Deliverable Phase 1 – Climate Risk assessment

Climate Resilience of Lodzkie Region (CliRes-LR)

Poland, Lodzkie

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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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Abbreviations and acronyms

Abbreviation / acronym	Description
WŁ	Lodzkie Region
AWC	Available Water Capacity
CDD	Consecutive Dry Days
ET0	Reference Evapotranspiration
FWI	Fire Weather Index
RDH	Risk Data Hub
RX1day	Maximum of 1-day accumulated precipitation
RX5day	Maximum of 5-day accumulated precipitation
RP	Return Period

Executive summary

This study presents the results of Phase 1 of the project entitled "Climate Resilience of Lodzkie Region (CliRes-LR)", implemented as part of the CLIMAAX initiative.

The aim of the work was to develop a preliminary Climate Risk Assessment (CRA) for the Lodzkie Region, including the identification and analysis of key climate phenomena using the CLIMAAX Handbook methodology and the ECMWF JupyterHub environment.

According to the assumptions of the Individual Action Plan (IFP), the original scope of the project included two workflows: heavy rainfall and hydrological drought. During implementation, after analyzing local needs and consulting with stakeholders, the scope was expanded to a third area – agricultural drought. This decision was due to the observed effects of climate change in the region and the planned cooperation within the project with the Polish Space Agency (POLSA) in the use of satellite data from the NSIS platform for future validation of results.

As part of the preparations for the assessment, to the cooperation was invited a group of local stakeholders representing public administration, academia, research institutes, the State Water Management Authority, emergency services, and advisory institutions. The culmination of this stage was a working meeting during which data needs, cooperation directions, and the plan for further actions in the field of climate resilience were discussed. Additionally, through the stakeholders, a survey was conducted among 1,347 residents of the Lodzkie Region regarding the awareness of the consequences of climatic phenomena and the level of climate risk considered acceptable by the respondents.

The risk analyses carried out showed a clear spatial differentiation of climate risk in the region. There is a trend of increasing intensity of extreme rainfall and its more frequent occurrence, as well as a deepening of water deficits, particularly in the central and northern parts of the region. This indicates increasing instability between phenomena of water surplus and shortage, which requires further monitoring and integrated analysis in the subsequent stages of the project.

During implementation, certain limitations in data availability concerning heavy rainfall were also identified, mainly related to the length of historical data series. However, the results obtained in Phase 1 provide a consistent reference base and a starting point for an in-depth assessment of climate risk in Phase 2 of the project.

The project team conducted regular working meetings – both in-person and online – enabling the ongoing exchange of data, coordination of activities, and collaborative development of results. In parallel, preparations are underway for promotional and informational activities aimed at disseminating the project results and engaging new partners.

Phase 1 concluded with the achievement of all planned results, the development of risk maps, and the identification of priority directions for further work, which will provide a solid foundation for a locally calibrated and comprehensive assessment of climate risk in the Lodzkie Region.

Due to the later start of the project, which was related to the region's later qualification as a beneficiary of the second call for proposals under the initiative, the Phase 1 of the project lasted four months instead of six.

1 Introduction

1.1 Background

The Lodzkie Region is located in the central part of Poland. The capital of the region is Łódź – the fourth largest city in the country. The area of the region covers approximately 18,000 km² and the population amounts to just under 2.4 million people (GUS, 2024). Lodzkie Region is an important transport hub, situated at the intersection of Poland's main road and railway routes. The region has a rich industrial heritage, particularly in the textile industry, and today it is also developing strong sectors in services, logistics and modern technologies.

The Lodzkie Region is located within the Central Polish Lowlands and its landscape is mostly flat, with some gentle elevations such as those found in the Łódź Upland. Rivers flowing through this region include the Pilica, Warta and Bzura. According to IPCC AR6 analyses for Central Europe, this region is experiencing intensifying climate change trends typical of both Southern Europe (heatwaves, droughts) and Northern Europe (intense precipitation) (IPCC AR6 WG1, 2021). The region is influenced by both warm temperate (from the south) and cool temperate (from the north) climatic zones. The transitional nature of this climate results from the oceanic and continental air masses.
The average annual temperature is around 9–9.5 °C, according to the measurements from meteorological stations in central Poland (Kubiak-Wójcicka, 2020), and the precipitation is fairly evenly distributed throughout the year, although summers tend to be warmer and more humid (IMGW-PIB, 2022). The annual precipitation total in the Lodzkie Region ranges from 500–600 mm in the eastern, northern and central parts of the region, to 600–700 mm in the western areas (IMGW-PIB, 2024). Natural conditions are favourable for agriculture, though the diversity of soils and relatively short growing season mean that the production of cereal crops, potatoes and vegetables dominate here.

1.2 Main objectives of the project

The objective of the project implemented by the Lodzkie Region under the CLIMAAX initiative is to conduct a detailed climate risk analysis for the region: increasing drought and intense rainfall. The developed analysis will be used to better address these issues in strategic and planning documents.
It is expected that the use of the CLIMAAX Handbook will enable the development of Climate risk assessment (CRA) models for the Lodzkie Region, using data available in pan-European databases and supplementing them in the next project phase with local data. The Handbook provides guidance on how to use technical support and outlines available tools, which in the long-term perspective will allow for the standardization of climate risk assessment methods and the development of sustainable solutions for climate adaptation and mitigation.

1.3 Project team

The project team is composed of employees of the Marshal's Office of the Lodzkie Region (and its subordinate unit), which performs tasks in the field of regional self-government administration on behalf of the Board of the Lodzkie Region – the regional governing authority.

To implement the project, the Team for the Implementation of the Project "Climate Resilience of Lodzkie Region" (CliRes-LR) was established by the Order of the Marshal of the Lodzkie Region No. 46/25. The Team includes employees from the following organizational units:

- Department of Regional Policy and Foreign Cooperation – coordinating the implementation of the project in terms of management and reporting, which has experience in carrying out international projects, for instance under the Interreg Central Europe 2021-2027 programme. Additionally, the Department is responsible for making the regional development policy, including the coordination of work on strategic and planning documents such as the Regional Development Strategy of the Lodzkie Region;

• Department of Climate and Environment – responsible, among others, for drafting and preparing the Region Environmental Protection Programme and monitoring its implementation, as well as undertaking activities aimed at promoting the development of the green economy and climate change mitigation;

• Office for Regional Planning for the Lodzkie Region (Environment and Landscape Team) – which the statutory tasks include conducting research, analyses, studies and monitoring, as well as preparing strategic and planning documents related to natural and cultural environment issues, landscape management, tourism and recreation;

1.4 Outline of the document's structure

The document includes the Climate risk assessment (CRA) for the Lodzkie Region for selected workflows based on the standard, five-stage risk assessment model, in accordance with the points: Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment, Monitoring & Evaluation, taking the local specificity into consideration and ensuring significant stakeholders' engagement, at the same time.

