, 2021-2100

4 Precipitation Changes

4.1 Historical precipitation patterns and current trends

A wet day is one with at least 1.00 millimetres of liquid or liquid-equivalent precipitation. The chance of wet days in Mykolaiv varies throughout the year.

The wetter season lasts 2.0 months, from May 10 to July 10, with a greater than 18% chance of a given day being a wet day. The month with the wettest days in Mykolaiv is June, with an average of 6.6 days with at least 1.00 millimetres of precipitation.

The drier season lasts 10 months, from July 10 to May 10. The month with the fewest wet days in Mykolaiv is August, with an average of 4.2 days with at least 1.00 millimetres of precipitation.

Among wet days, we distinguish between those that experience rain alone, snow alone, or a mixture of the two. The month with the most days of rain alone in Mykolaiv is June, with an average of 6.6 days. Based on this categorization, the most common form of precipitation throughout the year is rain alone, with a peak probability of 23% on June 14.

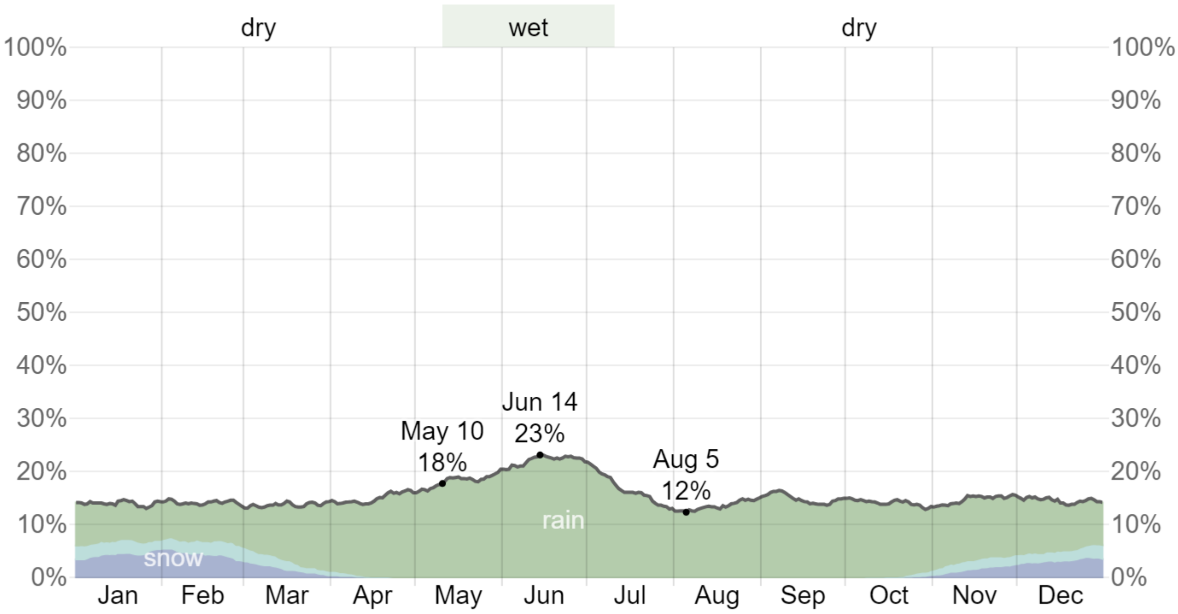

Figure 4-1: Daily chance of precipitation in Mykolaiv

Days of	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain	2.2d	2.1d	3.2d	4.4d	5.6d	6.6d	5.2d	4.2d	4.5d	4.3d	3.4d	2.9d
Mixed	0.7d	0.7d	0.5d	0.1d	0.0d	0.0d	0.0d	0.0d	0.0d	0.1d	0.5d	0.6d
Snow	1.3d	1.3d	0.5d	0.0d	0.0d	0.0d	0.0d	0.0d	0.0d	0.0d	0.5d	1.0d
Any	4.3d	4.1d	4.2d	4.5d	5.6d	6.6d	5.2d	4.2d	4.5d	4.4d	4.4d	4.5d

Figure 4-2: Days with various types of precipitation in Mykolaiv

Rainfall. To show variation within the months and not just the monthly totals, we show the rainfall accumulated over a sliding 31-day period centred around each day of the year. Mykolaiv experiences some seasonal variation in monthly rainfall.

The rainy period of the year lasts for 11 months, from February 25 to January 10, with a sliding 31-day rainfall of at least 13 millimetres. The month with the most rain in Mykolaiv is June, with an average rainfall of 38 millimetres.

The rainless period of the year lasts for 1.5 months, from January 10 to February 25. The month with the least rain in Mykolaiv is January, with an average rainfall of 12 millimetres.

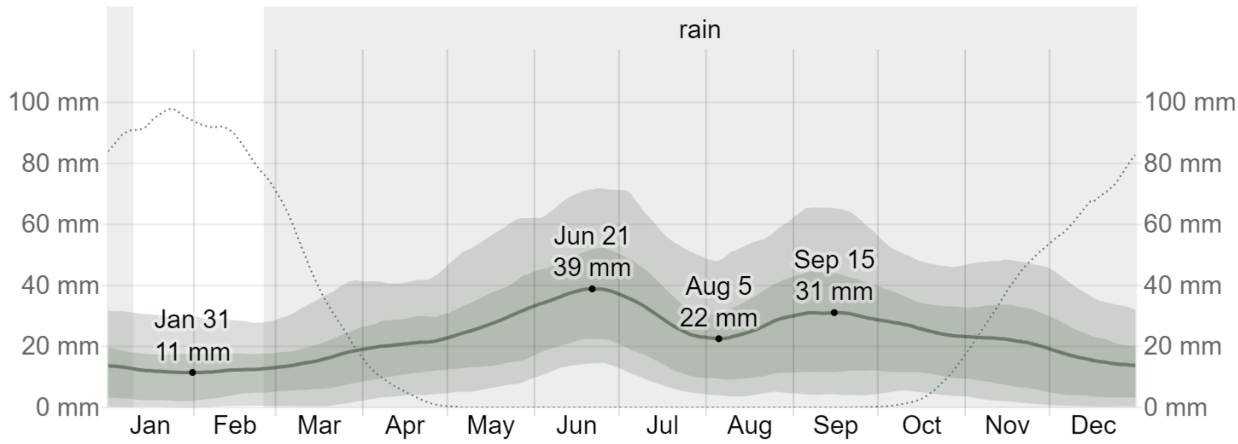

Figure 4-3: Average monthly rainfall in Mykolaiv

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	12.1mm	12.3mm	15.4mm	20.8mm	27.4mm	38.0mm	29.1mm	24.8mm	31.1mm	25.7mm	22.4mm	15.4mm

Figure 4-4: Amount of precipitation of rainfall by months in Mykolaiv

Snowfall. As with rainfall, we consider the snowfall accumulated over a sliding 31-day period centred around each day of the year. Mykolaiv experiences some seasonal variation in monthly snowfall.

The snowy period of the year lasts for 4.6 months, from November 6 to March 25, with a sliding 31-day snowfall of at least 25 millimetres. The month with the most snow in Mykolaiv is January, with an average snowfall of 94 millimetres.

The snowless period of the year lasts for 7.4 months, from March 25 to November 6. The least snow falls around July 16, with an average total accumulation of 0 millimetres.

