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Research, Assessment, and Development of Documents on Biodiversity, the Impact of Climate Change on Biodiversity, Habitat Restoration, and Long-Term Habitat Management

Climate Data Analysis And Scenario Development

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EXECUTIVE SUMMARY

This project “Research, assessment, and development of documents on biodiversity, the impact of climate change on biodiversity, habitat restoration, and long-term habitat management” offers an interdisciplinary approach by integrating spatial planning, legal frameworks, and ecological expertise alongside qualitative, scientific analysis. By combining knowledge from various fields, the aim is to create a comprehensive understanding of biodiversity challenges. The project emphasizes the importance of collaboration among environmental science, policy, and spatial design, creating a foundation for adaptive management strategies informed by both ecological data and spatial dynamics. This ensures that future actions are grounded in a well-informed, comprehensive perspective.

The project aims to identify and map key biodiversity areas at risk, focusing on Prizren, Suharekë, and the Sharr Mountains. Through field assessments, GIS data, spatial maps, spatial ecology analyses, and existing management plan reviews, critical habitats will be identified. These will be compared with historical and current climate patterns to predict future ecological changes and assess the impact of climate variability on biodiversity. Additionally, the project will evaluate the need for habitat restoration, documenting both the ecological and social benefits of restoration efforts.

This report first analyzes available climate data for Prizren, Suharekë, and the Sharr Mountains, using long-term observations from local and international sources to characterize temperature, precipitation, and seasonal patterns. By integrating environmental observations with historical climate records (and reanalyses, where available), it clarifies past variability and its implications for ecosystems and biodiversity resilience. It then evaluates regional climate projections to assess how future shifts in these variables could affect biodiversity, identify ecological vulnerabilities, and inform strategies for long-term habitat resilience.

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BACKGROUND

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Kosovo's ecosystems are already experiencing climate change: rising temperatures, reduced snowfall, shifting rainfall intensity, and more frequent extremes. These shifts threaten biodiversity—especially in mountainous and ecologically sensitive areas—and also disrupt agricultural cycles, water availability, and forest resilience. Yet climate data remain fragmented and rarely integrated into local environmental assessments, while scenario-based projections are still underused in biodiversity planning. Focusing on Prizren, Suharekë, and the Sharr Mountains, this two-part analysis addresses that gap: the first part consolidates and analyzes historical observations to quantify trends in temperature, precipitation, seasonality, and extremes, clarifying recent variability and its ecological implications; the second part translates global and regional climate scenarios into locally relevant projections to evaluate plausible future impacts on species and habitats, identify ecological vulnerabilities, and inform long-term monitoring, conservation priorities, and habitat resilience strategies.

INTRODUCTION

2

This report is part of a broader multi-phase initiative to strengthen the knowledge base for biodiversity monitoring, habitat restoration, and long-term ecological planning in Kosovo. While other phases address ecological impacts and policy frameworks, this document focuses on the climate drivers that underpin those decisions, providing both a rigorous baseline and a view of plausible futures for Prizren, Suharekë, and the Sharr Mountains.

Climate change refers to long-term shifts in temperatures and weather patterns driven largely by human greenhouse-gas emissions. Its impacts are global, but some regions are “hotspots” experiencing especially rapid changes; the Western Balkans, including Kosovo, is one such hotspot identified by the latest IPCC assessments. Kosovo has already witnessed more frequent extreme weather: rising average temperatures, more heatwaves, recurrent droughts, and episodes of heavy rains and flooding. Since the 1960s, summer heat extremes have increased, and devastating floods have occurred since the 1980s. These shifts are not abstract future risks—they are already affecting the environment, economy, and people. In a country where many livelihoods depend on agriculture and natural resources, warming and weather instability threaten biodiversity (the rich variety of species and ecosystems), agriculture (especially staple crops and food production), water security, and forest resilience.

The work is organized in two parts. The first compiles and analyzes available climate datasets—from local stations and international repositories and, where appropriate, reanalyses—to characterize long-term trends and variability in temperature, precipitation, humidity, wind, seasonality, and extremes across the three focus areas. Integrating these observations with historical environmental records clarifies recent and ongoing climate dynamics; rather than assessing ecological consequences in depth, this part establishes a transparent baseline to support evidence-based decision-making.

The second part examines future climate projections for Kosovo using internationally recognized modeling frameworks, primarily the CMIP6 multi-model ensemble, with emphasis on SSP1-2.6 (low-emissions) and SSP5-8.5 (high-emissions) pathways. It translates global and regional scenarios into locally relevant projections for near-, mid-, and longer-term horizons, including an outlook to 2050, to show how temperature, precipitation, and seasonality may diverge under different mitigation trajectories. In addition to framing these trajectories, the report outlines the expected directions of impact on biodiversity and agriculture—with particular attention to crop production—so that subsequent phases can develop detailed vulnerability analyses, scenario development, adaptation options, conservation priorities, and long-term habitat resilience strategies.

CLIMATE CHANGE HAS ALREADY AFFECTED THE REGION

3

KOSOVO HAS WARMED BY ABOUT 1 °C SINCE PRE-INDUSTRIAL TIMES, WITH SHARP INCREASES AFTER 2000, MAKING IT PART OF A REGIONAL CLIMATE "HOTSPOT." SUMMERS ARE HOTTER, WINTERS MILDER, AND EXTREME EVENTS LIKE WILDFIRES, FLOODS, AND DROUGHTS MORE FREQUENT. WHILE PRECIPITATION SHOWS NO LONG-TERM TREND, RAINFALL HAS BECOME INCREASINGLY ERRATIC, CLUSTERING INTO VERY WET OR VERY DRY YEARS. TOGETHER, THESE SHIFTS ARE STRAINING ECOSYSTEMS, AGRICULTURE, FORESTS, AND WATER RESOURCES.

3. Climate change has already affected the region

Relative to the pre-industrial baseline (1850–1900), Kosovo's mean air temperature has increased by about 1 °C, with recent years showing larger seasonal anomalies—especially during summer warm spells and at mid- to low-elevations. This magnitude is comparable to, and locally exceeds, the global average, aligning with the Western Balkans' designation as a climate-warming "hotspot." The warming signal has come with reduced snowfall, more frequent and intense heatwaves and drought periods, and heavier short-duration rainfall events—together elevating wildfire risk, straining water resources, and disrupting agricultural calendars and forest health. The figures that follow place these changes in context using a consistent 1979–2024 ERA5 reanalysis record (~30 km grid), complemented where relevant by local station observations; while reanalyses blend observations with model physics (and may smooth some local extremes in complex terrain), they provide a coherent, country-wide view where station coverage is sparse. The following diagrams show how climate change has affected Kosovo over the past 40 years based on ERA5 (1979–2024).

Recent extreme events in the region—including widespread wildfires in 2017 and 2022 and severe floods in 2023—are consistent with accelerated atmospheric warming and increasing climate variability, underscoring the tangible impacts of a rapidly changing climate.[1]

3.1 Yearly Temperature Change Kosovo

Kosovo has experienced a clear warming trend since 1979. As visualized in the ERA5-based data from Meteoblue (2024), the mean annual temperature has risen steadily, with a marked acceleration after the 2000s (see Fig. X). The warming stripes further emphasize that recent decades have been significantly hotter, with 2023 appearing among the warmest years on record. [2]

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[1] NATO Strategic Foresight Branch. Climate Security Impact Assessment: Strategic Foresight Analysis Supporting the NATO Climate Change and Security Impact Assessment. NATO HQ, July 2024. https://www.act.nato.int/publications

[2] ERA5 is the fifth-generation global climate reanalysis produced by ECMWF as part of the Copernicus Climate Change Service. It replaces the earlier ERA-Interim dataset and provides hourly climate estimates at ~31 km resolution, covering data from 1940 to present.

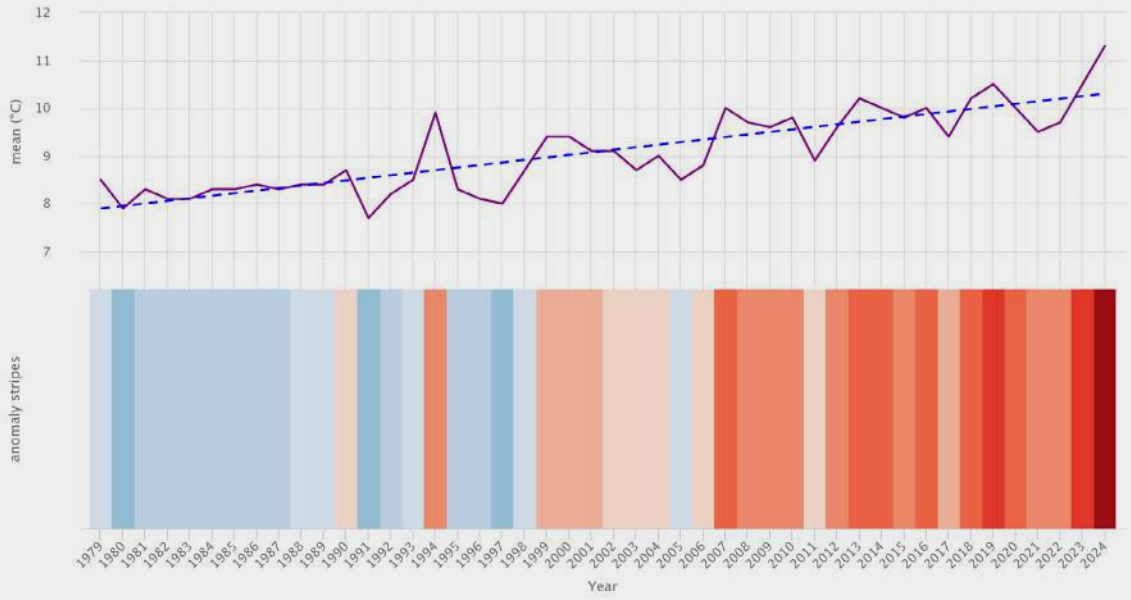


Figure 1. Yearly Temperature Change in Kosovo (1979–2024)

Data source: Meteoblue (2024). Graph based on ERA5 reanalysis data showing Kosovo's mean annual temperature trend. The dashed blue line represents the linear climate change trend, indicating a significant warming trajectory. The bottom panel shows annual temperature anomalies using warming stripes—blue for colder years, red for warmer years.

3.2 Yearly Precipitation Change - Kosovo

Kosovo's precipitation has shown high year-to-year variability, but no strong long-term trend in either direction is evident between 1979 and 2024. Unlike temperature, which displays a clear upward trend, precipitation patterns appear more sporadic and uncertain—consistent with climate change models that anticipate increased variability rather than a steady increase or decrease in rainfall. Notably, years of extreme dryness or wetness have become more clustered in recent decades, potentially signaling a rise in climatic instability even as the long-term annual average remains relatively constant.

Source: Copernicus Climate Data Store. ERA5 – Fifth generation of ECMWF atmospheric reanalyses of the global climate. https://cds.climate.copernicus.eu

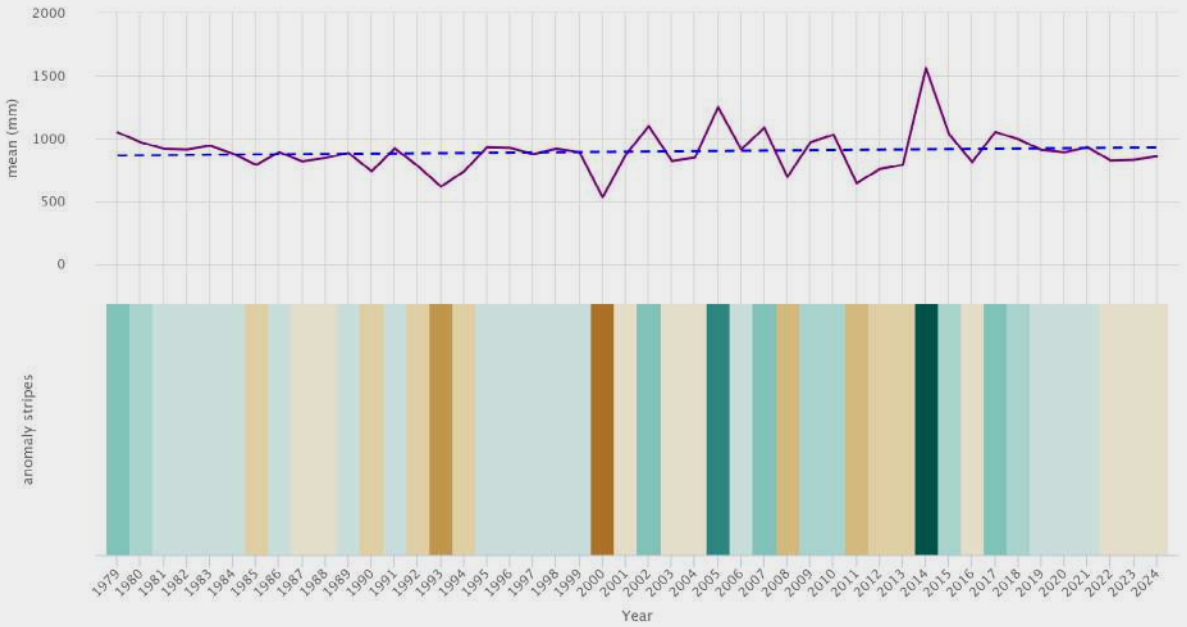


Figure 2. Yearly Precipitation Change in Kosovo (1979–2024)
Data source: Meteoblue (2024). Graph shows yearly mean precipitation trend and anomalies in Kosovo based on ERA5 reanalysis data. The dashed blue line represents the linear climate change trend, while the color bars indicate yearly anomalies (green = wetter, brown = drier).

3.3 Monthly Anomalies of Temperature and Precipitation

The monthly anomaly graphs for Kosovo from 1979 to 2025 illustrate a clear increase in climate variability. The upper graph displays temperature anomalies, showing a consistent rise in the frequency and intensity of warmer-than-average months—particularly after the year 2000—highlighted by the dominance of red bars. This trend aligns with broader global warming patterns. The lower graph shows monthly precipitation anomalies, which appear more erratic and do not exhibit a clear directional trend. Instead, they suggest increasing variability, with alternating periods of wetter- and drier-than-average months. Together, these graphs underscore the dual character of climate change in Kosovo: rising temperatures and unstable precipitation patterns.

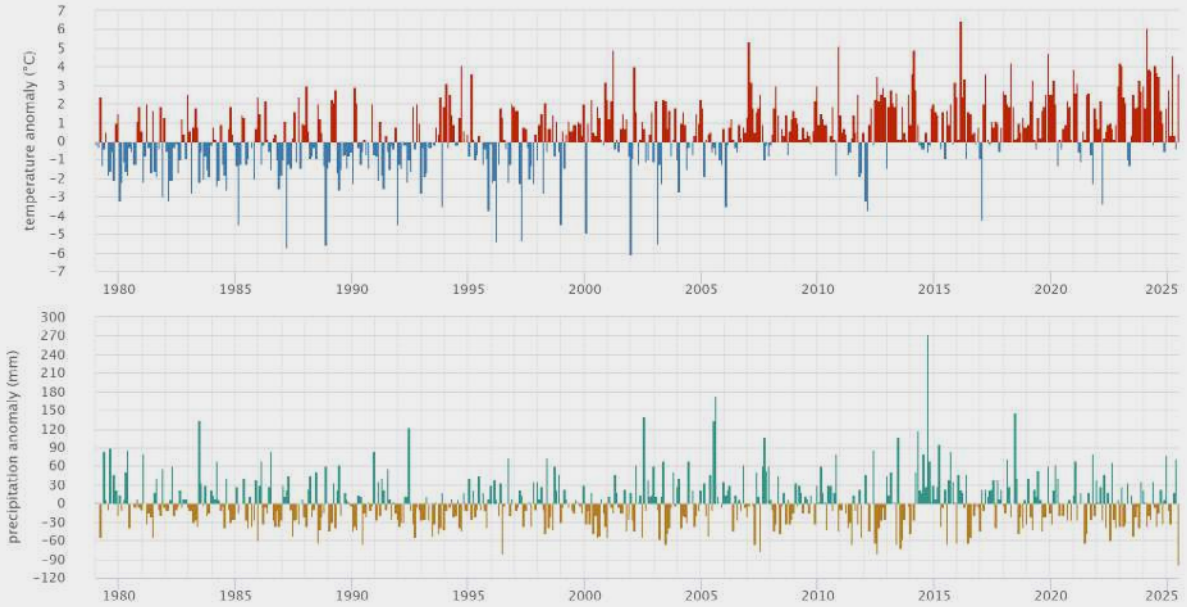


Figure 3. Monthly Anomalies of Temperature and Precipitation in Kosovo (1979–2025)
Data source: Meteoblue (2024). The top graph shows monthly temperature anomalies compared to the 1980–2010 average: red bars indicate warmer-than-average months, while blue bars show cooler-than-average ones. The bottom graph presents monthly precipitation anomalies: green bars show wetter months, and brown bars represent drier months. Data are based on ERA5 reanalysis for Kosovo (41.92°N, 24.70°E).

3.4 Kosovo Temperature and precipitation anomaly by month

Kosovo's precipitation patterns from 1979 to 2024 reveal high interannual variability but no clear long-term trend in either direction. While temperature trends demonstrate a consistent rise—particularly since the 2000s—precipitation changes appear more erratic, aligning with climate models that anticipate increased variability rather than linear shifts in rainfall. This is further reflected in monthly anomaly data: January temperatures in recent years have consistently been warmer than average, with notable spikes after 2007, while precipitation in January remains unpredictable, alternating between excess and deficit. November shows increasingly warmer temperatures since 2007, paired with a worrying trend of more frequent and intense dry anomalies. In contrast, December data show steady warming paired with erratic precipitation patterns, with recent years alternating between extreme dryness and sudden surges of wet anomalies. Although the mean annual precipitation has not changed drastically, the clustering of extreme wet or dry years—especially in winter months—suggests a growing instability in seasonal patterns, with implications for ecosystems.

