Deliverable Phase 1 – Climate risk assessment

Adapt on clime change in APV (CLIMACHANGE)

Republic of Serbia / Autonomous Province of Vojvodina

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HORIZON-MISS-2021-CLIMA-02-01 - Development of climate change risk assessments in European regions and communities based on a transparent and harmonised Climate Risk Assessment approach

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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	This deliverable provides a comprehensive assessment of relative and agricultural drought risks in the Autonomous Province of Vojvodina (APV), Serbia, as part of Phase 1 of the CLIMACHANGE project. Applying the standardized and harmonized CLIMAAX Framework, this report identifies key drought hazards, assesses regional vulnerabilities and exposures, and outlines preliminary conclusions. It sets a robust foundation for informed policymaking, targeted adaptation planning, and stakeholder engagement to enhance climate resilience and sustainability in Vojvodina.
Project name	Adapt on clime change in APV (CLIMACHANGE)
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Leading Institution	Provincial Secretariat for Urban Planning and Environmental Protection
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Abbreviations and acronyms

Abbreviation / acronym	Description
APV	Autonomous Province of Vojvodina
CAP	Common Agricultural Policy
CLIMAAX	CLIMate risk and vulnerability Assessment framework and toolbox
CLIMACHANGE	Adapt on Climate Change in APV (Project Acronym)
CRA	Climate Risk Assessment
GDP	Gross Domestic Product
IPA	Instrument for Pre-Accession Assistance
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
RCP	Representative Concentration Pathway
RHMZ	Hydrometeorological Institute of Serbia
SMA	Soil Moisture Anomalies
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathway

Executive summary

This report presents the results of the first phase of the CLIMACHANGE project conducted within the CLIMAAX framework, addressing critical climate risks—particularly **relative and agricultural drought**—in the Autonomous Province of Vojvodina (APV), Serbia. The deliverable supports the objectives of the Horizon Europe call HORIZON-MISS-2021-CLIMA-02-01, which emphasizes transparent and harmonized climate risk assessments to inform regional climate adaptation strategies.

Motivation:
Drought—both relative and agricultural—poses a mounting threat to Vojvodina's highly productive and agriculture-dependent economy. Climate change has led to increasing temperature extremes, shifting precipitation patterns, and prolonged dry spells, which directly undermine crop yields, rural livelihoods, and food security. The CLIMACHANGE project was initiated to provide local and regional stakeholders with scientifically grounded risk assessments that will serve as a foundation for future adaptation planning and resilient decision-making.

Main Results and Findings:
During this initial phase, the project team applied the CLIMAAX multi-risk assessment methodology to systematically evaluate both relative and agricultural drought risks. Key activities and outcomes included:

- **Methodological Scoping and Workflow Selection:**
  Two distinct workflows were applied—Workflow #1 assessing relative drought risk, and Workflow #2 evaluating agricultural drought impacts (e.g., crop yield loss due to precipitation deficit and evapotranspiration stress).
- **Data-Driven Risk Analysis:**
  The analysis revealed significant spatial variability in drought hazards, with districts such as North Banat, South Banat, Central Banat, and parts of South Bačka showing the highest combined exposure and vulnerability levels.
- **Stakeholder Involvement:**
  Stakeholder mapping and initial consultations involved institutions, local municipalities, agricultural cooperatives, NGOs, and research organizations, ensuring a participatory foundation for future phases.

The main conclusions of this assessment phase are:

- Both **relative and agricultural drought risks are intensifying** and are projected to escalate through 2080 under multiple climate scenarios (SSP1-2.6, SSP3-7.0, SSP5-8.5).
- **Agricultural drought**, even under a low-emission scenario (RCP2.6), is projected to cause up to 45% crop yield loss for maize and over 36% for wheat in some areas—clearly illustrating its economic and food security implications.
- Regions with insufficient irrigation systems, poor soil water retention, and high dependency on rain-fed agriculture face **disproportionate socio-economic risks**, including income instability, reduced agricultural productivity, and rural depopulation.
- **Current capacities and infrastructure are inadequate** to mitigate the rising risks, especially in high-risk districts such as Central and North Banat.

This deliverable provides a baseline for Phases 2 and 3, laying the groundwork for tailored adaptation strategies, advanced predictive modeling, and deeper stakeholder engagement.

Key Takeaways:

- Urgent, district-level interventions—particularly in high-risk areas—are needed to prevent long-term economic and environmental degradation.
- Expanding adaptive infrastructure (e.g., irrigation systems), enhancing data collection, and integrating drought-resistant agricultural practices are essential steps toward resilience.
- Stronger stakeholder collaboration and consistent policy integration will be vital to ensure sustainable adaptation pathways across the region.

By combining insights on both relative and agricultural drought, this assessment delivers a comprehensive understanding of Vojvodina's current and future climate risks, empowering regional actors to design evidence-based, locally tailored resilience strategies.

1 Introduction

1.1 Background

Vojvodina, an autonomous province located in the northern part of Serbia, is one of the country's most agriculturally significant regions. Spanning extensive plains, Vojvodina is characterized by fertile soils and developed agricultural infrastructure, which make it a central hub for crop production. The region's agricultural sector, primarily reliant on maize, wheat, soybeans, sunflowers, and sugar beet, contributes substantially to Serbia's GDP and is vital for both the local and national economy.

However, Vojvodina faces growing threats from climate change, particularly droughts. Increased temperatures, prolonged dry periods, and shifting rainfall patterns are negatively impacting soil moisture, crop yields, and groundwater availability. These climatic changes threaten not only regional water security and agricultural productivity but also rural livelihoods, economic stability, and environmental sustainability. Drought refers to periods of significantly reduced water availability compared to the climatological norms of a given region, rather than an absolute absence of precipitation. In the case of Vojvodina, drought is primarily characterized by deviations in seasonal precipitation levels, increased evapotranspiration due to rising temperatures, and declining soil moisture reserves. These conditions disrupt agricultural productivity, water availability, and ecosystem balance, making drought a critical climate risk for the region.

Historically, climate risk assessments in Vojvodina have depended largely on reactive approaches using historical meteorological data and limited predictive modeling. Comprehensive risk management frameworks that systematically integrate hazard, exposure, and vulnerability data are still developing, highlighting a pressing need for structured methodologies and improved adaptation planning at the regional level.

1.2 Main objectives of the project

The CLIMACHANGE project, implemented within the CLIMAAX framework (HORIZON-MISS-2021-CLIMA-02-01), aims to provide a comprehensive climate risk assessment specifically targeting relative and agricultural drought risks in Vojvodina. The project's primary objectives are to:

- **Implement the CLIMAAX Risk Assessment Methodology**: Apply a standardized and harmonized multi-risk assessment framework for accurately identifying drought hazards, vulnerable zones, and affected communities.
- **Enhance Precision in Risk Mapping**: Integrate high-resolution local datasets, such as regional climate projections and soil moisture indices, to achieve more precise identification and mapping of drought-prone areas.
- **Support Data-Driven Policymaking**: Generate scientifically robust data and insights that will directly inform regional adaptation policies, disaster risk reduction strategies, and agricultural planning.
- **Strengthen Local Adaptation Capacities**: Enhance the capabilities of local stakeholders—including policymakers, farmers, and community organizations—to manage climate-related risks effectively through targeted education and capacity-building initiatives.

The project addresses critical gaps identified in previous assessments, including limited availability of detailed local climate projections, inconsistent historical records, and insufficient coordination among stakeholders.

1.3 Project team

The project employs an interdisciplinary approach, bringing together a diverse team of experts and stakeholders:

- ***Scientists and Technical Experts***: Specialists *in climatology, hydrology, and data analytics responsible for generating climate projections, modeling drought indices, and assessing vulnerability. (Sanja Mrazovac Kurilić, PhD in Environmental Protection and Predrag Ilić PhD in interdisciplinary fields of environmental engineering)*
- ***Environmental Specialists****: Professionals evaluating ecological impacts, soil quality, agricultural productivity, and water* resource *sustainability. Predrag Ilić PhD in interdisciplinary fields of environmental engineering and Sanja Mrazovac Kurilić, PhD in Environmental Protection)*
- ***Policy and Governance Advisors****: Experts tasked with ensuring the practical integration of climate risk findings into policy* frameworks *and regional development strategies. (Tatjana Đurić M.Sc of Agriculture and Teodora Subotić, advisor for projects)*
- ***Community Engagement Specialists****: Professionals managing stakeholder consultations, public workshops, and knowledge* dissemination *efforts aimed at building awareness and local capacities (Tatjana Đurić, M.Sc. of Agriculture) I Teodora Subotić economist, advisor for projects Sanja Mrazovac Kurilić, PhD in Environmental Protection Predrag Ilić PhD PhD in interdisciplinary fields of environmental engineering and Sanja Mrazovac Kurilić, PhD in Environmental Protection)*
- ***Institutional Representatives****: Officials from local government bodies, including the Provincial Secretariat for Agriculture, Water* Management*, and Forestry, actively involved in shaping policies based on project insights. (Tatjana Đurić M.Sc of Agriculture and Teodora Subotić, economist, advisor for projects)*

This interdisciplinary composition ensures that the project outcomes are scientifically credible, practically relevant, and effectively implemented across all governance levels.

1.4 Outline of the document's structure

This document is organized in a logical, structured format designed to clearly communicate the findings and recommendations from the climate risk assessment:

- **Executive Summary**: Offers a concise overview of the project's objectives, methods, key findings, and conclusions, *enabling* readers to quickly grasp the essence of the deliverable without requiring further reading.
- **Introduction**: Provides background information about the region, the rationale behind conducting the climate risk *assessment*, key project objectives, and the structure of the team involved.
- **Climate Risk Assessment – Phase 1**: Details the methodology adopted from the CLIMAAX Handbook, including risk identification, hazard assessment, vulnerability, and exposure analyses, supported by relevant maps and data visualizations.
- **Conclusions (Phase 1)**: Summarizes the critical findings from the first phase, identifying high-risk areas, main vulnerabilities, and the primary adaptation challenges that need urgent attention.

- **Progress Evaluation and Future Contribution**: Explains how the findings from Phase 1 will guide subsequent phases, outlines achieved milestones, and highlights future tasks, including stakeholder workshops, policy recommendations, and data refinement.
- **Supporting Documentation**: Lists all project outputs, datasets, visualizations, and communication materials produced in this phase and made available through the Zenodo repository.
- **References**: Provides a structured and consistent listing of all sources cited within the document.

This structure ensures that readers, policymakers, and stakeholders can efficiently navigate the document, comprehend the risk assessment findings clearly, and readily identify actionable next steps for enhancing climate resilience in Vojvodina.

2 Climate risk assessment – phase 1

In alignment with the CLIMAAX Framework, this section outlines the initial phase of the Climate Risk Assessment (CRA) for Vojvodina, focusing on relative and agricultural drought risks. The process encompasses Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment, and Monitoring & Evaluation. This document details the Scoping phase, setting the foundation for subsequent steps.

