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ENVIRONMENTAL ISSUES OF ZAKARPATTIA

Manual

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Manual

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The manual contains scientific materials devoted to the coverage of contemporary environmental issues of Zakarpattia. Considerable attention is paid to the peculiarities of its natural conditions. Emphasis is placed on the preservation of biodiversity in the face of climate change. While devising this textbook, the authors resorted to the analysis of literary sources as well as the findings of their own research. It will benefit school teachers, students and postgraduates of higher educational institutions majoring in natural sciences, employees of the nature reserve fund, and representatives of the authorities.

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More information on the project is available on the links below:
https://idcr.info/current-project.php?id=11&lang=en
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CONTENTS

1.4. CHARACTERISTICS OF CURRENT CLIMATIC CONDITIONS AND CLIMATE CHANGE MANIFESTATIONS *(R. Ozymko, M. Karabiniuk)*

The climate is a long-term weather pattern derived from extended meteorological observations and serves as a fundamental geographical characteristic of a specific region (International Meteorological..., 1992). The climate of the Zakarpattia Region, akin to any other part of the planet, arises through the intricate interplay of factors such as radiation conditions, atmospheric circulation, and the underlying surface.

In accordance with one of the most widely employed Köppen-Geiger climate classification systems, Zakarpattia is categorised as Dfb (indicating a humid temperate continental climate with warm summers) (Fig. 1.4.1) (Peel et al..., 2007).

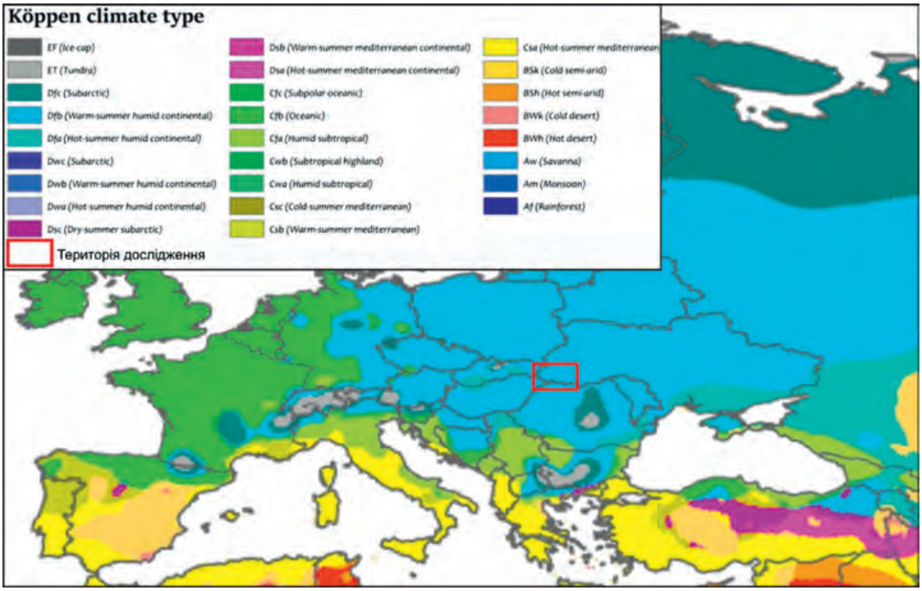

Fig. 1.4.1. Distribution of Europe's Territory According to Köppen-Geiger Climate Classification (Peel et al..., 2007)

The climate of Zakarpattia Region shares many similarities with that of Hungary, Slovakia, Romania, Poland, the Czech Republic, and the northern part of the Balkan Peninsula, and this resemblance is primarily shaped by the overarching atmospheric circulation patterns across Europe. The meteorological dynamics over the territory of Zakarpattia Region are generally influenced by atmospheric processes originating from the Atlantic and Eurasian regions. The key climatological centres of atmospheric influence (Stepanenko et al., 2015) that dictate this circulation include:

1. The Icelandic baric depression.
2. The Arctic anticyclone.
3. The Mediterranean baric depression.
4. The Azores anticyclone.

The Siberian winter anticyclone, with its extensions occasionally reaching the lowlands of Zakarpattia Region.

The interplay between these baric centres induces the transformation of air masses. During the winter season, the majority of cyclones originate from the Atlantic and Mediterranean regions and advance towards Zakarpattia Region. These cyclones tend to be deep and frequently bring about conditions such as ice, thaws, snowmelt, heavy rains, and often lead to winter floods in Zakarpattia and neighbouring areas (National Report..., 2012).

Another notable winter-related process is the eastern influence associated with the reinforcement of the anticyclone situated in the eastern part of the Eastern European Plain. On occasion, Zakarpattia Region experiences the impact of polar-origin anticyclones, which introduce cold air masses from the Arctic. The intrusion of Arctic air masses typically occurs in the rear section of cyclones, where intermediate or ultimate anticyclones take form. Such occurrences are associated with severe winters, which have become increasingly rare over the past two decades.

In spring, the Azores anticyclone gains strength as its extensions and cores reach Europe. This period witnesses a reduction in the frequency of western cyclones, with southern and southwestern cyclones making their way towards Poland or Belarus (Climate of Ukraine..., 2003). As summer arrives, advective processes weaken, while the significance of radiation and local factors grows. The Azores anticyclone experiences significant development, gradually expanding eastward. This influx of tropical air masses results in hot and dry weather conditions within the core of the Azores High. By autumn, the Azores anticyclone weakens, still retaining some influence during the early part of the season. Eventually, it diminishes, giving way to the growing impact of the Siberian High. This transition is accompanied by an upsurge in the frequency of western and southern cyclones (Sakali et al., 1985).

In summary, the weather patterns in Zakarpattia Region are predominantly shaped by the alternating effects of the Azores and Siberian anticyclones, along with the movement of cyclones from the Atlantic and Mediterranean regions. Despite the frequent presence of anticyclones and the associated continental influences, Zakarpattia's climate is milder compared to central and eastern Ukraine. This can be attributed to the fact that Zakarpattia Oblast is exclusively situated on the southwestern macro-slope of the Ukrainian Carpathians, whose watershed ridges provide a protective barrier against the incursion of cold and dry Arctic air masses from the north during winter. The climate of Zakarpattia Region displays remarkable diversity, characterised by warm, protracted summers and mild winters with frequent thaw periods.