2 Climate risk assessment (CRA) – phase 1

2.1 Scoping

2.1.1 Objectives

The objective of the Climate risk assessment is the **identification the key climate hazards** in the Lodzkie Region as well as the sectors the most vulnerable to those treats. The results will be used to develop recommendations for **climate risk management** in phase 3 of the project.

The analysis is limited by the **large-scale nature of the available climate data**, which makes it difficult to fully relate the findings to regional conditions. In addition, the region lacks a single institution responsible for a comprehensive approach to the climate adaptation process. The Lodzkie Region does not have a dedicated program or unit for managing adaptation processes, which results in activities in this area being dispersed across different sectors and strategic documents as well as actions carried out by stakeholders are not coordinated with one another.

2.1.2 Context

For approximately the past 10 years, institutions at all levels of governance have been undertaking a range of climate adaptation and mitigation activities. The interventions are of multi-level nature: regulatory, organizational, technical (investment) and promotional. In the area of identifying and addressing climate hazards and risks, the following actions have been undertaken:

at the national level, among others:

- the Catalogue for Good Practices in Adaptation to Climate Change *Klimada 2.0* (Environmental Protection Institute – National Research Institute);
- the environmental monitoring system regarding the impacts of climate change, particularly extreme events such as floods (IMGW) and droughts (IUNG), was expanded. The Lodzkie Region uses the nationwide Agricultural Drought Monitoring System operated by the Institute of Soil Science and Plant Cultivation (IUNG-PIB);
- an alert public notification system was established as part of the Government Security Center alerts (in the years 2020-2025, the Lodzkie Region received 39 notifications concerning rainfall)

at regional level, among others:

- Regional Parliament of the Lodzkie Region provided co-financing to local government units in the Lodzkie Region for:
  - *green infrastructure development („Lodzkie Region, the Garden of Poland – Nature-Friendly Gardens" [„Województwo Łódzkie Ogrodem Polski – Ogrody przyjazne Naturze*"]): 2023 – PLN 2,903,226 (SWŁ no. 639, 2023), 2024 – PLN 3,956,626.00 (SWŁ no. 752, 2024);
  - *renovation of small retention reservoirs*: 2023 – PLN 4,636,495.00 (SWŁ no. 655, 2023), 2024 – PLN 5,159,108.00 (SWŁ no. 749, 2024);
  - *development of the agricultural drought monitoring system (12 districts)*: 2023 –1,200,000 PLN (SWŁ no. 652, 2023);
- **"My Water" Programme** (WFOŚiGW Łódź/NFOŚiGW): 2023 – 1,336 agreements / PLN 7,615, 504.21; 2024 – 608 agreements / PLN 1,937,283.12. The result: 1,043 installations, 75 ,55 m³ of water managed per year (WFOŚiGW Łódź, 2025) (WFOŚiGW Łódź, 2025).

Climate change and extreme events are worsening the quality of life for residents of the Lodzkie Region, while anthropogenic pressure further reduces air and water quality. Rising temperatures and precipitation deficits are causing a decline in water resources; drought represents the main agricultural problem in the region. A significant part of the region experiences water shortages during the growing season – drought remains a key issue in agricultural areas (IUNG-PIB, 2023). In 2023, the average temperature in Poland was **10°C**, that is **1.3°C above the norm in years 1991–2020** – the year was extremely warm (IMGW-PIB, 2024). In the Lodzkie Region, thermal anomalies occurred (warm winter, hot summer, mild transitional seasons) as well as deviations in precipitation. For the northeastern part of the region (district: Łowicz, Rawa, Skierniewice, Brzeziny, Łódź East, Opoczno, Tomaszów, partially Piotrków, Radomsko, Łęczyca, Kutno), a greater influence of continental air masses and an extension of atmospheric drought periods is forecasted (Rozporządzenie Ministra Infrastruktury, 2022). Increasingly frequent **heavy rains and strong winds** lead to urban flooding in cities with limited infiltration and overloaded sewage systems (MPA Łódź, 2018). Drought reduces agricultural productivity, increases the risk of fires and limits the availability of drinking water. At the same time, the frequency of extreme events – heavy rains, floods and inundations – is rising. Losses from weather-related events in Poland are estimated at **approximately PLN 6 billion annually** and **PLN 115 billion in total** in the years 2005–2024 (SRKproj, 2025).

The management context is a key element of regional climate risk assessment. Regulatory and programme-related actions confirm the increasing importance of climate issues at both the national and regional levels:
• **National level:**
– *Drought Mitigation Plan* and *Water Shortage Prevention Program 2023–2027*;
– amendment to the *Environmental Protection Law* – obligation to develop Urban Adaptation Plans for cities with over 20,000 inhabitants;
• **Regional level:**
– *Development Strategy of the Lodzkie Region 2030* – actions for adaptation and reduction of water deficit (linked to the *European Funds for Łódź 2021–2027* programme);
– *Environmental Protection Program 2025–2028 (persp. 2032)*, *Spatial Development Plan* and *Landscape Audit* – drought counteracting solutions;
– *Territorial Just Transition Plan* – 35 districts supported in relation to CO_2 emission reduction and the transformation of the Bełchatów Energy Complex;
– actions of the government administration (Crisis Management Department / WCZK ŁUW) – operational flood protection plan, flood hazard and risk maps, risk management plans;

The most vulnerable economic sectors in the Lodzkie Region: **Agriculture and agri-food processing** (Klimada 2.0, 2020); **Energy, Industry, production, trade, Construction, Technical infrastructure, Medicine, pharmacy and public Health** (Muras, 2018), **Public finance, Tourism and recreation** (IBL, 2024, IBL, 2022).

The drought problem in the Lodzkie Region is influenced by both local and external factors:
- atmospheric factors of a global nature: changes in atmospheric circulation cause phenomena such as downpours, hailstorms or intense rainfall to become increasingly frequent,
- greenhouse gas emissions (Poland ranks 5th among European countries) the significant share of energy production based on fossil fuels (76.1% from conventional power plants, (BDL GUS, 2023),
- the climatic situation in neighbouring regions (such as Greater Poland, Kuyavian-Pomeranian and Masovian) can affect the water balance in the Lodzkie Region, both in terms of groundwater and surface water (Regulation of the Minister of Infrastructure, 2022),
- organizational factors, resulting in spatial planning policies and land use, as well as investments in valleys that reduce the conveyance capacity of watercourses,
- outdated urban sewage systems.
Activities aimed at retaining water in the landscape, mitigating the effects of heavy rainfall in urban areas, and increasing the resilience of agriculture (Catalogue of Good Practices, IOŚ-PIB, 2023) should include: creating small retention reservoirs and agricultural polders, channel retention, i.e. restoration of oxbow lakes, construction of terrain obstacles (embankments, flow-retarding steps), management of drainage ditches, collection of rainwater and use of this for irrigation (drip irrigation from storage), renaturalization of watercourses and river valleys, restoration of floodplains, reconstruction of wetlands and peatlands (where they historically occurred), fragmentary afforestation and creation of field tree lines, establishment of ecological corridors connecting forest fragments and wetlands, implementation of systems for local rainwater management, especially in urban areas, provision of subsidies for farms that store water and climate education of residents.