The 12 graphs below illustrate monthly anomalies in temperature and precipitation for Kosovo between 1979 and 2025, based on ERA5 data provided by Meteoblue. Each graph corresponds to a specific month, showing how that month's climate has deviated from the long-term average over the decades. Red and blue bars represent positive and negative temperature anomalies, while green and brown bars indicate wetter or drier than average precipitation. Together, these visualizations offer insight into seasonal shifts, long-term warming trends, and the increasing variability of rainfall—especially during winter months.
Extreme events are not visible in these data - they may have different frequency, and critical thresholds may be surpassed at a higher frequency.

Kosovo's precipitation patterns from 1979 to 2024 reveal high interannual variability but no clear long-term trend in either direction…

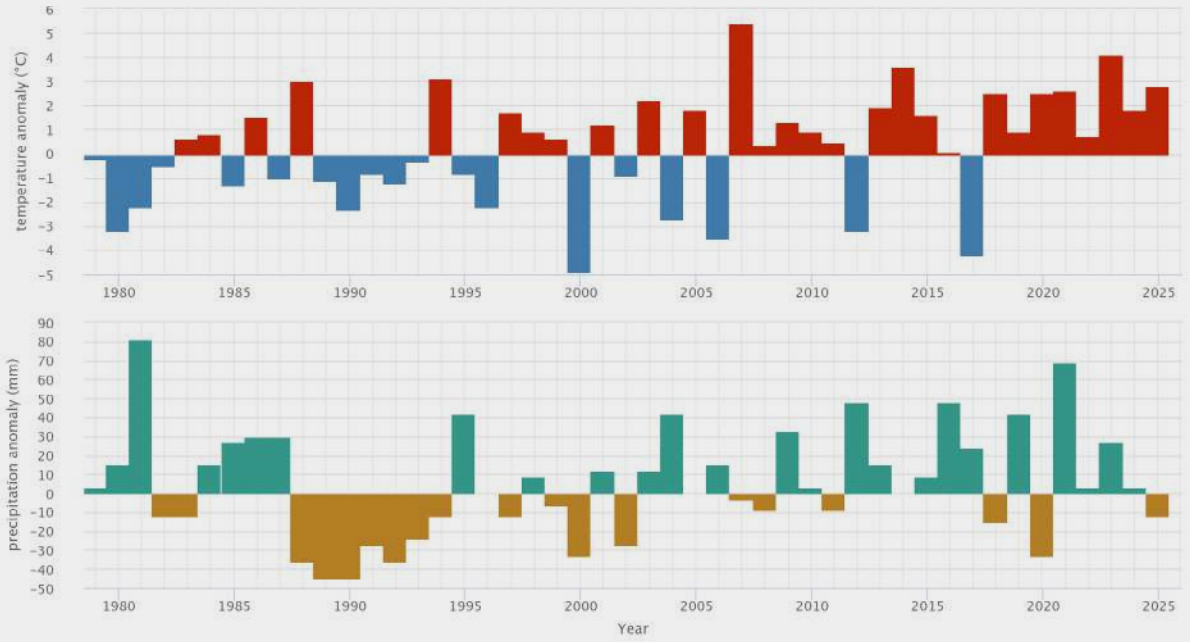


Figure 4. January Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

This figure presents monthly temperature and precipitation anomalies for January from 1979 to 2025 in Kosovo (41.92°N, 24.70°E). Data is sourced from Meteoblue using ERA5-based reanalysis. Temperature anomalies (top) are shown in red (positive) and blue (negative), revealing a pronounced warming trend in recent decades, particularly after 2000. Precipitation anomalies (bottom) are depicted in green (positive) and brown (negative), showing no clear trend but high interannual variability with alternating dry and wet extremes.
Data source: ERA5 reanalysis via Meteoblue (2024).

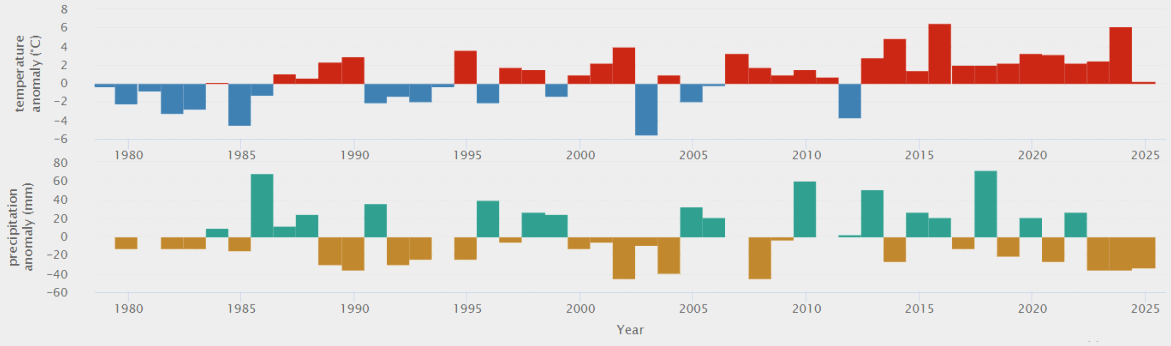


Figure 5. February Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

The graph shows a continued upward shift in temperature anomalies, with warmer-than-average Februaries dominating recent decades. Red bars increasingly outweigh blue ones, indicating the fading of colder winters. Precipitation anomalies show mixed patterns—irregular but frequent swings between drier and wetter Februaries, without a consistent trend.

Data source: ERA5 reanalysis via Meteoblue (2024).

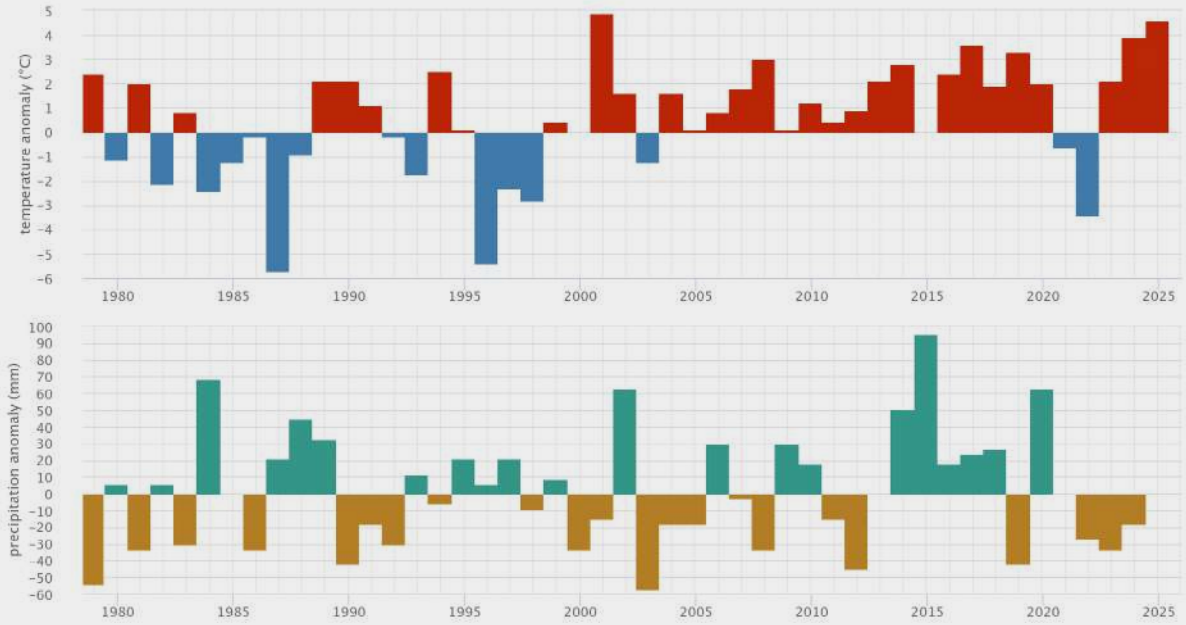


Figure 6. March Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

March shows strong warming over time, with blue bars (cooler anomalies) disappearing almost entirely in recent decades. Precipitation continues to fluctuate without a directional trend, though dry anomalies appear more frequently in the post-2000 period.

Data source: ERA5 reanalysis via Meteoblue (2024).

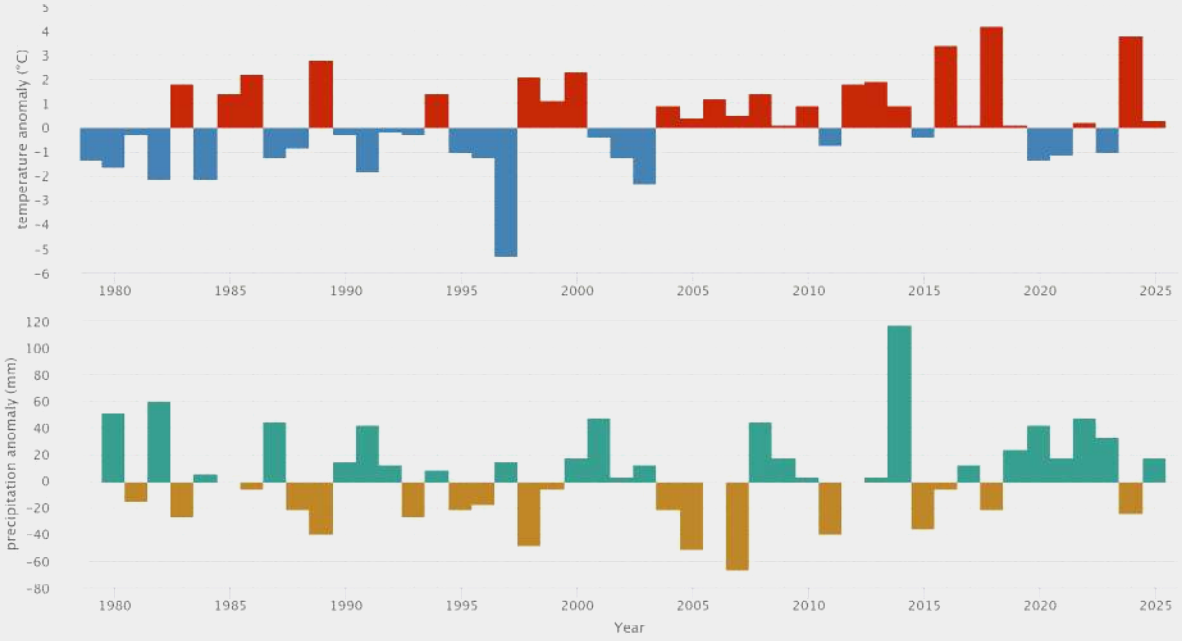


Figure 7. April Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

April presents clear temperature increases, especially after 2007, with red anomalies dominating. Precipitation shows instability, alternating between heavy and dry Aprils. The month has become increasingly erratic, especially in rainfall behavior.

Data source: ERA5 reanalysis via Meteoblue (2024).

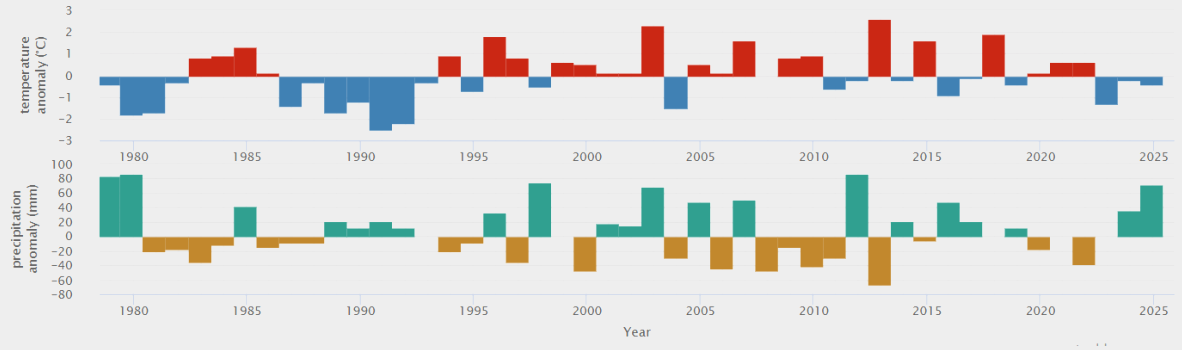


Figure 8. May Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

May reveals consistent warming trends with a dominance of red bars since 2000. Precipitation data indicates heightened volatility, with sharp swings in both directions, but no consistent increase or decrease.

Data source: ERA5 reanalysis via Meteoblue (2024).

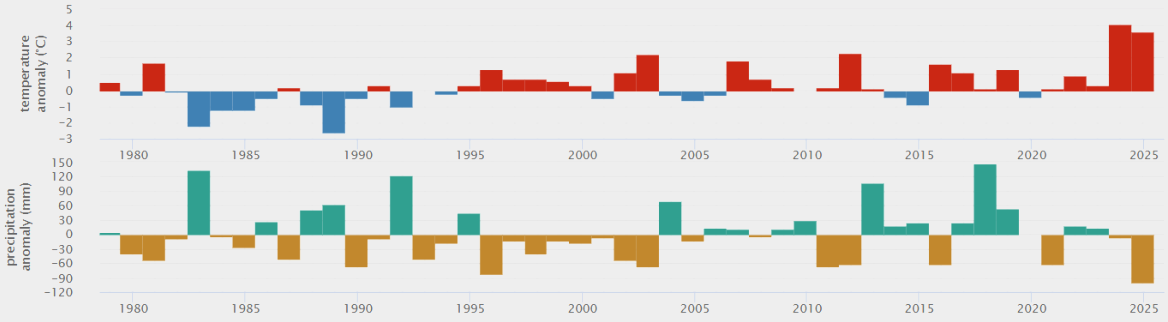


Figure 9. June Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

Warming is highly visible in June, with red anomalies exceeding +2°C in several years post-2010. Precipitation anomalies show frequent drought signals (brown bars), especially in the last decade, indicating increasing water stress during early summer.

Data source: ERA5 reanalysis via Meteoblue (2024).

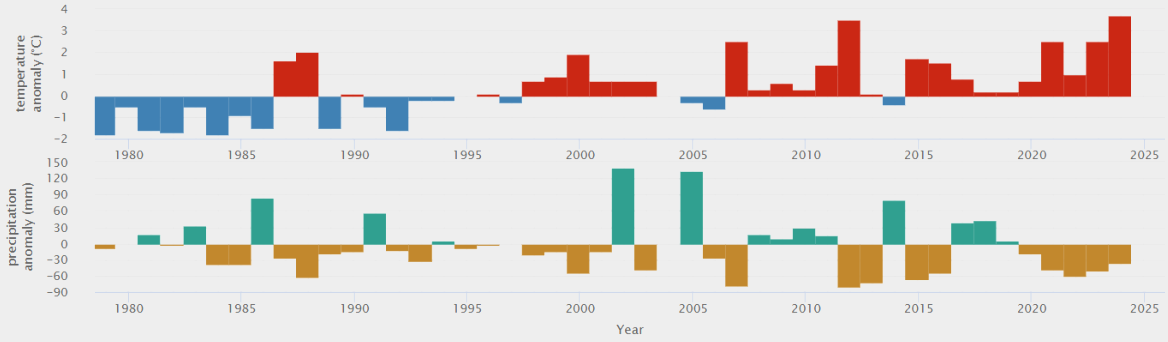


Figure 10. July Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

July is marked by sustained temperature increases, with warm anomalies present almost every year since 2000. Dry periods dominate the precipitation anomalies, suggesting intensified summer heat and reduced rainfall during peak summer months.

Data source: ERA5 reanalysis via Meteoblue (2024).

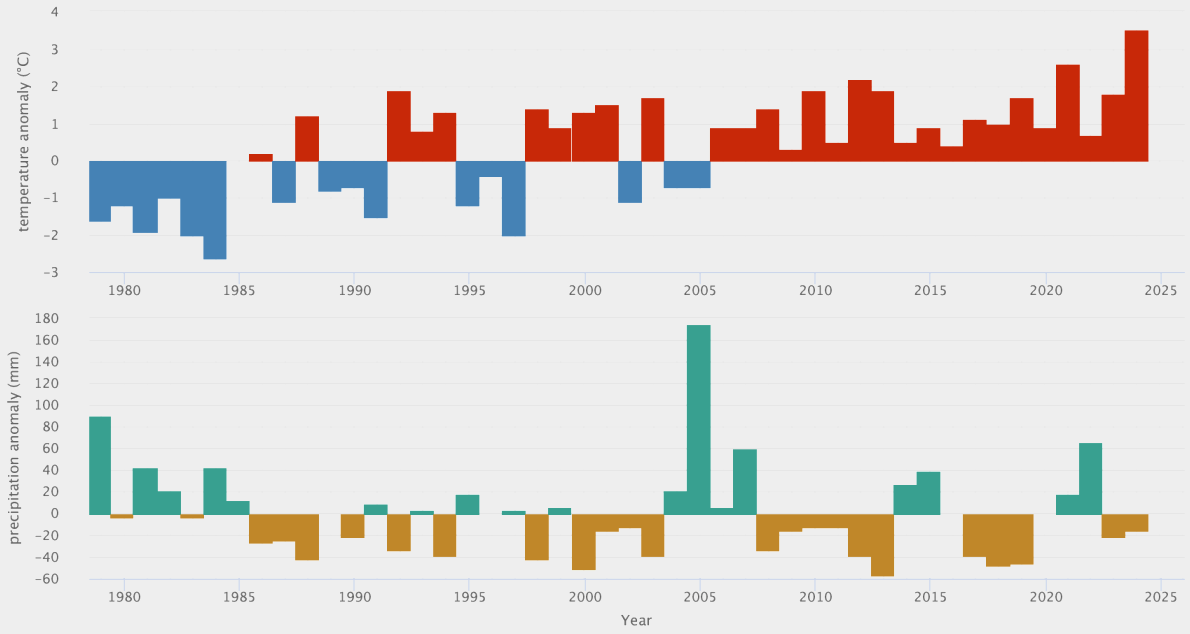


Figure 11. August Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

August continues the summer trend of persistent warmth, with an almost unbroken string of red bars since 2001. Precipitation anomalies remain mixed but tend to favor dryness in more recent years.

Data source: ERA5 reanalysis via Meteoblue (2024).