Another highly significant factor in shaping the climate is the land surface, encompassing the Earth's surface composed of soil, water, snow, and artificially created surfaces. This land surface engages in interactions with the atmosphere, influencing the exchange of heat and moisture and serving as a source of dust and condensation nuclei for the atmosphere. The attribute describing the unevenness of the underlying surface and its impact on the movement of air in the surface layer is referred to as "roughness" (International Meteorological..., 1992). The Carpathian Mountains wield a substantial influence over the climate in the Zakarpattia Region. This mountain range serves to weaken and alter the direction of air mass movement, simultaneously effecting transformations in the primary climatic characteristics of these air masses (Climate of Uzhhorod..., 1991). The prevailing wind patterns are contingent on the intricacies of the orography, river valley orientations, and mountain ranges. Consequently, mountain-valley winds are quite distinct in Zakarpattia, particularly during the warmer months. In addition to these, the region experiences föhn winds, though they are less prominent. These winds periodically move from the ridges to the valleys, ascending to higher altitudes where they cool and subsequently descend as heavier air masses, warming up considerably as they travel down the slopes towards the valleys. This results in the occurrence of a dry, warm wind (Ukrainian Carpathians..., 1988).

The Carpathians also exert a substantial influence on cyclogenesis, thus impacting the regional climate. As a cyclone approaches the mountain range, primarily its frontal section, there is an increase in atmospheric pressure due to flow convergence within the foothill areas. Subsequently, as the cyclone proceeds, concurrently with the rise in pressure on the windward side of the ridge, there is a decrease on the leeward side. This leads to the formation of two centres of reduced pressure, one on the windward macroslope and the other on the leeward side. The centre on the windward macroslope gradually fills, while the one on the leeward slope deepens and shifts eastward. This phenomenon in the evolution of cyclones is termed "segmentation" (Sakali et al., 1985).

Roughly one third of cyclones traversing the Carpathians from the western and southwestern directions undergo segmentation, with younger cyclones being particularly susceptible. This segmentation process, attributed to the mountain's impeding influence, is a primary reason Transcarpathia receives a notable amount of precipitation in comparison to other regions of Ukraine. Cyclones arriving from the west and southwest essentially discharge their precipitation, moisture, and heat over the region, contributing to the comparatively milder climate of Zakarpattia. This phenomenon stands in contrast to the region's high occurrence of anticyclones and the resultant continental influence (Climate of Ukraine..., 2003).

The intricate orography of the Zakarpattia Region gives rise to a “mosaic” climate, or topoclimates (mesoclimates), which are climates shaped by local factors such as relief, vegetation, water conditions, and others (International Meteorological..., 1992). The fundamental characteristics of the region's climate are dictated by the distinct patterns in the annual course of the primary meteorological elements, including temperature, precipitation, atmospheric pressure, wind, and more, and their spatial distribution.

The temperature regime takes shape under the influence of various factors, including the radiation regime, atmospheric circulation, and the characteristics of the underlying surface. Within the region, a complex distribution of air temperatures prevails, largely attributable to the challenging orographic conditions. In the mountainous segment of the region, air temperature changes are observed as altitude increases, with an average annual vertical temperature gradient ranging from 0.76 to 0.86 °C per 100 m of elevation. The altitudinal zonation of climatic conditions exhibits significant variations during different periods and seasons. Consequently, in winter, the temperature gradient is within the range of 0.4 to 0.7 °C, while in summer, it is notably higher, spanning from 1.0 to 1.1 °C (Climate of Ukraine..., 2003). As a result of the active inflow of cold air masses into river valleys and hollows from mountain peaks and ridges, the temperatures in these elevated areas can surpass those at lower hypsometric levels. These temperature inversions can persist for several days and are a characteristic feature during the winter period.

One of the primary indicators of the thermal regime is the average monthly air temperature, which is the arithmetic mean of the air temperature for the month, derived from the average daily values (International Meteorological..., 1992). Data regarding the average monthly air temperature regime serves as a valuable tool for addressing a wide range of practical and theoretical challenges. The annual fluctuations in the average monthly temperature closely align with the annual fluctuations in solar radiation.

The average temperature in January varies from -0.7 °C (Berehove) in the lowlands to -6.1 °C (Plai) in the mountains. In March, the average temperature turns positive in the foothill and lowland regions, ranging from +3.8 to +5.9 °C, while in the mountains, it varies from +0.6 to +2.8 °C, and in the highlands, it remains negative at -2.8 °C. During April and May, there is a significant increase in temperature: in the lowlands, temperatures range from +11.5 to +16.6 °C, and in the highlands, they range from +3.1 to +8.1 °C. The highest average monthly temperatures are experienced in

July and August: in the lowlands, temperatures reach +21.0 to +21.9 °C, in the mountains, they range from +16.2 to +18.6 °C, and in the highlands, temperatures hover between +13.2 and +13.4 °C (Fig. 1.4.2). Starting in September, a decline in air temperature is observed. The winter regime takes hold in lowland areas during the second decade of December and in the mountains, it sets in during the third decade of November (Climatological Standard Norms..., 2021).