2.1.3 Participation and risk ownership

The groups particularly vulnerable and prioritized in the context of climate risk assessment for the Lodzkie Region include: a) farmers and residents of rural areas, b) urban communities in areas with low water retention and high surface sealing, c) health-vulnerable individuals (seniors, children, chronically ill persons), d) local institutions involved in water and infrastructure management. These groups represent sectors and environments that should be prioritized in adaptation activities in the next stages of the CLIMAAX project. Below is a diagram of responsibilities for climate risk management in Poland (own work):

Table 1 Climate risk responsibility diagram (own work)

1. Key institutional levels
Central (government) level
• Council of Ministers (Prime Minister, Government)
– coordination of state policy, strategic decision-making.
• Ministry of Climate and Environment (MKiŚ)
– climate policy, environmental protection, emission reduction, adaptation to climate change
• Ministry of Internal Affairs and Administration (MSWiA)
– civil protection, crisis management
• Ministry of Infrastructure
– water management, transportation, critical infrastructure
• Ministry of Agriculture and Rural Development
– counteracting the effects of drought, support for farmers
• Ministry of Health
– health effects of heat waves, smog, natural disasters
Central institutions/agencies
• Government Security Center (RCB) – warnings, alerts, coordination of crisis response measures
• Institute of Meteorology and Water Management (IMGW-PIB) – weather forecasts, meteorological and hydrological warnings
• State Fire Service (PSP) – rescue operations (floods, storms, fires)
• State Water Management Authority "Polish Waters" – water management, flood protection, droughts
• Chief Inspectorate for Environmental Protection (GIOŚ) – environmental monitoring, including air pollution
Regional level
• Provincial Crisis Management Centers / Provincial Governors – coordination of response in the region
• Provincial Inspectorates for Environmental Protection (WIOŚ) – local monitoring
• Local governments (counties, municipalities, cities) – local adaptation plans, protection of residents, warning systems
• Volunteer Fire Departments (OSP) – support for the State Fire Service in rescue operations
2. Institutional links
RCB ↔ IMGW ↔ Provincial governors / Local governments → warning and crisis management system
MKiŚ ↔ Polish Waters ↔ Local governments → climate change adaptation, water management

PSP ↔ OSP ↔ Local governments → rescue and firefighting operations
Ministry of Agriculture and Rural Development ↔ ARiMR (Agency for Restructuring and Modernization of Agriculture) → aid to farmers affected by droughts or floods
Ministry of Health ↔ Sanitary Inspectorate ↔ Local governments → response to heat waves, air pollution

Survey conducted from 1 to 10 October 2025, among 1,347 residents of the Lodzkie Region showed that over 70% perceive the impact of climate change and 69% have experienced its effects (droughts, heatwaves, storms). The average risk acceptance level was 2.35 on a 1–4 scale; 19% of respondents were undecided. The greatest concerns are extreme events and rising living costs. Priority actions include water retention (66%), protection of green areas (58%) and education (32%). Most respondents consider government actions insufficient, expecting more local and transparent climate initiatives.

The indirect beneficiary of the project activities is the Marshal's Office of the Lodzkie Region, which will incorporate the results of the project analyses into plans, strategies and programs prepared on behalf of the Board of the Lodzkie Region, the entity implementing the project entitled "Climate Resilience of Lodzkie Region" (CliRes-LR).

2.2 Risk exploration

2.2.1 Screen risks (selection of main hazards)

The analysis of data from the IPCC Interactive Atlas (CMIP6) covered the indicators RX1day, RX5day, CDD and Snowfall for the period 2021–2040 relative to 1981–2010. Under the SSP1-2.6 scenario, precipitation intensity remains stable, whereas in SSP2-4.5, SSP3-7.0 and SSP5-8.5 it increases with emissions. Higher scenarios indicate a high risk of flash floods and the seasonal analysis confirms an increase in precipitation intensity in May–July and November, particularly after 2050.

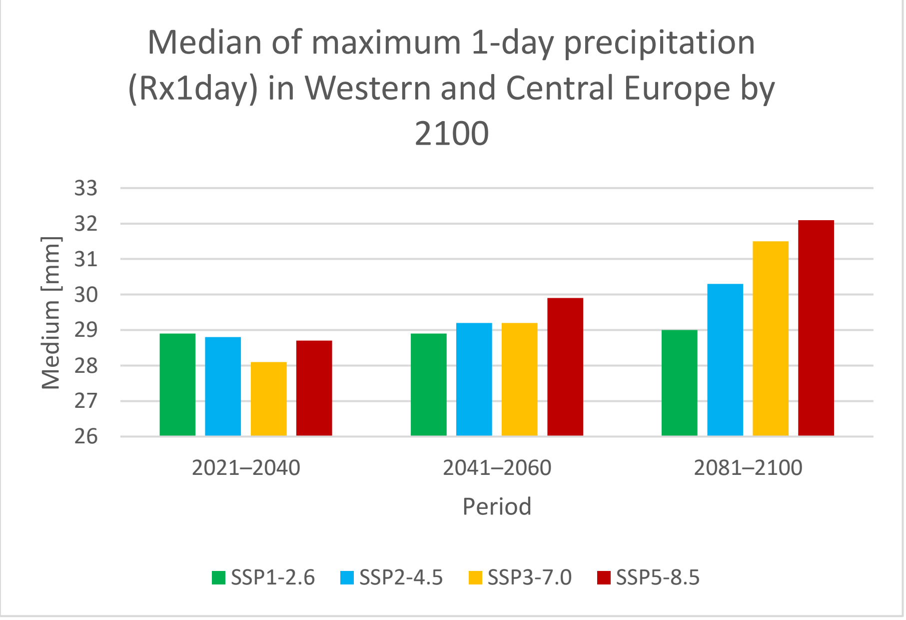

Figure 1 Median of 1-day precipitation (Rx1day index) in Western and Central Europe by 2100 for the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios (own elaboration based on IPCC Interactive Atlas, 2021)