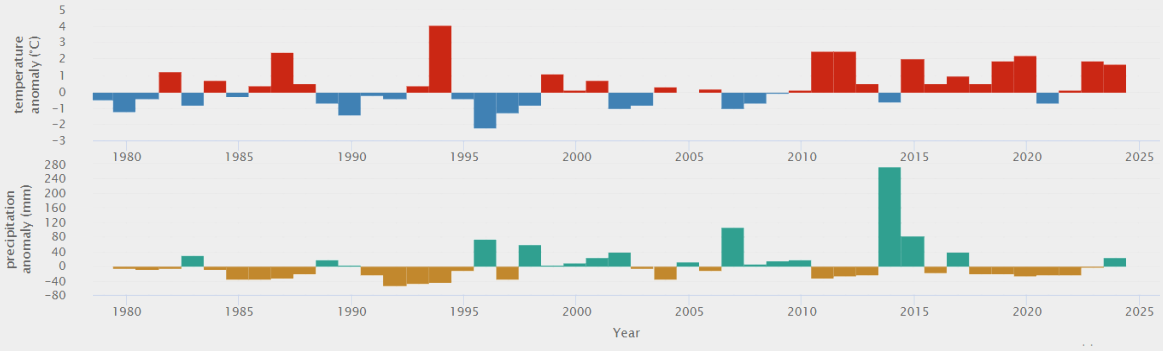


Figure 12. September Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

September shows a prolonged warming pattern and significant year-to-year rainfall variability. While not as consistently dry as the core summer months, recent years still show more brown bars than green.

Data source: ERA5 reanalysis via Meteoblue (2024).

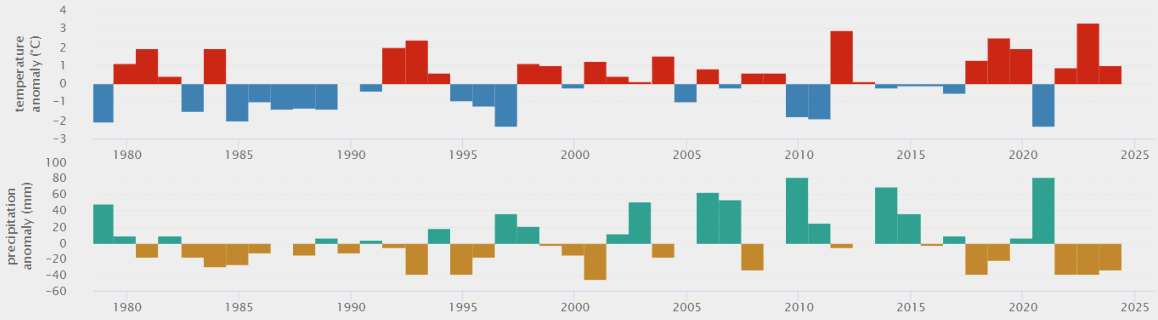


Figure 13. October Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

October reveals intensified warming from 2005 onward. Precipitation anomalies are evenly distributed between dry and wet years, with no significant trend. However, the simultaneous increase in temperature and variability in rainfall could affect autumn agricultural cycles.

Data source: ERA5 reanalysis via Meteoblue (2024).

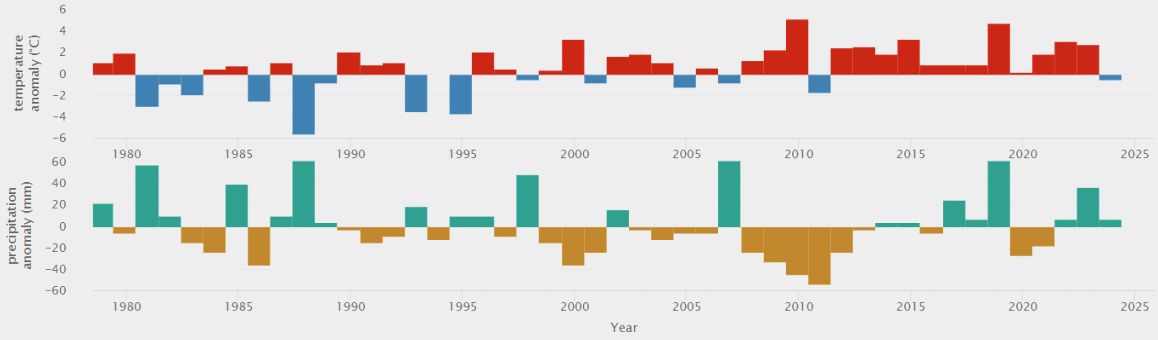


Figure 14. November Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

Warming is evident throughout recent Novembers, with red bars replacing nearly all blue ones since the late 2000s. A growing cluster of dry anomalies may suggest increasing late-autumn drought risk.

Data source: ERA5 reanalysis via Meteoblue (2024).

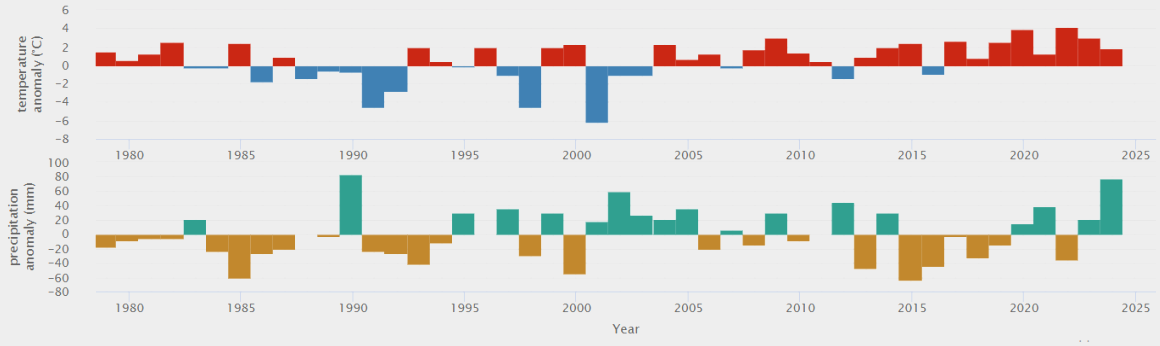


Figure 15. December Monthly Anomalies for Temperature and Precipitation in Kosovo (1979–2025)

December mirrors other winter months, with pronounced temperature increases in the last two decades. Precipitation remains unpredictable, alternating between extreme wet and dry months. These shifts challenge stable winter planning for agriculture and hydrology.

Data source: ERA5 reanalysis via Meteoblue (2024).

3.5 Historical Trends of Air Temperature in Kosovo

This chapter presents an analysis of near-surface (2 m) air temperature in Kosovo from 1960 to 2024, based on the ERA5 reanalysis dataset at approximately 9 km resolution. The data reconstructs past climate conditions, capturing both year-to-year fluctuations and the long-term warming trend observed over the last six decades. These historical patterns provide a critical baseline for understanding ongoing climate change and serve as a reference point for evaluating future projections.

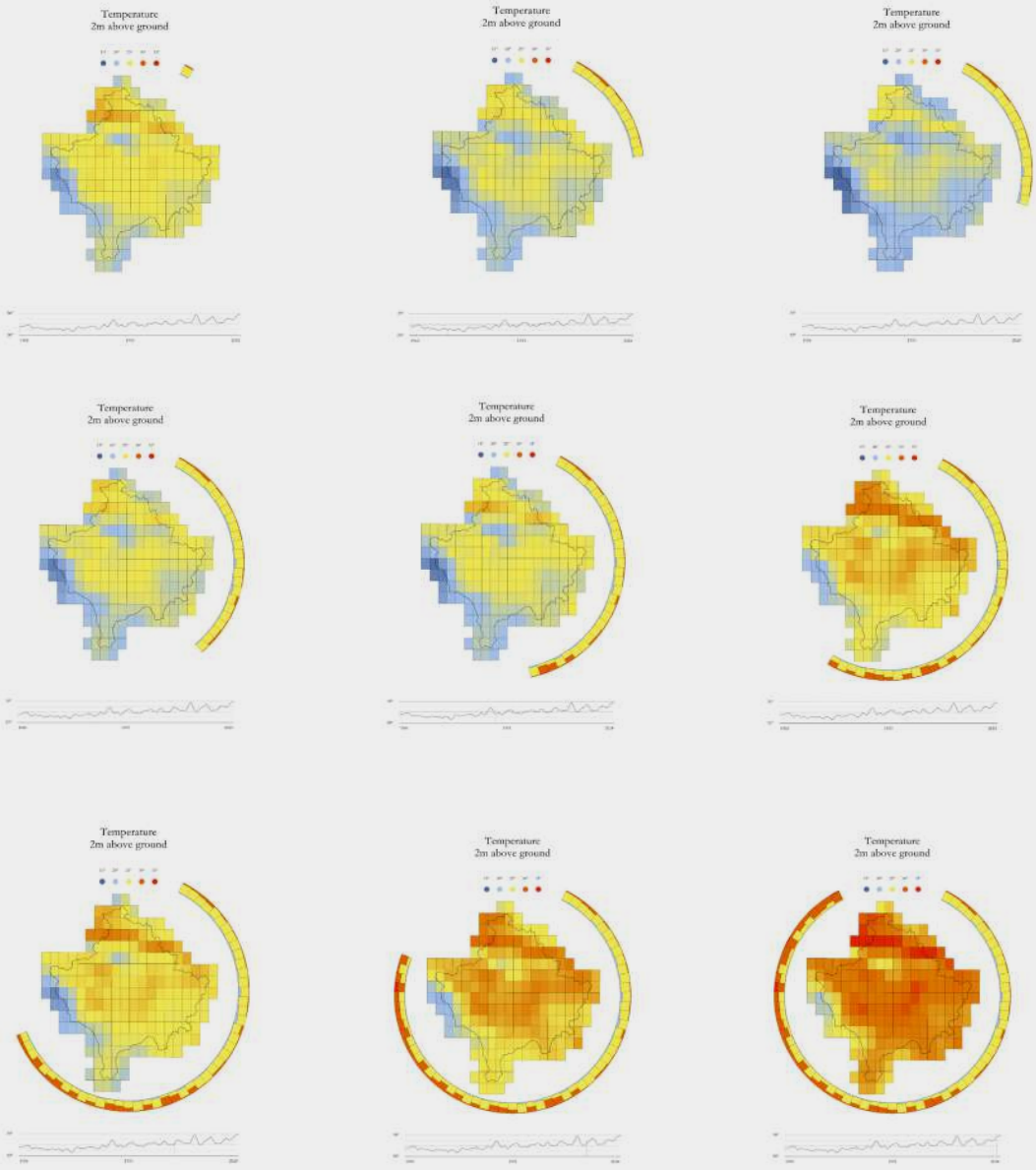


Figure 16. A climate visualization of Kosovo showing reconstructed near-surface (2 m) air temperatures from 1960 to 2024, based on the ERA5 reanalysis dataset (approx. 9 km resolution)

The central map of Kosovo is divided into grid cells, each shaded with a gradient that transitions from cooler tones (blue/light yellow) to warmer tones (orange/red). Each cell reflects the range of local temperatures during the reanalysis period, capturing historical variations across the territory.

Framing the map, a circular radial bar chart encodes annual average temperatures year by year, arranged clockwise from 1960 to 2024. Cooler decades appear in blue and yellow, while more recent years are increasingly dominated by orange and red, reflecting observed warming trends.

Below the map, a time series graph shows the trajectory of mean annual temperature, highlighting both interannual fluctuations and the overall increase across the six-decade period.

Together, these three visual elements – spatial variation, yearly distribution, and temporal trajectory – illustrate the progressive warming captured in the reanalysis record, providing a historical baseline against which future projections can be compared.

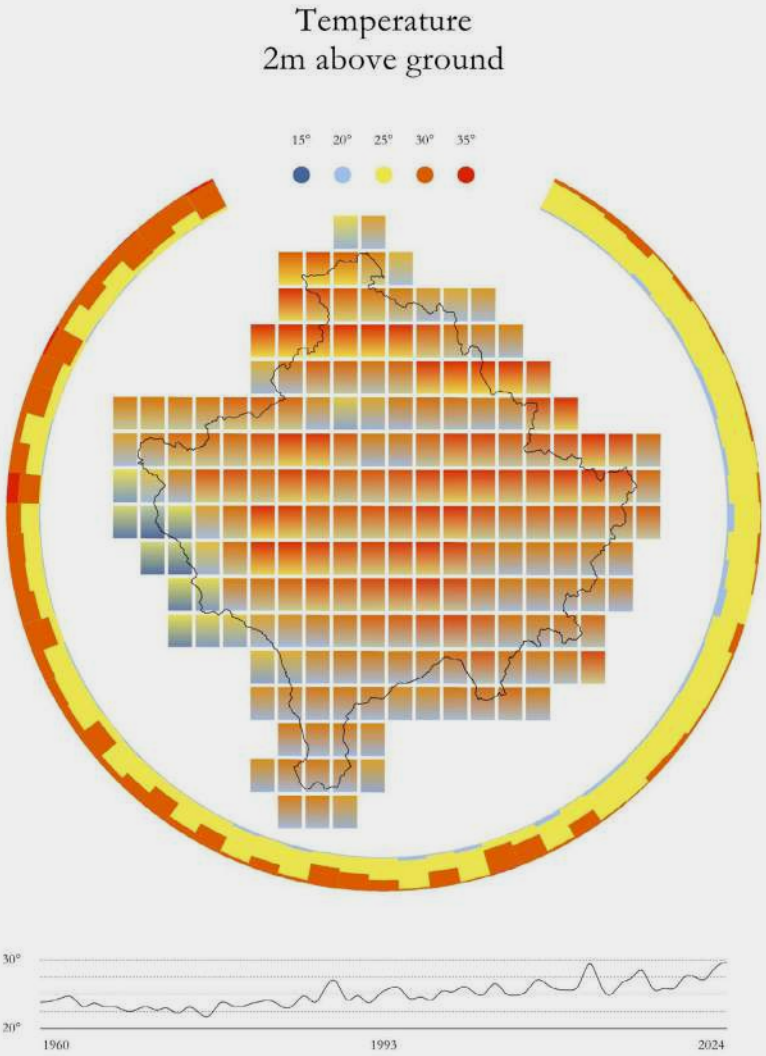


Figure 17. A composite climate visualization of Kosovo showing reconstructed near-surface (2 m) air temperatures from 1960 to 2024, based on the ERA5 reanalysis dataset (approx. 9 km resolution)

At the center, Kosovo is divided into grid cells, each shaded with a gradient from cooler tones (blue/light yellow) to warmer tones (orange/red), reflecting historical spatial variation in air temperatures across the territory.

Encircling the map, a radial bar chart organizes annual average temperatures year by year, moving clockwise from 1960 to 2024. Earlier decades appear in cooler blues and yellows, while recent decades are increasingly dominated by orange and red tones, capturing the historical warming trend.

Beneath the map, a time series graph traces mean annual temperature, showing fluctuations from year to year but a clear upward shift over the six-decade period. Together, the spatial map, radial distribution, and temporal graph integrate complementary perspectives, illustrating how local variation, yearly patterns, and long-term dynamics converge to reveal the observed trajectory of climate warming in Kosovo.

4. CURRENT CLIMATE POLICY FRAMEWORK

4

KOSOVO HAS ESTABLISHED ITS FIRST CLIMATE CHANGE LAW (2023) AND ALIGNED WITH EU AND REGIONAL FRAMEWORKS, SETTING TARGETS FOR DECARBONIZATION, ADAPTATION, AND SUSTAINABILITY. HOWEVER, IMPLEMENTATION IS SLOW, INSTITUTIONS LACK CAPACITY, AND PROGRESS REMAINS LIMITED. THOUGH NOT A UNFCCC SIGNATORY, KOSOVO HAS PLEDGED VOLUNTARY TARGETS; THE KEY CHALLENGE NOW IS SHIFTING FROM LAWS AND PLANS TO EFFECTIVE ACTION THROUGH STRONGER INSTITUTIONS AND FINANCING.

While the previous chapters focused on the analysis of observed climate data in Kosovo—highlighting changes in temperature, precipitation patterns, and extreme events over recent decades—this chapter shifts attention to the institutional and legal frameworks that define how Kosovo is preparing to respond to these challenges.
Kosovo's climate governance is shaped by a combination of internal environmental concerns, such as air pollution and water stress, and external policy drivers including EU accession requirements and international cooperation commitments like the Sofia Declaration. Although Kosovo is not a formal signatory to the UNFCCC or the Paris Agreement, it began a voluntary Nationally Determined Contribution (NDC) process in 2021, signaling a willingness to engage in global climate mitigation efforts.

A major turning point came in December 2023, when Kosovo adopted its first Climate Change Law, creating a legal foundation for coordinated climate action. The law mandates the development of a 30-year decarbonization strategy, a National Adaptation Plan (NAP), and a greenhouse gas monitoring and reporting system, to be led by the Kosovo Environmental Protection Agency (KEPA). This legal framework marks a structural shift from ad hoc environmental responses to more binding, long-term climate governance.

Despite this progress, Kosovo's climate planning is still in early stages. The Climate Strategy 2019–2028 and the draft National Energy and Climate Plan (NECP) outline important objectives, but implementation remains limited. Only one Climate Action Plan (2019–2021) has been adopted, with no progress reports published since. Moreover, municipal-level action is nearly absent, with local governments only obligated to draft energy efficiency plans, leaving broader climate adaptation and mitigation efforts largely unaddressed at the local scale.
In the sections that follow, this chapter analyzes the evolution of Kosovo's environmental legal framework, the institutional mandates for climate governance, and the existing gaps that need to be addressed in order to improve climate resilience and biodiversity protection.