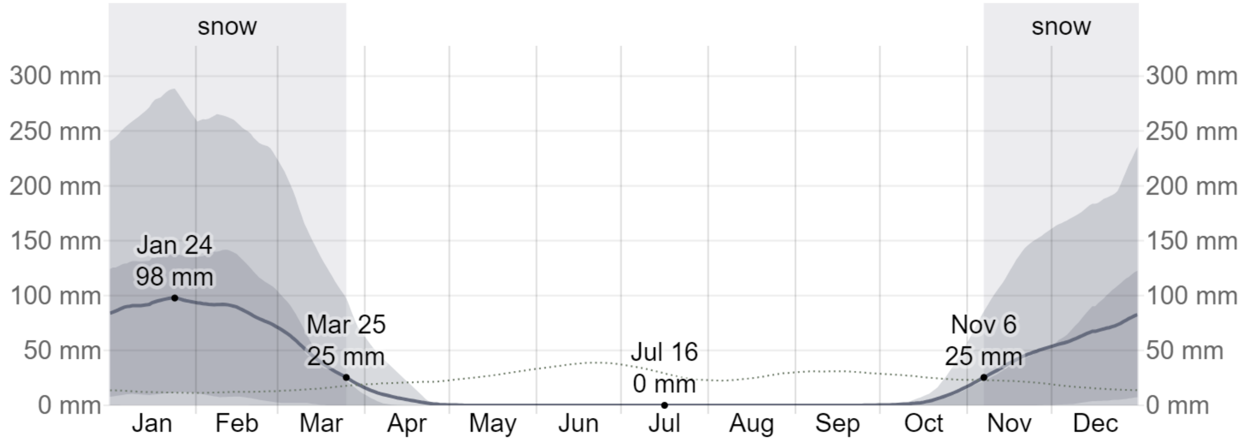

Figure 4-5: Average monthly snowfall in Mykolaiv

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snowfall	93.6mm	89.5mm	39.0mm	5.4mm	0.0mm	0.0mm	0.0mm	0.0mm	0.0mm	2.8mm	37.7mm	67.4mm

Figure 4-6: Amount of precipitation of snowfall by months in Mykolaiv

Precipitation patterns in Mykolaiv have undergone significant changes over the past century, influenced by both natural variability and anthropogenic factors. Historically, Mykolaiv, like much of southern Ukraine, has experienced a semi-arid climate with moderate precipitation levels. However, detailed analysis of historical models shows variations in annual precipitation.

During the early 20th century, Mykolaiv's precipitation was relatively stable, with average annual rainfall. However, data from the mid-20th century, particularly between 1950 and 1980, indicates a period of reduced rainfall, contributing to increased drought frequency in the region.

Recent data from the early 21st century suggest that precipitation patterns in Mykolaiv are becoming increasingly unpredictable. While some years have experienced above-average rainfall, others have been marked by significant deficits. This unpredictability is exacerbated by the ongoing effects of climate change, which are expected to increase the frequency and intensity of both droughts and heavy rainfall events in the region.

A study by the Ukrainian Hydrometeorological Institute indicates that average annual precipitation in Mykolaiv has slightly increased over the past two decades, yet the distribution of this rainfall has become more uneven, with longer dry spells interrupted by short periods of intense rainfall.

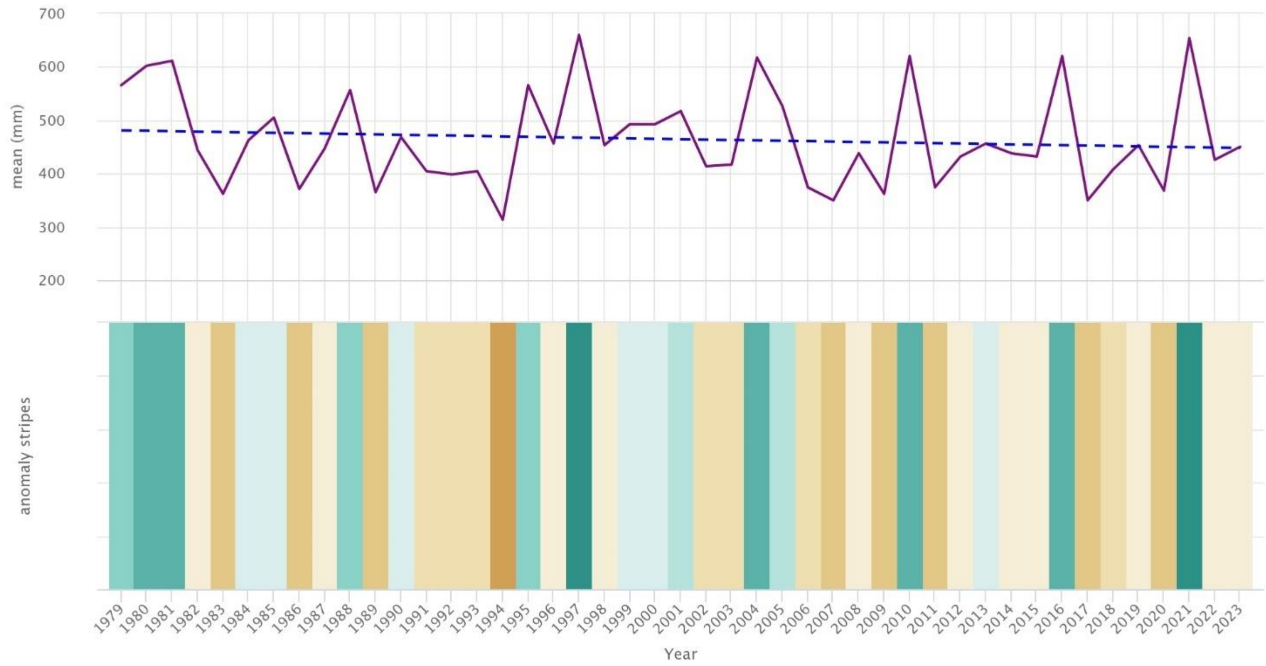

Figure 4-7: Yearly precipitation change in Mykolaiv, 1979-2023

The top graph shows an estimate of mean total precipitation for the larger region of Mykolaiv. The dashed blue line is the linear climate change trend. If the trend line is going up from left to right, the precipitation trend is positive and it is getting wetter in Mykolaiv due to climate change. If it is horizontal, no clear trend is seen and if it is going down conditions are becoming drier in Mykolaiv over time.

In the lower part the graph shows the so called precipitation stripes. Each coloured stripe represents the total precipitation of a year - green for wetter and brown for drier years.

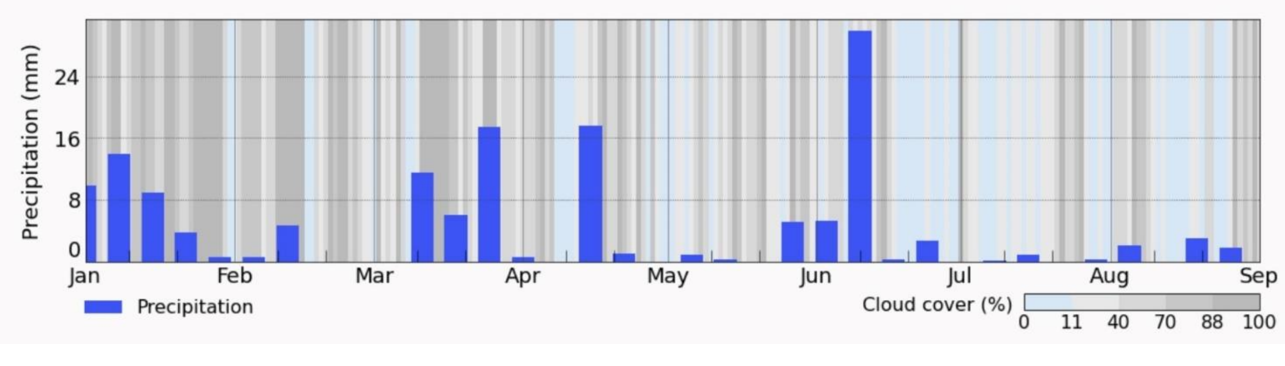

Figure 4-8: Amount of precipitation in Mykolaiv, 2024

4.2 Future precipitation projections

The total annual precipitation is projected to increase, while a decline is projected for the summer months in both the RCP 4.5 and RCP 8.5 scenario. The RCP 8.5 scenario shows high spatial variation within Ukraine. The southern areas will have a lower precipitation increase with a markable decrease during the warmer months and are projected to become dryer.