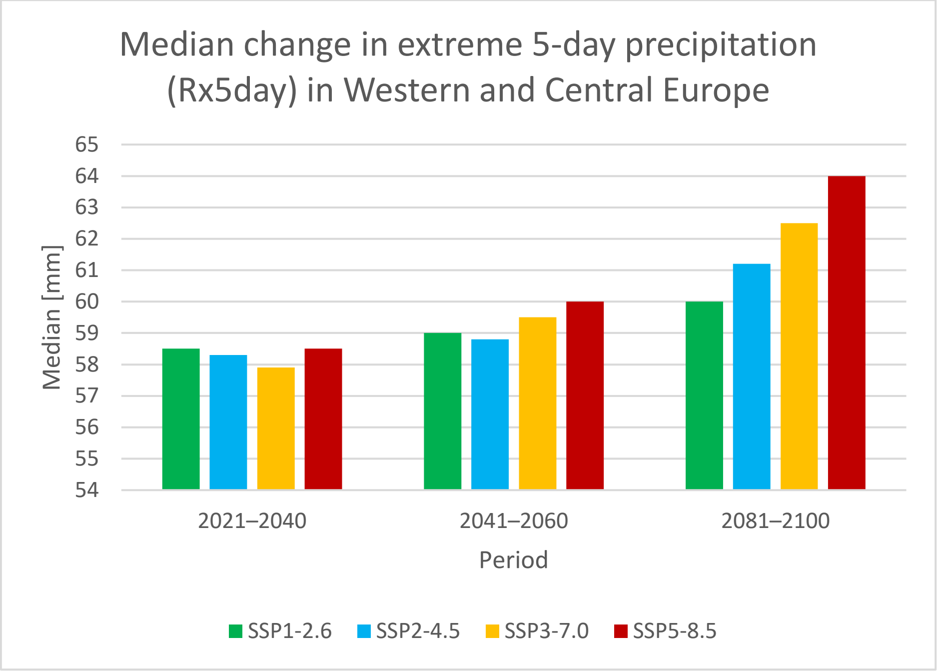

Figure 2 Median of 5-day precipitation (Rx5day index) in Western and Central Europe by 2100 for the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios (own elaboration based on IPCC Interactive Atlas, 2021)

The analysis of the CDD index, shown in Figure 3, indicates that under the SSP1-2.6 and SSP2-4.5 scenarios, the number of consecutive dry days remains nearly constant throughout the 21st century, hovering around 25 days, which corresponds to the current occurrence of dry periods. In high-emission scenarios, a systematic and significant increase in the length of dry periods is observed, with the SSP3-7.0 scenario potentially extending the dry period by about 4 days and SSP5-8.5 by approximately 6–7 days – meaning that the maximum number of consecutive days without precipitation could reach 31-32 days.

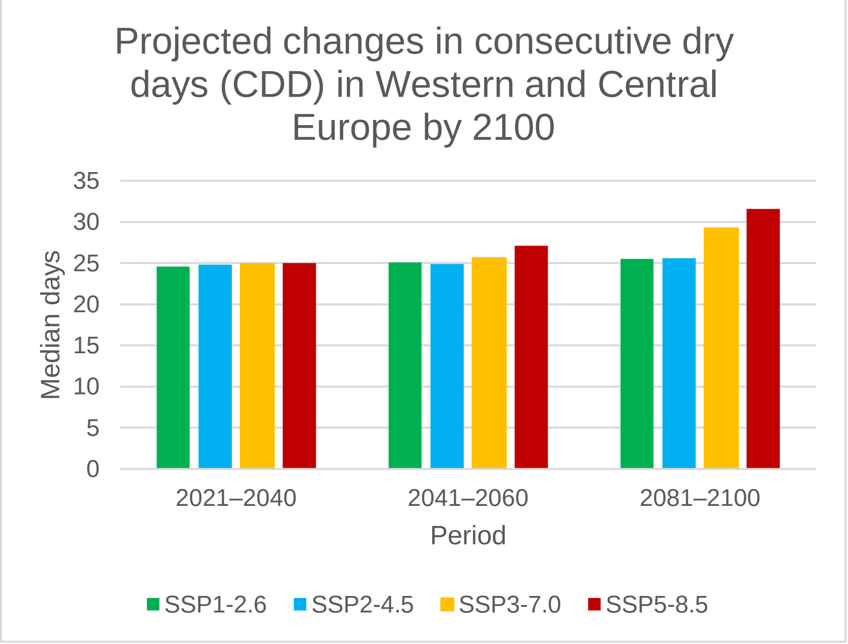

Figure 3 Projected changes in the number of consecutive dry days (CDD index) in Western and Central Europe by 2100 under the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios (own elaboration based on IPCC Interactive Atlas, 2021).

Another hazard analysed, presented in Figure 4, is snowfall amounts. It is clear that the higher the emissions, the more snowfall decreases. Even with an ambitious climate policy, it will not be possible to fully maintain current snowfall levels, but the reduction can be significantly mitigated. This means that in many parts of Western and Central Europe, snow will become a marginal phenomenon and the winter season will be drastically shortened. Furthermore, the seasonal strip analysis shows progressively lighter colours in the high-emission scenarios (SSP3-7.0 and SSP5-8.5) after 2050, indicating a decrease in snowfall during the winter months.

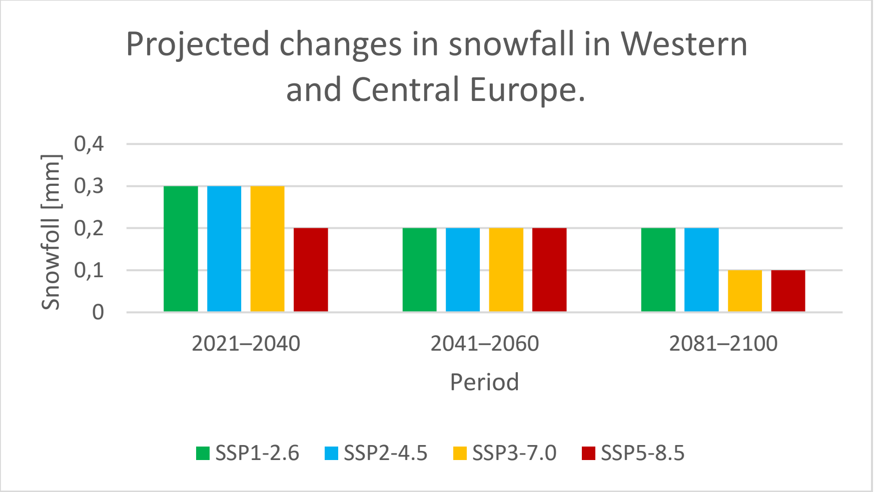

Figure 4 Projected changes in snowfall amount in Western and Central Europe by 2100 under the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios (own elaboration based on IPCC Interactive Atlas, 2021)

The full set of IPCC charts used in this section (Maximum 1-day Precipitation RX1day, Maximum 5-day Precipitation RX5day, Consecutive Dry Days CDD, Snowfall) has been prepared as the **"IPCC – Lodzkie" package** and made available in the Zenodo. See Chapter "Supporting Documentation".