2.1 Scoping

The Scoping phase establishes the objectives, context, and stakeholder engagement necessary for a comprehensive CRA. This foundational step ensures that the assessment is tailored to regional needs and aligns with policy frameworks.

2.1.1 Objectives

Purpose and Expected Outcomes: The primary purpose of this CRA is to systematically evaluate relative and agricultural drought risks in Vojvodina, aiming to: **Identify Vulnerable Areas**: Determine regions within Vojvodina that are most susceptible to relative and agricultural droughts. **Assess Impacts**: Determine the potential effects of droughts on agricultural productivity, economic stability, and socio-economic conditions.

Integration into Policy and Decision-Making: The outcomes of this CRA are intended to: **Inform Regional Policies**: Provide data-driven insights to regional authorities for developing targeted climate adaptation and disaster risk reduction strategies. **Guide Resource Allocation**: Assist in prioritizing investments in infrastructure, technology, and practices that mitigate drought risks. **Enhance Stakeholder Awareness**: Increase understanding among farmers, local communities, and businesses about drought risks and adaptive measures.

Limitations and Boundaries: Several constraints may influence the CRA: **Data Availability**: Limited access to high-resolution climate projections and detailed soil moisture data may affect the precision of future risk assessments. **Stakeholder Engagement**: Ensuring active participation from diverse stakeholders, including marginalized communities, is crucial yet challenging. **Uncertainties in Climate Models**: Variability in climate projections introduces uncertainties that must be acknowledged in the analysis.

2.1.2 Context

Historical and Current Situation of Climate Risk Management in Vojvodina: Historically, climate hazards in Vojvodina have been addressed using reactive measures, often after damage from events had already occurred. Previous risk assessments predominantly relied on historical meteorological data, satellite monitoring, and isolated crop modeling studies. While valuable, these approaches provided limited capacity for predictive modeling and lacked comprehensive socio-economic analysis. Institutions such as the Hydrometeorological Institute of Serbia (RHMZ) and regional agricultural research institutes have contributed valuable data; however, a standardized, proactive, and region-specific climate risk assessment framework remains a critical gap.

Problem and Regional Context: The primary challenge addressed by the CLIMACHANGE project is the increasing intensity and frequency of droughts in Vojvodina, aggravated by climate change, poor water resource management, and insufficient adaptation strategies. Droughts in Vojvodina have become recurrent phenomena, leading to significant reductions in crop yields, threatening rural livelihoods, and exacerbating socio-economic inequalities. As agriculture represents the economic

foundation of the region—contributing substantially to employment and the national GDP—effective management of these climate risks is crucial for maintaining economic stability and ensuring food security. The regional vulnerability is further amplified by inadequate water management infrastructure, limited irrigation capacity, inefficient water use practices, and inconsistent implementation of existing climate adaptation strategies. The increasing drought frequency thus highlights the urgent need for coordinated, evidence-based adaptation actions and resilient agricultural practices.

Governance Context of Climate Risk Assessment: Vojvodina's climate risk assessment and adaptation measures are governed by multiple national and regional policies, strategies, and legal frameworks, including:

- **Climate Change Adaptation Program (2023–2030)**: Outlines measures and responsibilities to enhance resilience to climate risks, specifically highlighting agriculture and water resources.
- **Law on Climate Change (2021)**: Establishes the regulatory framework for systematic reporting and the obligation to integrate climate risks into planning processes.
- **Water Management Strategy of Serbia (2017-2034)** Aims to improve monitoring and forecasting of water resources and to support adaptive water resource management.
- **Irrigation Development Program of Serbia (2022-2032)** A government-supported initiative focused on expanding and upgrading irrigation infrastructure to mitigate drought impacts on agriculture.
- **Development plan of AP Vojvodina for the period 2023-2030** with the force of ensuring continuity in planning the development of the Province.
- **Low-Carbon Development Strategy of the Republic of Serbia for the Period 2023–2030**, with Projections until 2050
- **Water Management Strategy for the Territory of the Republic of Serbia until 2034**
- **Water Management Plan for the Territory of the Republic of Serbia until 2027**
- **Nature Protection Program of the Republic of Serbia for the Period 2021–2023**
- **Energy Development Strategy of the Republic of Serbia until 2025**, with Projections until 2030
- **Draft Energy Development Strategy of the Republic of Serbia until 2040**, with Projections until 2050
- **Draft Integrated National Energy and Climate Plan of the Republic of Serbia for the Period until 2030**, with a Vision until 2050
- **Agriculture and Rural Development Strategy of the Republic of Serbia for the Period 2014–2024**
- **Draft National Program for Agriculture for the Period 2022–2024**
- **Draft National Rural Development Program for the Period 2022–2024**

Table 2-1 Key competencies of the local self-government unit in drafting important documents in the field of environmental protection and connection with climate change

Column name	*Column name*	*Column name*
Law on Environmental Protection ("Official Gazette of RS", No. 135/2004, 36/09, 36/09, 72/09, 43/09, 14/16, 76/18, 95/18, 95/18, 94/24) Art. 13	Plans and programs of the autonomous province and local self-government units Within the competencies determined by this and a special law, they adopt their plans and programs for the management of natural resources and goods, in accordance with the strategic documents referred to in Article 12 of this Law and their specifics.	Climate change should be integrated into these plans
Law on Environmental Protection ("Official Gazette of RS", No. 135/2004, 36/09, 36/09, 72/09, 43/09, 14/16, 76/18, 95/18, 95/18 and 94/24) Art. 61 to Art. 68	Adoption of external plans, which are an integral part of emergency response plans, Programs and plans of the autonomous province and local self-government units. Adopts the environmental protection program on its territory, i.e. local action and rehabilitation plan.	Climate change should be integrated into these plans as part of the risk assessment. Adaptation measures in LGU plans
Law on Waste Management ("Official Gazette of RS", No. 36/09, 88/10, 14/16 and 95/18, 35/23) Art. 13	Local waste management plan The Assembly of the local self-government unit adopts a local waste management plan which defines the objectives of waste management on its territory in accordance with the Strategy	The unresolved issue of waste leads to air emissions. Solving this problem has a positive effect
Law on Air Protection ("Official Gazette of RS", No. 36/10 of 30/13 and 26/21) Art. 31, 33, 36	Air quality plans Adoption of air quality plans Short-term action plans Plans in case of transboundary air pollution	Relationship between air quality, i.e. the amount of GHG gases and mitigation and adapt action measures
Law on Environmental Noise Protection ("Official Gazette of RS", No. 36/09, 88/10, 96/2021) Art. 21	Environmental noise protection action plan	The connection between transport and noise and hence climate change
Law on Nature Protection ("Official Gazette of RS", No. 36/09, 88/10, 91/10, 14/16, 95/18 and 71/21) Art. 52	Protected area management plan	Climate change should be integrated into these plans due to the sensitivity of biodiversity

Despite these policies, their implementation at the regional level remains inconsistent due to fragmented institutional responsibilities, limited coordination, and financial constraints, highlighting the importance of targeted interventions and improved cross-sectoral collaboration.

Relevant sectors and climate change impacts: Several key sectors in Vojvodina are particularly vulnerable to climate change, notably drought risks, and include:

- **Agriculture**: As the predominant sector, agriculture faces severe impacts from drought, including reduced crop yields (maize, wheat, soybeans), increased irrigation demands, and loss of agricultural productivity, negatively affecting rural livelihoods.

- **Water Resources**: Climate variability intensifies water shortages, challenging the existing water management systems, including groundwater extraction and surface water management.
- **Biodiversity and Ecosystems**: Extended drought periods degrade wetlands and natural habitats, diminishing biodiversity, ecosystem services, and overall environmental quality.
- **Energy Sector**: Hydropower generation is adversely affected by reduced river flows during droughts, while energy demands rise due to increased use of irrigation and cooling systems in hotter summers.
- **Rural Communities**: Socioeconomic repercussions include job losses, rural migration, increased poverty, and heightened vulnerability among already disadvantaged groups.

External Influences on the Problem: Climate risk management in Vojvodina is influenced by several external initiatives and international obligations:

- **European Union Integration and Climate Directives**: Serbia's EU accession process requires compliance with the EU Green Deal, Common Agricultural Policy (CAP), and broader climate directives, influencing regional adaptation strategies.
- **Danube River Basin Management Plans**: As part of the Danube Basin, Vojvodina is bound by transnational agreements on water management, affecting local decision-making and resource allocation.
- **International Cooperation and Funding Programs**: Initiatives like the Instrument for Pre-Accession Assistance (IPA) and World Bank-supported climate resilience programs offer financial and technical resources, promoting improved regional climate adaptation strategies.

Possible Adaptation Interventions: Addressing drought risks in Vojvodina requires an integrated, multi-sectoral approach that incorporates technological, nature-based, policy-driven, and community-focused interventions. These measures aim to enhance resilience by mitigating the impacts of water deficits relative to climatological norms:

- **Improved Water Management Infrastructure**: Expanding and modernizing irrigation networks, promoting water-efficient technologies (e.g., drip irrigation, precision agriculture), and optimizing water distribution systems to ensure efficient use during dry periods.
- **Diversification of Crop Selection**: Encouraging the adoption of drought-resilient and water-efficient crop varieties suited to fluctuating precipitation patterns, supported through targeted research, incentives, and farmer training programs.
- **Integrated Water Resource Management**: Implementing watershed management strategies, enhancing groundwater recharge, restoring wetlands, and adopting nature-based solutions to improve regional hydrological balance.
- **Enhanced Monitoring and Early Warning Systems**: Strengthening forecasting capabilities, real-time soil moisture tracking, and early warning dissemination to enable proactive drought response measures and informed decision-making.
- **Soil and Land Conservation Practices**: Promoting sustainable land management strategies such as no-till farming, cover cropping, organic amendments, and agroforestry to improve soil moisture retention and reduce drought susceptibility.
- **Economic Instruments and Risk Mitigation**: Developing financial mechanisms, such as subsidized drought insurance schemes and government-backed resilience funds, to

support farmers and agribusinesses in managing economic losses during prolonged dry conditions.

- **Capacity Building and Community Engagement**: Conducting training programs, awareness campaigns, and multi-stakeholder workshops to enhance local adaptive capacity and strengthen community-based drought preparedness initiatives.

Through these coordinated interventions, Vojvodina can effectively manage **drought** risks, ensuring long-term agricultural sustainability, reducing socio-economic vulnerabilities, and enhancing regional resilience to climate variability and future water availability challenges.

2.1.3 Participation and risk ownership

The stakeholder involvement process in the CLIMACHANGE project commenced with a comprehensive stakeholder mapping exercise, identifying and categorizing key actors based on their influence, interest, and roles in managing climate risks, particularly drought. This initial step provided a clear foundation for subsequent stakeholder engagement activities, ensuring inclusive and representative participation throughout the project lifecycle.