		Baseline	ssp126	ssp245	ssp370	ssp585
Annual mean precipitation anomaly (mm)	1991-2020	479				
	2020-2039		550	547	543	537
	2040-2059		541	531	521	518

Figure 4-9: Projected climate change for different scenarios derived from CMIP6 at the location of Mykolaiv. The data is obtained from the World Banks Climate Knowledge Portal. The anomaly is against the period 1995-2014. The values shown are the median of the model ensemble.

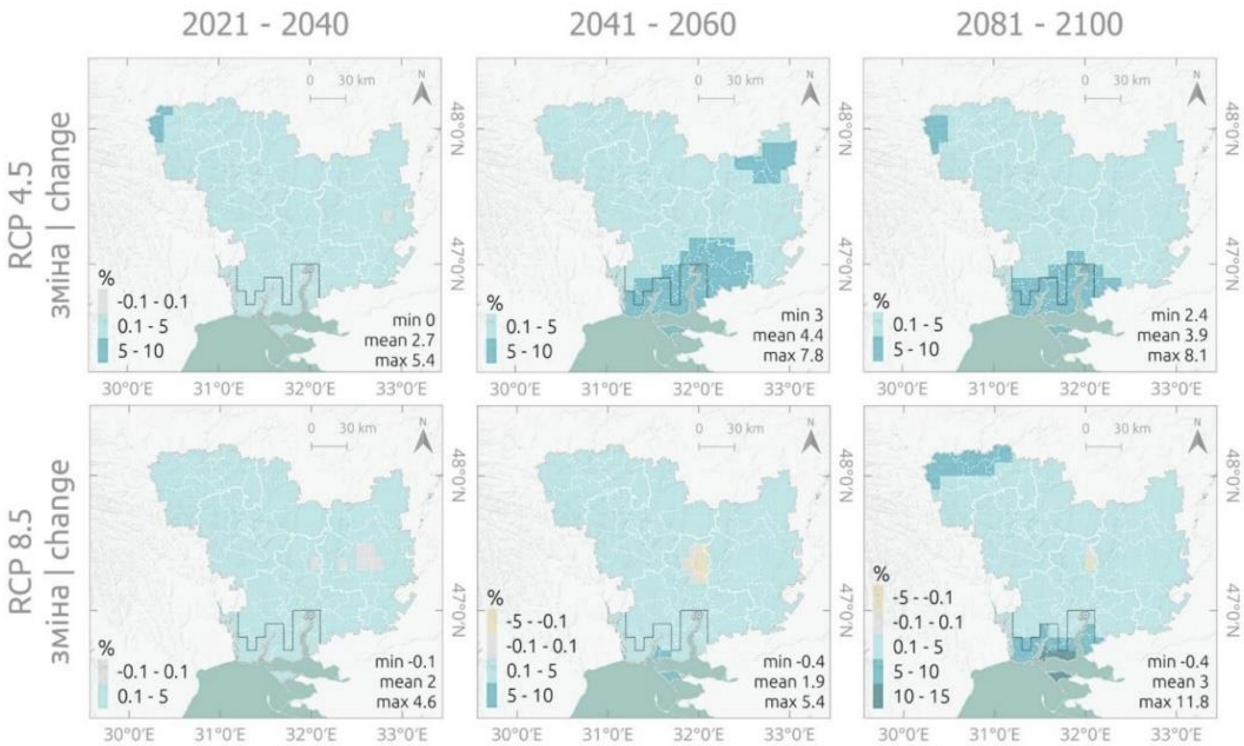

Figure 4-10: Annual precipitation in Mykolaiv, 2021-2100

5 Sea Level Rise

5.1 Sea level data

The Black Sea, along whose northern coast the Mykolaiv region is situated, has seen notable changes in sea level over the past century. Historically, the sea level in the Black Sea basin has been relatively stable with minor fluctuations caused by natural factors such as tectonic activity and changes in water inflow from rivers and precipitation. However, in the latter half of the 20th century, the global rise in sea levels, driven by climate change and the melting of polar ice caps, began to have an impact on the Black Sea region, including Mykolaiv region.

Between 1900 and 1950, the sea level rise in the Black Sea was minimal, averaging around 1-2 mm per year. However, from the 1960s onward, the rate of sea level rise began to accelerate, mirroring global trends. By the late 20th century, the sea level rise had increased to approximately 3-4 mm per year.

In the 21st century, the trend of rising sea levels has continued and even intensified. Recent observations indicate that the Black Sea's level is rising by an average of 3.5 mm per year, with some years witnessing even higher increases due to extreme weather events and climatic anomalies. The Mykolaiv region, being a coastal region, is particularly vulnerable to these changes.

5.2 Future projections of sea level rise

The changes in the Black Sea resulting from global warming and the associated rise in sea levels are influenced by the balance of freshwater in the sea basin (precipitation, evaporation, river discharge), air temperature, and wind patterns over the Black Sea. Additionally, changes in sea level in the northern part of the Aegean Sea, as well as temperature and salinity variations of the waters flowing into the Dardanelles from the Aegean Sea, are crucial factors. These factors are further compounded by the tectonic movements of the Earth's crust, whether subsidence or uplift.

According to the Representative Concentration Pathways (RCP) scenarios, by 2100 (relative to the period of 1986-2005), the following global sea level rise projections are expected:

- RCP2.6 (low emissions scenario): 0.4 m (mean) / 0.26-0.55 m (likely range)
- RCP4.5 (intermediate scenario): 0.47 m (mean) / 0.32-0.63 m (likely range)
- RCP6.0 (intermediate scenario): 0.48 m (mean) / 0.33-0.63 m (likely range)
- RCP8.5 (high emissions scenario): 0.63 m (mean) / 0.45-0.82 m (likely range)

In Ukraine, the Institute of Mathematical Machines and Systems Problems of the National Academy of Sciences has assessed the probable sea levels of the Black and Azov Seas for 2010-2100 based on the global IPCC climate change scenarios. The modeling was conducted under the RCP4.5 and RCP8.5 scenarios. The findings regarding sea level rise are as follows:

- The sea level changes (along with temperature and salinity) are heavily influenced by both the climatic changes in the Black Sea basin and the changes in the Mediterranean Sea, which in turn depend on global climate changes.

- A rise of 0.36 m and 0.46 m is expected by 2100 according to the RCP4.5 and RCP8.5 scenarios, respectively.

Thus, by 2100, the maximum projected global sea level rise is 0.82 meters under the high greenhouse gas emissions scenario. A representative study for the Black Sea indicates a sea level rise of 0.46 meters, which correlates with global estimates. Based on the principles of flood zone calculation, the maximum probable value of 0.82 meters has been adopted.

	ssp126		ssp245		ssp370		ssp585	
	Rate mm/yr	Sea level rise (m)	Rate (mm/yr)	Sea level rise (m)	Rate (mm/yr)	Sea level rise (m)	Rate (mm/yr)	Sea level rise (m)
2030	3.0	0.09	3.0	0.09	3.0	0.09	4.0	0.09
2050	4.0	0.17	5.0	0.18	5.0	0.19	5.0	0.20
2080	4.0	0.31	6.0	0.36	7.0	0.38	8.0	0.41

Figure 5-1: Projected Sea level rise at Mykolaiv (NASA's Sea Level Projection Tool)

6 Flooding Risks

6.1 Historical Flood Data

Flooding events in Mykolaiv region have been documented throughout history, primarily due to the region's geographical location near major rivers such as the Southern Buh and the Inhul. These rivers are prone to overflow during periods of heavy rainfall, snowmelt, or in the event of ice jams. Historical records indicate that significant floods have occurred periodically, with varying degrees of impact on the local population, infrastructure, and agriculture.