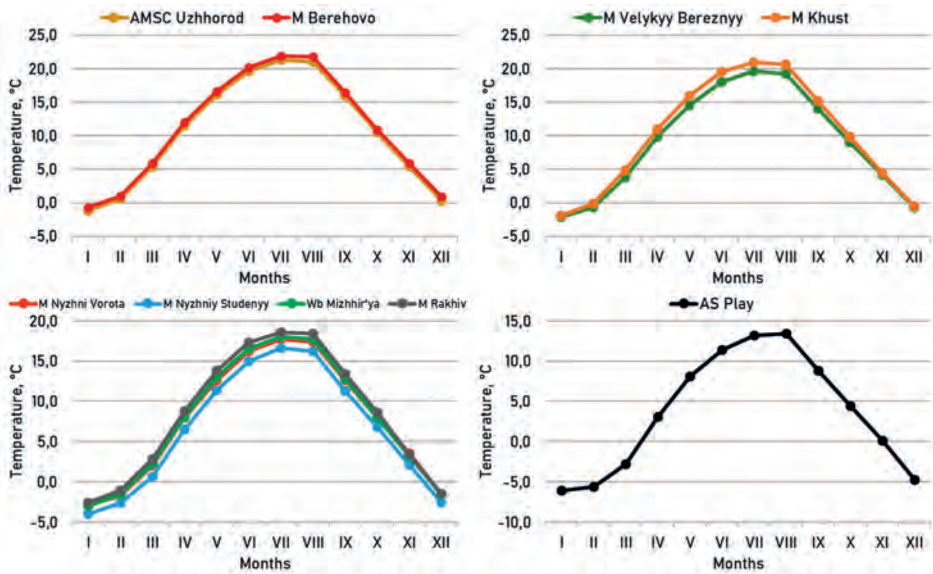

Fig. 1.4.2. Graphs of average monthly air temperatures according to weather stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

In the foothill and lowland regions of the area, the average annual temperatures are relatively high, ranging from +9.1 to +11.1 °C, while in the mountains, they range from +6.4 to +8.3 °C. On the exposed peaks at elevations of 1200-1400 metres above sea level, the average annual temperature is approximately +3.6 °C. The absolute maximum air temperature recorded in lowland and foothill areas stands at +38.6 °C (Berehove and Uzhhorod), in the mountains, it reaches +36.3 °C (Rakhiv), and in the highlands, it is +26.9°C (Plai). On the other end of the spectrum, the absolute minimum air temperature noted in lowland and foothill regions is -32.5 °C (Berehove), in the mountains, it drops to -31.6 °C (Nyzhni Vorota), and in the highlands, it registers at -27.6 °C (Climatological Standard Norms..., 2021).

In the lowland areas of Zakarpattia Region, the average daily temperature reaches +15 to +20 °C for 80 days per year. For a period of more than 1 to 1.5 months annually, temperatures surpass +20 to +25°C. In the mountainous region, these average daily temperatures are experienced for only 1 to 2 days during the summer. In the mountains, average daily temperatures ranging from +10 to +15 °C are recorded for 83 days each year (Climatological Standard Norms..., 2021).

The growing season, defined by average daily air temperatures at or above +5 °C, extends for 229-241 days in lowland and foothill regions, typically commencing between 17-25 March and concluding between 9-14 November. In mountain valleys, the growing season spans 198-219 days, typically starting from 29 March to 11 April and ending between 26 October to 3 November. The cumulative positive air temperatures above +5 °C during this period range from 3100 °C in the foothills to 3640 °C in the lowlands, and from 2340 to 2880 °C in mountainous areas (Agricultural Climate Handbook..., 2013).

The period of active crop vegetation, characterised by average daily air temperatures of +10 °C and above, typically lasts for 174-192 days in lowland and foothill regions, with a usual onset between 13-18 April and termination between 9-13 November. In mountainous areas, this period spans 140-170 days, commencing from 24 April to 8 May and ending between 25 September to 11 October. The sum of positive air temperatures above +10 °C during this period ranges from 2700 °C in the foothills to 3240 °C in the lowlands, and from 1920 °C to 2540 °C in mountainous areas (Agricultural and Climatic Handbook..., 2013).

The second most critical climatic characteristic is precipitation. The annual average precipitation in Zakarpattia Region varies significantly, ranging from 650 to 1500 mm. This considerable discrepancy can be attributed to the presence of mountains, which induce orographic uplift of air masses leading to subsequent cloud formation. Precipitation is distributed quite unevenly across the region. In lowland areas, the average annual precipitation amounts to 650-750 mm, in foothill areas, it ranges from 850-1050 mm, and in high mountain ranges and mountain valleys, it can reach up to 1500 mm (Climatological Standard Norms..., 2021).

In general, the region receives 250-600 mm of precipitation during the cold season (November-March) and 400-900 mm during the warm season (April-October). The winter months exhibit minimal variation in terms of precipitation, with February predominantly registering the lowest amounts (45-100 mm) (Figure 1.4.3). In lowland and foothill areas, March experiences relatively low precipitation (40-75 mm). In April, there is the lowest amount of precipitation throughout the year, with 40-60 mm in lowland and foothill areas, 65-85 mm in the mountains, and 90 mm in the highlands (Plai). Precipitation then rapidly increases in May, reaching its peak in June and July (70-170 mm). In some years, this maximum occurs in other months. For instance, in June 1960, Uzhhorod recorded 242 mm of precipitation, and in October 1974, it reached 288 mm, which represents 355-480 % of the monthly precipitation norm. By August, the amount of precipitation decreases significantly to 55-100 mm and then experiences a slight increase towards the end of the year, ranging from 50-140 mm (Climatological Standard Norms..., 2021).

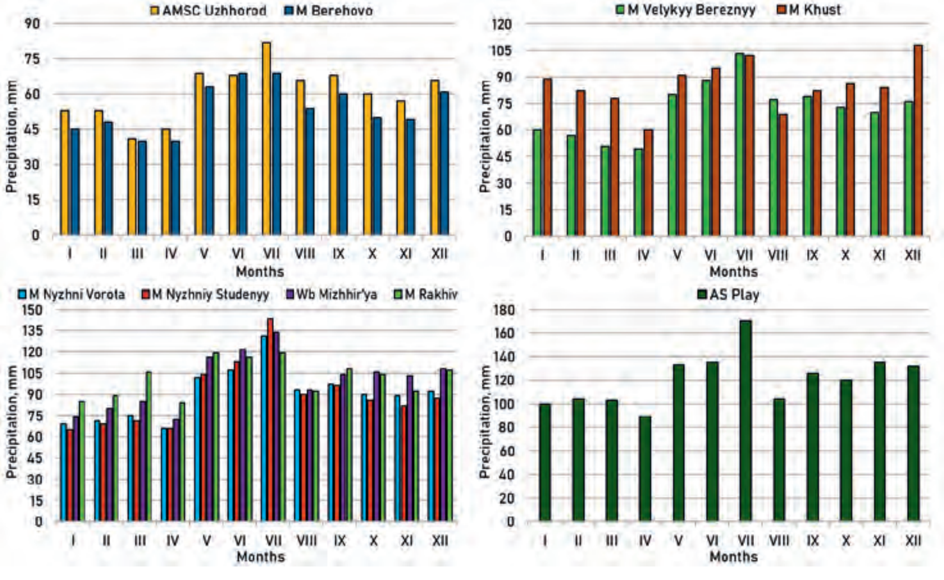

Fig. 1.4.3. Diagrams of the average monthly precipitation according to the data of meteorological stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