Based on **DRMKC Risk Data Hub** (DRMKC, 2023) for the Lodzkie Region, three primary climate hazards are significant:

- **Extreme heat**
  The region, especially the metropolitan area of Łódź, is characterized by a high level of risk related to heat waves: WBGT (Wet Bulb Globe Temperature) indicators in RDH for a 20-year return period range between 26–35°C, placing the region in the highest risk category. Multi-risk analysis shows that in 2020, heat risk values in cities averaged **4–6**, with a projected increase to **6–7.5** by 2030. This effect is particularly dangerous for vulnerable groups: the elderly, children and chronically ill individuals. In the Lodzkie Region, an additional factor is the persistent **urban heat island** phenomenon, confirmed by research (Bobrowska-Korzeniowska et al., 2024).
- **Wildfire**
  Three views were used for the analysis DRMKC:
  a) **FWI – 2-year return period (frequent episodes):** predominantly **low/moderate** values, which means regular, seasonal conditions conducive to ignition.
  b) **FWI – 30-year return period (rare, strong episodes):** share of **yellow/red** areas increases; for the Lodzkie Region, the reported values are around **50–100 FWI**, which means that in extremely dry seasons the risk of large fires becomes significant (although lower than in Southern Europe).
  c) **Forest Fire – "Combination of danger by thermal anomalies, fire weather and burnable fuel"**: a composite index combining thermal anomalies, fire weather and availability of combustible fuel. In the Lodzkie Region, extensive High/Very High zones (orange/red) are visible, particularly in central and southern parts of the region with a high share of coniferous forests and agroforestry mosaic.

- **River flood**
  In the “Population at risk” layer, most of the Lodzkie Region falls into the lowest exposure classes (values <1 or 1–10 people), indicating that the hazard is local and marginal. At the same time, the Losses – Flood module (2000–2024) records incidents likely related to intense rainfall and localized flooding, rather than classical high-flow events of major rivers. Those at risk include residents of valley areas and users of technical infrastructure.

The RDH analysis shows that although flood risk models indicate a marginal significance of this hazard in the Lodzkie Region, historical data confirm recorded flood incidents in 2000–2024. This is likely due to localized flooding associated with intense rainfall rather than classical riverine floods. This means that when assessing climate risk in the region, both hydrological models and empirical observations should be considered. The full set of screenshots from DRMKC used in this section (heat, forest fire – 2y/30y, river-flood population, losses-flood 2000–2024, GHSL exposure, multi-risk 2020/2030) has been prepared as the **“DRMKC – Lodzkie (atlas, hazard/exposure/vulnerability/losses layers)” package** and made available in the Zenodo repository. See Chapter 5 “Supporting Documentation”.

The Copernicus Atlas contains both observed and future projected data at the European country level, therefore, the analysis focused on data available for Poland. Data from CMIP6 model projections were used for the SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios, relative to the baseline period1850-1900.

- Maximum consecutive dry days - CDD) (days):

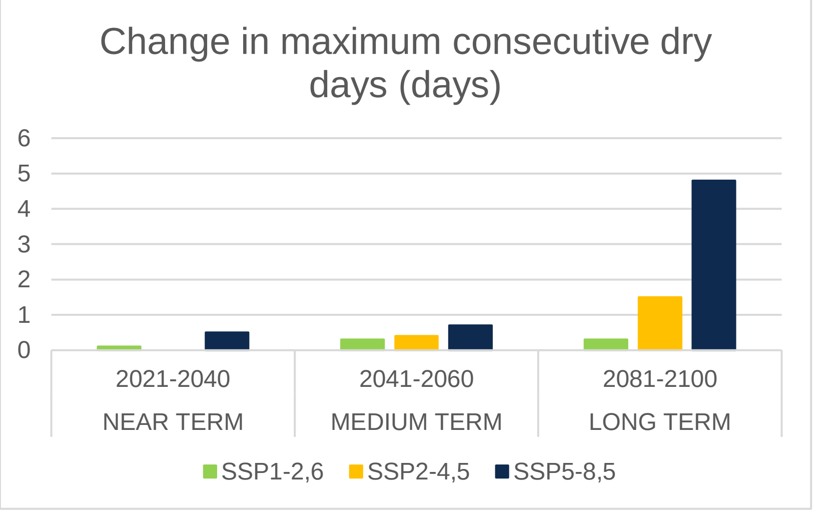

Figure 5 Projected changes in the maximum number of consecutive dry days (CDD index) in Poland by 2100 under the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios (based on data from the Copernicus Climate Interactive Atlas, 2021)

According to the analysis (Figure 6), under the SSP1-2.6 scenario, droughts in Poland remain moderate. In SSP2-4.5, the number of dry days and consecutive days without precipitation increases, particularly in agricultural regions such as Lodzkie Region. In SSP5-8.5, CDD is projected to increase by about 5 days compared to the 1850–1900 period, indicating a high risk of agricultural drought.

- Mean soil shallow moisture content (kg/m²)

The analysis of soil moisture changes relative to the 1850–1900 period indicates intensifying summer droughts across all scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5). By 2040, the area experiencing negative changes in soil moisture increases, particularly in spring and summer, signaling progressively drier vegetative seasons and a decline in agricultural productivity. The most pronounced decrease is projected under the SSP5-8.5 scenario.

- Mean of daily accumulated snowfall precipitation (mm/day)

Data presented in Figure 6 show a downward trend – the higher the emission level, the thinner the snow cover. In the SSP5-8.5 scenario, snow cover nearly disappears in many regions of Poland by the end of the 21st century.