One of the earliest recorded floods in the Mykolaiv region occurred in the early 20th century, exacerbated by a combination of heavy rains and spring snowmelt. The floodwaters caused considerable damage to agricultural lands and disrupted transportation routes. In the mid-20th century, another major flood struck the region, leading to the destruction of numerous homes and necessitating large-scale evacuation efforts. The Southern Buh River, in particular, has been the source of several significant flooding events, with the most severe floods often occurring during the spring months when the river swells due to snowmelt from upstream areas.

In more recent history, Mykolaiv region experienced substantial flooding in 1997, when a combination of heavy rainfall and rapid snowmelt led to one of the most destructive floods in decades. This event resulted in widespread damage to both urban and rural areas, and prompted the implementation of new flood management and mitigation strategies by local authorities.

The last flood, caused by the destruction of the Kakhovka Hydroelectric Power Plant by russian occupiers on June 6, 2023, led to the flooding of 13 settlements in Mykolaiv region located near the Kherson region. In these settlements, 540 houses were completely submerged. Overall, around 4,000 households were affected, including areas that became inaccessible. A total of 680 people, including 123 children, were evacuated from the flooded areas. Since the flooding, one person has died.

6.2 Potential floods

Current trends indicate that the frequency and severity of flooding events in the region may be increasing due to the effects of climate change. Rising temperatures and changing precipitation patterns are contributing to more intense and unpredictable flood events, posing an ongoing threat to the region.

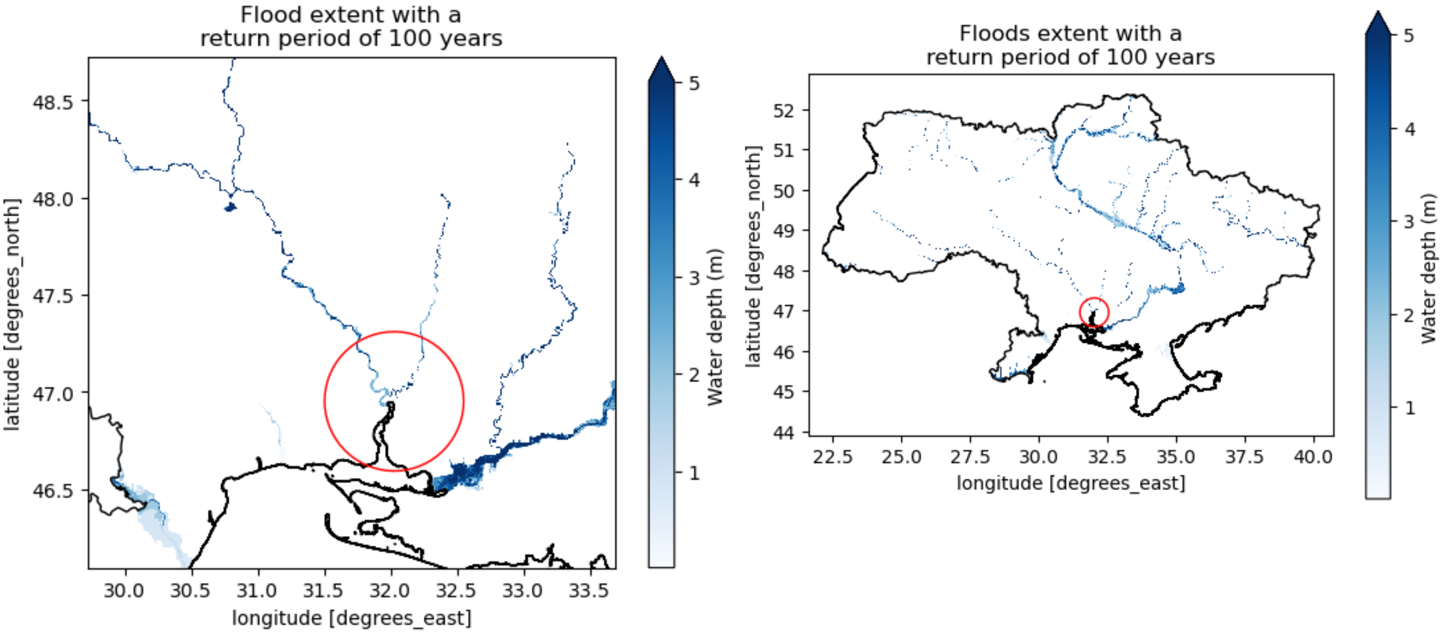

Figure 6-1: Flood extent with a return period of 100 years, shown for all of Ukraine (right) and Mykolaiv (left).

7 Impact of war on climate change

Unfortunately, the consequences of military actions will also affect the climate in Ukraine, particularly in the southern and eastern regions, and their ability to adapt. For instance, the destruction of the Kakhovka Hydroelectric Power Station and the loss of the Kakhovka Reservoir will lead to increased continentality of the climate, rising air temperatures in spring and early summer, and consequently, a shift in the onset of the warm period, summer, vegetation periods, and active vegetation periods, as well as changes in the thermal resources and duration of these periods.

The moisture regime of the surrounding areas may also change significantly. The most considerable changes are likely to occur in the spring-summer season, manifesting as a decrease in atmospheric moisture content, and consequently, a reduction in cloud cover and precipitation. This region falls within the risky farming zone of Ukraine. Rising air temperatures and increasing moisture deficits, compounded by global climate changes, could lead to increased aridity and desertification of significant areas in the region. The risk of dust storms, dry winds, and extreme fire hazards is expected to increase.

Green spaces also have a significant impact on the climate. They alter temperature and moisture regimes and reduce CO2 concentrations in the atmosphere. In the steppe regions of Ukraine, they also serve a protective function—shielding fields and settlements from dust storms. Thanks to the forest belts planted in these regions during the 1960s-70s, dangerous dust storms were successfully mitigated.

For over 30 years, no severe dust storms have been observed in this area. Currently, military actions are taking place in the forest belts and forests planted in these regions, with a significant portion already destroyed and more likely to be destroyed. Therefore, it can be predicted that another consequence of the war in Ukraine will be an increase in the frequency and intensity of dust storms, which will also affect Europe.

The characteristics of natural and anthropogenic environmental elements reflect the pre-war state of the environment in the Mykolaiv region. The reasons for the discrepancy between environmental elements and pre-war indicators include:

- Use of environmental elements as military targets;
- Damage to infrastructure: Essential infrastructures like water pipelines, treatment facilities, and power lines supplying ecologically important sites have been damaged;
- Damage to industrial facilities: The destruction of industrial sites has led to environmental degradation;
- Illegal extraction of natural resources;
- Harm to agricultural enterprises and lands.
- Damage to natural reserves and protected areas: Significant harm has been done to natural reserves and protected territories.
- Widespread fires: Large-scale fires have further degraded the environment.

Updating information on the natural and anthropogenic environment elements in the Mykolaiv region will become possible:

✓ After the cessation of military actions and the demining of the Mykolaiv region (including natural reserves and protected areas), followed by comprehensive scientific research on the environmental state;

✓ Following an assessment of the damage caused;

✓ After the resumption of the collection and dissemination of official state statistical information, provided that all regions of Ukraine receive complete administrative data.

8 Sectoral impacts of climate changes

The sensitivity of an economic sector or territory to climate change refers to the extent to which a system or object is affected by a negative or favorable impact of a climate indicator change. The key feature of sensitivity is that it is not dependent on the geographical location of the sector and is determined specifically by its nature.

The vulnerability of economic sectors and territories to changes in climatic indicators will depend not only on their sensitivity but also on the degree of impact from the change in the climatic factor. In this case, the geographical location of the sector and the projections based on scenarios of changes in climatic factors will be particularly important.