Significant fluctuations in precipitation are observed both between years and, in certain years, among months. On average, there are 135-154 days per year with precipitation of ≥0.1 mm in the lowland and foothill regions, 170-191 days in the mountains, and 194 days in the highlands. However, when considering a threshold of ≥5 mm of precipitation, the average annual number of days decreases markedly. In lowland and foothill areas, it amounts to 42-63 days, in the mountains it falls within the range of 66-73 days, and in the highlands, it reaches 86 days (Climatological Standard Norms..., 2021).

Another crucial climatic indicator is the daily precipitation, which provides insights into the soil's moisture saturation, the frequency of hazardous meteorological events related to precipitation, and more. Over the course of a year, the lowest average daily precipitation is typically observed in January, ranging from 3-6 mm. In contrast, the highest daily precipitation occurs in July and August during intense heavy rains, averaging between 7-11 mm (Fig. 1.4.4). To illustrate, on June 26, 2016, at the hydrological station Luhy in Rakhiv district, a remarkable 89.7 mm of rain fell within 1 hour and 30 minutes, equivalent to 77 % of Rakhiv's monthly precipitation norm. Similarly, at the avalanche station Play on August 12, 2014, 100.0 mm of rain was recorded over a 9-hour period, amounting to 96% of the monthly precipitation norm. The absolute daily maximum precipitation in Zakarpattia Region was documented from 1000 to 0600 UTC on November 4-5, 1998, in Ruska Mokra (Tiachiv raion), where an astounding 157 mm of rain fell (Climatological Standard Norms..., 2021).

Relative humidity, alongside temperature and precipitation, represents one of the fundamental climate attributes. It quantifies the degree of air moisture saturation at a given temperature, expressed as a percentage, making it a valuable indicator of climate "dryness" (International Meteorological..., 1992). The distinctive features of the region's physical and geographical positioning, its topography, a significant proportion of forested areas, and other contributing factors contribute to elevated air humidity in Zakarpattia Region (Fig. 1.4.5).

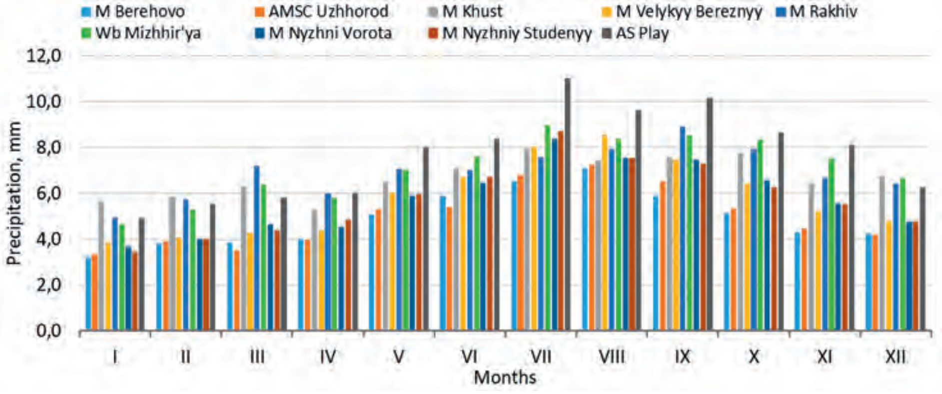

Fig. 1.4.4. Diagram of the average daily precipitation according to the data of weather stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

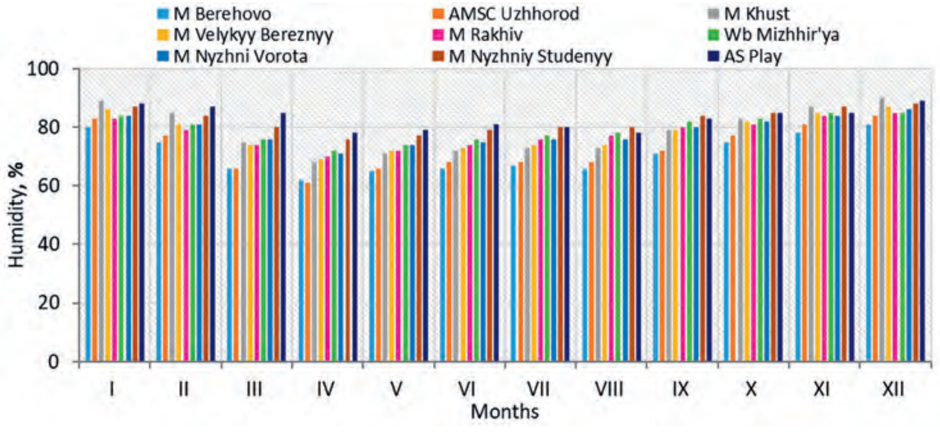

Fig. 1.4.5. Diagram of the average relative humidity according to the data of weather stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

The highest relative humidity levels (75-90 %) occur during winter, while the lowest (60-80 %) are experienced in spring. Throughout the year, relative humidity exhibits relatively consistent values without significant peaks or troughs. In the lowland regions of the area, the annual average relative humidity hovers around 70%, while in the mountains, it reaches approximately 80 %. Occasions when relative humidity falls to 30 % and below are classified as "dry days". On average, the region witnesses 10-12 such dry days annually. April sees the most dry days, typically numbering 3-4, followed by 1-2 dry days in May (Climatological Standard Norms..., 2021).