Relevant Stakeholders: The stakeholder landscape for this project is diverse, encompassing multiple sectors and governance levels:

Governmental Institutions: Provincial Secretariat for Agriculture, Water Management, and Forestry: Central authority responsible for policy formulation, agricultural support measures, drought mitigation initiatives, and allocation of resources; **Hydrometeorological Institute of Serbia (RHMZ)**: Provides essential meteorological data, drought forecasting, and early warning systems; **Ministry of Environmental Protection**: Oversees policy development and enforcement regarding climate adaptation and sustainable resource management and **Municipal Authorities**: Local governments actively involved in the practical implementation of drought mitigation measures, land-use planning, and supporting local farming communities.

Non-Governmental Organizations and Civil Society Groups: Environmental NGOs: Advocate for sustainable agriculture, soil and water conservation, and climate change adaptation and **Community-based Organizations**: Facilitate local participation, awareness-raising campaigns, and mobilization of rural communities towards climate resilience.

Academia and Research Institutions: University of Novi Sad (Faculty of Agriculture, Faculty of Sciences, etc.): Conducts climate-related research, including the development of drought-resistant crops and sustainable soil management practices and **Institute of Field and Vegetable Crops, Novi Sad**: Provides critical research data on crop productivity and resilience under drought conditions, supporting the agricultural sector.

Private Sector and Agribusiness: Agricultural Cooperatives and Farmer Associations: Key groups directly affected by drought risks, whose involvement ensures the practical relevance and applicability of adaptation strategies; **Agricultural Insurance Providers**: Offer drought risk insurance, contributing to financial stability for farmers and **Irrigation Technology Providers**: Supply and innovate irrigation solutions crucial for sustainable agricultural water management.

Vulnerable and Exposed Groups: Particular attention was paid to involving representatives of groups most vulnerable to drought impacts: **Smallholder Farmers**: Highly susceptible due to limited resources and dependence on rain-fed agriculture; **Rural Communities and Agricultural Workers**: Directly affected economically by reduced agricultural productivity and employment opportunities; **Livestock Producers**: Facing water shortages and reduced feed availability, heavily impacted by

prolonged drought periods and **Women and Youth in Rural Areas**: Often facing additional socio-economic barriers, their representation ensures inclusive and equitable adaptation strategies.

Regulation of Risk Ownership: Risk ownership within the climate adaptation context is clearly defined among stakeholders based on their responsibilities, capabilities, and influence: **Governmental Entities**: Hold primary responsibility for policy formulation, resource allocation, and enforcement of adaptation measures; **Agricultural Producers and Private Sector**: Responsible for implementing adaptive agricultural practices, investment in irrigation infrastructure, and ensuring compliance with regulatory frameworks; **Academic and Research Institutions**: Provide scientific knowledge, data, and innovative solutions for effective climate risk management and **Civil Society Organizations**: Facilitate community participation, advocate for vulnerable groups, and support the dissemination of knowledge and adaptive practices. Defining acceptable levels of risk within the community involves balancing economic viability, environmental sustainability, social equity, and technological capacities. Stakeholder consultations revealed a general consensus that proactive, preventative measures should aim at minimizing drought-related economic and social disruptions, particularly safeguarding agricultural productivity and rural livelihoods.

Communication of Results: Effective communication of the project's outcomes will leverage multiple channels to ensure comprehensive dissemination and uptake: **Regional and Local Authorities**: Policy briefs and detailed reports will guide informed policymaking, enabling authorities to prioritize climate adaptation measures; **Farmers and Agribusinesses**: Practical guidelines, early warning alerts, and educational materials will be delivered through workshops, seminars, and targeted digital platforms; **Academia and Scientific Community**: Results and datasets from the CRA will be shared via publications, academic forums, and open-access repositories to promote broader research collaboration and **General Public and Civil Society**: Awareness campaigns through traditional media (radio, TV), social networks, and local media will ensure wider public awareness of drought risks and the importance of sustainable water and agricultural practices. By strategically involving diverse stakeholders and clearly defining risk ownership, the CLIMACHANGE project ensures broad acceptance, effective implementation, and long-term sustainability of climate risk management strategies in Vojvodina.

2.2 Risk Exploration

Risk exploration initiates the process of climate risk assessment by broadly screening and identifying climate-related hazards, exposures, and vulnerabilities relevant to Vojvodina. This phase involves engagement with key stakeholders and considers public concerns to ensure that the assessment focuses on the most significant and apparent risks affecting the region, thereby guiding subsequent detailed analyses and targeted adaptation strategies.

2.2.1 Screen risks (selection of main hazards)

The **CLIMACHANGE** project addresses climate hazards that significantly impact agricultural productivity, economic stability, and community livelihoods in Vojvodina. Through stakeholder consultations and preliminary assessments, the following key climate-related hazards have been identified as the most relevant: **Droughts** – increasingly frequent periods of reduced water availability compared to climatological norms, driven by variable precipitation, rising temperatures, and heightened evapotranspiration, disrupting agricultural productivity, water supply, and overall ecosystem balance; **Heatwaves** – prolonged periods of extreme summer temperatures that exacerbate drought conditions, placing stress on crops, livestock, and water resources; **Flooding Events** – although less frequent, localized heavy rainfall can lead to flash floods, damaging

agricultural land, infrastructure, and disrupting water management systems; **Soil Degradation and Desertification** – extended drought conditions accelerate soil erosion, loss of organic matter, and land degradation, reducing long-term agricultural viability. Among these hazards, **drought** has emerged as the most critical and recurring challenge affecting the entire region. Given its significant impact on water availability, food security, and economic resilience, it will be the primary focus of this risk assessment.

Droughts in Vojvodina have intensified over recent decades, significantly impacting all districts, with the most severe effects observed in **North Banat, South Banat, Central Banat, and parts of South Bačka**. These areas are particularly vulnerable due to inadequate irrigation infrastructure, sandy soils with low water retention capacity, and a high dependency on rain-fed agriculture. The most affected groups include **farmers and agricultural producers**, who face reduced crop yields, increased production costs, and economic losses; **rural communities and agricultural workers**, experiencing unemployment, income instability, and deteriorating socio-economic conditions; **livestock producers**, struggling with water shortages and reduced feed availability; and **smallholder farmers**, who are particularly vulnerable due to their limited access to financial resources, infrastructure, and adaptive technologies.

Observed and Expected Hazards: Current observations indicate increasing frequency and severity of drought events, decreasing groundwater levels, significant fluctuations in precipitation, and rising temperatures. Future climate projections suggest: Continued warming trends leading to intensified drought conditions; Increased frequency of extreme drought events, especially during critical crop-growing seasons; Reduced overall precipitation and altered rainfall patterns further exacerbating drought impacts and potential for increased soil degradation and declining agricultural productivity in the medium and long term. These projected hazards underline the urgency of implementing effective adaptation measures.

This Climate Risk Assessment explicitly focuses on **drought**, given its significant implications for regional agriculture, the economy, and community resilience.

Available Data and Knowledge: The available datasets in Zenodo.

Further Data and Knowledge Needs: Despite the available datasets, several information gaps remain and must be addressed to improve future risk assessments: **High-resolution climate projections** specific to Vojvodina, essential for localized vulnerability mapping and risk analysis; **Detailed socio-economic data**, particularly data on income distribution, rural employment patterns, and access to adaptive resources, to enhance vulnerability assessments; .Addressing these gaps will strengthen the region's capacity for proactive drought risk management, enabling more effective planning and targeted adaptation measures.

2.2.2 Workflow selection

This section identifies and elaborates on the risk workflows selected from the CLIMAAX Handbook, relevant to the identified hazard of drought. Additionally, it details the specific vulnerable groups and exposed areas that will be addressed within these workflows.

2.2.2.1 Workflow #1: Relative Drought Risk Management

Exposed Areas: This workflow specifically targets **areas across Vojvodina**, focusing on regions which are highly sensitive to fluctuations in precipitation and soil moisture. Based on historical drought occurrences and preliminary vulnerability assessments, the following districts have been

identified as particularly exposed: **North Banat District** – characterized by sandy soils, low irrigation coverage, and a high proportion of rain-fed farming; **South Banat District** – frequently experiences drought events due to limited adaptive infrastructure; **Central Banat District** – marked by declining groundwater levels and inadequate irrigation systems, leading to significant drought vulnerability; **Bačka District** – noted for substantial reliance on rain-fed crops and limited water retention in soils, exacerbating drought impacts.

Vulnerable Groups: The **relative drought** workflow will explicitly consider groups most directly impacted by drought, including **smallholder farmers**, who are particularly vulnerable due to limited financial resources, inadequate access to irrigation technologies, and higher dependency on climate-sensitive crops; **rural communities**, facing socio-economic instability due to reduced agricultural productivity, job losses, and diminished food security; **agricultural workers**, experiencing decreased employment opportunities and economic hardship during prolonged drought periods; **livestock producers**, directly affected by decreased water availability and shortages of fodder, threatening animal health and economic viability; and **agribusinesses**, suffering reduced profitability due to lowered agricultural yields and increased operational costs linked to drought mitigation.

2.2.2.2 Workflow #2: Agricultural Drought Risk Management

Exposed Areas: Through an initial vulnerability analyses, we have pinpointed several districts as particularly at risk: North Banat District, (sandy soils, minimal irrigation, and a high reliance on rain-fed farming) ; South Banat District, known for frequent drought occurrences; Central Banat District, where declining groundwater levels and poor irrigation systems contribute to notable drought vulnerability; and Bačka District, where the heavy dependence on rain-fed crops and low soil water retention heighten the effects of drought.

Vulnerable Groups: This drought-related analysis will specifically address the groups most affected by such events. Smallholder farmers, rural communities, agricultural workers, livestock producers, agribusinesses...

2.2.3 Choose Scenario

Relevant Scenario Assumptions for Vojvodina:

Workflow #1:

Defined Scenario for **Historical Baseline (1981–2015):**

Scenario 0 (Historical) will serve as the baseline for assessing future projections and vulnerabilities, providing a reference point for evaluating climate trends and guiding strategic adaptation decisions.

To ensure a **comprehensive assessment** and meaningful results, two temporal horizons were selected to represent **various plausible future conditions**:

Near-future (up to 2050):

- Significant warming, leading to increased frequency, intensity, and duration of drought events.
- Substantial shifts in agricultural production patterns, necessitating greater reliance on irrigation and drought-resistant crops.
- Broader implementation of large-scale water management interventions and adaptive land-use policies.

Far-future (up to 2080):

- Severe climate impacts with frequent, prolonged, and intense drought conditions threatening regional agricultural viability.
- Drastic alterations in crop suitability, requiring fundamental transformations in regional agricultural systems.
- Increased risk of desertification and soil degradation in vulnerable areas, absent aggressive and sustained adaptation efforts.

Useful Scenarios from CLIMAAX Workflow: To frame this risk assessment practically and inform decision-making, the following standardized climate and socio-economic scenarios were selected from the CLIMAAX framework:

- **Shared Socio-Economic Pathways (SSPs) and RCPs**: **SSP1-2.6** (Sustainability pathway): Moderate population growth, increased environmental awareness, proactive policies; **SSP3-7.0** (Regional rivalry): High population growth, fragmented international collaboration, limited adaptation and **SSP5-8.5** (Fossil-fueled development): High economic growth, rapid technological development, but minimal climate action.