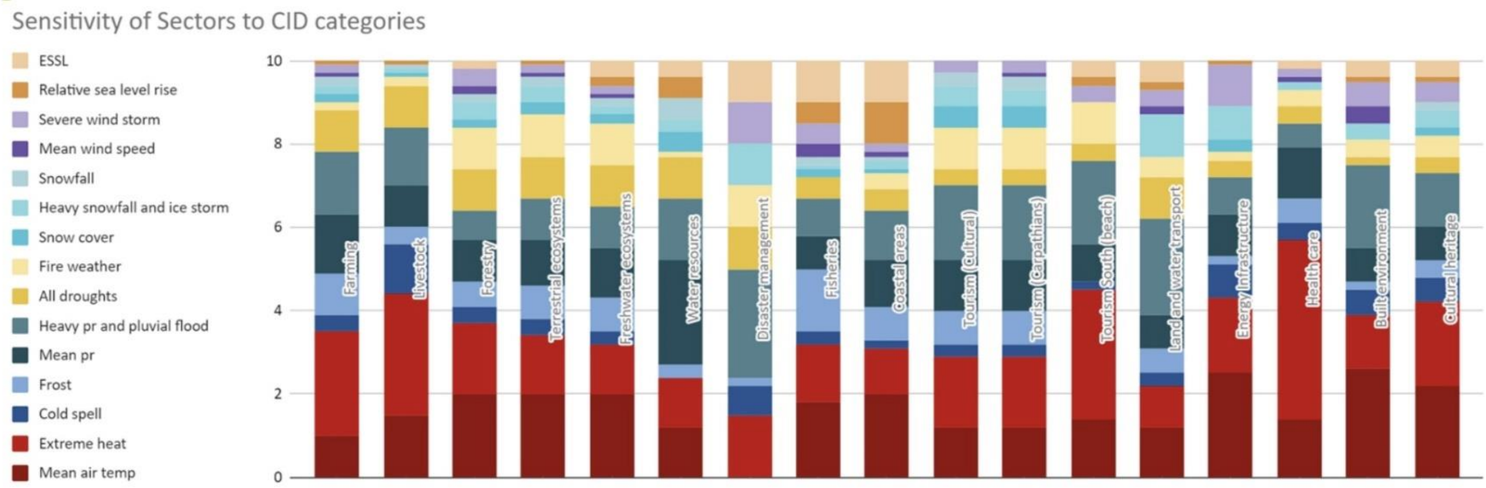

Figure 8-1: Sensitivity of economic sectors to categories of climatic factors

Agriculture

According to assessments, the agriculture sector is particularly sensitive to extreme heat, rising average air temperatures, and decreasing average precipitation, as well as to the increasing duration of droughts and the frequency of extreme rainfall events. Additionally, it is highly sensitive to an increase in frosts, which cannot be ruled out, especially in the near future. The sector is less sensitive to increasing fire hazards, wind gusts, and average wind speed, as well as the reduction of snow cover. Agriculture has low sensitivity to changes in other factors.

Overall, the vulnerability of the agriculture sector to climate change, under two scenarios and over three future periods, is represented on maps as a percentage of the maximum possible vulnerability, with a corresponding range from low (<20%) to very high (>50%).

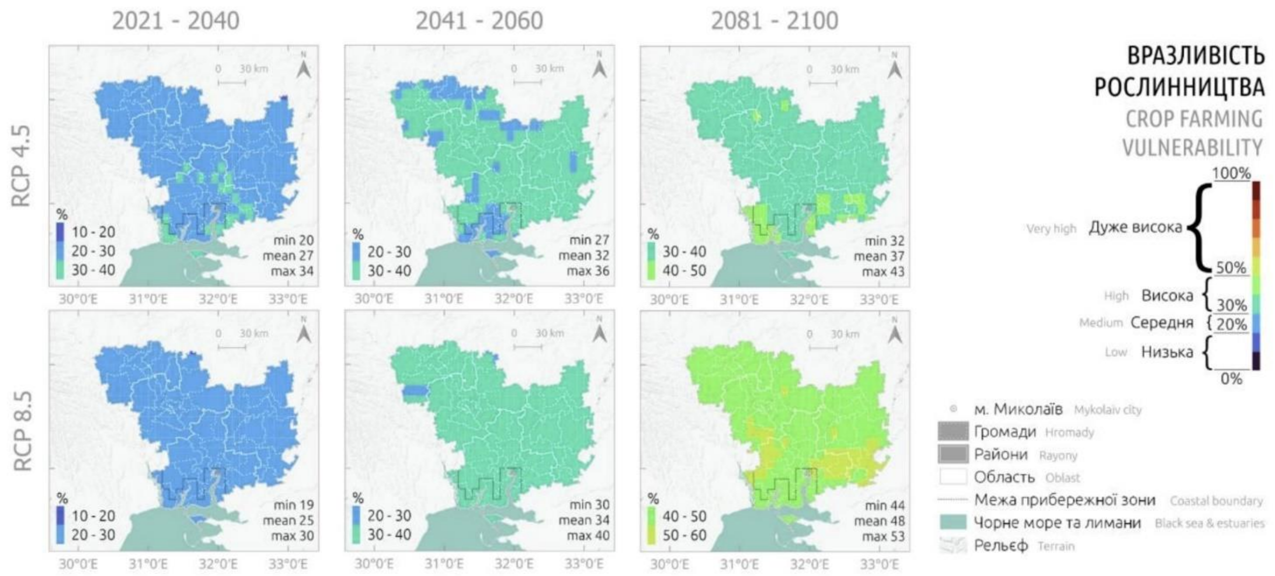

Figure 8-2: Crop farming vulnerability

In the near future (2021-2040), the agriculture sector in the Mykolaiv region will face high risks from increasing droughts and fire-prone weather according to the aggregated RCP scenarios. The next significant risk factor for the crop production sector in this region is the increase in extreme heat. During the 2021-2040 period, changes in extreme heat factors across the Mykolaiv region will predominantly lead to high risks for the crop production industry.

Additionally, the decrease in average precipitation during this period will result in somewhat uneven risks for the sector throughout the Mykolaiv region. By the mid-century (2041-2060), in certain communities located in the southeastern part of the region, the risks associated with the reduction in average precipitation will intensify and become significantly high.

The negative impacts of climate change in Ukraine, particularly the increased frequency and intensity of extreme weather events, include reduced soil fertility, decreased agricultural crop productivity, the need to develop and implement new varieties more resistant to droughts and high temperatures, and the expansion of irrigation practices.

There is an urgent need to address issues related to land degradation and desertification, restore anthropogenically altered ecosystems, improve the structure of agricultural land, and refine farming practices to create a balanced ratio between agricultural lands and ensure environmental safety and territorial equilibrium.

Water resources

Global climate changes have become increasingly noticeable for the region's water resources. According to estimates of possible changes in local water resources in Ukraine in the 21st century, a significant decrease in flow is expected in the lower reaches of the Southern Buh River, gradually reaching an average annual flow of 18.7 m^3/s by 2061-2080, compared to the current norm of 91.4 m^3/s. This reduction in flow is associated with warming and a decrease in atmospheric precipitation.

The water resources sector is expected to be most sensitive to changes in climate indicators related to moisture and aridity, particularly a reduction in average precipitation and droughts. The sector is also quite sensitive to increases in average and extreme warming indicators, the increase in downpours and rain floods, and slightly less sensitive to the reduction of snow cover and snowfall, as well as changes in coastal factors such as the relative rise in sea level.

Overall, the vulnerability of the water resources sector to climate change under two scenarios and in three future periods is presented on the maps below as a percentage of the maximum possible with corresponding divisions from low (<20%) to very high (>50%).