Wind represents the third primary climate attribute, following air temperature and precipitation. At meteorological stations, wind is characterised as the horizontal movement of air in relation to the earth's surface and is quantified in metres per second (m/s). Wind direction is determined using a 16-degree angular system spanning from 0 to 360°. The direction and speed of the wind are contingent on the seasonal dispersion of baric systems and the interplay between them. In the lowland regions of Zakarpattia Region, south and southeast winds prevail significantly, while in the foothills, north and northwest winds are dominant. In the mountains, north and south winds prevail, and on exposed summits, the southwest wind is prevalent (Fig. 1.4.6).

The wind regime is heavily influenced by the underlying surface, specifically the topography of the region, which significantly distorts the horizontal movement of air. Most meteorological stations are situated in deep, sheltered mountain valleys, and their data solely represent the local wind patterns, failing to provide a comprehensive overview of wind distribution across the region. For instance, in areas such as Mizhhiria, Nyzhni Vorota, and Nyzhniy Studenyi, the predominant north and south wind directions align with the meridional orientation of the valleys of the Rika, Studenyi, and Latorytsia rivers, where the meteorological stations are positioned.

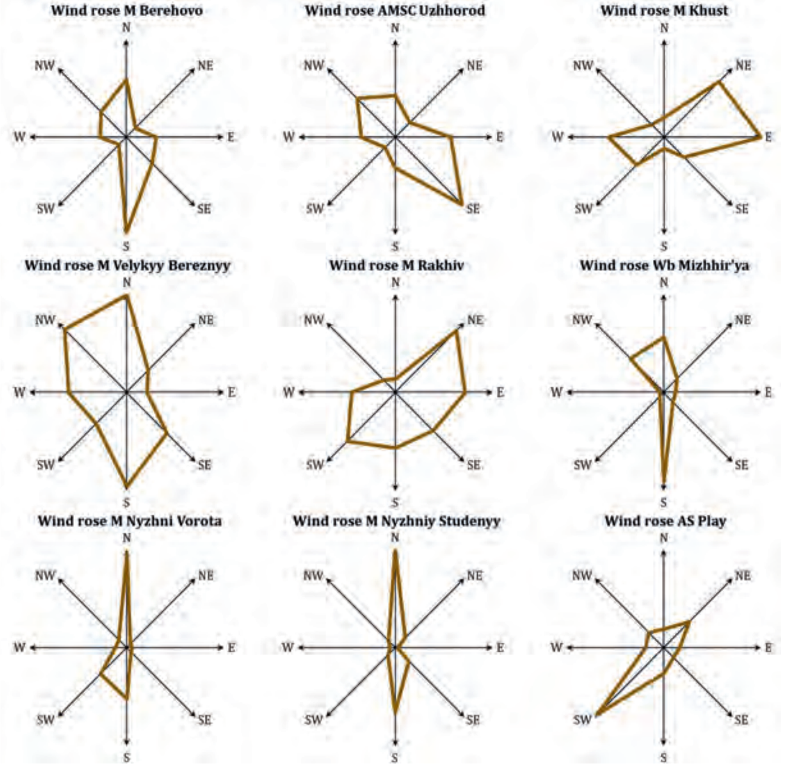

Fig. 1.4.6. Annual wind roses according to weather stations in Zakarpattia Region during 1991-2020 (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

The average annual wind speed across the region is 1.8 m/s. The highest recorded wind speed in the highlands of the region was 44 m/s on 13 October 1980 at Slipstream, while in the lowlands, it reached 30 m/s on 8 August 1978 at the Aviation Meteorological Station Uzhhorod (Civil) ("AMSC Uzhhorod") (Climatological Standard Norms..., 2021). In the highlands (St. Plymouth), winds of 40 m/s are most frequently observed from January to March. Winds with speeds of ≥15 m/s are most characteristic of winter and spring, resulting from the vigorous flow of cold air masses from the northeast through the mountain system of the Ukrainian Carpathians (Climatological standard norms..., 2021). Their occurrence diminishes significantly in the summer when they manifest as potent, short-term daytime squalls. These squalls are often accompanied by heavy rains, hail, and other perilous meteorological phenomena. Throughout the year, wind speeds of up to 5 m/s (16-46%) are most prevalent in lowland areas, while speeds of up to 3 m/s (15-72%) are common in mountain valleys (Climatological Standard Norms..., 2021).

The Zakarpattia Region is also characterised by the development of mountain-valley circulation, which is driven by heat radiation and the cooling of surface air layers. Mountain-valley winds follow a periodic pattern, blowing from the valleys towards the mountains during the day and reversing direction at night. These winds are particularly noticeable in the valleys of the Uzh, Latorytsia, Borzhava, Rika, Tereblya, and Teresva. Less frequently, foehn wind are observed in Zakarpattia Region – these are often strong and gusty winds characterised by high temperatures and low relative humidity, which can sometimes blow from the mountains to the valleys. They lead to accelerated snowmelt and, during the warm season, contribute to air drying (humidity dropping below 30 %), which can have a detrimental effect on vegetation.

Current Trends and Manifestations of Climate Change

Throughout Earth's history, the climate has undergone constant changes, giving us every reason to expect that this trend will persist. Scientific research of the Earth's surface and analysis of long-term instrumental observations confirm the fact of global climate change, with unique characteristics varying by region. This change affects the entire geographical shell in different ways, including increasing global temperatures, rising sea levels, warming of the world's oceans, melting glaciers, and more. Climate change, which has been taking place over the past decades, continues to be of interest to scientists, NGOs, and governments worldwide. As a result, methods for forecasting global climate change and its possible consequences are being increasingly actively developed, with mathematical methods of modelling atmospheric processes at the forefront (Fifth National..., 2009).

Climate change is having a multifaceted impact on various aspects of human existence and the environment. In recent decades, Europe has seen significant climate-related changes in the species composition, proportions, and habitats of animals, insects, birds, and plants. Extreme temperatures recorded in the first decade of the 2000s had a negative impact on human health, resulting in an increase in hospitalizations and heat-related deaths. Scientists estimate that, in Europe alone, the number of deaths due to record temperatures during the summer of 2003 exceeded 70,000. Climate change has also contributed, with a high degree of certainty, to the spread of infectious diseases among animals (Ukraine and Politics..., 2016).