Additionally, scenarios incorporating future water demand and socio-economic development are critical to understanding potential resource constraints and socio-economic pressures affecting regional vulnerability.

Workflow #2:

Rcp26 scenario for period (2006-2050) will serve as the baseline for assessing future projections and vulnerabilities, providing a reference point for evaluating climate trends and guiding strategic adaptation decisions.

2.3 Risk Analysis

This section describes how the selected risk workflows from the CLIMAAX Handbook were systematically applied in the Vojvodina region. The analysis combined hazard, exposure, and vulnerability data to generate a comprehensive relative drought risk assessment. The primary datasets utilized correspond to the methodologies detailed in the CLIMAAX Handbook.

Risk assessment elements: The following core attributes were systematically analyzed:

- **Hazard Assessment:** historic drought conditions (**hazard_raw**)
- **Exposure Assessment:** cropland distribution, livestock density, population distribution, and water stress (**exposure_raw**)
- **Vulnerability Assessment:** share of rural population (**overall_ruralshr**) and GDP per capita (**overall_gdpcap**)

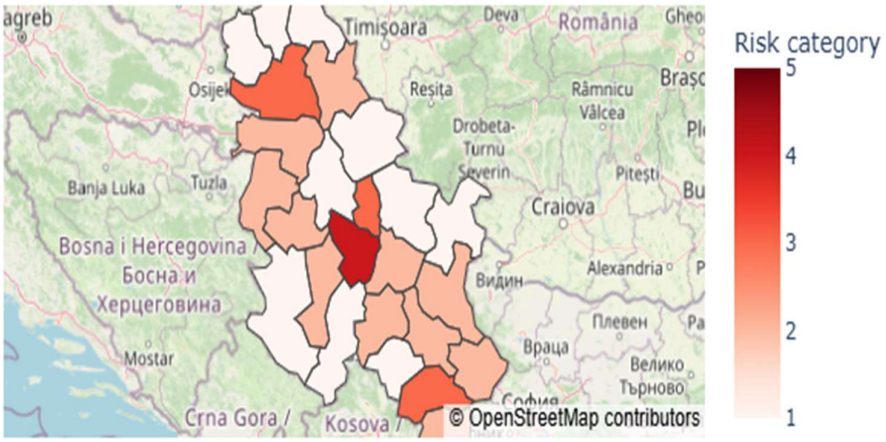

Figure 2-1 Drought Risk in Serbia (1:10 M), historic

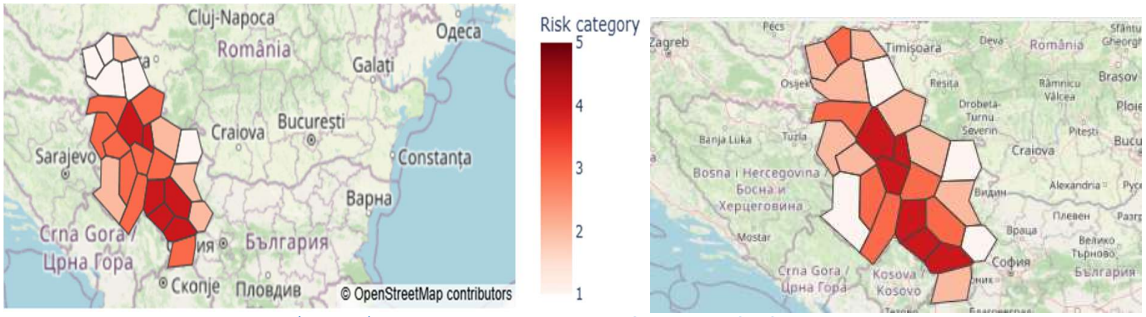

Figure 2-2 Drought Risk in Serbia (1:10 M), SSSP1-26 scenario, near future and far future

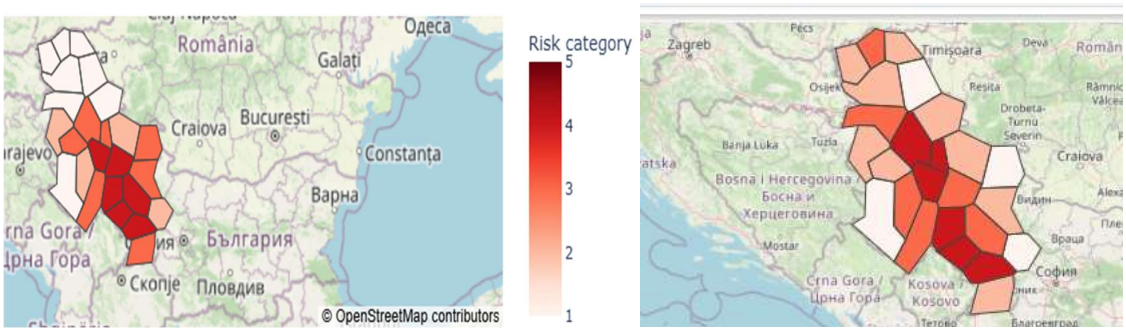

Figure 2-3 Drought Risk in Serbia (1:10 M), SSSP3-70 scenario, near future and far future

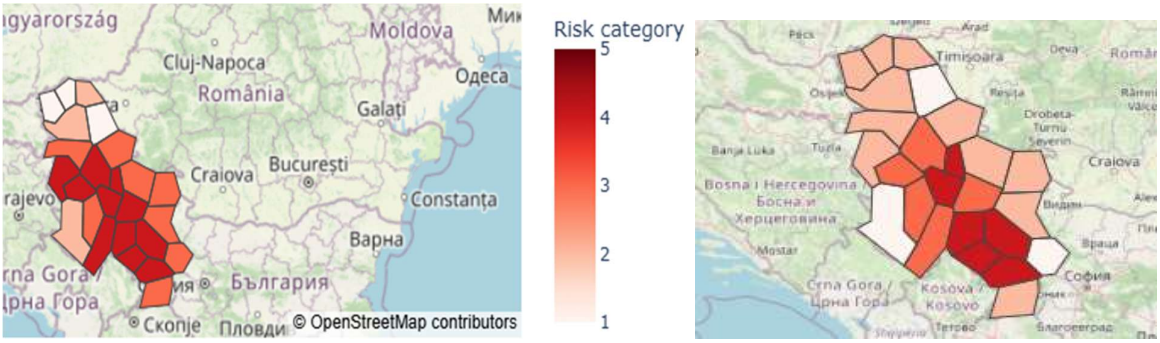

Figure 2-4 Drought Risk in Serbia (1:10 M), SSSP5-85 scenario, near future and far future

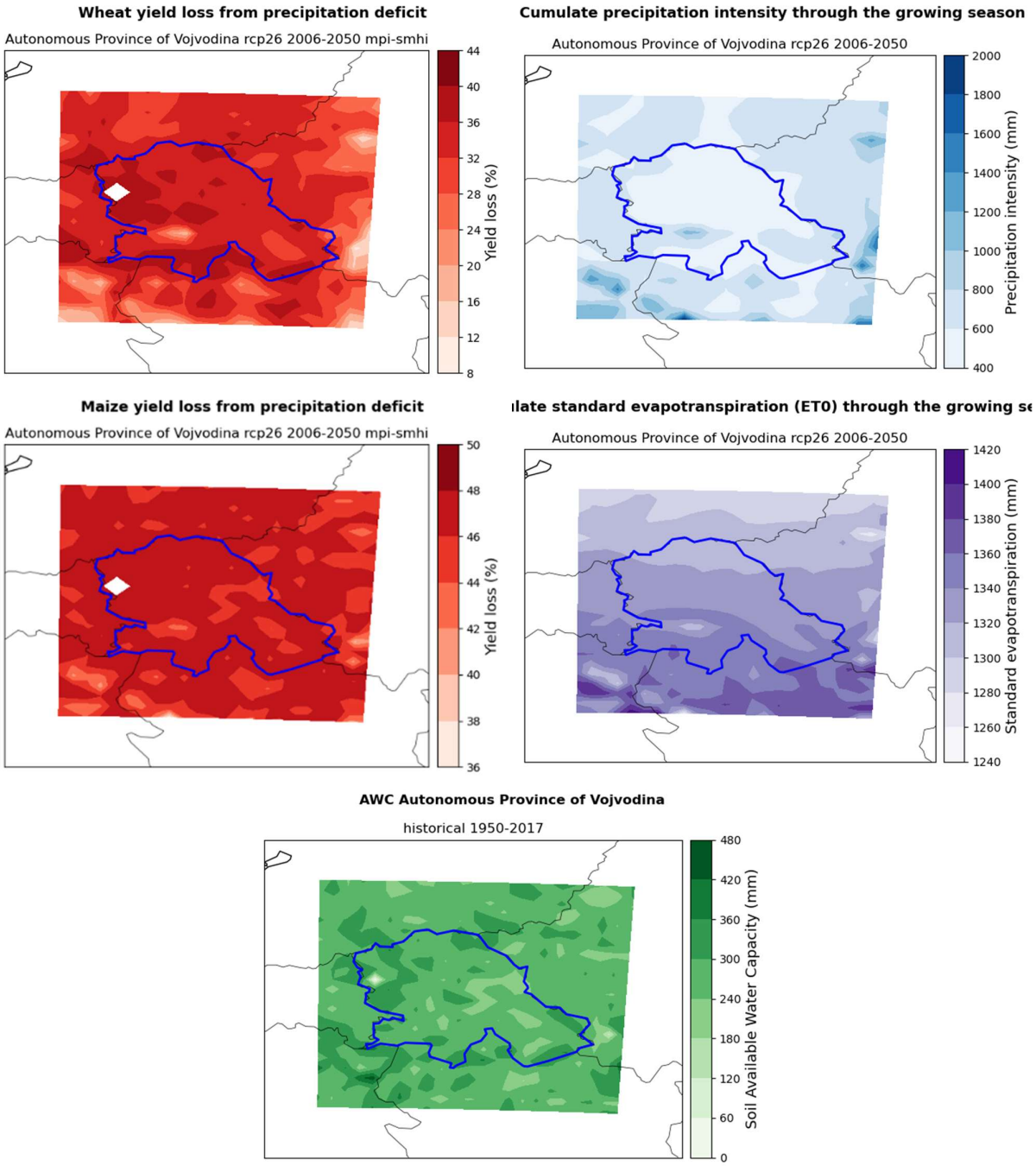

Figure 2-5 Agricultural drought Risk in Serbia (1:10 M), rcp26 scenario

2.3.1 Workflow #1: Relative Drought Risk Management

The first workflow primarily addresses relative drought risks, integrating data on drought hazards, water availability, agricultural exposure, and socio-economic vulnerability.