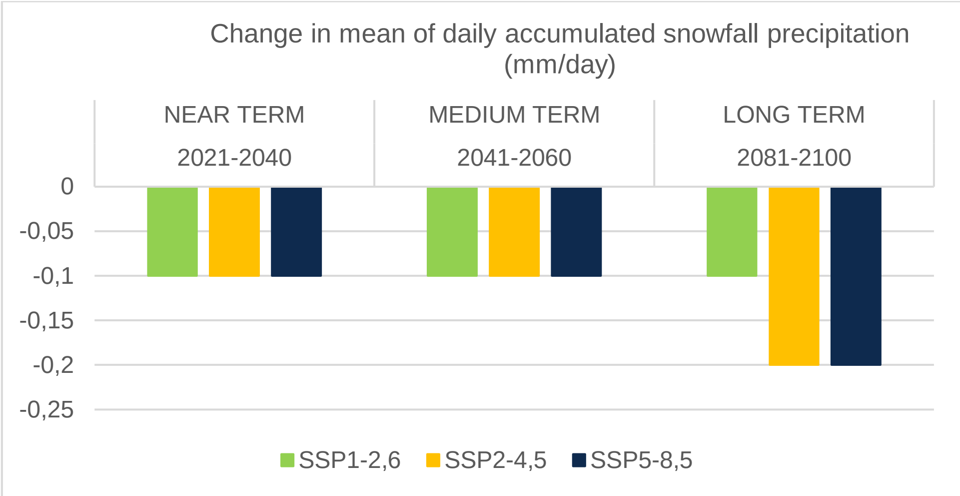

Figure 6 Projected changes in the mean daily cumulative snowfall in Poland by 2100 under the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios (based on data from the Copernicus Climate Interactive Atlas, 2021)

Seasonal stripes charts of the mean daily accumulated snowfall show seasonal changes in average daily snowfall in Poland under climate scenarios relative to the 1850–1900 baseline period. In the low-emission scenario (SSP1-2.6), snowfall still occurs, although at lower intensity than in the past. Poland retains some winter characteristics but with a clear warming signal. Under current trend continuation (SSP2-4.5 scenario), winters become less snowy.

- **Maximum of 1-day accumulated Precipitation (mm/day)**

One-day precipitation amounts in Poland increase across all greenhouse gas emission scenarios – the higher the scenario, the greater the risk of extreme rainfall.

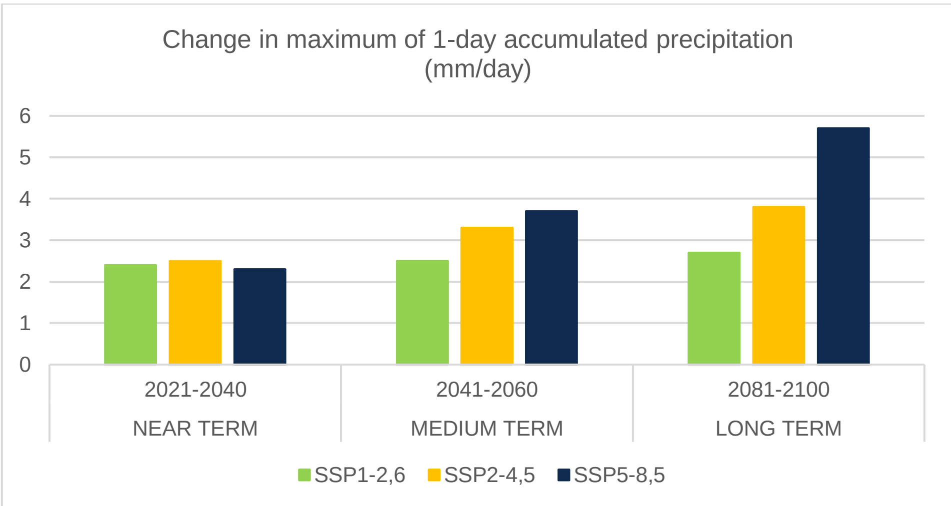

Figure 7 Projected changes in maximum 1-day precipitation in Poland by 2100 under the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios (based on data from the Copernicus Climate Interactive Atlas, 2021)

Analysis in Figure 7 indicates increases in mean annual values relative to the 1850–1900 baseline period. In central Poland, a moderate increase is expected, but the largest rise, of nearly 6 mm/day, may occur under extremely high greenhouse gas emissions. In summer, the amount of intense convective precipitation (storms, heavy downpours) will generally increase, while in winter more precipitation will fall as rain rather than snow.

- Maximum of 5-day accumulated precipitation (mm/day)

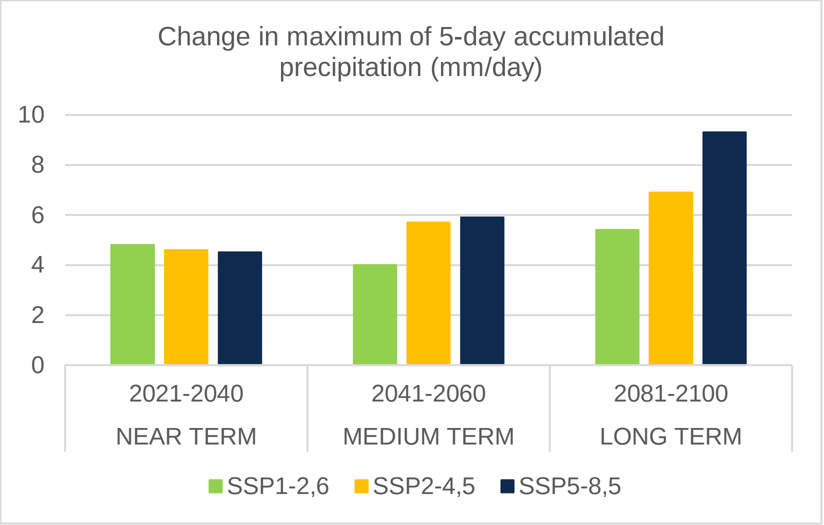

Figure 8 Projected changes in maximum 5-day precipitation in Poland by 2100 under the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios (based on data from the Copernicus Climate Interactive Atlas, 2021)

When analyzing the data presented in Figure 8, under the low-emission scenario (SSP1-2.6), only a minimal increase in five-day precipitation intensity is projected in the distant future, despite emission reductions. The SSP2-4.5 scenario, continuing current trends, shows a noticeable increase, particularly after 2080, when the risk of more intense precipitation will be higher. The largest increase, along with more frequent extreme weather events, is projected under the no-emission-reduction scenario (SSP5-8.5). After 2080, the index could rise sharply to 9 mm over 5 days.

- Heavy precipitation days - above 10 mm. Most climate models show an increase in the number of days with precipitation above 10 mm per year in Poland in the second half of the 21st century.

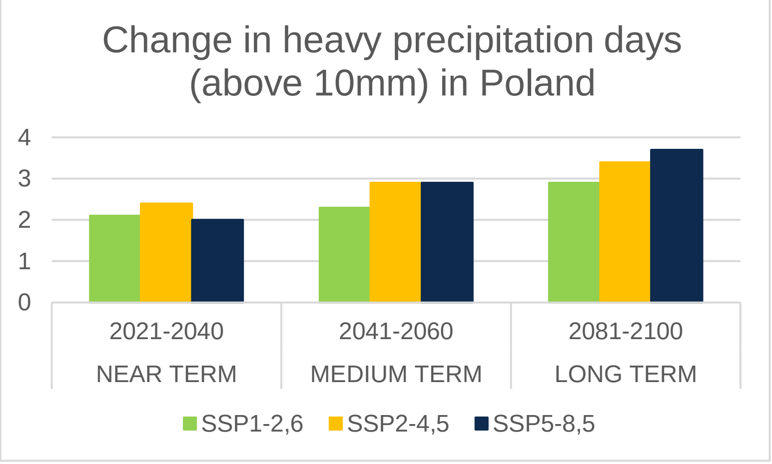

Figure 9 Projected changes in the number of days with very heavy precipitation (above 10 mm) in Poland by 2100 under the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios (based on data from the Copernicus Climate Interactive Atlas, 2021).