4.1 Legal Framework and Institutions

Kosovo has established a foundational legal framework for environmental protection and climate action in recent years. The core legislation is the Law on Environmental Protection No. 03/L-025, which aims to "promote the establishment of [a] healthy environment" and gradually align Kosovo's environmental standards with international norms. In 2024, the Law No. 08/L-250 on Climate Change – Kosovo's first dedicated climate law – was adopted, creating a basis for climate change mitigation and adaptation measures in line with international agreements and a transition to a carbon-neutral economy. This Climate Change Law establishes a system for monitoring, reporting and verification of greenhouse gas emissions and defines the obligations of relevant state authorities. Other key laws include the Law on Air Protection from Pollution No. 08/L-025 (2022), which mandates measures to improve air quality and ozone layer protection, and recent legislation on industrial pollution (Law on Integrated Pollution Prevention and Control, 2023) aligning with EU directives. Sectoral laws have also been updated to support sustainability

– for example, a revised Law on Waste No. 08/L-071 incorporates circular economy principles like waste prevention and Extended Producer Responsibility, and a new Law on Forests No. 08/L-137 (2023) emphasizes sustainable forest management for carbon sequestration and biodiversity protection.

Several institutions are charged with implementing these laws. The lead agency is the Ministry of Environment, Spatial Planning and Infrastructure (MESPI), which formulates policies and oversees environmental governance. Under MESPI, the Kosovo Environmental Protection Agency (KEPA) monitors environmental conditions and prepares the annual State of the Environment Report. KEPA collects data on air, water, soil, biodiversity, and climate indicators to inform policy improvements. A multi-stakeholder Climate Change Council has been (re)established to coordinate climate policy across sectors. Other bodies like the Ministry of Economy (responsible for energy policy), municipalities, and inspectorates also play roles in enforcement and implementation.

4.2 National Policies and Programs on Sustainability and Climate Change

Kosovo has developed several national strategies and action plans to advance sustainability, promote renewable energy, and address climate change mitigation/adaptation. The Climate Change Strategy 2019–2028, along with a detailed Climate Change Action Plan 2019–2021, set forth policies to reduce greenhouse gas emissions and strengthen climate resilience. These documents outline measures across energy, industry, transport, agriculture, and forestry to curb emissions and adapt to climate impacts. Following on, Kosovo's government approved an updated Climate Change Strategy 2019–2028 with similar goals, though implementation of the planned measures has lagged. To complement mitigation efforts, the government is also developing a Climate Change Adaptation Strategy to address vulnerabilities like droughts, floods, and water scarcity.

In the energy sector – the largest source of Kosovo's emissions – policies focus on transitioning away from coal and increasing renewables. The Energy Strategy 2022–2031 (approved in March 2023) sets an ambitious vision for a just energy transition. It targets at least 35% of energy from renewable sources by 2031 (up from a very low share in 2021) and plans for 1.3–1.6 GW of new solar and wind capacity. The strategy also calls for phasing out aging lignite (coal) power plants – which currently produce ~88% of Kosovo's electricity – and replacing them with cleaner sources over time. In line with this, Kosovo has introduced incentives for solar panel installation in homes and businesses, and has piloted projects on energy efficiency and waste-to-energy through partnerships with NGOs and donors. A draft National Energy and Climate Plan (NECP) for 2025–2030 has been prepared to integrate energy, climate and efficiency targets, although it awaits formal adoption. The NECP and forthcoming Long-Term Decarbonization Strategy (required by the new Climate Change Law) will be critical for setting 2030 and 2050 emission targets and guiding investment in low-carbon infrastructure.

Beyond climate mitigation, Kosovo's national programs also tackle environmental sustainability more broadly. A National Environmental Strategy 2013–2022 guided actions on air quality, water resource management, waste management, and biodiversity conservation. This is being succeeded by a new Strategy for Environmental Protection and Sustainable Development 2022–2030, though its adoption has been delayed. Meanwhile, specific programs have targeted urgent issues such as poor air quality – e.g. the Air Quality Strategy 2013–2022 and investments in air monitoring – and solid waste, via the Kosovo Integrated Waste Management Strategy 2021–2030 and cleanup of hundreds of illegal dumpsites. Kosovo has also implemented public awareness campaigns and small-scale initiatives: for instance, a tariff on single-use plastic bags (with an aim to ban them) to reduce plastic waste. These policies reflect Kosovo's recognition of sustainability as a cross-sectoral priority, encompassing not only climate change but also pollution control, resource efficiency, and green economic development. The challenge remains to translate strategies into action through consistent funding and enforcement.

4.3. International Commitments and Agreements

Although Kosovo is not a member of the United Nations and thus not an official party to the UN Framework Convention on Climate Change (UNFCCC) or the Paris Agreement, it has voluntarily aligned itself with global climate goals. In November 2020, Kosovo, along with its Western Balkan neighbors, endorsed the Sofia Declaration on the Green Agenda for the Western Balkans. By signing onto this Green Agenda, Kosovo committed to the EU's vision of a carbon-neutral continent by 2050 and agreed to pursue actions under five pillars: decarbonization, circular economy, pollution reduction, sustainable agriculture, and biodiversity protection. Concretely, Kosovo has pledged to work towards a 2050 net-zero emissions target and to implement the EU's climate and environmental acquis as part of this regional agenda. The Green Agenda commitments include specific goals such as phasing out coal, boosting renewable energy, improving energy efficiency, and enhancing climate adaptation across the Western Balkans.
In the absence of formal UNFCCC obligations, Kosovo is framing its own contributions. It has prepared a voluntary Nationally Determined Contribution (NDC), which was showcased at a side event during COP28 in 2023. Kosovo's draft NDC reportedly sets a goal of reducing GHG emissions by up to 49% by 2030 relative to 2016 levels, alongside increasing the share of renewables to at least 35% by 2030. These targets mirror the ambition of neighboring countries' Paris Agreement pledges, underscoring Kosovo's intent to "play its part" in the global climate effort despite its unique status.

Kosovo is also a Contracting Party to the Energy Community Treaty, a key international framework that binds it to adopt EU energy and climate regulations. Under the Energy Community, Kosovo had a renewable energy target of 25% by 2020 (which it aimed to achieve through its National Renewable Energy Action Plan). It is now expected to contribute to 2030 region-wide targets on emissions reduction, renewables, and energy efficiency set by the Energy Community. Indeed, the new Climate Change Law explicitly seeks to transpose the EU's Energy Union Governance Regulation into Kosovo's law, reflecting obligations under the Energy Community and the Stabilisation and Association Agreement. The Energy Community also requires Kosovo to develop

integrated NECPs and a 2050 decarbonization strategy, and to prepare for instruments like the EU Emissions Trading System. Additionally, Kosovo has entered other environmental accords through regional cooperation channels. For example, it participates in initiatives supported by the Regional Cooperation Council and GIZ on climate adaptation and disaster risk reduction in the Western Balkans. It has also signaled adherence to European standards via trade agreements – a recent free trade arrangement with EFTA notes Kosovo's Climate Change Law as a basis for its climate commitments. Overall, Kosovo's external commitments reinforce its alignment with European and global climate objectives, even as it lacks formal treaty obligations.

4.4. Alignment with EU Climate Policies and Standards

As a potential EU candidate country (Kosovo formally applied for EU membership in 2022), Kosovo is striving to align its policies with EU climate and environmental standards. Under the Stabilisation and Association Agreement (SAA) with the EU, Kosovo must approximate a wide range of EU environmental legislation, from air and water quality directives to climate policy regulations. The recent legislative efforts demonstrate partial progress in adopting the EU acquis. For instance, the Law on Climate Change incorporates elements of the EU Governance Regulation and lays the groundwork for Kosovo's National Energy and Climate Plan and long-term climate strategy, in line with EU requirements. Similarly, Kosovo's laws on air protection, waste management, chemicals, and nature protection are being updated to reflect EU directives (e.g. introducing EU principles like polluter-pays and EPR in the waste law). In March 2023, Kosovo adopted a Law on Industrial Emissions (Integrated Pollution Prevention and Control) to start aligning with the EU's Industrial Emissions Directive. The government has also drafted an Environmental Protection and Sustainable Development Strategy 2022–2030 to mirror European Green Deal objectives, though this strategy is still awaiting approval.

Despite these efforts, the European Commission assesses Kosovo as still at an early stage of preparation in Chapter 27 (Environment and Climate Change) of the EU acquis. The 2023 EC Progress Report noted only limited progress in the past year, urging Kosovo to increase political commitment and administrative capacity for environment and climate action. Key EU-aligned plans remain pending: Kosovo has yet to formally adopt its NECP and a 2050 Climate Neutrality Roadmap, which are necessary for full alignment with EU climate targets. Implementation is another concern – Kosovo must not only pass laws but ensure they are enforced in practice to meet EU standards on waste recycling, air pollution limits, water treatment, nature conservation, etc. The European Commission specifically recommended Kosovo improve waste management (collection, recycling, and closure of illegal dumpsites), implement the climate strategy and action plan, and prepare a detailed roadmap to meet the Green Agenda and EU climate acquis. Meeting EU standards will also involve establishing systems like an emissions monitoring and trading mechanism compatible with the EU Emissions Trading System, as well as strengthening environmental impact assessment procedures to EU levels.

4.5. Effectiveness of Policies

Kosovo's climate and environmental policies have laid important groundwork, but their effectiveness has been limited by slow implementation and ongoing challenges. The adoption of modern laws (e.g. on climate change, air, waste) is a positive first step, creating the legal basis for action. However, there is a well-recognized gap between legislation and execution. For example, while the Climate Change Law provides a framework, actual climate mitigation projects are lagging and Kosovo remains the most carbon-intensive economy in Europe due to heavy reliance on lignite coal for power. The two old coal-fired power plants still supply nearly 90% of electricity, resulting in high GHG emissions and frequent air pollution – indicating that energy transition policies have yet to yield tangible change. Renewable energy development has been slow (renewables were only ~6% of electricity in 2021, despite targets and incentive programs. On climate adaptation, Kosovo is still in early stages; recent droughts and floods have exposed the country's vulnerability and the need to accelerate resilience-building measures.

Institutional and financial constraints significantly undermine policy effectiveness. Kosovo's environmental authorities face low capacity and resources, with insufficient technical staff and funding to enforce regulations. Implementation of strategies often depends on donor support, and many initiatives remain donor-driven pilots rather than sustained government programs. Local governments, responsible for services like waste management and pollution control, often lack the infrastructure to carry out mandates – evidenced by the persistence of hundreds of illegal dumpsites and substandard landfills. Monitoring and data collection have improved (KEPA now produces regular environmental reports), but enforcement actions such as pollution fines, environmental liability for damages, and compliance checks on industries are still weak. As a result, air and water quality remain below EU norms, and Kosovo has made only modest progress towards its renewable energy and efficiency goals. The European Commission's verdict that Kosovo is at an "early stage" in this sector underscores that policies on paper have not yet translated into sufficient on-the-ground improvements.

Areas for improvement: To enhance the effectiveness of its climate policies, Kosovo will need to take a comprehensive approach:

- Kosovo must move from planning to action. This includes issuing the necessary secondary regulations under the Climate Change Law (for example, rules for GHG monitoring and reporting, or feed-in tariffs/auctions for renewables) and rigorously enforcing existing laws. The "polluter pays" principle should be applied in practice through fines and liability for environmental damage. Improving the capacity of environmental inspectors and harmonizing legislation on environmental liability and crimes will deter violations.

- Substantial investment in human and technical capacity is needed for MESPI, KEPA, and municipal environmental units. More trained staff, better equipment (e.g. air and water monitoring stations, inspection tools), and higher budgets would enable these institutions to implement policies effectively. Donor-funded projects (EU, World Bank, GIZ, etc.) have

helped draft laws and strategies; now Kosovo should allocate domestic funds to sustain these efforts and reduce reliance on external support. Enhancing inter-ministerial coordination – for instance, between the energy, environment, agriculture, and transport sectors – is also critical for integrated climate action.

- Accelerate the Energy Transition: Reducing Kosovo's dependence on lignite is paramount for both climate mitigation and public health. This will require scaling up renewable energy deployment (solar, wind, hydropower) by improving investment conditions and grid infrastructure. The government's target of 35% renewables by 2030 is ambitious and will need streamlined permitting, financing mechanisms, and possibly regional power market integration to handle variable solar/wind power. Energy efficiency programs (building insulation, efficient stoves, industrial efficiency) should be expanded to cut energy waste and emissions. Additionally, developing energy storage and cross-border electricity trade will help balance the grid as coal plants are phased out. The World Bank estimates that achieving net-zero emissions by 2050 in Kosovo is feasible but requires decommissioning all lignite plants by 2045 and investing roughly $5.5 billion by 2050 in renewables and supporting infrastructure – highlighting the scale of effort needed.

- Kosovo should promptly adopt pending strategic documents – notably the National Energy and Climate Plan and the Long-Term Decarbonization Strategy – and begin implementing them. Clear interim targets (for 2025, 2030) and assignment of responsibilities in these plans will guide ministries and municipalities in taking action. Likewise, the delayed Environmental Protection and Sustainable Development Strategy 2022–2030 should be approved and put into practice. Having updated, EU-aligned strategies is also important for attracting international climate finance and technical assistance.

- Building societal support for climate policies can improve their effectiveness. Kosovo has made progress with grassroots initiatives (e.g. campaigns on recycling, tree planting, solar panel promotion). These should be scaled up, and citizens should be engaged in monitoring and demanding enforcement of environmental rules. The Aarhus principles of public access to information and participation, though not formally binding, could be adopted to involve NGOs and communities in decision-making. Greater transparency (e.g. open data on pollution) and education on climate issues can create bottom-up pressure for implementation.

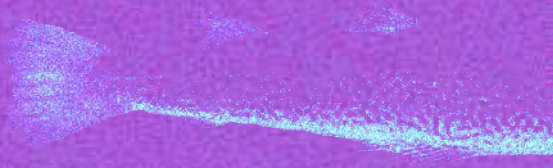
- Finally, Kosovo can improve outcomes by fully tapping into international programs. The EU's Green Agenda for the Western Balkans comes with an Action Plan and funding opportunities for climate-related investments – Kosovo should develop bankable projects (renewable energy, sustainable transport, waste management systems, etc.) to draw on these funds. Closer cooperation with neighboring countries on initiatives like transboundary river management or regional energy markets will also help, as climate challenges do not stop at borders. Ensuring Kosovo is involved in Western Balkan climate dialogues and initiatives (even if informally at COPs or through RCC) can bring technical know-how and keep its policies aligned with evolving EU standards. Overcoming the limitations imposed by its

political status – for instance, finding ways to access climate finance mechanisms despite not being a UNFCCC party – will be important for implementation.

Kosovo has made strides in establishing laws and plans for climate action and environmental protection, aligning closely with EU and regional frameworks. The focus now must shift to implementation. Strengthening institutions, securing funding, and undertaking concrete projects will determine whether Kosovo can meet its sustainability goals. With continued reforms and support, Kosovo can improve its environmental performance and gradually close the gap towards EU climate standards, benefitting both its citizens and the broader fight against climate change.

LIKELY EFFECTS OF OBSERVED CLIMATE CHANGE ON BIODIVERSITY IN KOSOVO

5



BY 2100, KOSOVO'S CLIMATE IS PROJECTED TO WARM BY +1.5–2 °C UNDER LOW EMISSIONS BUT UP TO +6.5 °C UNDER HIGH EMISSIONS, WITH SUMMERS HEATING THE MOST. PRECIPITATION WILL LIKELY DECREASE IN SUMMER AND INCREASE IN WINTER, RAISING DROUGHT AND FLOOD RISKS. MORE FREQUENT HEATWAVES AND SEVERE LOSS OF SNOW COVER WILL FURTHER STRAIN BIODIVERSITY, WATER RESOURCES, AND ECOSYSTEMS.

Although we cannot directly measure the full ecological impact of climate change in Kosovo due to the absence of long-term biodiversity monitoring programs and historical species baselines, the existing climate data already point to significant transformations in the ecological fabric of the region. Without consistent documentation of past species distribution, abundance, and phenology, it is difficult to draw precise cause-and-effect relationships between climate variables and biodiversity loss. However, the climate signals observed—particularly the persistent rise in temperatures, increased frequency of extreme weather events, and the erratic shifts in seasonal rainfall—are known to have profound ecological consequences elsewhere, and are likely to be shaping ecosystems in Kosovo in similarly disruptive ways.

In mountainous areas like the Sharr range, where biodiversity is especially rich and often tied to narrow elevation bands, even small increases in temperature can push species beyond their thermal thresholds, forcing them to migrate upward or disappear altogether. Alpine flora and cold-adapted fauna—many of which are endemic or regionally significant—are particularly vulnerable, as they often cannot move beyond the shrinking climatic niches available at higher altitudes. The delayed onset of snow, premature melting, and irregular frost cycles disrupt soil stability, vegetation patterns, and hydrological flows that many species depend on.

In freshwater systems, such as rivers and glacial lakes fed by mountain snowmelt, erratic precipitation and prolonged droughts alter water levels and temperature regimes, impacting aquatic biodiversity and degrading critical riparian habitats. These fluctuations can lead to habitat loss for fish, amphibians, and aquatic invertebrates, while also increasing vulnerability to pollution and eutrophication. In agricultural zones like Suharekë and parts of Prizren, the shortening of growing seasons and higher incidence of heat stress may indirectly reduce biodiversity by affecting crop diversity, pollinator presence, and soil microbial health—key components of agro-ecosystems.

In the context of the Balkans, where ecosystems are already fragmented by human activity, and where conservation data remains patchy, these climatic shifts compound existing vulnerabilities. The intersection of ecological fragility, political boundaries, and socio-economic pressures places Kosovo in a particularly complex position—one where regional cooperation, climate-informed land use, and improved monitoring systems become not just beneficial, but necessary. With this in mind, and drawing from broader scientific literature and comparable mountain and continental systems, we outline below the likely effects of the observed climate change trends on biodiversity in Kosovo.

Because aquatic insects are habitat-sensitive and occur in well-characterized ecological niches, they are highly valuable in assessing the potential for habitat restoration. Studying relatively intact sites (e.g. in protected areas) alongside degraded ones (e.g. in non-protected zones) enables the identification of reference conditions and informs practical, site-specific restoration strategies that consider both biological needs and landscape dynamics.

1. **Phenological Shifts**

Rising temperatures, especially during spring and autumn, likely cause species to alter their life cycles — such as earlier flowering of plants, premature insect emergence, or earlier migration of birds. These shifts can lead to phenological mismatches, where predators and pollinators no longer sync with the availability of their food or host species.