Table 2-2 Data overview workflow #1

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
Historical drought indices	Rural population share, GDP per capita	Cropland, Livestock density, Population	Drought risk categories (1–5)

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
(SPI), Soil Moisture Anomalies (SMA)		distribution, Water stress index	

2.3.1.1 Hazard assessment

Key findings include:

- Consistent drought occurrences across Vojvodina, particularly pronounced in Srem, South Banat, and South Bačka.
- increased drought intensity in recent decades, with drought events becoming more frequent and severe.
- persistent water deficits critical for agricultural productivity

2.3.1.2 Risk assessment

Integrating hazard, exposure, and vulnerability data provided a comprehensive risk classification into five categories (1 – lowest risk; 5 – highest risk), as depicted on the relative drought risk maps (Fig. 2.1-2.4).

Interpretation of the Drought Risk Maps (Fig. 2.1-2.4): The drought risk maps clearly delineates spatial variability in relative drought risks across Vojvodina (north part of Serbia only) :

- **Moderate Risk (Category 3 – medium red):** Evident in South Banat, and parts of South Bačka and Srem, reflecting substantial drought exposure, limited irrigation infrastructure, and socio-economic vulnerabilities.
- **Lower Risk (Categories 1–2 – lighter shades):** North Banat indicate relatively lower drought exposure due to better-developed infrastructure and lower rural vulnerability.

The mapped risk levels provide essential spatial targeting to prioritize adaptation measures effectively.

Summary and Recommendations Based on Risk Analysis:

- Districts categorized in the highest risk levels (especially South Banat, parts of South Bačka and Srem) require urgent, targeted adaptation interventions, including expanding irrigation, promoting drought-resistant crops, and implementing comprehensive soil conservation measures.
- Districts with high risk (North Banat) should prioritize improving irrigation systems, soil moisture retention practices, and proactive socio-economic measures, including drought insurance and farmer education programs.
- Moderate-risk areas can benefit from proactive measures focused on sustainable agricultural practices, better groundwater management, and improving socio-economic resilience through targeted community programs.

This detailed risk analysis provides critical spatial insights essential for informed regional adaptation planning, policy development, and resource allocation.

2.3.2 Workflow #2: Agricultural Drought Risk Management

Map title: Wheat yield loss from precipitation deficit

Scenario: RCP2.6 (2006–2050)

Wheat yield loss varies across the region, ranging from approximately 12% to 44%.

The central and eastern parts of Vojvodina experience higher losses, with red hues indicating more than 36% loss.

This suggests that precipitation deficits will significantly affect wheat production, even under a relatively optimistic climate scenario like RCP2.6.

Map title: Cumulative precipitation intensity through the growing season

Scenario: RCP2.6 (2006–2050)

Total rainfall during the growing season varies from 600 mm to 2000 mm. The central regions show lower precipitation intensity, which correlates with higher wheat and maize yield losses seen in other maps. Rainfall deficits during key growth periods are a primary driver of crop stress in the region.

Map title: Maize yield loss from precipitation deficit

Scenario: RCP2.6 (2006–2050)

Yield losses for maize are extremely high and widespread, with most of the region shaded deep red, indicating losses above 45%. Maize is more sensitive to water stress than wheat, likely due to higher water requirements during critical growth stages. This scenario points to severe production threats to maize even under low-emission pathways.

Map title: Cumulative standard evapotranspiration (ET0)

Scenario: RCP2.6 (2006–2050)

ET0 ranges from 1240 mm to over 1400 mm.

This represents the potential water loss due to evaporation and transpiration from crops and soil.

Higher ET0 values in the south and west of Vojvodina indicate greater water demand, contributing to crop yield stress when not offset by rainfall.

Map title: Available Water Capacity (AWC) Autonomous Province of Vojvodina (1950–2017)

AWC ranges from 60 mm to over 420 mm, indicating substantial soil water retention capacity.

Regions with lower AWC (lighter green) are more vulnerable to precipitation deficits.

This historical baseline is crucial for understanding drought resilience: areas with low AWC + high ET0 + low precipitation are most at risk.

2.4 Preliminary Key Risk Assessment Findings

The preliminary key risk assessment synthesizes findings from the hazard, exposure, and vulnerability analyses to evaluate climate-related risks comprehensively. Additional analyses are shown in Figures 2-6, 2-7, 2-8 and 2-9. This figures provides a systematic examination of relative drought risks across Vojvodina, offering a detailed analysis based on historical evidence, current trends, and potential future impacts under different scenarios.

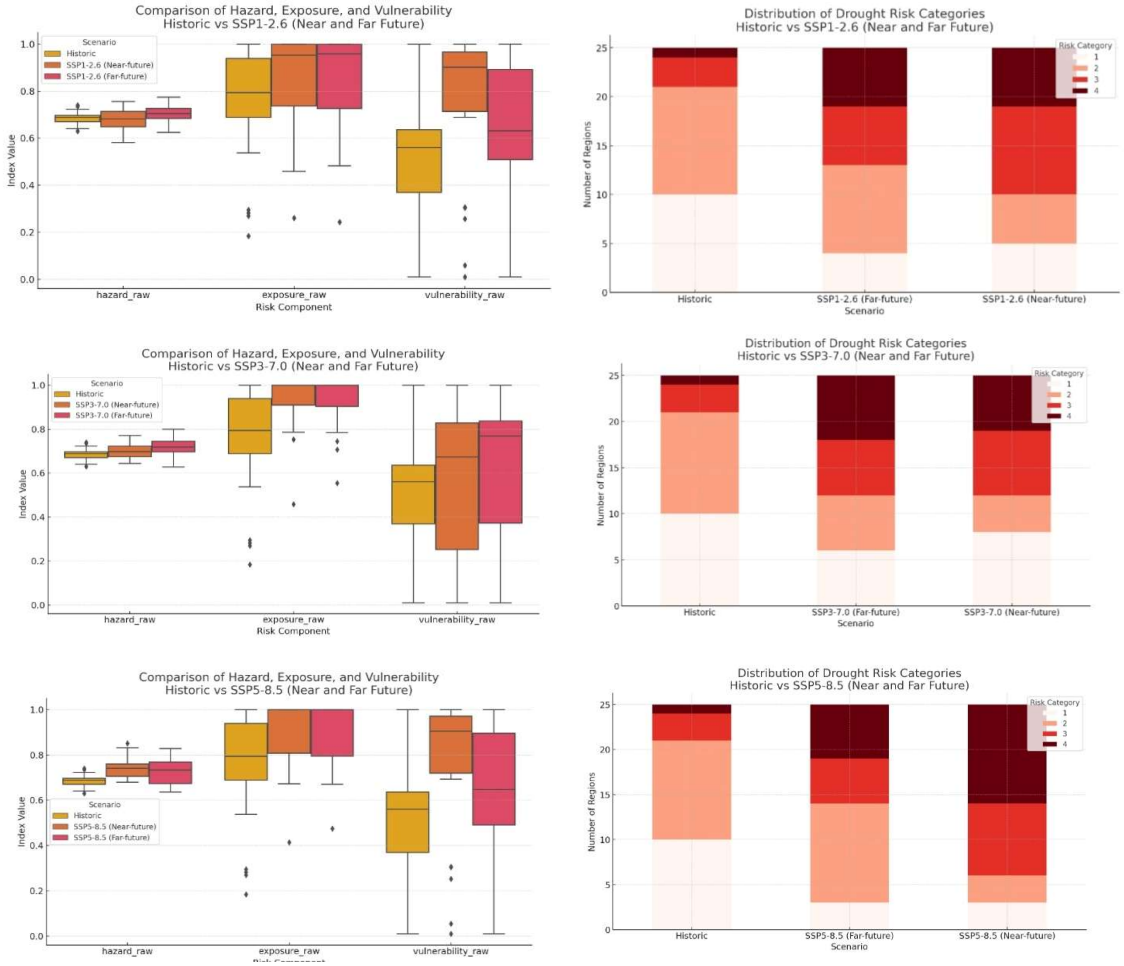

Figure 2-6 Relative drought Risk in Serbia - comparation of hazard, exposure, vulnerability and risk, under different scenarios

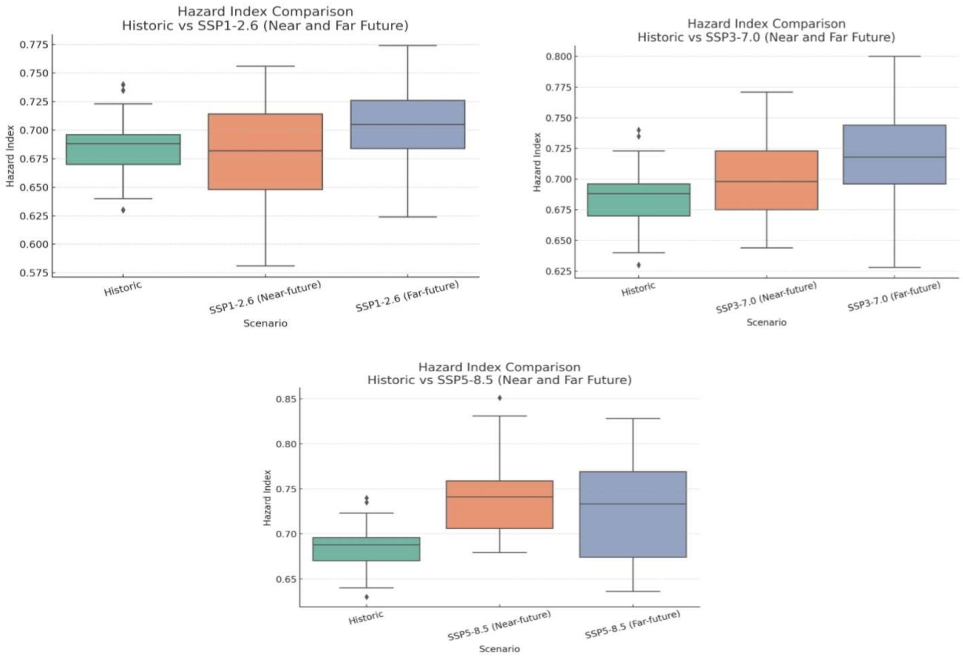

Figure 2-7 Relative drought Risk in Serbia - hazard index comparation under different scenarios