In 1987-1988, the World Meteorological Organisation (WMO), together with the United Nations Environment Programme (UNEP), established the Intergovernmental Panel on Climate Change (IPCC), which laid the foundation for systematising knowledge in the field of climate change. According to the IPCC's guiding principles, the IPCC's work is "an assessment based on a complete, objective, and open basis of scientific, technical, and socio-economic information relevant to understanding the scientific basis of the risks of anthropogenic climate change, potential adverse impacts of climate change, and opportunities for adaptation and mitigation" (Manukalo and others, 2018).

In order to preserve the planet's climate and ensure human security, the Paris Agreement was signed in December 2015 to limit greenhouse gas emissions to avoid a 2 °C rise in the average global temperature compared to pre-industrial levels (currently, the temperature has risen by almost 1°C and the concentration of carbon dioxide in the atmosphere has reached 404 ppm). In addition to rising air temperatures, extreme natural events have become more frequent, causing significant damage to the economy and public health.

According to the IPCC forecasts, Europe is likely to experience an increase in average temperatures and temperature maximums, an increase in the uneven distribution of precipitation, with an increase in the uneven distribution of precipitation between Northern and Southern Europe. An analysis of precipitation patterns in the twentieth century in the Northern Hemisphere revealed a slight increase in precipitation – 0.5-1.0 % per decade – in most regions of high and middle latitudes, and in the second half of the century, the probability of heavy precipitation increased slightly. The number of daily heavy precipitation events leading to flooding has increased (Fifth National..., 2009; IPCC Climate.., 2014).

The territory of Zakarpattia Region is also affected by global climate change at the regional level. In the relatively recent past, it is worth noting the catastrophic consequences of the floods of 1992, 1998, 2001, 2008 and 2010 in the western regions of Ukraine, which demonstrated the urgent need to take measures to reduce the risks of natural disasters of hydrometeorological origin. It should also be taken into account that the economic losses caused by natural disasters significantly exceed those caused by man-made disasters.

When analysing climate change in the Zakarpattia Region, we will focus on two main climate characteristics: surface air temperature and precipitation. It is changes in the redistribution of heat and precipitation that lead to changes in all other components of the climate system. In order to objectively identify climatological changes in air temperature and precipitation, a comparative analysis of data from two consecutive standard climatological norms for the periods 1961-1990 and 1991-2020, approved by the WMO, was performed.

In winter, relatively warm and humid air masses from the North Atlantic often reach western Ukraine, resulting in consistently higher temperatures in Zakarpattia. Anticyclones from the east are relatively rare in the Carpathian region (Balabukh..., 2008). Consequently, during the period from 1991 to 2020, only January recorded negative average monthly air temperatures in the lowland part of Zakarpattia Region, with a value of -1.2 °C at the AMSC Uzhhorod (Fig. 1.4.7). In contrast, during the previous standard climatological period (1961-1990), negative average monthly air temperatures were observed throughout the entire winter.

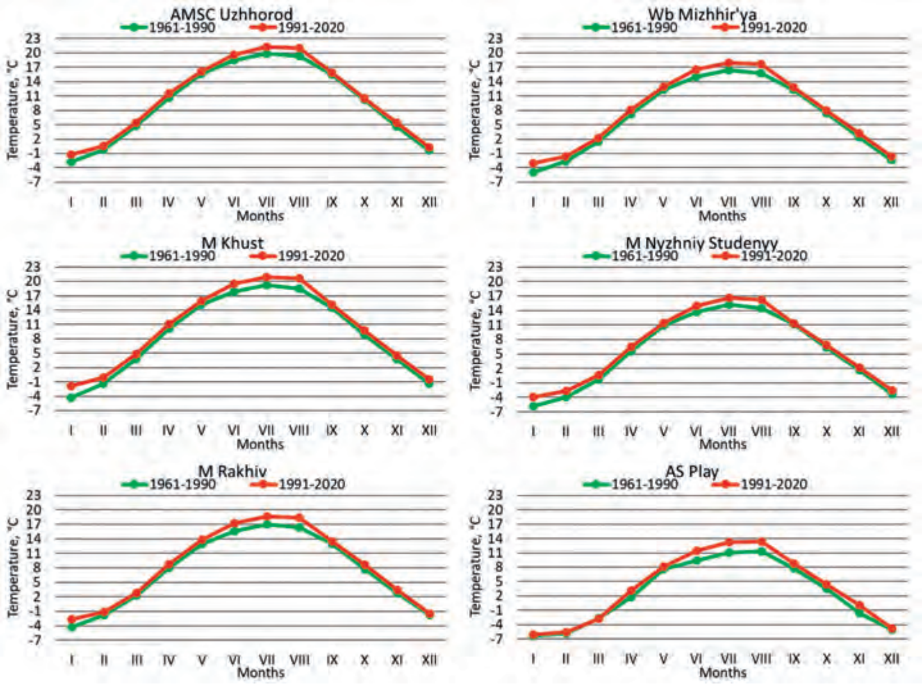

Fig. 1.4.7. Comparison of graphs of average monthly air temperatures according to weather stations in Zakarpattia Region during 1961-1990 and 1991-2020. (compiled by the authors according to the data of the Central Geophysical Observatory named after B. Sreznevsky Central Geophysical Observatory)

The annual variation of average monthly air temperatures in Zakarpattia Region over two consecutive climatological periods is depicted in Figure 1.4.7. Notably, for the past three decades, higher values of average monthly temperatures were recorded in every month compared to the 1961-1990 period. The most significant differences were observed in January and June to August (0.2-2.4 °C), while the smallest differences occurred in March to May (0.4-1.4 °C) and September to October (0.2-1.0 °C). The most substantial temperature contrasts were found in January. For example, in the city of Khust, the average air temperature in January increased by 2.4°C, and in the highlands of the region (Plai), it increased by 0.2 °C (Climatological Standard Norms..., 2021).These increases in average monthly temperatures in winter primarily result in reduced snow cover height and stability, while in summer, they lead to moisture deficits and droughts. Such changes have a direct impact on agriculture. The comparative analysis of average monthly temperatures undoubtedly confirms the phenomenon of global warming, which is also evident in Zakarpattia Oblast.