Figure 9 indicates that even under the sustainable development scenario (SSP1-2.6), Poland experiences an increase in intense precipitation, raising the risk of localized flooding. In the high-emission scenario (SSP5-8.5), the number of days with heavy rainfall could increase by up to 4 days per year compared to the 19th century.

The full set of charts from the Copernicus Climate Interactive Atlas used in this section (Maximum 1-day Precipitation, Maximum 5-day Precipitation, Consecutive Dry Days CDD, Heavy precipitation days - above 10 mm, Mean of daily accumulated snowfall precipitation, Mean soil shallow moisture content) including seasonal stripes for Mean of daily accumulated snowfall precipitation and Mean soil shallow moisture content, has been prepared as the **“Copernicus – Lodzkie” package** and made available in the Zenodo repository. See Chapter 5 “Supporting Documentation”.

Summary: The Lodzkie Region is located among the areas with **increasing climate risk**. More frequent **heavy rainfalls and localized flooding** as well as **prolonged drought periods** are projected. Models indicate an increase in the number of consecutive dry days and a decline in soil water retention, exacerbated by **temperature rise and the urban heat island effect**. The region’s most serious challenge remains the **water shortage and the risk of agricultural drought**, which limit agricultural potential and the quality of life for residents.

2.2.2 Workflow selection

The selection of workflows was based on the analysis of data from the Copernicus Climate Atlas, the IPCC Interactive Atlas and the DRMKC Risk Data Hub. It was identified that, for the Lodzkie Region, the most significant phenomena are hydrological events related to water deficit and excess, which cause the greatest losses in the agriculture and infrastructure sectors.

Initially, according to the Individual Flow Plan (IFP), the analysis included two workflows: Relative Drought and Heavy Rainfall. During the implementation, following data analysis and consultations with local stakeholders, it was decided to extend the scope to include Agricultural Drought – a phenomenon of increasing economic and social importance in the region.

Selection of these three workflows is justified by the following considerations: each of the chosen workflows corresponds to a different aspect of the hydrological cycle and their combined application makes it possible to capture the full spectrum of risks – from water deficit to water excess – and to identify areas requiring adaptive measures.

2.2.2.1 Relative Drought

– it reflects a long-term precipitation deficit and a reduction in water resources, leading to low river levels and a decline in groundwater tables.

2.2.2.2 Agricultural Drought

– it directly affects crop yields, the economy and the region’s food security. It is crucial from the perspective of the agricultural sector, which occupies a significant part of the region.

2.2.2.3 Heavy rainfall

– an increasingly frequent phenomenon causing local flooding and flash floods, particularly in the Lodzkie agglomeration zone and areas with low soil permeability.

2.2.3 Choose Scenario

The analysis adopted three climate scenarios: **SSP1-2.6, SSP2-4.5 and SSP5-8.5**, covering pathways from low to high greenhouse gas emissions. SSP1-2.6 assumes effective climate policies and emission reductions, SSP2-4.5 represents the continuation of current trends (the baseline scenario for Poland), while SSP5-8.5 reflects increasing emissions and the dominance of fossil fuels. These scenarios enable the assessment of climate change impacts up to the year 2100 and the analysis of key phenomena relevant to the region, such as droughts, heavy rainfall, and heatwaves. Verification of detailed indicators (e.g., CDD, Rx1day, R10mm) will be conducted during the Risk Analysis phase.

2.3 Risk analysis

2.3.1 Workflow #1 – Relative drought

Table 2 Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Drought hazard (dH) derived from the WASP (Weighted Anomaly Standardized Precipitation index), calculated form monthly precipitation sums (CMIP6/ISIMIP3b). dH = probability of exceeding the regional median of „severe precipitation deficits" for the specified period of time (1981–2015, 2031–2060, 2071–2100)	**GDP per capita** (Global CWatM; negative correlation) + **Rural population** (Global CWatM; positive correlation): aggregated using DEA to **dV** (at NUTS-3 level)	**Cropland** (SPAM; future: cropland z GCAM), **Livestock density** (FAO GLW), **Water stress** (WRI Aqueduct v4), **Population** (EUROSTAT; future: Global CWatM): aggregated using DEA to derive **dE** (at NUTS-3 level).	**Relative drought risk = dH × dE × dV** (relative index, scale 0–1; not comparable between time periods). Lodzkie Region: highest values in the skierniewicki subregion; elevated in piotrkowski; lover in city Lodz and sieradzki subregion; Nonlinear variability between scenarios and time horizons.

2.3.1.1 Hazard assessment

The analysis of the WASP index indicates that in Poland, the risk of precipitation deficits and droughts **will intensify in the coming decades**. However, the magnitude of this risk varies depending on the emission scenario.

In the SSP3-7.0 scenario, WASP values are higher than in SSP5-8.5, which means a smaller precipitation deficit. This is likely the result of seasonal precipitation distribution: in SSP5-8.5, a significant increase in winter and spring rainfall is projected, which partially compensates for summer droughts, thus lowering the annual index value. As highlighted in IPCC AR6 (SPM, sections B.3 and C.2, p. 19 and 23), global warming leads to intensification of the hydrological cycle and increase of the seasonal precipitation variability. In Europe, more frequent and intense extreme precipitation events are expected, but simultaneously there is a growing risk of agricultural and ecological droughts, especially with a temperature rise of 2°C or more.

In the analyses proposed in the JupyterHub notebooks, an indicator such as WASP presents results on an annual or seasonally averaged scale. This approach tends to conceal seasonal differences: higher winter and spring precipitation may lower the annual deficit index, even though summer droughts are clearly intensifying. According to IPCC projections for Central and Western Europe, an **increase in winter and spring precipitation and a decline in summer rainfall** are expected, with seasonal contrasts intensifying alongside ongoing climate warming (IPCC AR6 WG1, 2021, Regional Fact Sheet – Europe). It is worth noting here that the current analytical tool lacks an explicit distinction between winter–spring and summer precipitation deficits, which limits the full interpretation of drought risk in the case of the Lodzkie Region.