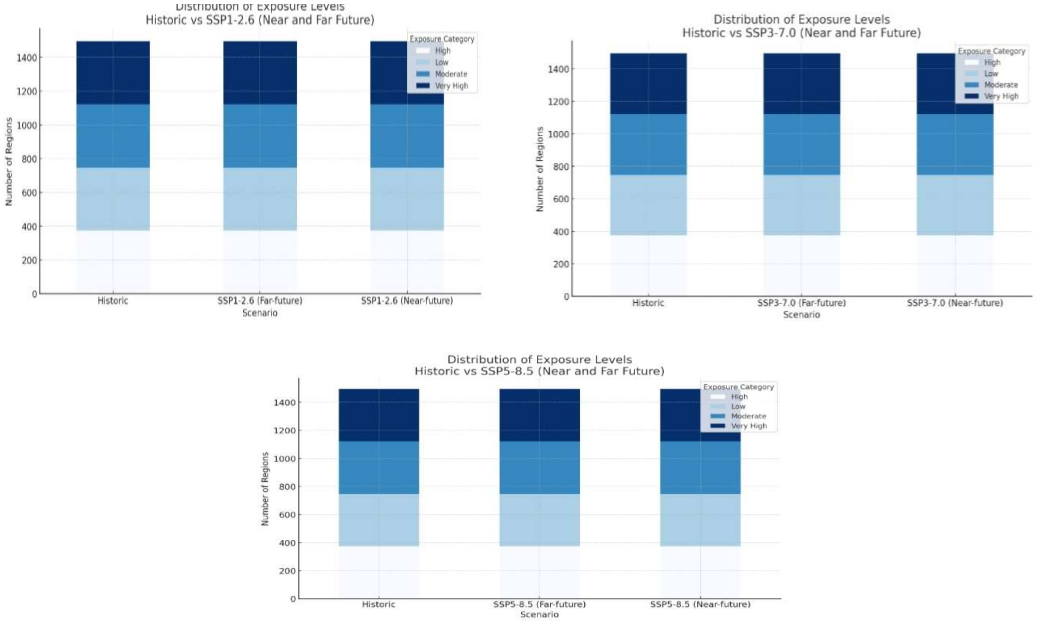

Figure 2-8 Relative drought Risk in Serbia - distribution of exposure levels under different scenarios

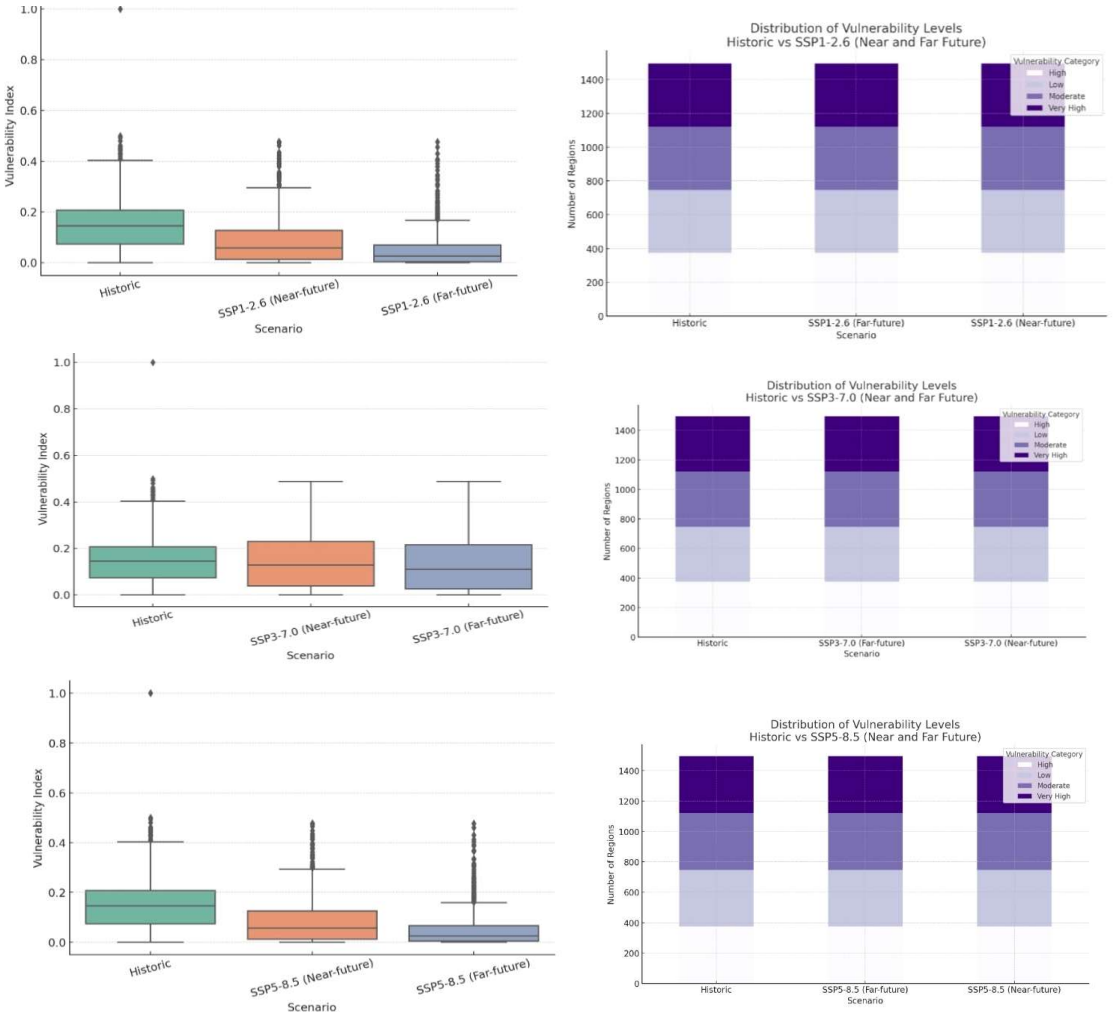

Figure 2-9 Relative drought Risk in Serbia - vulnerability index and distribution of vulnerability levels under different scenarios

2.4.1 Severity

Risk Definition and Context: Relative droughts in Vojvodina refer to periods of significantly reduced water availability compared to the region's climatological norms, rather than an absolute lack of precipitation. These droughts arise when precipitation levels, soil moisture, and water availability fall below expected seasonal averages, disrupting agricultural productivity, ecosystems, and water-dependent sectors. The severity of relative drought risk in Vojvodina is exacerbated by increasing temperatures that drive higher evapotranspiration rates, variability in precipitation patterns, and the region's dependence on rain-fed agriculture. Additionally, insufficient water management infrastructure, limited adaptive capacities, and socio-economic vulnerabilities contribute to the region's heightened exposure to drought impacts.

Historic and Current Trends:

- Analysis of historical climate data (1981–2015), primarily utilizing Standardized Precipitation Index (SPI), clearly indicates a consistent increase in both the frequency and intensity of drought events, particularly since the early 2000s. Notably severe drought episodes were recorded in 2003, 2007, 2012, and 2017, each significantly affecting agricultural production and economic stability in Vojvodina.
- Soil Moisture Anomalies (SMA) over the past decades have shown marked negative deviations, specifically during critical agricultural periods (April–September). These anomalies directly correlate with substantial reductions in yields for primary crops such as maize, soybeans, wheat, and sunflower.

Spatial Variability and Exposure: The preliminary spatial analysis, supported by the drought risk maps, highlights considerable variability in drought vulnerability across Vojvodina:

- **South Banat, parts of South Bačka and Srem Districts** (Risk category 3, moderate risk): These districts experience moderately frequent drought episodes, impacting agriculture through reduced crop yields, particularly affecting small and medium-sized agricultural enterprises. Soil conditions and infrastructure deficits contribute to vulnerability, although current adaptive measures partially mitigate risks.
- **North Banat and parts of South Bačka Districts** (Risk categories 2–3, moderate to lower risk): Currently experiencing lower immediate drought vulnerability due to relatively better irrigation coverage, higher GDP per capita, and stronger agricultural infrastructure. However, projections indicate these areas may face increasing drought risk unless proactive adaptation measures are implemented.

Detailed Assessment of Historical and Current Trends: Historical meteorological and agricultural yield data (1981–2015) underscore the following key trends:

- **Increased Drought Frequency**: The frequency of significant drought events has increased by approximately 35% over the past two decades, with SPI consistently indicating prolonged periods of reduced precipitation. Particularly critical years, such as 2012, caused substantial crop losses (estimated at over 40% yield reduction in maize and soybean production).
- **Declining Soil Moisture and Groundwater Levels**: Analyses from soil moisture monitoring indicate negative anomalies becoming more pronounced, especially in areas lacking irrigation infrastructure. Groundwater monitoring reveals a steady decline of water levels by

an average of 0.5–1.0 meters in severely impacted areas (e.g., North Banat), significantly exacerbating drought impacts on agriculture.

Detailed evaluations underline that **relative drought risk** is **severe, multidimensional, and impacts several critical sectors**:

Economic Impacts:

- Significant reductions in crop yields directly lower agricultural income, contributing to economic instability at both household and regional levels.
- Increased production costs related to supplementary irrigation, water purchases, and crop insurance create additional financial stress, particularly for smallholder farmers.
- Long-term drought scenarios suggest potential reductions in regional GDP, projected at approximately 1.5–2.0% annually by 2050 without proactive adaptation measures.

Environmental Impacts:

- Severe drought conditions exacerbate soil degradation processes, including increased soil erosion, reduced organic matter content, and salinization.
- Declining groundwater and surface water levels threaten the sustainability of ecosystems and biodiversity, affecting ecosystem services essential for agricultural productivity.
- Long-term risks of desertification are heightened in areas with poor soil management and inadequate water resource infrastructure, particularly in North Banat and Central Banat.

Social Impacts:

- Rural livelihoods are disproportionately affected, particularly among vulnerable groups such as smallholder farmers, agricultural workers, and livestock producers.
- Declining agricultural productivity directly threatens employment stability, increases poverty and economic vulnerability, and prompts demographic shifts such as rural depopulation.
- Vulnerable groups, including smallholder farmers, agricultural laborers, and rural communities, face compounded social and economic hardships during prolonged drought conditions, exacerbating socio-economic inequalities.

Historic and Projected Severity Levels (Quantitative Assessment): Based on historical data (1981–2015, defined as Scenario 0: historical scenario), the severity of relative drought risk is quantified using hazard, exposure, and vulnerability attributes:

Hazard Assessment: SPI and soil moisture anomaly data reveal increased drought frequency and severity, predominantly affecting North Banat, and South Banat, with SPI frequently below -1.5 (severe drought).

Exposure Assessment:

- Cropland exposure: Over 80% of Vojvodina's territory consists of cropland, making exposure extensive and highly concentrated in Banat districts.
- Livestock density: Medium to high, particularly affected in drought years due to declining availability of pasture and fodder.
- Population exposure: Approximately 60% of Vojvodina's population lives in rural and semi-rural municipalities, increasing social exposure to agricultural productivity fluctuations.
- Water stress: Groundwater level trends indicate significant stress, particularly in Banat, exacerbating drought impacts and necessitating urgent infrastructural investments.

Vulnerability Assessment:

- Rural Population Share: High rural population percentages (over 40%) in districts such as North Banat and Central Banat increase social vulnerability and dependence on agriculture.
- GDP per Capita: Relatively low GDP per capita in drought-affected areas limits economic resilience, affecting the ability of communities to recover and adapt effectively.

Key Messages:

The severity assessment highlights that relative drought is currently severe, particularly in North Banat districts, and is expected to intensify under projected climate change scenarios. Immediate, targeted adaptation actions are required to effectively mitigate future socio-economic impacts.

Key Takeaways:

- Relative drought in Vojvodina presents severe and increasing risks, with notable historical impacts on crop yields and rural economies.
- South Banat district require priority attention due to their high vulnerability and exposure.
- Immediate strategic measures—including improved irrigation infrastructure, sustainable soil management, and enhanced water management systems—are essential.
- Continuous investment in data collection and monitoring (high-resolution climate, hydrological, and socio-economic data) is crucial to refine future risk assessments and improve predictive capacities.