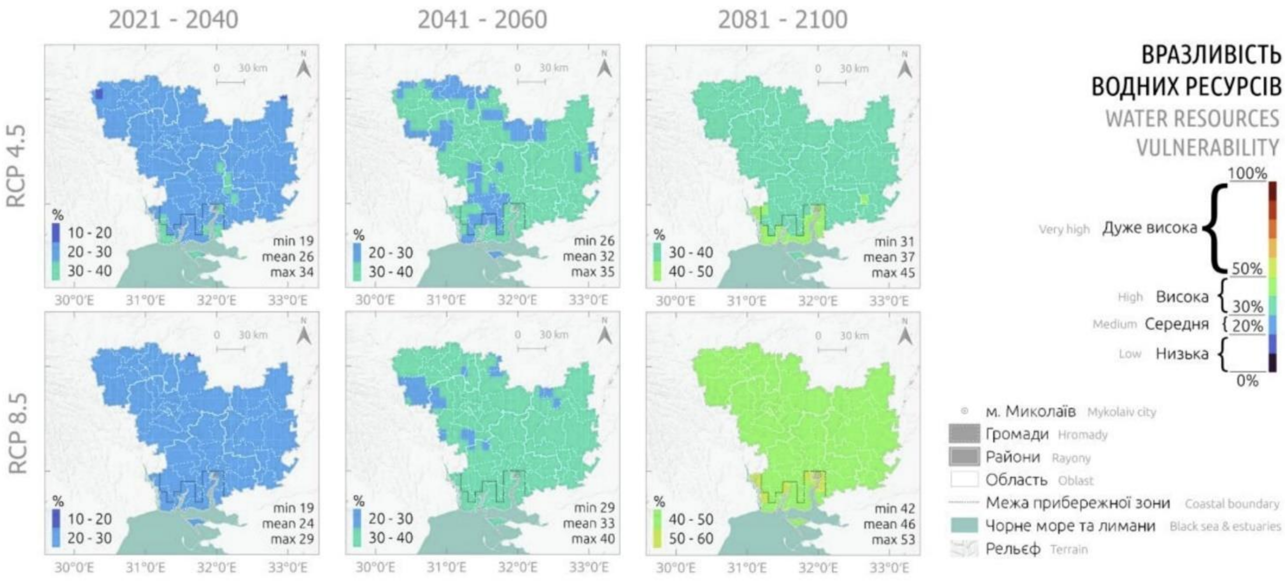

Figure 8-3: Water resources vulnerability

In addition to the impact of climate change on the water resources of the Mykolaiv region, significant damage has also been caused by the military actions resulting from the russian invasion. Russian forces have conducted numerous attacks, leading to the destruction of water supply infrastructure in the region. This has caused disruptions in water supply, contamination of water resources, and posed threats to public health. Specifically, main water pipelines supplying water to settlements have been damaged, severely limiting access to drinking water.

These damages exacerbate the region's vulnerability to climate change, particularly in the context of reduced water availability and increased risks associated with droughts and other extreme weather conditions.

Infrastructure

Climate change affects the physical infrastructure of the city - buildings, roads, waste water treatment and energy systems, and this, in turn, affects the way of life of its inhabitants and their prosperity.

The energy infrastructure is particularly sensitive to warming, including increases in average air temperature and extreme heat, as well as cold waves and frosts. Additionally, the sector shows high sensitivity to a decrease in average precipitation, the increase of droughts, and fire-prone weather conditions. The increase in wind gusts and wind speeds also poses significant risks to the energy infrastructure. Conversely, a reduction in snow cover and snowfall could have a somewhat positive impact on this sector.

Overall, the vulnerability of the energy infrastructure to climate change across two scenarios and three future periods is depicted in the maps, showing percentages from the maximum possible, with a corresponding range from low (<20%) to very high (>50%).

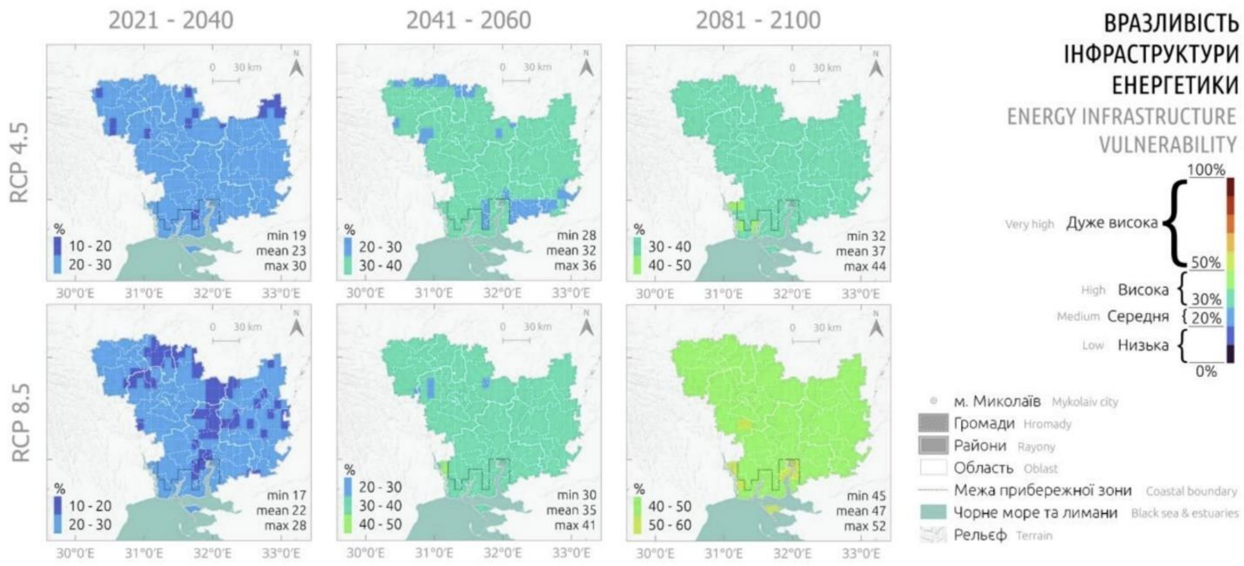

Figure 8-4: Energy infrastructure vulnerability

According to expert assessments, buildings are most sensitive to warming, which includes increases in average surface air temperature and extreme heat. The sensitivity is lower but still significant concerning changes in moisture/dryness indicators, specifically the increase in heavy rains and rain-induced floods, the decrease in average precipitation, and the rise in droughts and fire-prone weather conditions. The sector is also highly sensitive to the increase in wind gusts. A reduction in snow cover and snowfall is likely to have a positive impact on the building sector. The sensitivity of buildings to increases in cold waves and frosts, which cannot be excluded, especially in the near term, is also quite significant. Additionally, the vulnerability of buildings to sea-level rise and increased storm surges has been assessed at 0.7 points overall, and these coastal factors are particularly relevant for the Mykolaiv region.

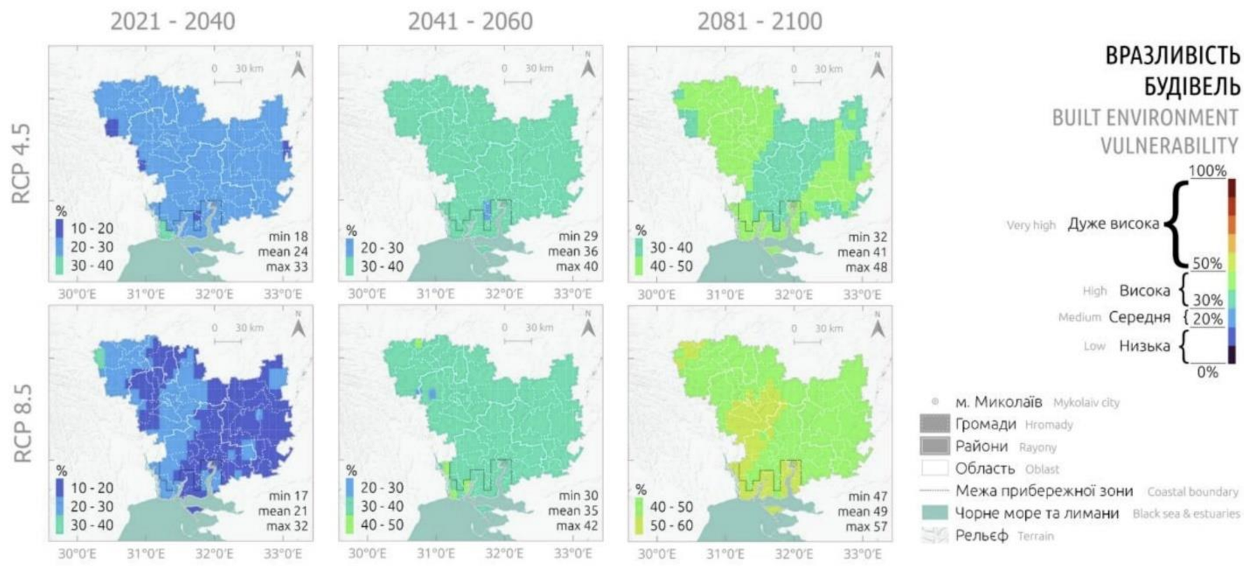

Figure 8-5: Built environment vulnerability

Human health

The health sector is most sensitive to increases in extreme heat and average air temperatures. The sector also has significant sensitivity, albeit to a lesser extent, to decreases in average precipitation, increases in droughts and fire-prone weather conditions, and to cold waves and frosts.