2. **Habitat Stress and Species Decline**

Increased frequency of droughts, heatwaves, and unpredictable rainfall affects water availability, soil moisture, and vegetation structure — putting stress on forest ecosystems, wetlands, and alpine meadows, all of which are critical biodiversity hotspots in Kosovo.

Species sensitive to temperature and water availability (such as amphibians, certain plants, and aquatic invertebrates) are likely already experiencing population stress or range contraction.

3. **Shifts in Species Distribution (Altitudinal & Latitudinal)**

As temperatures rise, many species tend to migrate upward or northward in search of suitable climates. In mountainous regions like Sharr, this can result in a loss of habitat for cold-adapted species that have nowhere higher to go. This can also increase competition as lowland species move into new areas.

4. **Disruption of Ecological Relationships**

With changing temperatures and rainfall, the timing and behavior of interacting species (pollinators and plants, herbivores and vegetation, predators and prey) can become unsynchronized, disrupting established ecological networks and weakening overall ecosystem function.

5. **Increased Vulnerability to Invasive Species and Pests**

Warmer winters and drier summers may facilitate the spread of invasive plant species, pests, and pathogens, which often thrive in disturbed or stressed ecosystems. This can outcompete native species and reduce biodiversity.

6. **Ecosystem Fragmentation and Reduced Resilience**

Climate change interacts with other pressures (urbanization, pollution, land degradation) to fragment habitats, making it harder for species to move and adapt. This decreases ecosystem resilience, limiting the capacity of landscapes to recover from shocks.

5.1 Overview of climate projections for Kosovo

In the context of accelerating climate change and its anticipated ecological consequences, this report outlines key objectives aimed at enhancing our understanding of future climate conditions in Kosovo and supporting a deeper examination of biodiversity challenges.
The goal of this report is to:

1. **Provide a clear, evidence-based overview of climate projections for Kosovo**
This includes synthesizing the latest scientific data from internationally recognized sources such as CMIP6 and IPCC reports, with a focus on projecting how climate variables like temperature and precipitation are expected to change over time. The analysis is tailored specifically to Kosovo's context, ensuring the data is both regionally relevant and scientifically robust.

2. **Compare projections under different emission pathways (SSP1-2.6 vs SSP5-8.5)**
By contrasting a low-emissions scenario (SSP1-2.6) with a high-emissions trajectory (SSP5-8.5), the report highlights how future climate outcomes will depend significantly on global mitigation efforts. This comparison helps identify the range of possible futures and underscores the importance of policy decisions taken today.

3. **Present key divergences in future temperature and precipitation trends**
The report outlines anticipated increases in average and extreme temperatures, changes in seasonal precipitation patterns, and the frequency of extreme events such as droughts or heavy rainfall. These divergences are not only critical from a climatological perspective but also for understanding their downstream effects on biodiversity, agriculture, and human well-being.

4. **Serve as a basis for later biodiversity impact assessments and adaptation strategies**
The findings presented here will form the foundation for subsequent phases of the project, including ecological vulnerability mapping, resilience assessments, and the development of adaptive management plans. By establishing a scientifically grounded understanding of projected climate changes, the report enables targeted responses to safeguard ecosystems and support biodiversity conservation in Kosovo.

This report draws on internationally recognized sources to evaluate projected climate conditions for Kosovo. The primary aim is to synthesize future climate scenarios based on varying emissions pathways and to identify key differences in projected temperature and precipitation patterns. The methodology combines model-based climate projection data with regional interpretative reports to ensure both scientific rigor and contextual relevance.

5.2 Data Sources and Models Used

To assess the future climate trajectories for Kosovo, this analysis relies on a combination of global climate models, open-access climate data platforms, and regional studies that offer localized interpretations. The use of multiple, complementary sources ensures both scientific credibility and contextual relevance, enabling a more nuanced understanding of potential climate developments under different emissions scenarios.

The primary data sources include:

- **CMIP6 Multi-Model Ensemble:** The Coupled Model Intercomparison Project Phase 6 (CMIP6) provides standardized climate model outputs under Shared Socioeconomic Pathways (SSPs).
- **Copernicus Climate Data Store (CDS):** Regional projections (bias-adjusted) for Europe and the Balkans using EURO-CORDEX downscaled models, offering higher resolution.
- **Köppen–Geiger classification projections (Beck et al., 2023):** 1-km climate-zone maps for 1901–2099 (historical and SSP futures), created by downscaling/bias-correcting a constrained subset of CMIP6 models and providing confidence layers—used here to translate temperature/precipitation projections into spatially explicit, ecologically readable climate typologies for Kosovo and the Balkans.

5.3 Variables Analyzed

Understanding how climate change may alter ecological conditions in Kosovo requires selecting variables that are both climatically significant and ecologically relevant. The indicators below were chosen based on their proven impact on ecosystems, species distributions, water availability, and overall biodiversity resilience. Together, they provide a multifaceted view of how climate dynamics may evolve under different future scenarios.

The following key climate variables were selected based on their availability from trusted sources such as CMIP6 (via the World Bank Climate Change Knowledge Portal and Copernicus Climate Data Store):

- **Average Annual Temperature:** Projected change in degrees Celsius from the historical baseline (1981–2010), critical for assessing long-term warming trends.
- **Seasonal Temperature Extremes:** Focused on summer (June–August, JJA) and winter (December–February, DJF), representing stress periods for both natural ecosystems and agricultural systems.
- **Annual and Seasonal Precipitation:** Expressed as percentage change from baseline values, important for evaluating shifts in water availability and hydrological patterns.

These variables form the core of this analysis due to their consistent availability, reliability across models, and direct relevance to biodiversity resilience and ecosystem health.

5.4 Limitations

While this report draws on internationally recognized models and datasets, several limitations must be acknowledged to ensure the responsible interpretation of the findings:
Limited Availability of Kosovo-Specific Bias-Corrected Data: Although global models such as CMIP6 and downscaled regional datasets like EURO-CORDEX offer valuable insights, high-resolution, bias-corrected data specifically tailored to Kosovo's topography and microclimates are scarce. As a result, much of the analysis relies on broader regional extrapolations from the Western Balkans, which may not capture localized climatic nuances—especially in ecologically sensitive zones like mountain valleys or karst landscapes.

- **Uncertainty Across Models and Scenarios:** All climate models contain degrees of uncertainty, stemming from variations in model architecture, emission assumptions, and socio-economic trajectories. This is particularly evident when comparing outcomes under SSP1-2.6 versus SSP5-8.5. To address this, the report emphasizes the range of plausible outcomes rather than presenting any one scenario as definitive.
- **Incomplete Representation of Certain Variables:** Variables such as snow cover, crucial for ecosystems in mountainous areas like the Sharr Mountains, are less consistently modeled and sometimes entirely absent from public-facing datasets. Their high variability and sensitivity to elevation, microclimate, and land use mean that localized research and ground-based monitoring remain necessary complements to model-based projections.
- **Temporal Gaps and Generalizations:** While three distinct future periods are considered (2021–2040, 2041–2060, 2081–2100), interpolations between these intervals may overlook sudden shifts or extreme events that could occur in the short-term due to tipping points or feedback loops.

OVERVIEW OF CLIMATE MODELS AND DATA SOURCES

6

KOSOVO'S CLIMATE MODELS (CMIP6, EURO-CORDEX, KÖPPEN–GEIGER) PROJECT STRONG WARMING OF +1.5–2 °C UNDER LOW EMISSIONS AND UP TO +6.5–7 °C UNDER HIGH EMISSIONS BY 2100, WITH HOTTER SUMMERS, MILDER WINTERS, AND MAJOR SNOW LOSS. PRECIPITATION IS EXPECTED TO DROP IN SUMMER AND RISE IN WINTER, HEIGHTENING DROUGHT AND FLOOD RISKS. KÖPPEN–GEIGER MAPS SHOW A SHIFT FROM CONTINENTAL-MOUNTAIN TO MEDITERRANEAN-TEMPERATE AND STEPPE REGIMES, LEAVING ALPINE CLIMATES CONFINED TO HIGH PEAKS—POSING SERIOUS CHALLENGES FOR ECOSYSTEMS, WATER, AND LAND USE.

This chapter presents a detailed analysis of the main climate models and sources used in this report. Each source contributes unique insights about Kosovo's climate future under different global greenhouse gas emission scenarios. The following sections go through each model individually, summarizing both methodological notes and projected changes in key variables like temperature and precipitation.

To understand Kosovo's future climate under different emissions scenarios, this section draws on two complementary sources of climate projections.
The first analysis relies on the CMIP6 Global Multi-Model Ensemble, which provides global-scale projections at a resolution of approximately 100 km. These outputs help identify broad climate trends under standardized scenarios (SSPs), offering a clear view of overall shifts in temperature, precipitation, and seasonal dynamics.

The second analysis builds on the EURO-CORDEX regional projections from the Copernicus Climate Data Store (CDS), which offer a much finer spatial resolution of about 12.5 km. These downscaled models allow for a more detailed, spatially explicit interpretation, helping to uncover sub-national variations, particularly relevant for biodiversity, land use planning, and ecosystem resilience.

6.1. CMIP6 Global Multi-Model Ensemble

The Coupled Model Intercomparison Project Phase 6 (CMIP6) provides a standardized framework used by climate modeling centers worldwide. It simulates future climate conditions based on different global development and emission trajectories known as Shared Socioeconomic Pathways (SSPs).

Scenarios included:
- **SSP1–2.6 (low emissions):** rapid decarbonization and sustainable development.
- **SSP2–4.5 (intermediate):** stabilization through moderate mitigation.
- **SSP5–8.5 (high emissions):** fossil-fuel intensive, minimal mitigation.

These scenarios enable analysis of conservative, middle-ground, and worst-case outcomes.
According to multi-model simulations under the CMIP6 framework, Kosovo is projected to experience significant climate changes across all major emission pathways, with the degree of change intensifying under higher-emissions scenarios. Annual average temperatures are expected to rise by +1.5 to +2.0 °C under SSP1–2.6, +2.5 to +3.5 °C under SSP2–4.5, and reach between +4.5 and +6.5 °C under SSP5–8.5 by the end of the century.
Seasonally, summer temperatures show the most extreme increases, with projections of +6 to +7 °C under SSP5–8.5, a shift that would place serious stress on water availability, biodiversity, and agriculture. Winters also warm substantially, particularly under the high-emissions pathway. Precipitation patterns shift markedly: winter precipitation increases, while summer rainfall declines sharply, especially under SSP5–8.5, resulting in prolonged dry periods and higher drought risk. The models also anticipate increased frequency and intensity of heatwaves, alongside reduced snow cover, particularly in Kosovo's mountain regions like the Sharr Mountains. The decline in snow seasonality could have significant implications for ecosystems that depend on cold-season water cycles.

These projections confirm that under a high-emissions future, Kosovo would face substantial disruptions to its hydrological balance, ecological zones, and seasonal cycles — all of which are critical factors for long-term biodiversity resilience and land use planning.

Variable	SSP1–2.6 (Low)	SSP2–4.5 (Medium)	SSP5–8.5 (High)
Annual Temperature	+1.5 to +2.0 °C	+2.5 to +3.5 °C	+4.5 to +6.5 °C
Summer Temperature	+2.0 to +3.0 °C	+3.5 to +4.0 °C	+6.0 to +7.0 °C
Winter Temperature	+1.5 to +2.5 °C	+3.0 to +4.0 °C	+5.0 to +6.0 °C
Summer Precipitation	–5 % to –10 %	–10 % to –20 %	–20 % to –25 %
Winter Precipitation	+5 % to +10 %	+10 % to +15 %	+15 % or more
Heatwave Frequency	Slight increase	Strong increase	2–3× more frequent
Snow Cover Duration	Reduced	Strong decline	Severe loss (shift to rain)

Summary of CMIP6 Climate Projections for Kosovo by Scenario

Climate projections for Kosovo under the CMIP6 multi-model ensemble highlight increasingly severe changes across key variables under higher emission pathways:

- Annual Temperature is expected to increase across all scenarios. Under SSP1–2.6 (low emissions), the rise is moderate (+1.5 °C to +2.0 °C), while SSP5–8.5 (high emissions) shows a dramatic increase up to +6.5 °C by the end of the century.
- Summer Temperature increases are particularly sharp, reaching +6.0 °C to +7.0 °C under SSP5–8.5. This represents a critical stressor for ecosystems, agriculture, and water availability.
- Winter Temperatures also rise substantially, from +1.5 °C to +6.0 °C depending on the scenario, potentially disrupting snow cycles and overwintering species.
- Summer Precipitation declines across all pathways, ranging from a –5 % decrease under SSP1–2.6 to as much as –25 % under SSP5–8.5, indicating growing risk of summer drought and water stress.
- Winter Precipitation shows the opposite trend, increasing across scenarios, with more than +15 % under SSP5–8.5. However, this shift may not compensate for summer drying and could increase winter flood risks.

- Heatwaves become more frequent and intense, especially under high emissions, where they are projected to occur 2 to 3 times more often than baseline.

Snow Cover Duration is projected to decrease sharply. Under SSP5–8.5, this may result in a near-complete loss of persistent snow in many areas, replaced by winter rainfall. This is especially critical for mountainous ecosystems such as those in the Sharr Mountains.

6.2 Copernicus Climate Data Store – EURO-CORDEX Regional Projections

The Copernicus Climate Data Store (CDS) provides high-resolution regional climate projections through the EURO-CORDEX initiative, an essential tool for assessing climate impacts at the sub-national scale. Unlike the CMIP6 global models, which operate at a coarser resolution (~100 km), EURO-CORDEX offers downscaled outputs at approximately 12.5 km resolution across Europe. This enables more localized and spatially detailed insights, particularly valuable for biodiversity studies, ecosystem resilience, and land-use planning in complex terrains like Kosovo.
The EURO-CORDEX projections are based on the same global SSP scenarios but use regional climate models (RCMs) to refine patterns of change, accounting for local topography, land cover, and climatic dynamics. These projections are especially relevant when spatial precision is required — for example, to assess ecological vulnerability in mountainous areas such as the Sharr region or to model the hydrological impacts of summer droughts at the watershed level.

The visualization illustrates projected near-surface (2 m) summer air temperature in Kosovo, derived from the CORDEX-EUR dataset under the RCP4.5 scenario for the period 2021–2100 at a spatial resolution of approximately 12 km, accessed through the Copernicus Climate Data Store. At the center, Kosovo is divided into grid cells, each shaded according to the legend above, representing the progression from cooler to warmer summer temperatures across the territory. This spatial layer is encircled by a radial bar chart, which arranges annual values year by year, tracing the evolution of summer temperature distributions throughout the analysis period. Beneath the map, a time series summarizes the trajectory of mean summer temperature, highlighting fluctuations across the century while marking the overall upward trend. Together, these three visual layers provide complementary perspectives: from spatial variation across Kosovo, to the yearly distribution of seasonal values, to the long-term summer warming trend projected through the 21st century.

Figure 18. Projected near-surface (2 m) air temperatures in Kosovo, showing spatial variation, yearly distribution, and long-term warming trends across the century.

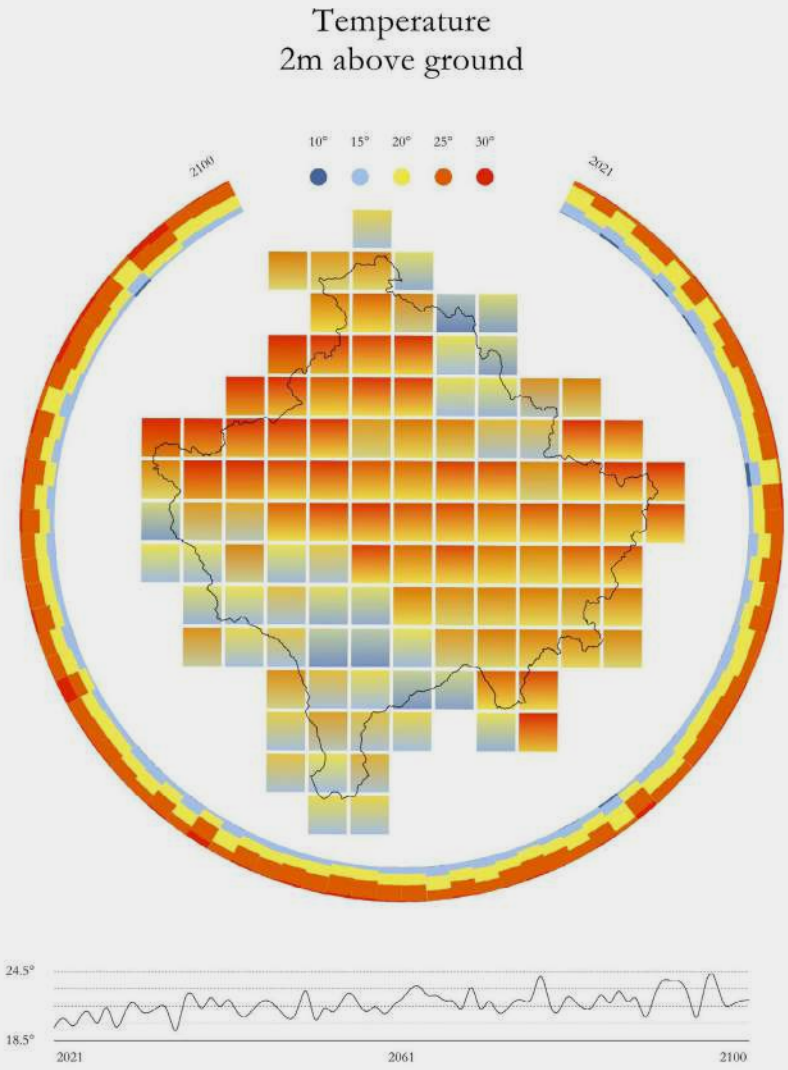


Figure 19. A composite climate visualization of Kosovo showing projected near-surface (2 m) air temperatures under future scenarios.