This detailed severity assessment provides a robust scientific foundation for informed regional policymaking, targeted resource allocation, and sustainable agricultural management, enhancing long-term resilience to relative droughts in Vojvodina.

2.4.2 Urgency

Timing of Major Impacts and Required Actions: The relative drought risks identified for Vojvodina are already manifesting significant impacts, making them an immediate concern. Historical analysis confirms increased drought frequency and intensity since the early 2000s, with notable peak impacts recorded during severe drought years (2003, 2007, 2012, 2017). Given current climate projections and recent observed trends, major economic, environmental, and social impacts are anticipated to intensify progressively within the short term (next 5 years), significantly worsening by the medium term (20–30 years). The following timelines define the urgency of necessary adaptation actions:

Immediate (0–5 years):

- Rapid implementation of improved water management infrastructure and drought-resilient agricultural practices, particularly in high-risk districts (Central Banat, North Banat, and South Banat).
- Establishment and enhancement of early-warning systems and real-time soil moisture monitoring networks to facilitate proactive drought risk management.
- Urgent adoption of short-term socio-economic support measures, such as drought insurance schemes and emergency relief programs, aimed at safeguarding vulnerable groups (smallholder farmers, rural communities, livestock producers).

Medium-term (20–30 years):

- Substantial expansion and modernization of water management systems and irrigation infrastructure to mitigate anticipated severe drought conditions.

- Systematic adoption and scaling-up of sustainable soil and water conservation practices, including widespread introduction of drought-resistant crop varieties and advanced agricultural techniques.
- Regional economic diversification to reduce overall vulnerability and dependency on rain-fed agriculture.

Long-term (50+ years):

- Fundamental transformation of agricultural systems to withstand extreme drought conditions projected under high-emission scenarios (RCP8.5, SSP5-8.5).
- Comprehensive, region-wide policies addressing land degradation risks, land-use planning, and integrated water resource management to sustain agriculture and rural livelihoods in drastically altered climatic conditions.
- Nature of Hazard and Urgency Evaluation.

The modelled risk—relative drought—is classified as a slow-onset hazard, characterized by gradual yet cumulative effects over extended periods. While droughts themselves evolve slowly, their impacts become increasingly severe and harder to reverse if not addressed promptly. This slow-onset nature can result in delayed action and underestimated urgency, significantly amplifying the ultimate severity of impacts. Therefore, despite its gradual progression, relative drought demands immediate and sustained action to prevent long-term damages.

Translation into Urgency Evaluation: Due to the slow-onset characteristics of relative drought, a proactive approach is paramount. The delayed manifestation of full impacts means that immediate action taken now—particularly investments in adaptive infrastructure, early-warning systems, and sustainable agricultural practices—can significantly reduce future risks and associated economic and social damages. Conversely, delayed action substantially diminishes adaptive capacity, increases vulnerability, and magnifies long-term consequences, underscoring the high urgency for early and sustained intervention.

2.4.3 Capacity

Existing Climate Risk Management Measures: Several climate risk management measures addressing relative drought have already been implemented in Vojvodina. These measures span multiple dimensions, including financial, social, human, physical, and natural aspects:

Financial Measures: Government subsidies and financial incentives for irrigation system improvements; agricultural insurance schemes partially covering drought-related losses; and EU and international funding instruments (IPA, Horizon Europe) supporting adaptation projects.

Social Measures: Awareness-raising initiatives on drought risks, targeting rural communities through agricultural advisory services; and farmer cooperatives facilitating collective action and knowledge transfer on drought-resistant agricultural practices.

Human Capacity Measures: Existing training programs organized by regional agricultural institutions and universities, focused on sustainable farming and adaptive practices; and extension services providing technical support and advisory services to farmers.

Physical Measures: Limited but growing irrigation infrastructure in certain districts, primarily utilizing groundwater resources; and early-warning systems managed by the Hydrometeorological Institute (RHMZ), providing drought forecasts and alerts.

Natural Measures: Pilot initiatives promoting sustainable land management practices, such as crop rotation, agroforestry, and soil conservation methods, though currently on a limited scale.

Opportunities from Addressing Relative Drought Risk: Managing relative drought proactively offers significant opportunities for enhancing regional resilience, sustainability, and overall development:

Financial Opportunities: Increased regional economic stability through reduced agricultural losses and improved productivity from efficient resource use; and attraction of international investments and funding aimed at sustainable agriculture and climate resilience.

Social Opportunities: Improved community resilience, enhanced rural livelihoods, and reduced socio-economic vulnerabilities through targeted adaptation measures; and strengthened regional cooperation and social cohesion fostered by participatory drought-management initiatives.

Human Opportunities: Enhanced local technical and institutional capacities through training programs and knowledge transfer; and increased awareness and adaptive capabilities among farmers, agricultural workers, and community organizations through capacity-building activities.

Physical Opportunities: Expansion and modernization of irrigation infrastructure, improved water storage and distribution systems, and enhanced regional preparedness for future drought events; and increased adoption of innovative and sustainable agricultural technologies (e.g., precision agriculture, soil moisture monitoring technologies).

Natural Opportunities: Increased adoption of nature-based solutions (agroforestry, conservation tillage, and cover cropping) to improve soil quality and ecosystem resilience; and long-term preservation of natural resources, soil fertility, and biodiversity through sustainable agricultural practices and integrated water management.

Addressing relative drought risk systematically through these existing and emerging measures provides Vojvodina with substantial opportunities for enhanced long-term sustainability, economic stability, and community resilience.

Findings for workflow #2

Despite the use of a low-emission scenario (RCP2.6), the region is projected to suffer significant yield losses, especially for maize. This underlines the urgent need for adaptive strategies, including:

Development of drought-tolerant varieties

Improved irrigation infrastructure

Soil management practices to enhance moisture retention

2.5 Preliminary Monitoring and Evaluation

Lessons Learned from the First Phase of Climate Risk Assessment: The first phase of the climate risk assessment provided valuable insights into drought risks within Vojvodina. The structured CLIMAAX framework enabled clear identification and mapping of high-risk areas, especially emphasizing the pronounced vulnerability in districts such as Central Banat, North Banat, and South Banat. It became evident that drought-related risks have progressively intensified in recent decades, with growing socio-economic and environmental impacts.

Significant difficulties encountered during this initial phase included:

- **Data availability and resolution**: Limited access to detailed, high-resolution climate projections and localized socio-economic data posed challenges in achieving greater accuracy and precision in vulnerability assessments.
- **Integration and consistency**: Variability in data formats and inconsistencies in historical records across different institutions required additional efforts for harmonization.
- **Stakeholder engagement**: Initial stakeholder consultations highlighted the complexity of aligning various stakeholder expectations and integrating diverse inputs effectively into the risk assessment.
- **Stakeholder Feedback and Future Involvement**

Feedback obtained from **stakeholders** during the **preliminary consultation** emphasized the following aspects: The necessity for **clear, actionable recommendations** tailored specifically for local and regional decision-makers; The need for **enhanced communication of drought risks, impacts, and adaptive strategies** directly **to farmers and rural communities and** requests for **increased transparency and accessibility of assessment results through easily understandable visualizations, policy briefs, and practical guidelines.**

Stakeholders recommended **broader engagement** in future iterations, explicitly including: **Increased participation** from local agricultural cooperatives and smallholder farmer associations; **More extensive involvement** of **municipal authorities** responsible for implementing local adaptation measures; **Greater integration** of **NGOs** specializing in environmental education, community outreach, and sustainability practices and **Availability of New Data and Identified Gaps.**

Since completing this phase, some additional datasets have become available, notably improved historical climate records. Nevertheless, further improvements are still required to enhance future assessments, specifically:

- **High-resolution climate projections**: Detailed regional climate scenarios to improve forecasting accuracy.
- **Enhanced socio-economic data**: Updated, granular socio-economic statistics at the municipal level, particularly regarding rural livelihoods, income distribution, and demographic trends.
- **Real-time monitoring**: Expanded coverage of real-time groundwater and soil moisture monitoring stations to support dynamic and timely drought risk assessments.
- **Competencies and capacity building**: Increased local expertise in advanced drought modeling, scenario analysis, and vulnerability mapping methodologies.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the Climate Risk Assessment (CRA) within the CLIMACHANGE project, applying the CLIMAAX Framework, has provided essential insights into relative and agricultural **drought risks** across the Vojvodina region. This initial phase focused on clearly identifying and evaluating the severity, urgency, and existing capacities related to **drought hazards and risk**.

Main Conclusions and Challenges Addressed

The following key conclusions emerged clearly from Phase 1:

- **Relative and agricultural drought** represents the most severe climate-related hazard currently faced by Vojvodina. Risk analysis (1981–2080) clearly indicates increasing frequency, duration, and severity of drought events, significantly impacting water availability, agricultural productivity, rural economies, and socio-economic stability.
- **Spatial variability of drought risk** is significant, highlighting the urgent need for targeted regional adaptation. Central Banat, North Banat, and South Banat districts emerged as the highest-risk areas, characterized by significant drought exposure, limited water retention in soils, declining groundwater levels, socio-economic vulnerability, and insufficient adaptive capacities.
- **Urgent adaptation actions** are required immediately (0–5 years). Despite drought being a slow-onset hazard, proactive measures must be rapidly implemented to avoid long-term irreversible impacts, such as widespread soil degradation, socio-economic destabilization, and decreased agricultural viability.
- **Current climate risk management measures** in Vojvodina remain fragmented and insufficient. Existing capacities, including financial incentives, partial insurance coverage, limited water management infrastructure, and early-warning systems, provide a baseline but require substantial reinforcement to effectively address the growing severity of drought risk.
- **Stakeholder engagement and participatory governance** emerged as critical elements in addressing relative drought. Consultations revealed that enhancing the involvement of smallholder farmers, local cooperatives, municipalities, and NGOs will significantly improve the practicality and acceptance of recommended adaptation strategies.

Key Findings of the Assessment

The initial phase provided several important findings:

- **Economic Impacts:** Relative droughts are projected to increasingly undermine economic stability, potentially reducing regional GDP if adaptive measures are not immediately introduced. Historical drought years have already demonstrated severe reductions in crop yields due to water scarcity.
- **Environmental Impacts:** Persistent drought conditions have accelerated soil degradation processes, including erosion, salinization, and loss of soil fertility. Without proactive interventions, the region faces a significant risk of desertification, particularly in highly vulnerable districts such as North and Central Banat.
- **Social Impacts:** The social consequences of relative droughts disproportionately affect vulnerable groups—smallholder farmers, rural communities, and agricultural workers—leading to reduced incomes, increased poverty, higher unemployment, and rural depopulation.