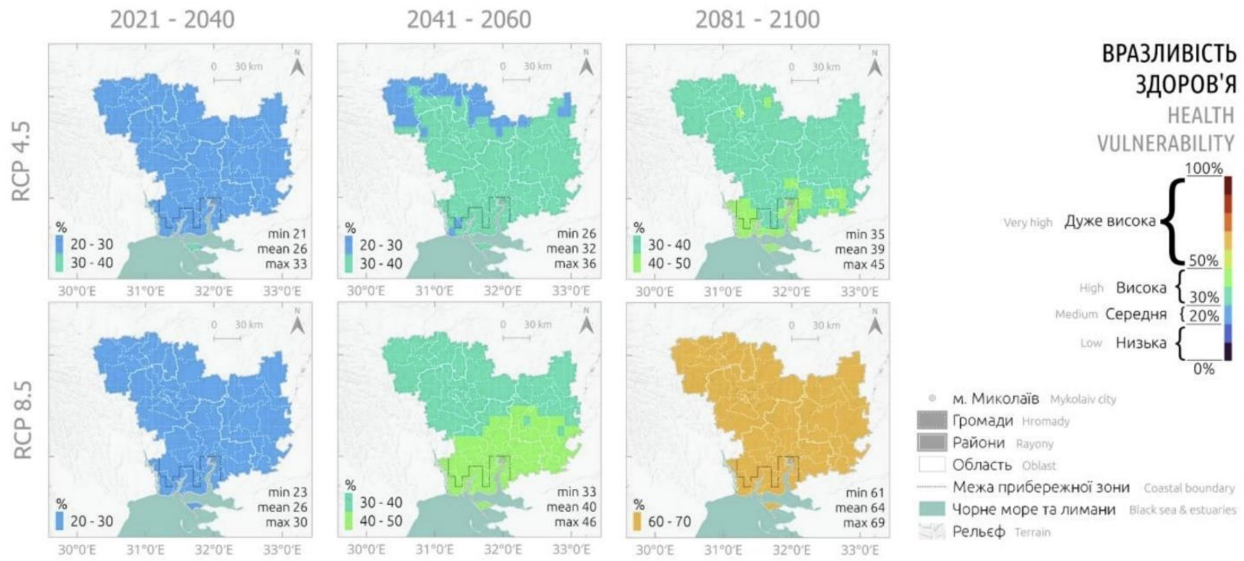

Figure 8-6: Health vulnerability

Climate change, rising air temperatures, sudden fluctuations in atmospheric pressure, and pollution of water sources, air, and soil contribute to the emergence of non-communicable diseases, the spread of infectious diseases, and the exacerbation of chronic conditions.

One of the consequences of the negative impact of climate change on the population is the creation of favorable ecological conditions for the development of vectors of transmissible diseases in different climatic and geographical regions of the country, leading to an increase in infectious diseases.

The rise in environmental temperatures and prolonged heat waves affect the production process, the supply of food products, and the deterioration of drinking water quality, which can result in cases of foodborne toxic infections.

Additionally, the prevalence of allergic diseases are expected to increase due to changes in the vegetation period of allergenic plants and the increased concentration of pollen in the air.

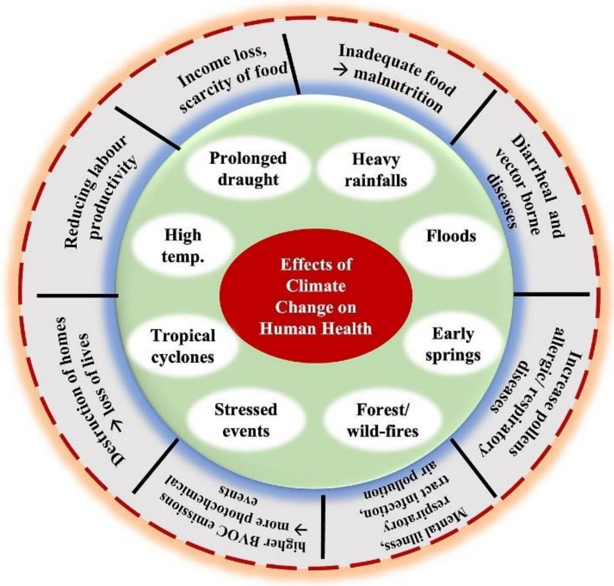

Figure 8-7: Illustration of the impact of climate change on human health

9 Climate change adaptation and mitigation

9.1 International climate cooperation

The Paris Agreement was signed at the UN International Climate Talks in 2015. Already a year later, the agreement entered into force - immediately after it was approved by 55 countries responsible for more than 55% of global greenhouse gas emissions. As of now, 194 countries have ratified or acceded the Paris Agreement. Ukraine was among the first twenty countries that approved the Agreement at the state level.

The main goal of the Paris Agreement is to keep global warming on Earth within 2°C and to make maximum efforts to stop warming at 1.5°C. This means that humanity must limit emissions of greenhouse gases, which are produced by burning fossil fuels and cause global warming.

In accordance with the Paris Agreement, the EU has raised its 2030 target and presented updated Nationally Determined Contributions to the UN Framework Convention on Climate Change, which was discussed in another of our articles. In implementing the Paris Agreement, the EU collaborates with international partners, encouraging and supporting the achievement of the highest goals and showing solidarity in the fight against the effects of climate change.

The Energy Community (Albania, Bosnia and Herzegovina, Kosovo, North Macedonia, Georgia, Moldova, Montenegro, Serbia, and Ukraine) has intensified its work on adopting the 2030 Energy and Climate Framework (in Ukraine, the Strategy for Environmental Safety and Climate Change Adaptation was adopted on October 20, 2021), a Decarbonization Roadmap, and Governance Regulation on renewable energy and energy efficiency.

To align its policies and legislation with the European Green Deal, Ukraine has initiated a targeted dialogue with the EU, leading to the creation of several programs ("Horizon Europe" in 2021-2027; Partnerships and Missions), reforms (the EU Common Agricultural Policy), strategies (on biodiversity; "From Farm to Fork"; on sustainable and intelligent mobility), etc.

9.2 Governance and local measures

The Cabinet of Ministers of Ukraine, by Decree No. 1363-r dated October 20, 2021, approved *the Strategy for Environmental Security and Climate Change Adaptation for the period until 2030* (hereinafter – the Strategy).

This Strategy was developed with the aim of enhancing environmental security and reducing the impacts and consequences of climate change in Ukraine.

The strategic goals include:

- Strengthening the adaptive capacity and resilience of social, economic, and environmental systems to climate change.

- Creating organizational prerequisites and scientific-methodological support for the implementation of state climate adaptation policy.
- Promoting the development and integration of climate change adaptation measures into national, regional, local, and sectoral policies, strategies, action plans, and risk management.
- Improving the education and awareness system, enhancing the knowledge of decision-makers, as well as human and institutional capacities for climate change mitigation, adaptation, impact reduction, and early warning.