At the center, a gridded map of Kosovo illustrates local temperature variations, with each square cell shaded to reflect shifts from cooler tones (blue/light yellow) to warmer tones (orange/red), capturing the spatial dimension of warming across the territory.

Encircling the map, a radial bar chart arranges annual values year by year, tracing the evolving distribution of temperatures over the entire century. This circular layer highlights how cooler years gradually give way to warmer ones, with later decades dominated by orange and red segments.

Beneath the map, a time series graph summarizes the overall trajectory of mean annual temperature, marking fluctuations across years while clearly depicting a long-term upward trend.

Together, these three elements – spatial map, radial distribution, and temporal graph – integrate complementary perspectives, illustrating how localized variation, yearly cycles, and long-term warming patterns converge to reveal the progressive impacts of climate change in Kosovo.

Summary of EURO-CORDEX Projections for Kosovo

The EURO-CORDEX models confirm and deepen the trends shown by global simulations while offering sharper geographic contrast:

- Annual Temperature is projected to increase steadily across all scenarios, with Kosovo experiencing a rise of:
  - +1.4 °C to +2.1 °C under SSP1–2.6
  - +2.5 °C to +3.8 °C under SSP2–4.5
  - +4.5 °C to +6.3 °C under SSP5–8.5 by 2100
- Summer Temperatures exhibit the most extreme shifts, particularly under SSP5–8.5, where values may increase:
  - Up to +7.0 °C, especially in southern and lowland areas
  - This implies significant heat stress, evaporative loss, and biodiversity pressure
- Winter Temperatures rise less sharply but steadily, reaching up to +5.5 °C to +6.0 °C in some regions under SSP5–8.5. This reduces the duration and intensity of cold spells, with consequences for overwintering species and snow cover.
- Precipitation Trends show:
  - Winter Rainfall Increases between +10% and +20%, enhancing the risk of soil erosion and winter flooding
  - Summer Rainfall Decreases between –10% and –30%, intensifying drought frequency and pressure on agriculture
- Snow Cover and Cold Days decline sharply, especially under SSP5–8.5, with many mountainous regions shifting toward a winter rain regime. This has cascading effects on cold-dependent ecosystems, freshwater availability, and traditional agricultural calendars.
- Heatwaves become more frequent and prolonged, particularly in the SSP5–8.5 scenario, where the number of hot days (Tmax >35 °C) may double or triple compared to current levels.

These regional projections provide spatially explicit evidence that climate change will not affect Kosovo uniformly. For instance, mountainous zones may retain some snow under medium scenarios, while lowland agricultural areas may face intensified heat and water scarcity. Such granularity supports more targeted adaptation strategies, from forest planning to agricultural transition pathways.

6.3 Köppen–Geiger classification projections

The Köppen-Geiger climate classification provides an additional layer of analysis for understanding projected climate change in Kosovo and the wider Balkan region. Unlike purely numerical temperature and precipitation models, the Köppen-Geiger system translates these variables into recognizable climate zones, making visible the spatial shifts in climate typologies over time. The maps (1901–2099) offer both a historical perspective and future projections under different greenhouse gas concentration scenarios.

The Köppen–Geiger system classifies climate into five major groups (A tropical, B arid, C temperate, D cold/continental, E polar) and 30 sub-types using threshold rules on monthly temperature and precipitation and their seasonality. Because it was designed to align with broad vegetation patterns, it's a powerful way to translate complex climate signals into spatially explicit, ecologically meaningful zones. For biodiversity planning, it complements numeric projections by showing where climate envelopes shift across landscapes.

The maps used are from the 1-km Köppen–Geiger maps (Version 2) by Beck et al. (2023). Historical maps (1901–1930, 1931–1960, 1961–1990, 1991–2020) are built from high-resolution, observation-based climatologies; future maps (2041–2070, 2071–2099) are derived by downscaling and bias-correcting CMIP6 projections for seven SSP scenarios (including SSP1-2.6, SSP2-4.5, SSP5-8.5). Crucially, the authors screen CMIP6 models and keep a subset ($n \leq 42$) with plausible CO_2-warming rates, reducing bias and uncertainty relative to using all models.

What the Köppen–Geiger classification adds beyond CMIP6 and EURO-CORDEX in this report is its ability to provide spatial explicitness at a fine 1 km resolution, making visible where temperate, Mediterranean, or continental zones are projected to expand or contract within Kosovo—particularly in regions such as Prizren, Suharekë, and the Sharr mountains—while also capturing elevation-driven effects that are critical for habitats and ecological corridors. In addition, it offers ecological readability by translating physical temperature and precipitation variables into climate-biome zones, a language that is directly accessible and usable by conservation practitioners and land-use stakeholders. Finally, because the maps are derived from constrained CMIP6 SSPs, they are consistent with our broader scenario framework while minimizing the influence of overly warm-biased models, thereby improving reliability for biodiversity and land-use planning.

6.3.1 Kosovo- and Balkans-specific interpretation of Köppen–Geiger projections

For Kosovo and the broader Balkan Peninsula, the Köppen–Geiger climate classification maps provide more than a visual exercise—they illustrate the deep transformations underway in the region's climate identity. Historically, the Balkans have functioned as a transitional zone, a climatic meeting point between Mediterranean influences from the south and continental and alpine conditions from the north and east. Kosovo, situated in the heart of this transitional belt, has long embodied this duality.

In the baseline climatology of the 20th century (1901–2000), Kosovo was predominantly characterized by Cfb climates—temperate, fully humid, with warm summers. These were widespread in valleys and mid-altitude areas, shaping the conditions for diverse ecosystems and enabling traditional forms of agriculture. The higher-altitude zones, especially in the Sharr Mountains, the Accursed Mountains, and other alpine ridges, carried Dfb climates—cold, fully humid, with warm summers. These colder zones ensured snow reliability, preserved alpine meadows, and maintained distinct ecological niches for species adapted to longer winters.

Over the course of the 21st century, however, Kosovo's climate zones undergo a profound transformation. In the late 20th and early 21st century baseline (1995–2014), the country is largely characterized by a continental climate, with cold winters and warm summers, complemented by alpine conditions in the highlands and a modified Mediterranean influence in the southwest. By mid-century (2040–2059), the continental zones begin to shrink as winters become milder and snow cover diminishes. Mediterranean conditions expand into the western and southern lowlands, while high-altitude areas shift toward temperate mountain climates, with shorter winters and reduced snowfall. Toward the end of the century (2080–2099, under high-emission scenarios), this trend intensifies: Mediterranean climate zones dominate most of Kosovo's lowlands and central plains, continental conditions nearly vanish, and alpine climates are confined to the highest peaks, which themselves experience shorter snow seasons.

In effect, Kosovo transitions from a predominantly continental-mountain country—defined historically by cold winters, snow reliability, and alpine ecological niches—toward one shaped largely by Mediterranean-temperate conditions, with far-reaching implications for ecosystems, water availability, and agriculture.

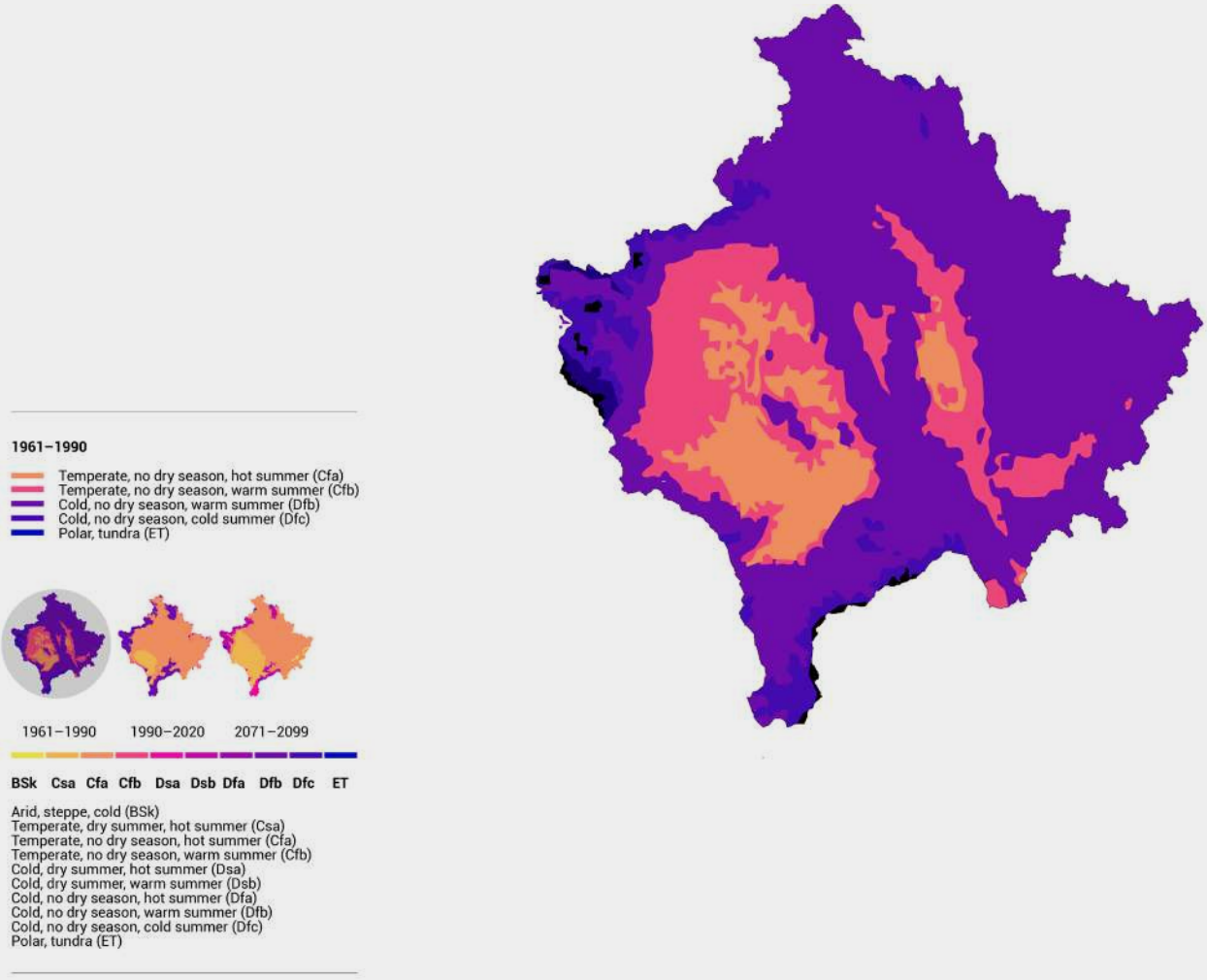


Figure 20 — 1961–1990 (historical climate)

Most of Kosovo is classified as Dfb (cold/continental, fully humid, warm summer), indicating cold winters and relatively mild summers across the plains and mid-elevations. Western lowlands show Cfb (temperate, fully humid, warm summer), while the highest ridgelines of the Sharri (Šar) Mountains and Bjeshkët e Nemuna / Accursed Mountains include pockets of Dfc (cold, fully humid, cold summer). This configuration supported reliable snow seasons in the mountains, alpine meadows, and year-round humid conditions in the lowlands.
Source: Beck, H. E., T. R. McVicar, N. Vergopolan, A. Berg, N. J. Lutsko, A. Dufour, Z. Zeng, X. Jiang, A. I. J. M. van Dijk, & D. G. Miralles (2023). High-resolution (1 km) Köppen–Geiger maps for 1901–2099 based on constrained CMIP6 projections.

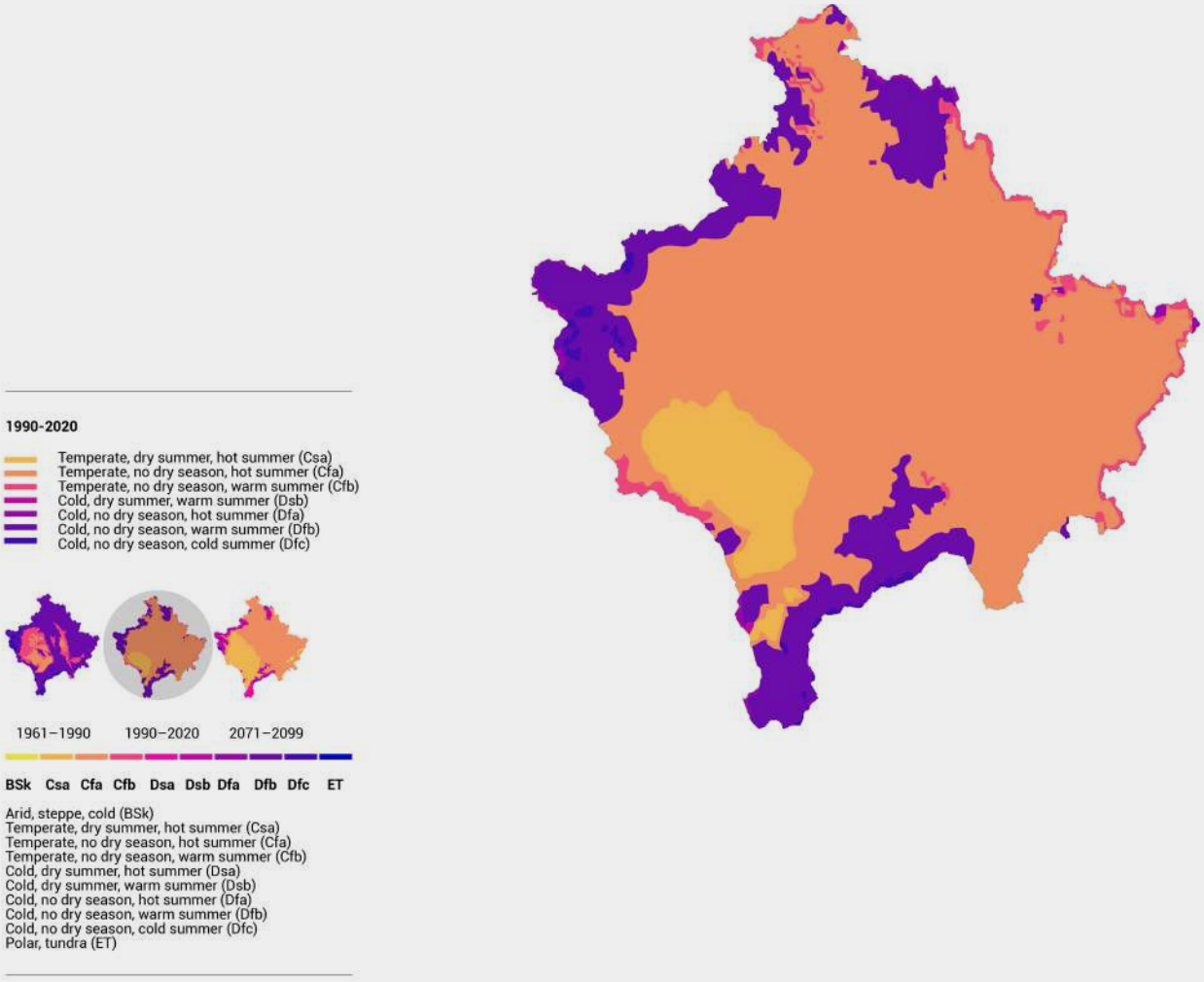


Figure 21 — 1991–2020 (current climate)

A clear warming and tempering signal appears. Cfb expands farther toward central and southern Kosovo, and localized areas of Cfa (temperate, fully humid, hot summer) emerge in warmer lowlands. Dfb retreats toward higher terrain, reflecting milder winters and fewer snow days. In the southwest (around Prizren and Gjakova), the Mediterranean influence in summer becomes more evident, foreshadowing a shift toward hotter, drier warm seasons.
Source: Beck, H. E., T. R. McVicar, N. Vergopolan, A. Berg, N. J. Lutsko, A. Dufour, Z. Zeng, X. Jiang, A. I. J. M. van Dijk, & D. G. Miralles (2023). High-resolution (1 km) Köppen–Geiger maps for 1901–2099 based on constrained CMIP6 projections

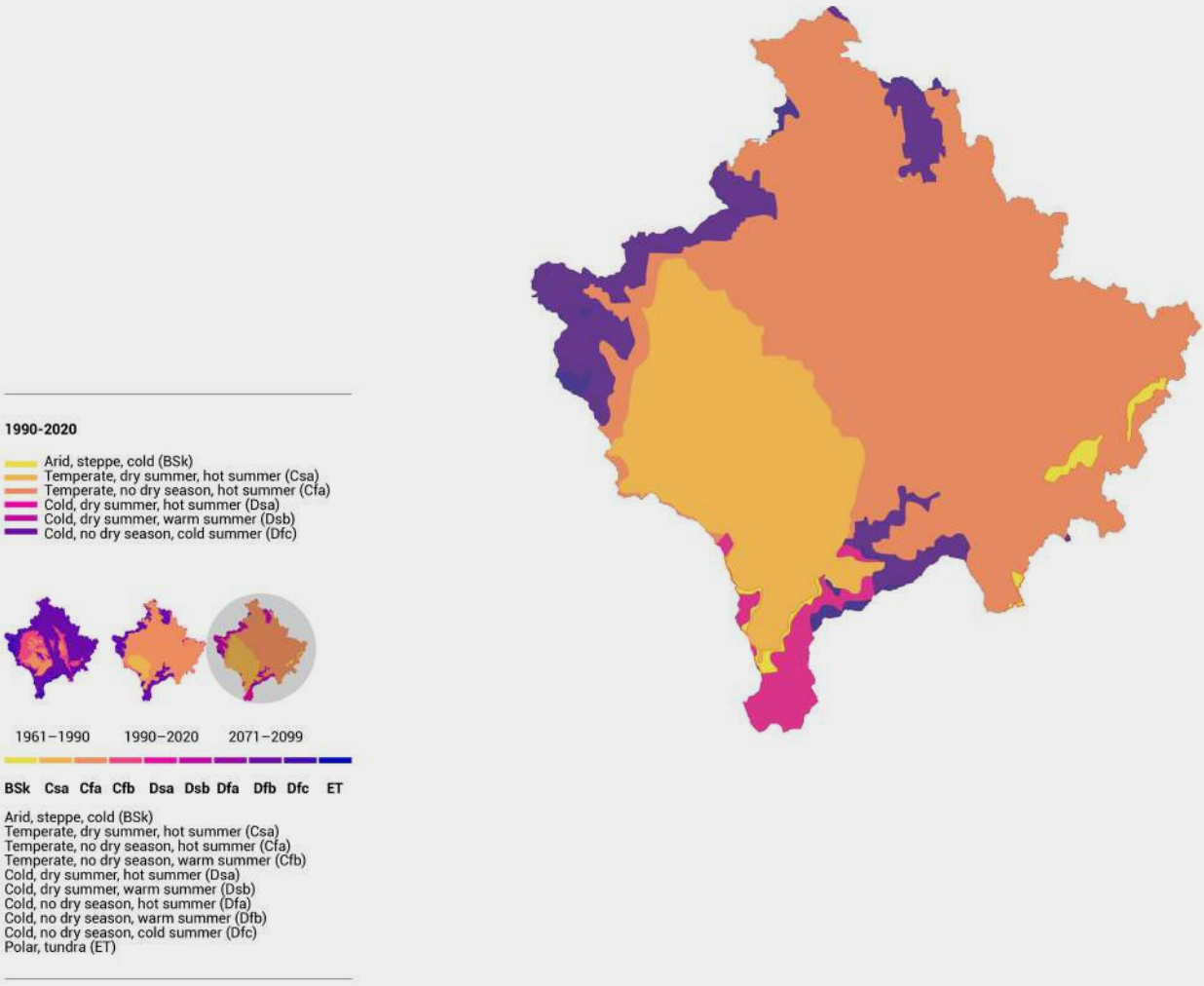


Figure 22 — 2071–2099 (SSP4-6.0)

Under the medium emissions pathway SSP4-6.0 (SSP460), continental classes Dfb/Dfc contract sharply and persist mainly on the highest crests of the Sharri and Accursed ranges. Central and southern parts of the country shift predominantly to Cfa and, in many lowland areas, to Csa (Mediterranean, dry summer, hot summer), implying longer, hotter, and drier summers and milder, wetter winters. Overall, Kosovo's climate identity transitions from continental-mountain toward a Mediterranean–temperate profile, with shorter snow seasons and greater warm-season water stress.