Throughout the entire period of instrumental meteorological observations in Zakarpattia, the lowest average monthly air temperature was recorded at Plai in February 1985 (-14.2 °C), and the highest was recorded at the AMSC Uzhhorod in August 1992 (+24.5 °C). On rare occasions, the lowest average monthly air temperature can be recorded not in winter, but in March (Balabukh..., 2013). February tends to be about 2 °C warmer than January, despite the similarities in atmospheric circulation and radiation conditions between these months. February experiences more dynamic changes in atmospheric processes, leading to faster air mass shifts and increased wind speeds. This, in turn, results in sharp fluctuations in air temperature. For instance, during the years 1964, 1966, 1968, 1969, 1972, 1974, 1980, 1987, 1990, 1995, 2000, 2002, 2012, 2016, and 2017, the average monthly temperature in January in the lowland part of the region was ≥5 °C lower than in February. In 1965 and 2012, it was ≥3 °C higher (Climatological Standard Norms..., 2021).

Over the past three decades, temperature contrasts between July and August have also decreased. For example, in the city of Khust, in 1961-1990, the difference in average monthly temperatures between July and August was 0.7 °C, and in 1991-2020, it was 0.3 °C. In general, August is closer to July in terms of temperature.

Calculations regarding the recurrence of changes in average air temperature between months have indicated that in the lowland part of the region, February was warmer than January in 68 % of all years, with only 31 % of the years being colder. The transition from January to February marks a sharp increase in average monthly temperatures. March typically sees an average temperature 3-6°C higher than in February. April, characterised by increased solar radiation, experiences the most significant temperature rise, with an upward difference of 5.9-6.2 °C between the average air temperatures in April and March. The steady rise in average air temperature continues into May, with May temperatures being 4.6-5.0 °C higher than in April. Meteorologically, May is a month that approaches summer. The increase in air temperature in summer is relatively gradual, amounting to 1.2-3.2 °C (Climatological Standard Norms..., 2021).

The increase in average monthly air temperatures and the rise in solar radiation inflow are nearly identical, but some differences exist (Adapting to Change..., 2015). The highest temperature values are most frequently recorded in July (56 % of cases), followed by August (35 % of cases), and rarely in June (9% of cases) (Climatological Standard Norms..., 2021). In August, as the length of daylight hours decreases, and the sun's height above the horizon diminishes, the average temperature begins to gradually decline (by 0.2-0.4 °C). However, in 27 % of cases, August exhibits higher temperatures than July. For instance, in 1962, 1971, 1974, 1979, 1984, 1986, 1992, 1993, 1996, 1997, 2000, 2011, 2015, 2017, 2018, 2019, and 2020, the average August temperature was 1-2°C higher than that of July. In September, a significant drop in air temperature commences. From August to September, it decreases by 4.7-5.4 °C, from September to October by 4.4-5.6 °C, from October to November by 4.3-5.3 °C, and from November to December by 4.7-5.1 °C (Climatological Standard Norms..., 2021).

During the modern climatological period, positive values of average monthly air temperatures are observed in the lowland part of the region from February to December (11 months), while in the previous period (1961-1990), it was only 9 months (from March to November). In the mountainous part of the region, positive values of average monthly temperatures persist from March to November, and in the highlands, from April to November. In the lowlands and foothills, temperatures exceed +15 °C from May to September (5 months) (Climatological Standard Norms..., 2021). In some years, average monthly air temperatures can deviate significantly from their long-term values and exhibit wide variations. In abnormally cold winter months, deviations can reach 7-8 °C, while in abnormally warm months, the deviations are 5-7 °C (Balabukh, Lukianets..., 2015).

An indicator of air temperature variability in the long-term context is its average annual value. The average annual air temperature is the arithmetic mean of the air temperature for the year, calculated using 12 monthly averages (Guidelines..., 2017).

To represent the long-term dynamics of average annual air temperatures, we selected data from the Uzhhorod Meteorological Centre, situated in the regional center of Zakarpattia Region – the city of Uzhhorod. Consequently, we calculated the average annual temperature values for each year within two consecutive 30-year observation periods (1961-1990 and 1991-2020) (Fig. 1.4.8). Upon analysis, it becomes evident that during the current climatological period, there is a marked upward trend in the average annual temperature values, as indicated by the increasing linear trend. In the preceding climatological period, such changes were absent, with the linear trend being nearly neutral (Ozymko..., 2020).

Figure 1.4.8 leads to the conclusion that in the Zakarpattia region, as well as globally, a persistent climate warming trend is observed. This trend has been particularly pronounced since the late 1990s. Such climate change is resulting in a shift in the seasonal boundaries, alterations in the biodiversity of ecosystems, and more. Changes in the thermal characteristics of the air also have adverse effects on human health, contributing to an increase in various chronic diseases and heightened meteorological sensitivity.

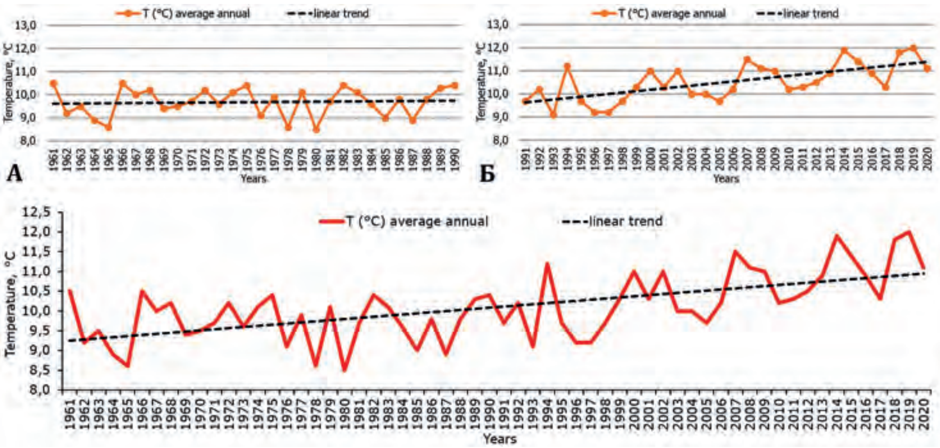

Fig. 1.4.8. Graphs of average annual air temperatures at the AMSC Uzhhorod during 1961-1990 (A) and 1991-2020 (B) (Ozymko..., 2020)