The achievement of the objectives of state policy on environmental security and climate change adaptation will be carried out in two stages:

- By 2025, the goal is to stabilize the environmental situation by implementing European environmental norms and standards in areas such as industrial pollution, waste management, air quality, forest management, water resource management, biodiversity, and chemical safety (assessing the risks of socio-economic sectors and natural components to the effects of climate change, spreading environmental and climate knowledge, and increasing public environmental awareness and preparedness to respond to natural disasters caused by global climate change).

- By 2030, significant progress is expected in enhancing environmental security and adapting to the effects of climate change (ensuring continuous and timely environmental and climate monitoring, and fostering effective partnerships between the state, businesses, the public, and the scientific sector for environmental protection and low-carbon development.

The implementation of this Strategy is ensured by central and local executive authorities as well as local self-government bodies.

The Ministry of Environmental Protection and Natural Resources (Ministry of Environment) is responsible for organizational support, monitoring the implementation of the Strategy, and coordinating the activities of central and local executive authorities.

The implementation of the Strategy's provisions is expected to enhance environmental security and climate change adaptation in Ukraine.

Additionally, the *Operational plan* for the implementation of the Strategy for Environmental Safety and Climate Change Adaptation for the period until 2030 has been approved by the Decree for the years 2022-2024.

Mykolaiv was among the priority regions for the development of the *Climate Change Adaptation Strategy for Mykolaiv region.* The aim of this Strategy is to prioritize measures that support the adaptation of economic sectors and specific areas in the Mykolaiv region to climate change. The document consists of five sections, which include:

- Strategy objectives;
- Parameters of the natural and anthropogenic environment;

- Climate change analysis according to scenarios up to the end of the 21st century;
- Risk and vulnerability assessment of key economic sectors to climate change;
- Climate change adaptation measures.

Particular attention is given to the sectors of agriculture, forestry, water resources, critical infrastructure, healthcare, tourism, and cultural heritage. A total of 171 adaptation measures are proposed for implementation from 2024 to 2030.

Three main directions for climate change adaptation are proposed, with a total of six (6) horizontal resilience measures described as follows:

Action 1.1: Promoting Sustainable Development through Regional/Local Action Plans. This action includes the following measures:

- Measure 1.1.1: Support for districts and territorial communities in the region in the preparation and implementation of Sustainable Energy and Climate Action Plans.

- Measure 1.1.2: Provision of consultancy services for studies, including the assessment of large- and medium-scale project proposals addressing the impacts of climate change on infrastructure, environment, biodiversity, water resources, agriculture, flood risks, and inundations.

Action 1.2: Managing Risks from Climate Change and Extreme Weather Events. This action includes the following measures:

- Measure 1.2.1: Development of early warning systems for emergencies.

- Measure 1.2.2: Measures to enhance the staffing and material resources of the Operational Rescue Service for Civil Protection units in the Mykolaiv region.

Action 1.3: Monitoring the Implementation of the Climate Change Adaptation Strategy and Implementation Plan. This action includes the following measures:

- Measure 1.3.1: Establishment and staffing of a climate change department within the structure of the Mykolaiv Regional State Administration, with responsibilities including monitoring the implementation of the Plan. It is proposed to involve experts from universities and scientific institutions in the region to support the department's monitoring objectives.

- Measure 1.3.2: For monitoring and implementation purposes, support universities and research institutions in the Mykolaiv region in order to us the outcomes of their scientific research activities (e.g., research projects, PhD theses, bachelor's and master's dissertations).

Due to fruitful cooperation with the Mykolaiv Regional Hydrometeorological Center and the Civil Protection Department of the Mykolaiv Regional Military Administration, the analyticaldispatch center of the office receives hydrometeorological, hydrological bulletins, water flow forecasts, storm warnings, and reports on the state of natural safety.

The agreed Instruction on the procedure for interaction and mutual information of the Main Department of the State Emergency Service of Ukraine in the Mykolaiv region and the Regional Office of Water Resources in the Mykolaiv region in the event of emergency situations (events) is in effect.

Besides, the city of Mykolaiv has made a commitment to the Making Cities Resilient 2030 initiative, as Mykolaiv is a partner in the Horizon project under the EU-UKRAINE-PACT program together with the Nordic Institute for Urban Resilience (Sweden). They are currently under contract with the United Nations Office for Disaster Risk Reduction to help us join the Making Cities Resilient 2030 initiative and conduct an assessment against a specific resilience scorecard. By participating in the initiative, the city commits:

1. to apply the "Ten Essentials of the Making Cities Resilient Initiative", raise awareness and understanding of resilience and disaster risk reduction among city officials and the general public;

2. to develop or improve the strategy of resilience and disaster risk reduction based on development plans to promote risk awareness with a clear monitoring and evaluation plan;

3. to implement and support specific resilience and disaster risk reduction measures on the basis of structural units of the city council; integrate and institutionalize resilience and measures in all urban areas develop a portfolio of projects that can be funded.

In the context of climate change, increasing risks of natural disasters and man-made disasters caused by russia's military aggression, the issue of developing a municipal office for decarbonization and energy efficiency, which is designed to help the community implement energy efficiency measures to accelerate the green transformation in all spheres of life and increase urban resilience.

Within the framework of the work of this decarbonization office, in the direction of increasing urban resilience, a set of measures is proposed, namely:

1) "Mykolaiv Clean Air" - Installation of Air Fresh Max - air quality monitoring stations in three key locations, in remote areas of the city, in different directions, which will allow monitoring and recording the state of the ambient air.

2) "Monitoring of two rivers" - Mykolaiv is a peninsula in terms of geographical location, and is washed by two rivers - Ingul and Southern Buh. River water quality monitoring stations in two key locations, in remote areas of the city located on opposite sides of the world, which will allow monitoring and recording of river water quality are proposed to be installed.

10 Conclusion

The assessment of climate change impacts and responses across the various sections highlights the multifaceted nature of climate risks and the diverse strategies employed to address them. From Chapter 2 to Chapter 9, it is evident that climate change poses significant challenges to environmental, economic, and social systems, necessitating a comprehensive and coordinated approach to adaptation and mitigation.

Climate change affects multiple sectors, each with its unique vulnerabilities and needs. Agriculture is particularly sensitive to shifts in temperature and precipitation, requiring innovative adaptation strategies to maintain productivity and sustainability. Water resources are increasingly threatened by changes in availability and quality, exacerbated by contamination and reduced flow. Infrastructure and public health systems are under pressure from extreme weather events and rising temperatures, highlighting the need for resilience-building measures.

International efforts, such as those outlined in the Paris Agreement, play a crucial role in guiding global climate action. Ukraine’s commitment to these international frameworks is reflected in its national strategies and policies, which aim to enhance environmental security and climate resilience. The Strategy for Environmental Security and Climate Change Adaptation establishes a clear roadmap for integrating climate considerations into national and regional policies, with specific goals for 2025 and 2030.

Local initiatives, such as the Mykolaiv Climate Change Adaptation Strategy, underscore the importance of regional and localized actions in managing climate risks. These strategies prioritize sectors most vulnerable to climate impacts and outline specific measures to address these challenges, including improved infrastructure, early warning systems, and enhanced monitoring capabilities.

To effectively address the challenges posed by climate change, it is essential to continue enhancing sectoral resilience through targeted adaptation measures. Upgrading and repairing critical infrastructure to withstand climate impacts is a priority, as is supporting local climate action plans and initiatives. Active participation in international climate agreements and collaboration with global partners will further strengthen efforts to mitigate and adapt to climate change.

Overall, the comprehensive approach detailed in these sections reflects a robust commitment to addressing climate risks and building resilience across all sectors, ensuring a coordinated and effective response to the challenges posed by climate change.

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