Source: Beck, H. E., T. R. McVicar, N. Vergopolan, A. Berg, N. J. Lutsko, A. Dufour, Z. Zeng, X. Jiang, A. I. J. M. van Dijk, & D. G. Miralles (2023).

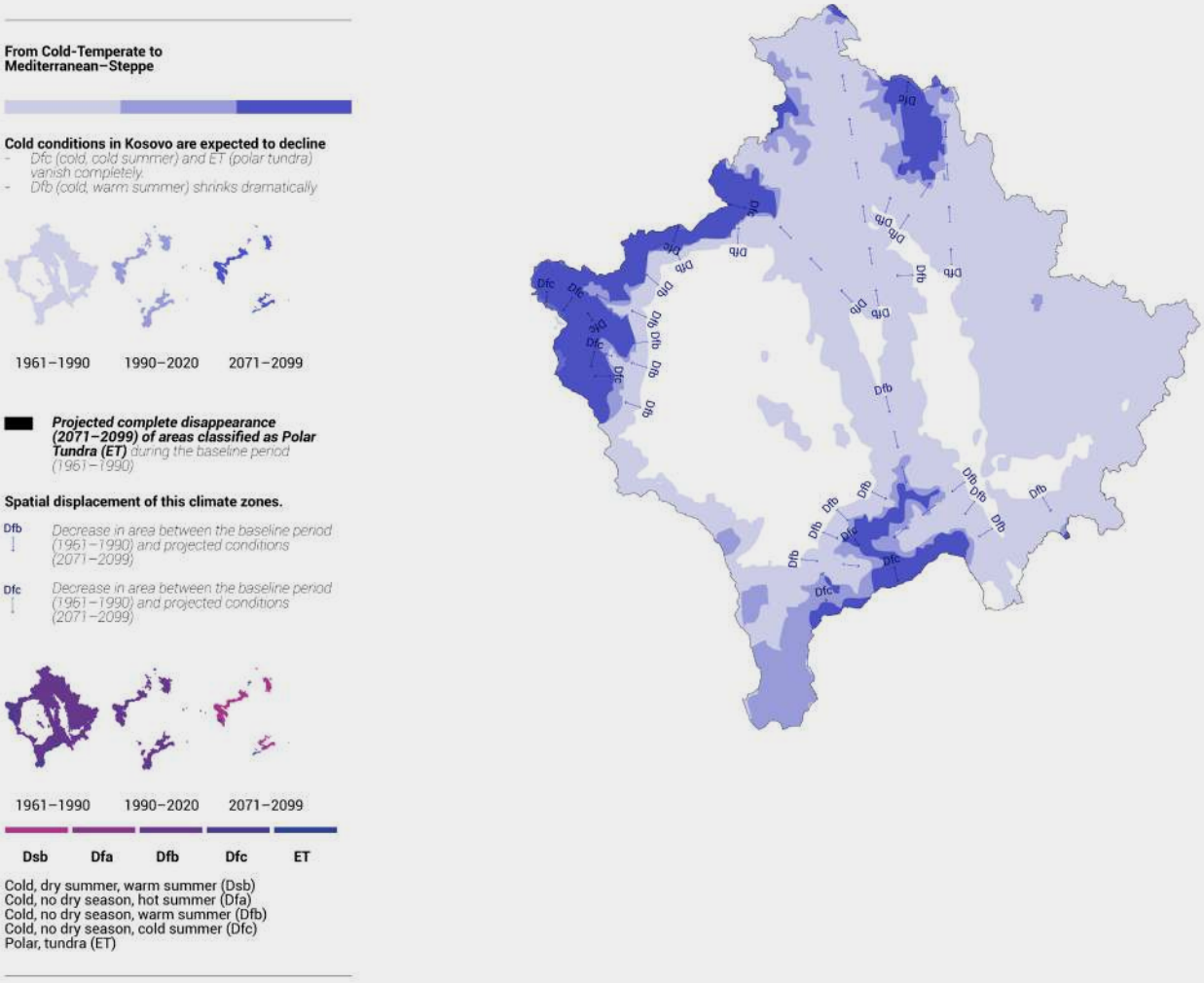


Figure 23 — Decline of Cold Climate Zones in Kosovo

Figure 23 illustrates the progressive decline of cold climate zones in Kosovo, showing a marked shift from predominantly cold-temperate conditions during 1961–1990 toward warmer and more arid classifications by 2071–2099. High-altitude Dfc (cold, cold summer) and ET (polar tundra) zones that characterized the historical climate are projected to vanish entirely, while Dfb (cold, warm summer) areas shrink dramatically. The map highlights substantial spatial displacement of climate zones, with cold classes (Dfc, Dfb, Dsb) retreating to higher elevations.
Source: Beck, H. E., T. R. McVicar, N. Vergopolan, A. Berg, N. J. Lutsko, A. Dufour, Z. Zeng, X. Jiang, A. I. J. M. van Dijk, & D. G. Miralles (2023).

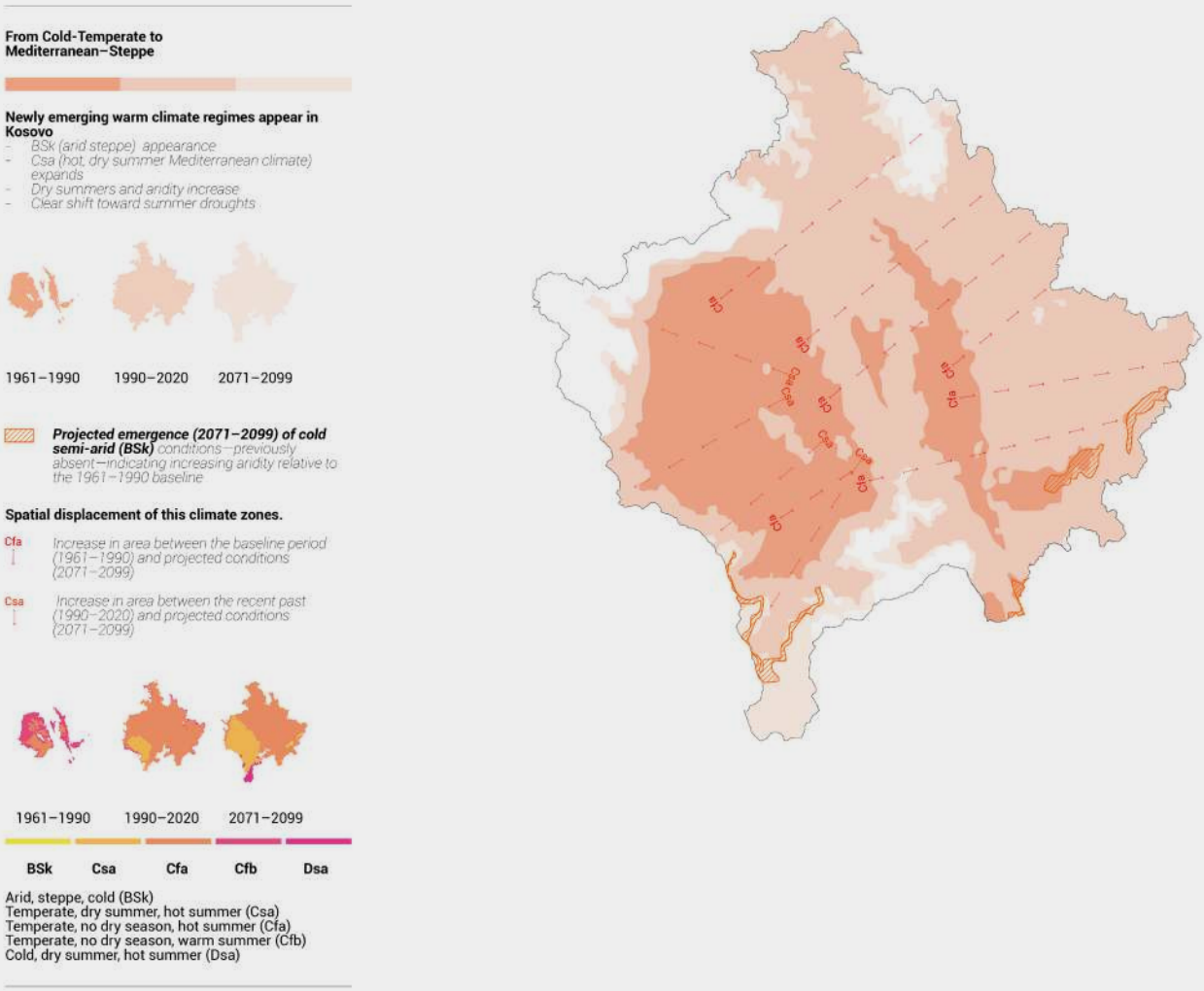


Figure 24 — Newly emerging warm climate regimes appear in Kosovo

Figure 24 emphasizes the growth of warm and dry climates in Kosovo, complementing the cold-zone retreat shown in Figure 23. While the baseline climate (1961–1990) was dominated by cold-temperate classifications, the recent past (1990–2020) introduced Csa (Mediterranean hot, dry summer) climates in lowlands and expanded Cfa (hot summer, no dry season) areas. Projections for 2071–2099 show a clear shift toward Mediterranean–steppe conditions, with BSk (cold steppe) emerging for the first time and Csa spreading extensively. Dry-summer climates (Csa, Dsa) increase in elevation, reflecting intensifying summer drought and reduced precipitation. Together, these patterns confirm a transition to hotter, more arid climate regimes, with steppe and Mediterranean systems replacing much of the former cold-temperate landscape.

Source: Beck, H. E., McVicar, T. R., Vergopolan, N., Berg, A., Lutsko, N. J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A. I. J. M., & Miralles, D. G. (2023). High-resolution (1 km) Köppen–Geiger maps for 1901–2099 based on constrained CMIP6 projections.

As the Köppen–Geiger projections extend into the 21st century, the maps reveal a profound transformation. Several key dynamics stand out:

1. Northward advance of Mediterranean climates (Csa, Csb):
From the south—Greece, Albania, and North Macedonia—Mediterranean climates begin to expand and creep into Kosovo's southern valleys. This process brings hotter, drier summers with prolonged dry-season stress, conditions historically uncommon in Kosovo. By mid- to late-century under high-emission scenarios (SSP5-8.5), these Mediterranean classifications could dominate much of southern Kosovo, fundamentally reshaping both agriculture and ecological systems.

2. Contraction of temperate climates (Cfb):
The once-dominant Cfb zone, representing temperate and humid conditions, retreats significantly. It survives primarily in central and northern Kosovo, often at slightly higher altitudes, but its characteristics shift toward warmer annual averages. This shrinking and warming of the Cfb belt reduces the climatic buffer that once separated Kosovo from Mediterranean regimes, effectively erasing the middle ground that supported a rich diversity of forests and mixed agricultural systems.

3. Retreat of cold mountain climates (Dfb):
The alpine Dfb classification shrinks dramatically, confined to the highest ridges of the Sharr Mountains and the Accursed Mountains. Snow-reliant ecosystems that depended on sustained cold seasons become increasingly vulnerable. Winters shorten, snowpack reliability declines, and precipitation shifts toward rain rather than snow. The ecological consequence is the fragmentation or disappearance of cold-adapted habitats, leading to the potential local extinction of species unable to migrate or adapt.

4. Emergence of climate stress gradients:
As Mediterranean climates push northward, while continental climates retreat upward into diminishing alpine pockets, Kosovo finds itself at the heart of a stress gradient. The lowlands will increasingly experience heat and drought, while highlands will endure unstable snow and precipitation regimes. This dual stressor landscape creates challenges not only for biodiversity but also for water resources, agriculture, and forestry.

These projected changes mirror and reinforce findings from CMIP6 model ensembles, the World Bank's Climate Change Knowledge Portal (CCKP), and regional assessments by IUCN and USAID, which all converge on several central themes:

- Hotter, drier summers are becoming the new norm, with greater frequency of heatwaves.
- Declining snow reliability and shorter winters are expected, undermining hydrological cycles and threatening ecosystems dependent on snowmelt.
- Water stress and scarcity will become structural challenges, particularly in southern and western Kosovo, exacerbated by shifts in seasonal precipitation.
- Forestry and agriculture face unprecedented strain, with species such as European beech (Fagus sylvatica) and Norway spruce (Picea abies) projected to experience significant decline in viability.
- Biodiversity corridors and species migration become critical concerns, as Kosovo lies at a crossroads of northward and altitudinal shifts in flora and fauna.

Taken together, the Köppen–Geiger projections position Kosovo and the Balkans as one of Europe's frontline regions of climatic transformation. The Balkans, long described as a buffer zone between Mediterranean and continental climates, are now increasingly pulled into the Mediterranean system. This shift has profound implications:

- For ecosystems: loss of cold-climate refugia and homogenization of habitats.
- For agriculture: increased vulnerability of traditional crops and pressure to transition toward drought-resistant varieties.
- For water governance: declining snowpack and shifting rainfall patterns jeopardize river flows and groundwater recharge, raising the stakes for transboundary water cooperation.
- For land-use planning: the disappearance of once-stable climate identities requires new frameworks of adaptive spatial and ecological governance.

In sum, the Köppen–Geiger maps make visible a future in which Kosovo's climatic profile becomes increasingly Mediterranean, while its alpine zones contract into isolated remnants. What was once a land of climatic diversity and transition risks becoming a landscape of ecological vulnerability. These transformations are not only environmental but also social and political, demanding rethinking of resource management, adaptation policies, and cross-border ecological collaboration in the decades ahead.

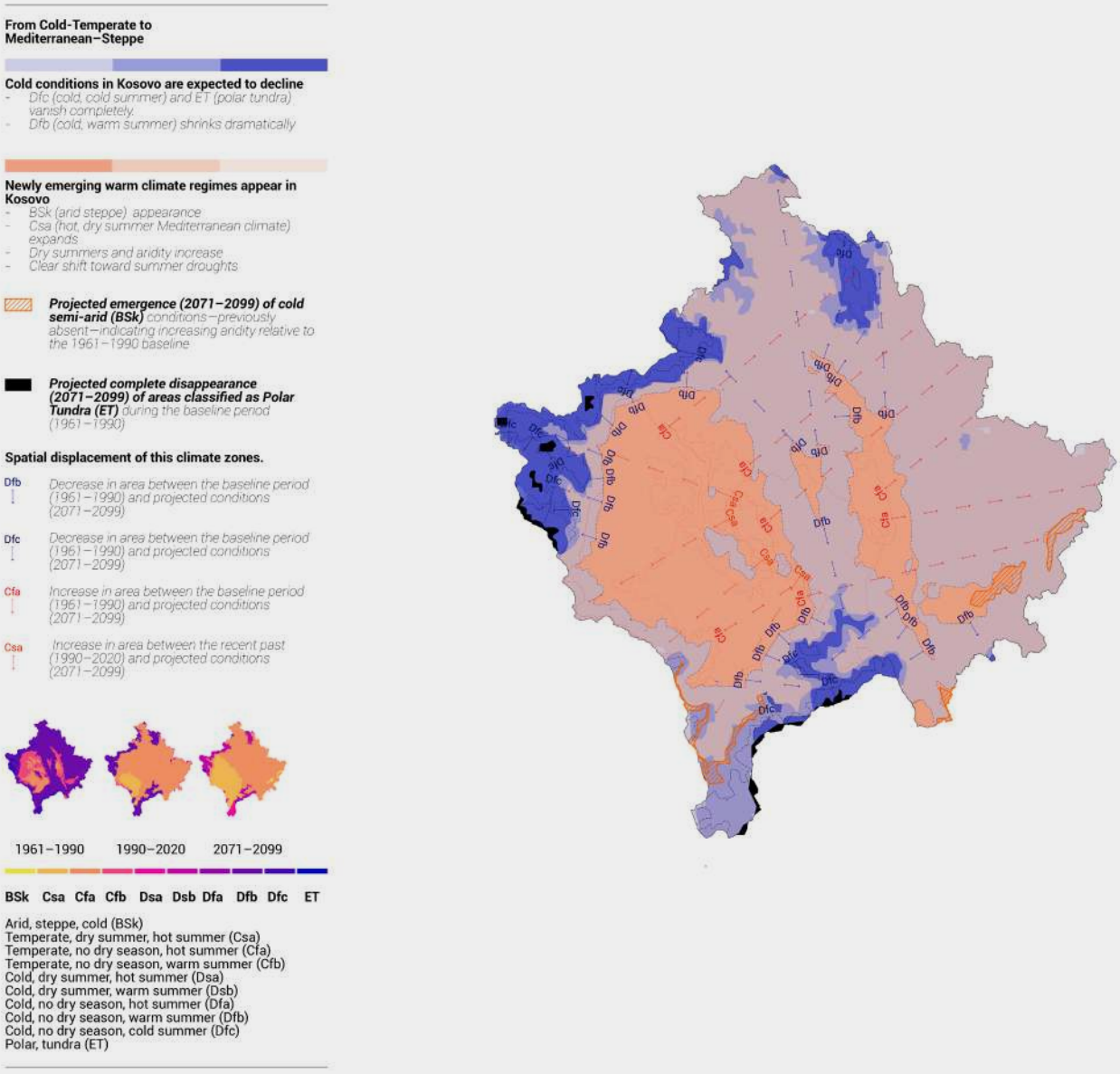


Figure 25 — Spatial Displacement of Climate Zones in Kosovo under Historical, Recent, and Future Conditions

This map illustrates the spatial displacement and evolution of Köppen–Geiger climate zones in Kosovo across three time periods: the baseline (1961–1990), recent past (1990–2020), and future projections (2071–2099). Cold-temperate climates (Dfc, Dfb, ET) are retreating toward higher elevations, with polar tundra (ET) projected to disappear entirely. Simultaneously, warm and dry climates (Csa, BSk, Dsa) are expanding into lower-lying regions, reflecting increasing temperatures, intensifying summer droughts, and rising aridity. Arrows indicate the direction of climate zone movement, highlighting a general shift from cold, humid conditions toward Mediterranean–steppe regimes, with implications for ecosystems, water resources, and agricultural suitability.