The annual variation of average monthly precipitation in Zakarpattia Region over two consecutive climatological periods is illustrated in Figure 1.4.9. Firstly, it is evident that during 1991-2020, there was a reduction in precipitation across the region during the summer months. The most significant changes occurred in June, with a decrease of 20-50 mm compared to the previous climatological period (1961-1990). In the annual precipitation pattern, the peak has shifted from June to July. Conversely, there was an increase in precipitation of 10-30 mm in September-October. The smallest changes in annual rainfall occurred during winter. In December-January, the average monthly precipitation decreased by 2-20 mm, while in February, it increased by 5-15 mm. Interestingly, the proportion of rainfall has increased during the winter months over the past three decades, which is atypical for Zakarpattia Region in the past. During spring, the amount of precipitation decreased by 9-15 mm. The most significant changes were observed in the highland zone of the region (Plai), where, in January, April, June, and August, the average monthly rainfall decreased by 25-50 mm (Climatological Standard Norms..., 2021).

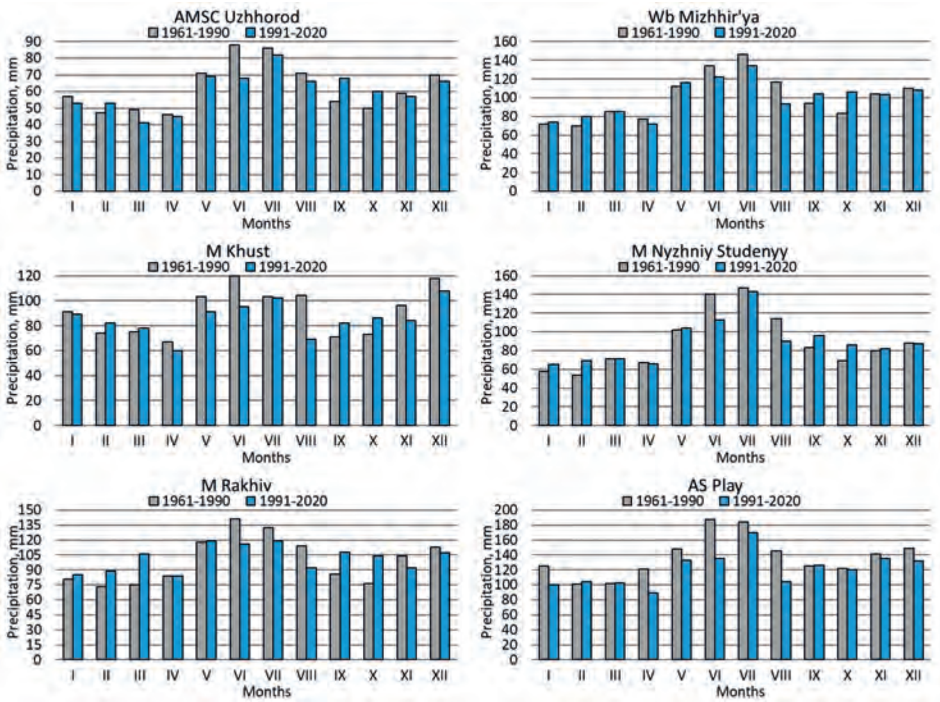

Fig. 1.4.9. Comparison of diagrams of average monthly precipitation according to meteorological stations in Zakarpattia Region during 1961-1990 and 1991-2020. (compiled by the authors according to the data of the Central Geophysical Observatory named after B. Sreznevsky)

Climatological changes in the precipitation regime across the region are considerably more intricate than those in air temperatures and are characterised by significant spatial and temporal disparities. Both positive and negative deviations in precipitation are observed during different seasons and months. The increase in the proportion of liquid precipitation during winter disrupts the stable snow cover and results in more frequent winter floods in the rivers of Zakarpattia Region. Such climatological shifts in the precipitation regime and phase state indicate a shift in the seasons and a transformation in the climate type, leading to alterations in vegetation and changes in agriculture, among other effects.

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1.5. SOILS AND VEGETATION COVER *(V. Sabadosh)*

Soils

Soil is a special natural formation emerging as a result of converting the upper layers of the lithosphere under the influence of water, air, climate factors and living organisms (in particular, under the influence of human-induced activities). Soil cover of the territory of Zakarpattia oblast formed in various conditions of relief, climate, moisture as well as vegetation cover and human-induced activities. Soil formation processes differ greatly in the mountainous and plain parts of the region. In the mountainous part of the region brown earth soil formation type is prevalent. The main factor here is the mountainous relief, which determines the spatial mosaic of vegetation cover and weather indicators. Brown mountain-forest, sod brown, mountain grassland brown soils prevail here.

Brown mountain-forest soils (brown soils) are the most common in the mountainous part of Zakarpattia, they cover mountain slopes within the forest belt from the foothills to heights of 1100-1200 m above sea level in the western and 1500-1550 m above sea level in the eastern parts of the oblast. The nature of brown soils is barely affected by the species composition of forests – the properties of the soil in beech, spruce and mixed forest stands differ little. Brown mountain-forest soils can have a high humus content, but this indicator fluctuates in a fairly wide range – under native forests it reaches 10-15%, under secondary grasslands it is up to 5-7%, and on arable lands it decreases to 3-5%. High acidity is typical of brown soils.

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The manual contains scientific materials devoted to the coverage of contemporary environmental issues of Zakarpattia. Considerable attention is paid to the peculiarities of its natural conditions. Emphasis is placed on the preservation of biodiversity in the face of climate change. While devising this textbook, the authors resorted to the analysis of literary sources as well as the findings of their own research. It will benefit school teachers, students and postgraduates of higher educational institutions majoring in natural sciences, employees of the nature reserve fund, and representatives of the authorities.

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