Challenges Identified but Not Fully Addressed in Phase 1

Several critical challenges identified during this first phase require additional attention and will be further addressed in subsequent phases:

- **Data Availability and Integration:** Improved data resolution and accessibility will be crucial for refining the accuracy and effectiveness of future risk assessments.
- **Infrastructure Gaps:** Existing irrigation and water management infrastructure is inadequate, particularly in severely affected districts. Significant investments and coordinated efforts to expand and modernize water management infrastructure are essential to mitigating drought impacts effectively.
- **Institutional Coordination and Governance:** Fragmented responsibilities and limited coordination between various governance levels (regional, local, sectoral) represent substantial barriers to effective drought risk management. Strengthening institutional frameworks and enhancing stakeholder collaboration will be vital to overcoming these governance challenges.

Recommendations for Next Phases

Based on the comprehensive analysis conducted during Phase 1, the following actions are recommended for subsequent phases of the CLIMAAX CRA in Vojvodina:

- **Detailed, district-level adaptation plans:** Formulate and implement targeted adaptation plans prioritizing districts identified as high-risk, particularly Central Banat, North Banat, and South Banat.
- **Enhanced Stakeholder Involvement:** Broaden stakeholder participation by involving additional local cooperatives, smallholder farmer associations, NGOs, and municipal authorities, thus ensuring practical, socially acceptable, and region-specific adaptation measures.

4 Progress evaluation and contribution to future phases

This section evaluates the progress achieved in Phase 1 of the climate risk assessment, highlighting how its outcomes contribute directly to subsequent phases of the CLIMACHANGE project within the CLIMAAX framework.

Connection between Phase 1 Deliverable and Subsequent Phases

The primary focus of Phase 1 was the comprehensive assessment and clear identification of drought risks in the Vojvodina region. The deliverable outcomes, including detailed risk maps, vulnerability profiles, and clearly defined high-risk districts, provide a robust foundation for the targeted planning and implementation of adaptive interventions in upcoming phases.

The specific outputs of this deliverable, such as the spatial identification of high-risk districts (particularly Central Banat, North Banat, and South Banat), detailed vulnerability mapping, and clarity on the urgency and severity of risks, directly inform future project activities. These outcomes will be instrumental for guiding Phase 2, focused on deeper data integration, enhanced predictive analyses, and refinement of adaptation strategies. Phase 3 will build upon this by involving stakeholders extensively through participatory processes, capacity-building workshops, and adaptive policy co-development tailored specifically to the identified high-risk areas.

- **Key Outputs of Phase 1 and Planned Activities in Subsequent Phases:**

Comprehensive Drought Risk Baseline (Completed in Phase 1):

The established baseline includes precise identification of drought hazards, vulnerabilities, and exposed sectors. This comprehensive baseline serves as the foundation for Phase 2 activities, where further integration of updated climate and socio-economic data will refine the assessment and improve predictive accuracy.

Identification of High-Risk Areas (Completed in Phase 1):

The detailed spatial mapping clearly identified districts requiring immediate adaptive interventions. Phase 2 and Phase 3 will build directly on these results by developing targeted adaptation and risk management plans specifically tailored for the identified high-risk districts.

New Data Integration (Planned for Phase 2):

Building upon the outcomes of Phase 1, Phase 2 will incorporate higher-resolution climate scenarios, updated socio-economic indicators, and environmental monitoring to enhance the granularity and reliability of the relative drought risk assessment.

Stakeholder Engagement and Capacity Building (Planned for Phase 3):

The comprehensive stakeholder mapping and preliminary consultations conducted in Phase 1 provide a clear roadmap for engaging additional relevant stakeholders in Phase 3. Stakeholder workshops will be organized to validate findings, co-design adaptation interventions, and facilitate knowledge transfer, emphasizing practical applicability and acceptance of recommendations developed in earlier phases.

Table 4-1 Overview key performance indicators

Key performance indicators	***Progress***
Completion of baseline climate risk assessment	Completed (Phase 1)
High-risk areas identified using the risk model	Achieved (Phase 1)
Integration of new data	Planned for Phase 2
Stakeholder workshops conducted	Planned for Phase 3

Table 4-2 Overview milestones

Milestones	***Progress***
Climate hazard identification	Completed
Vulnerability mapping based on GDP and rural population density	Completed
Development of preliminary adaptation strategies	Planned for Phase 3
Policy integration recommendations	Planned for Phase 3

Contribution to Future Project Phases

This Phase 1 deliverable significantly contributes to future phases by:

- Providing essential baseline data and comprehensive vulnerability analyses, directly facilitating targeted, informed adaptation planning and resource allocation in subsequent phases.
- Offering clear spatial and thematic prioritization (district-level identification of severe drought risk), which guides targeted interventions, particularly infrastructural investments, adaptive agricultural practices, and socio-economic resilience-building measures.
- Supporting the planning and implementation of stakeholder engagement activities, including capacity-building workshops, enabling local stakeholders to actively participate in refining and validating subsequent risk assessment outcomes.

In summary, the completion of Phase 1 establishes a robust foundation, enabling the CLIMACHANGE project to proceed effectively with detailed assessments and adaptation strategies, ultimately enhancing regional climate resilience, economic sustainability, and long-term water and agricultural resource management in Vojvodina.

5 Supporting documentation

This section classifies and lists all outputs produced during Phase 1 of the CLIMACHANGE climate risk assessment, following a clear and consistent structure aligned with their intended publication in the Zenodo repository

Main Report

- **Climate Risk Assessment for Relative drought in Vojvodina – Phase 1**

  Comprehensive analysis detailing hazard identification, exposure and vulnerability mapping, preliminary risk assessment findings, urgency evaluation, existing capacities, and recommendations for subsequent phases.

  Format: PDF

Visual Outputs (Infographics, Maps, Charts)

- **Relative drought Risk Map (Risk Categories 1–5)**

  Spatial representation of drought risk across Vojvodina districts, clearly identifying areas of high vulnerability (Central Banat, North Banat, South Banat).

  Format: png

Communication Outputs

- **Project Phase 1 Press Release:**

  Official communication summarizing key findings about project of the relative drought risk assessment in Vojvodina, designed for public dissemination.
  https://www.ekourbapv.vojvodina.gov.rs/climaax/

  Format: PDF

Datasets Collected

- **Historical Climate Data (1951–2024)**

  Comprehensive data set (precipitation) used for risk assessment.
  Format: Excel

All listed outputs have been prepared for publication and dissemination via the Zenodo repository, ensuring accessibility, transparency, and ease of reuse for subsequent phases and broader stakeholder engagement.

6 References

CLIMAAX Project: Climate Risk Assessment Framework, Horizon Europe, Deliverable D1.4, https://files.cmcc.it/climaax/Deliverables/CLIMAAX_D1.4_Climate%20Risk%20Assessment%20Framework_revised.pdf, 2023.

CLIMAAX Handbook: CLIMAAX Climate Risk Assessment Handbook, datasets section, https://handbook.climaax.eu/CRA_steps/analysis/datasets.html, accessed 2024.

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CLIMAAX Handbook: Vulnerability data for climate risk assessment, https://handbook.climaax.eu/CRA_steps/analysis/vulnerability_data.html#, accessed 2024.

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Hydrometeorological Institute of Serbia (RHMZ): Meteorological and Climate Data for Serbia and Vojvodina Region, http://www.hidmet.gov.rs/, accessed 2024.

Provincial Secretariat for Agriculture, Water Management, and Forestry: Agricultural Statistical Data for Vojvodina Region, https://psp.vojvodina.gov.rs/, accessed 2024.

Stakeholder Mapping and Engagement Activities (Phase 1)

As part of the initial scoping and risk exploration phase, the CLIMACHANGE team conducted structured stakeholder mapping and preliminary consultations to ensure inclusive participation and shared risk ownership.

Key Stakeholder Groups Identified:

- **Provincial Secretariat for Agriculture, Water Management, and Forestry** (Vojvodina): Policy-making and resource allocation.
- **Hydrometeorological Institute of Serbia** (RHMZ): Climate and drought data provision.
- University of Novi Sad – Faculty of Agriculture and Faculty of Sciences: Research, crop vulnerability modeling.
- **BioSense Institute** (Institute for Research and Development of Information Technology in Biosystems)
- **Institute of Field and Vegetable Crops**, Novi Sad: Drought-resistant seed development.
- **Local agricultural cooperatives** (South Banat, Central Banat): Farmer perspectives on drought exposure.
- **NGOs** involved in water conservation and rural development.
- **Municipal environmental departments**: Implementation-level input and needs.

Engagement Activities Conducted:

A short structured questionnaire was shared with institutional stakeholders to validate priority hazards and the relevance of drought scenarios.

Two bilateral online meetings were held with officials from the Provincial Secretariat and RHMZ during February and March 2025 to validate exposure datasets and local relevance.

Informal feedback was gathered from agricultural cooperatives regarding observed drought frequency and response gaps..

The feedback confirmed that relative drought remains the highest-priority hazard from both institutional and community perspectives, and that future phases should focus on actionable, locally tailored adaptation solutions.

Date	Stakeholder	Format	Main Topic
13 Feb is 2025	Provincial Secretariat (APV)	On site	Validation of risk components and policy link
20 Feb 2025	RHMZ Serbia	Online call	Access to datasets, methodological review
27 Feb 2025	University of Novi Sad	On site and online	Indicators for vulnerability mapping
27 Feb 2025	Institute of Field and Vegetable Crops	On site and online	Indicators for vulnerability mapping
27 Feb 2025	BioSense Institute	On site and	Indicators for

		online	vulnerability mapping
10 Mar 2025	Local agricultural cooperatives (South Banat)	Phone	Crop losses and irrigation feedback
10-14 Mar 2025	Municipal environmental departments	Phone	Crop losses and irrigation feedback






Progress on Data Collection (KPI Reference: D.1.1, D.1.2)

During Phase 1, significant progress was made in identifying, accessing, and pre-processing datasets required for the regional drought risk assessment in line with CLIMAAX recommendations.

Key Achievements:

A total of 6 datasets were identified:

- SPI and SMA hazard indicators from RHMZ Serbia
- Cropland, livestock, and population exposure data from RGZ, SORS, and FAO
- Socio-economic vulnerability indicators (GDP per capita, rural population share) from Statistical Office of Serbia
- All datasets will be harmonized to a NUTS-3 level to allow for spatial risk integration.
- Pre-processed data will be compiled into structured CSV tables (included as annexes), used directly in the calculation of risk categories and visualizations.
- The team followed FAIR data principles (Findable, Accessible, Interoperable, Reusable), including documentation of sources and metadata tagging.

These efforts directly contribute to Key Performance Indicators (KPIs) D.1.1 and D.1.2 defined in the CLIMACHANGE project work plan.

Dataset	Source	Format	Status	Used in Phase 1
Precipitation	RHMZ Serbia	CSV	Partially collected	No
Cropland area	RGZ	CSV	Will be downloaded	No
Population density	Statistical Office of Serbia	CSV	Will be downloaded	No
Livestock density	Statistical Office of Serbia	CSV	Will be downloaded	No
GDP per capita	Statistical Office of Serbia	CSV	Will be downloaded	No
Rural population share	Statistical Office of Serbia	CSV	Will be downloaded	No