Source: Beck, H. E., McVicar, T. R., Vergopolan, N., Berg, A., Lutsko, N. J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A. I. J. M., & Miralles, D. G. (2023). High-resolution (1 km) Köppen–Geiger maps for 1901–2099 based on constrained CMIP6 projections.

Limitations and good practice

While Köppen–Geiger classifications are a powerful tool to visualize climate trajectories, they remain proxies rather than direct ecological outcomes. A change in class should not be read as an automatic biome shift: ecosystems also depend on soils, CO_2 fertilization effects, disturbance regimes (such as fire or pests), invasive species, and land-use dynamics. The maps indicate climatic potential, not guaranteed vegetation transformations. Moreover, Kosovo's complex terrain adds another layer of uncertainty. Even at 1-km resolution, high-relief processes like snow–ice feedbacks or orographic precipitation are not fully resolved, meaning mountainous areas such as the Sharr and Kopaonik ranges must be interpreted with caution and ideally paired with local meteorological and ecological monitoring. Finally, while confidence layers in the dataset illustrate the spread among models within a given emissions scenario, they do not encompass the broader uncertainty between scenarios themselves — a gap that becomes more pronounced toward the end of the century. For best practice, these projections should therefore be treated as boundary conditions and combined with ground-based observation, ecological knowledge, and adaptive land management strategies to avoid over-interpretation.

CLIMATE CHANGE HOTSPOT

7

KOSOVO IS A CLIMATE HOTSPOT, WARMING FASTER THAN THE GLOBAL AVERAGE WITH HOTTER, DRIER SUMMERS, WETTER WINTERS, SHRINKING SNOW COVER, AND SHIFTING CLIMATE ZONES. THESE CHANGES HEIGHTEN RISKS TO WATER, AGRICULTURE, FORESTS, AND BIODIVERSITY, WHILE LIMITED ADAPTIVE CAPACITY AND CROSS-BORDER DEPENDENCIES MAKE WATER-FOCUSED ADAPTATION AND REGIONAL COOPERATION URGENT.

South-Eastern Europe is increasingly recognized as a climate change hotspot, with the Western Balkans experiencing warming at a rate higher than the global average. [3]
The region's recent extreme events — such as the widespread wildfires in 2017 and 2022 and the severe floods that struck Kosovo in 2023 — are expected to grow in both frequency and intensity due to ongoing atmospheric warming. [4]

Kosovo sits at the junction of continental and Mediterranean climate regimes and spans steep elevation gradients from lowland basins to the Sharri/Šar and Bjeshkët e Nemuna/Accursed ranges. That geography concentrates climate contrasts over short distances and amplifies risk: basins are prone to summer heat and dryness, while uplands increasingly experience intense cold-season rainfall and rain-on-snow events. This physical setting places Kosovo within southern–southeastern Europe's well-documented hotspot of rapid warming, drying summers, and intensifying heavy precipitation in the cool season—patterns identified by the IPCC and recent WMO/C3S assessments for Europe. [5-6] In short, the region is warming fast, summers are becoming hotter and drier, and heavy precipitation episodes are strengthening, especially outside summer; Kosovo displays all three signals.

Recent experience underscores this shift. The January 2023 floods affected multiple municipalities, damaging homes, public facilities and infrastructure, and prompting coordinated UN support and loss estimates.[7] At the same time, European climate reporting documents an exceptional run of heat in 2023–2024 and record-setting heatwaves in southeastern Europe, consistent with a step-change in summer heat stress.[8] These observations mirror the modeled future: under CMIP6/EURO-CORDEX pathways, Kosovo warms substantially (strongest in summer), summers tend to dry, and the cool season becomes wetter and more variable, with more frequent extremes (heatwaves, droughts, heavy rainfall) and declining snow cover—especially under higher emissions.[9]

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[3] OSCE (2024). Regional Assessment for South-Eastern Europe: Security Implications of Climate Change. Vienna: Organization for Security and Co-operation in Europe
[4] NATO Strategic Foresight Branch. Climate Security Impact Assessment: Strategic Foresight 3 Analysis Supporting the NATO Climate Change and Security Impact Assessment. NATO HQ, July 2024. https://www.act.nato.int/publications
[5] IPCC (2021). AR6 WGI Regional Fact Sheet: Europe.
[6] C3S & WMO (2024). European State of the Climate 2023—Summary
[7] UNDP Kosovo & SURGE Data Hub (2023). Damage Assessment Following the January 2023 Floods.
[8] C3S & WMO (2025). European State of the Climate 2024.
[9] IPCC (2021). AR6 WGI Regional Fact Sheet: Europe.

Translating those physical changes into spatially explicit terms helps decision-makers. High-resolution (1 km) Köppen–Geiger mapping based on a constrained subset of CMIP6 models shows a clear re-zoning of climate envelopes across Kosovo through the century.[1] In the recent baseline (1995–2014), most of the country is continental with warm summers; alpine/mountain climates dominate the highest ridges; and a modified Mediterranean influence is already visible in the southwest. By mid-century, continental zones shrink as winters soften and snow reliability declines; Mediterranean-type conditions push further into western and southern lowlands; and mountain belts trend toward milder temperate regimes (less snow, more winter rain). By late century under high emissions, Mediterranean climates dominate most lowlands and plains, continental classes nearly vanish, and alpine signatures persist only on the highest crests. In effect, Kosovo's climatic identity shifts from continental–mountain toward Mediterranean–temperate—compressing ecological gradients and resetting baselines for biodiversity, water, and land use. [10]

That re-zoning has direct ecological implications. Cold-adapted and moisture-dependent species lose area and connectivity as alpine habitats contract and snow seasons shorten; heat and summer aridity raise stress on beech/spruce belts and increase fire weather risk; and riparian systems face alternating flood–drought extremes as hydro-seasonality changes (wetter winters/springs, drier summers).[11-12] For agriculture, longer, hotter summers and greater year-to-year variability challenge rain-fed systems, increase irrigation demand, and elevate pest and disease pressures typical of warmer regimes. The World Bank's Kosovo CCDR notes substantial near-term adaptation investment needs to protect people and assets from these hazards.[13]

Water is the common thread in Kosovo's multi-hazard profile. In the warm season, higher evaporative demand and fewer summer rains drive soil-moisture deficits, crop stress, and competition for water among households, farms, ecosystems, and hydropower. In the cool season, heavier precipitation and a higher rain-to-snow ratio elevate pluvial/riverine flood and erosion risk, especially where floodplains are constrained. Reduced snow storage shifts and shortens spring melt pulses, altering baseflows and challenging both ecosystems and water-resource operations. These dynamics make freshwater and riparian habitats strategic priorities for monitoring, restoration, and nature-based retention.

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[10] Beck, H. E., et al. (2023). High-resolution (1 km) Köppen–Geiger maps for 1901–2099 based on constrained CMIP6 projections. Scientific Data 10, 724. https://doi.org/10.1038/s41597-023-02549-6
[11] IUCN ECARO (2023). ADAPT Kosovo Scoping Study—Nature-Based Solutions.
[12] JRC (2024). Status of Environment and Climate in the Western Balkans.
[13] World Bank (2024). Kosovo Country Climate and Development Report (CCDR).

Vulnerability is heightened by exposure and capacity constraints. Kosovo's reliance on rain-fed agriculture and limited storage makes it sensitive to warm-season drying; forests and protected areas must absorb faster-than-historical climatic shifts; infrastructure built for a different hydro-climate faces new failure modes; and health systems bear combined burdens from heat, air quality, and vector-borne risks.[14] Regional biodiversity and NbS assessments in the Western Balkans emphasize strengthening nature-based resilience (e.g., floodplain reconnection, riparian buffers, forest structure management) to buffer these changes while delivering co-benefits.

Climate risk in Kosovo also has transboundary and security dimensions. NATO's climate–security assessment highlights how climate stressors complicate operations and resilience across the Balkans, including where NATO is present; OSCE mapping identifies climate–security "hotspots" and promotes cross-border risk reduction. Basin-scale governance matters, as floods and droughts propagate along shared rivers and across borders, making data-sharing, early warning, and cooperative investments essential. [15]

All projections and observations carry uncertainty, and good practice requires acknowledging limits. Köppen–Geiger classes are climate proxies—not biomes—so ecological outcomes also depend on soils, CO_2 fertilization, disturbance (fire, pests), invasive species and land use. Complex terrain processes (orographic precipitation, snow/ice feedbacks) can be under-resolved even at 1 km, so mountain interpretations should be paired with local meteorological and ecological monitoring. Confidence layers portray model spread within scenarios, not between them, and scenario uncertainty widens toward late century. Projections are best treated as boundary conditions to guide adaptive, iterative management rather than point predictions.

Taken together, these lines of evidence explain why Kosovo qualifies as a climate hotspot: (i) it sits within Europe's warming–drying belt where changes are among the strongest; (ii) its topography and position at a climate boundary concentrate risk and accelerate climate-zone shifts; (iii) observed extremes already align with modeled tendencies toward drier, hotter summers and heavier cool-season rainfall; (iv) exposure and capacity constraints magnify impacts on water, ecosystems, agriculture, health and infrastructure; and (v) transboundary rivers and a sensitive security context raise the stakes for cooperative risk management.[6] For this project, that points to practical priorities: water-centric adaptation (monitoring, riparian restoration, nature-based retention, ecological flows), protection and connection of mountain refugia and climate corridors, integration of climate services into municipal and sectoral decisions, and alignment with CCDR-identified investments and regional NbS programs to crowd-in finance and implementation capacity.

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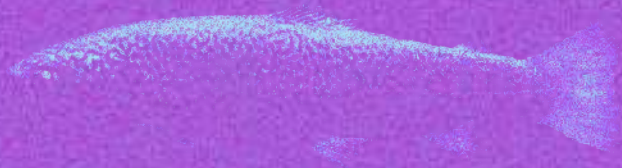
[14] World Bank (2024). Kosovo Country Climate and Development Report (CCDR).
[15] UN Kosovo Team (2024). Annual Results Report 2023 (flood impacts).

CONCLUSIONS

8



PROJECTIONS CONSISTENTLY SHOW KOSOVO WARMING SUBSTANTIALLY, WITH SUMMER HEAT INTENSIFYING AND WINTERS BECOMING MILDER, ALONGSIDE WETTER COOL SEASONS AND DRIER SUMMERS. THESE CHANGES DRIVE A PRONOUNCED SHIFT FROM COLD-TEMPERATE TO MEDITERRANEAN–STEPPE CLIMATES, WITH ALPINE ZONES RETREATING TO THE HIGHEST PEAKS. THE RESULTING PATTERNS HEIGHTEN RISKS OF HEAT STRESS, DROUGHT, AND FLOODS, WITH PROFOUND IMPLICATIONS FOR BIODIVERSITY, AGRICULTURE, AND WATER SYSTEMS. ADAPTATION WILL DEPEND ON TARGETED MONITORING, CLIMATE-RESILIENT LAND MANAGEMENT, AND PROACTIVE WATER AND HAZARD PLANNING.

What the projections consistently show. Across scenarios, Kosovo warms substantially, with the magnitude driven by global emissions: roughly +1.5–2.0 °C under SSP1-2.6 and up to +4.5–6.5 °C under SSP5-8.5 by late century. Summer warming is strongest (up to +6–7 °C in SSP5-8.5), while winters also warm notably. Precipitation redistributes rather than simply rising or falling: wetter winters (+5% to >+15%) and drier summers (–5% to –25%), implying higher flood risk in the cool season and greater drought stress in the warm season. Heatwaves increase in frequency (up to 2–3×), and snow cover duration declines sharply, especially in the mountains. These signals are consistent across the CMIP6 ensemble and EURO-CORDEX downscaling for the Western Balkans.

What this means spatially (Köppen–Geiger). Translating those changes into climate zones reveals a clear geographic shift: expansion of Mediterranean-type conditions into lowlands and valleys, contraction of temperate (Cfb) belts toward higher ground, and strong retreat of cold mountain (Dfb/Dfc) climates to the highest crests (e.g., Sharri/Šar and Bjeshkët e Nemuna/Accursed). This spatially explicit lens aligns with the physical projections and makes the implications legible for biodiversity, land use and water management.

At-a-glance: climate-zone trajectory

- Baseline (1995–2014). Continental climate dominates (cold winters, warm summers); mountain/alpine climate in the highlands (Šar, Bjeshkët e Nemuna) with long snowy winters; a transitional Mediterranean influence in the southwest (Prizren, Gjakova).
- Mid-century (2040–2059). Continental zones shrink (milder winters, reduced snow); Mediterranean influence expands into western/southern lowlands; high mountain zones shift toward milder temperate mountain climates (less snow, more winter rain, shorter cold season).
- End-century (2080–2099, high emissions). Mediterranean climates dominate most lowlands and central plains; continental climate nearly disappears; alpine character persists only at the highest peaks—effectively a transition toward a Mediterranean–temperate country profile.

Implications for biodiversity, land and water

- Biodiversity: Rising heat and summer aridity, shorter winters, and altered runoff regimes push species and communities beyond current climatic envelopes—particularly cold-adapted and moisture-dependent taxa. Connectivity (northward and upslope) becomes critical as ranges shift.
- Forests & agriculture: Stress increases for beech and spruce; crop and pasture systems face hotter, drier summers and greater inter-annual variability. Adaptation hinges on drought-tolerant varieties, shade/windbreaks, soil moisture conservation, and fire risk management.
- Water & hazards: Drier summers and heavier cool-season rains raise both drought (growing season) and flood/erosion (winter–spring) risks. Reduced snowpack shortens and shifts meltwater pulses, affecting baseflows and storage. These dynamics elevate the importance of freshwater and riparian habitats—your stated priority for monitoring and restoration.

Limitations and good practice

Köppen–Geiger classes are climate proxies, not biomes: actual ecological outcomes also depend on soils, CO_2 fertilization, disturbance (fire/pests), invasives and land use. Complex terrain processes (e.g., orographic precipitation, snow/ice feedbacks) can be under-resolved even in high-resolution products, so mountain interpretations should be paired with local monitoring. "Confidence" layers reflect model spread within a scenario, not between scenarios—uncertainty widens toward late century. Treat projections as boundary conditions to guide adaptive, evidence-based management.

Actionable next steps:

- Targeted monitoring: Establish long-term monitoring for freshwater/riparian systems (flows, temperatures, ecological condition), snowpack and soil moisture to capture the shifting hydro-seasonality.
- Spatial planning for resilience: Use Köppen–Geiger shifts alongside habitat maps to identify ecotone hotspots, climate corridors (upslope/northward), and priority restoration areas in Prizren, Suharekë and the Sharri landscapes.
- Sectoral adaptation: Support forest transition strategies (species mix, structure, fuel management) and agricultural adaptation (varietal shift, irrigation efficiency, soil/vegetation cover).
- Risk management: Prepare for wetter winters/drier summers via floodplain reconnection, green retention, drought plans and transboundary water cooperation.
- Iterative assessment: Revisit scenarios and downscaled datasets periodically; integrate local observations to reduce uncertainty and adjust actions over time.

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About EC

EC Ma Ndryshe is a community-based organization, established in 2006, committed to sustainable development through an inclusive approach.

EC's activism envisions a Kosovo where democratic governance is participatory, transparent, and accountable, ensuring that institutions, communities, and stakeholders work together towards sustainable development.

This vision promotes inclusive decision-making, stronger policies, and greater public participation, ensuring that sustainability is an integral part of governance at both local and national levels.

Through better institutional coordination, evidence-based policymaking, and citizen engagement, EC's work aims to bridge the gap between communities and institutions, ensuring that good governance leads to tangible and lasting change.

Vision statement

"Empowering a resilient and inclusive Kosovo, where communities actively shape sustainable, digitalized, and conscientious institutions."

Mission statement

"EC Ma Ndryshe supports democratic governance and sustainable development in Kosovo by fostering sustainable socioeconomic, cultural, and green growth through digital education, environmental stewardship, community mobilization, advocacy for participatory public decision-making, and the cultivation of strategic partnerships."

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