2.3.1.2 Risk assessment

The analysis indicates **diverse, non-linear changes** in risk over time and across scenarios. The highest values remain in the Skierniewice subregion, while elevated levels are observed in the Piotrków subregion. In the Lodzkie Region and the Sieradz subregion, the risk remains stable and lower. In the SSP3-7.0 scenario for 2080, the risk in the Skierniewice subregion decreases compared to 2050, which confirms the absence of a uniform trend. General conclusions on hydrological drought risk in the Lodzkie Region: **lack of consistent long-term trend, significant spatial differentiation, non-linear patterns of change, problems for adaptation**.
The results and datasets used in this section on hydrological drought hazard and risk were compiled as the **package "Charts and data for hydrological drought hazards and risks"** and made available in the Zenodo repository. See Chapter 5 "Supporting Documentation".

2.3.2 Workflow #2 – Agriculture drought

Table 3 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
AWC – Available Water Capacity, source: FAO/IIASA GAEZ v4 (res06/LR/awc/), expressed in mm of water per soil profile; **ET0** – Reference Evapotranspiration (mm/day), source: FAO/IIASA GAEZ v4 (res06/LR/et0/)	Irrigation availability – share of cropland equipped for irrigation, source: FAO/IIASA GAEZ v4 (GLCSv11_12_5 m.tif) expressed as % of total cropland area	**Crop production [t]** – total crop production, source: MapSPAM (Harvard Dataverse, 2010, DOI: 10.7910/DVN/PRFF8V) **Crop aggregated value** [originally GK$, PPP adjusted, equivalent to 2010 USD] – aggregated crop value, source: FAO/IIASA GAEZ v4 (V/2010/all_2010_val.tif)	**Revenue loss risk** = hazard (yield loss) × exposure (production&value) × vulnerability (irrigation) Relative indicators of *lost opportunity* cost at the NUTS-2 level. Model results indicate yield losses of up to **30–35 % for wheat** and **10–25 % for maize**, with the **highest income losses** projected in the **northern and south-eastern parts of the region** under RCP4.5 and RCP8.5 scenarios.

2.3.2.1 Hazard assessment

The soil water capacity (AWC) in the Lodzkie Region shows spatial variability, as illustrated in Figure14. Soils with medium water capacity (150–250 mm) dominate. The highest values (300–400 mm) occur locally, mainly in areas with heavier, clay-rich soils. The lowest values (approx. 100 mm) occur in the central and southeastern parts of the Lodzkie Region.

In the 2046–2050 perspective (RCP2.6), the total precipitation during the growing season is projected to range between 650–950 mm, compared with the regional average of 550–700 mm. Higher precipitation levels are expected in the Lodzkie agglomeration, Skierniewice and Radomsko regions, where urban development predominates.

The ETO values in the Lodzkie Region vary from approximately 1250 to 1425 mm, indicating a relatively high water demand in the coming decades. The higher the ETO, the greater the soil water loss, which particularly affects the northern and western parts of the region. This suggests an increased need for crop irrigation or the selection of more drought-resistant species**.**

2.3.2.2 Risk assessment

The maps present maize yield loss resulting from precipitation deficits in the Lodzkie Region for the period 2046–2050, prepared using three climate scenarios: RCP2.6, RCP4.5 and RCP8.5, as well as the MPI-SMHI model. All maps show the percentage of maize yield loss caused by insufficient rainfall, using a uniform color scale where losses range from 10% to 32.5%. Precipitation deficit will be a significant limitation for maize production in the Lodzkie Region by the mid-21st century, with the western part of the region, in particular.

The maps presenting wheat yield loss for the Lodzkie Region for the period 2046–2050, based on three climate scenarios: RCP2.6, RCP4.5 and RCP8.5, as well as the MPI-SMHI model, show the average yield losses ranging from 20% to 30%, reaching up to 35% in some areas, which indicates high sensitivity of wheat to precipitation deficit. The greatest losses are projected to occur in the agricultural belt of the northern part of the Lodzkie Region (running east–west) and in the southeastern part of the region (marked in dark red on the maps).

The maps presenting the projected income losses from maize (MAIZ) and wheat (WHEA) cultivation caused by **the precipitation deficit** for the period 2046-2050 according to the RCP 2.6 climate scenario (i.e. the variant which assumes a reduction in greenhouse gas emissions). In both cases, irrigated areas may account for up to 10% of agricultural land. For maize (MAIZE), the range of income losses without irrigation is smaller compared to wheat (WHEA). Wheat shows mostly losses up to EUR 60,000 without irrigation. The northern part of the Lodzkie Region is particularly vulnerable to higher wheat losses (WHEA) without irrigation, where losses may reach even up to EUR 90,000 near the border of the region.

The results of the analyses on agricultural drought hazards and risk used in this section have been complied as **the "Charts and data for agricultural drought hazards and risk" package** and made available in the Zenodo repository. See Chapter 5 "Supporting Documentation".

2.3.3 Workflow #3 – Heavy rainfall

Table 4 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
EURO-CORDEX climate data (scenario RCP 8.5,model chain ICHEC-EC-EARTH / KNMI-RACMO22E) at 0.11° (~12 km) resolution. Analysed variable: **daily precipitation sums (pr)** processed into **24-hour IDF curves** for two time periods 1976–2005 and2041–2070 – **Path *B***.	**Vulnerability considered indirectly**, according to the CLIMAAX methodology (Extreme Precipitation Critical Thresholds). The standard sensitivity of infrastructure and ecosystems to 24-hour heavy rainfall events was assumed.	**Spatial exposure** – area of the Lodzkie Region (bbox [18.0, 50.98, 20.80, 52.40], WGS 84). The Area of Interest (AOI) was analysed on the EURO-CORDEX grid (~12 km).	- **Analysed indicators**: Return Period (shift) and Intensity (Magnitude shift) derived from 24-hour IDF 24 curves. - **Base variable:** daily precipitation (pr) from EURO-CORDEX RCMs (ICHEC-EC-EARTH / KNMI-RACMO22E, RCP 8.5). **Time periods:** 1976–2005 (historical) and 2041–2070 (projected). **Range:** RP = 2–200 years; dominant classes 5–20 years; intensity change (RP = 10 years) –20 % to +70 %, median ≈ +12 %. **Result:** hazard-based proxy risk indicating **increased frequency and/or intensity of extreme daily precipitation**, pointing to **a higher risk of pluvial floods and local inundations**.

2.3.3.1 Hazard assessment

The comparative analysis for the periods 1976–2005 and 2041–2070 (RCP8.5) showed an increase in the intensity of 24-hour extreme precipitation by 5–25%, locally reaching60–70%. The largest increases are projected in the southwestern and northeastern parts of the region, which means a higher risk of localized flooding and drainage system overloads. The median 10-year return period precipitation rises from 41.7 to 44.7 mm (approx. 7%) and threshold values may reach 50–60 mm/24h, which confirms the trend of more intense cloudbursts in the region.

2.3.3.2 Risk assessment

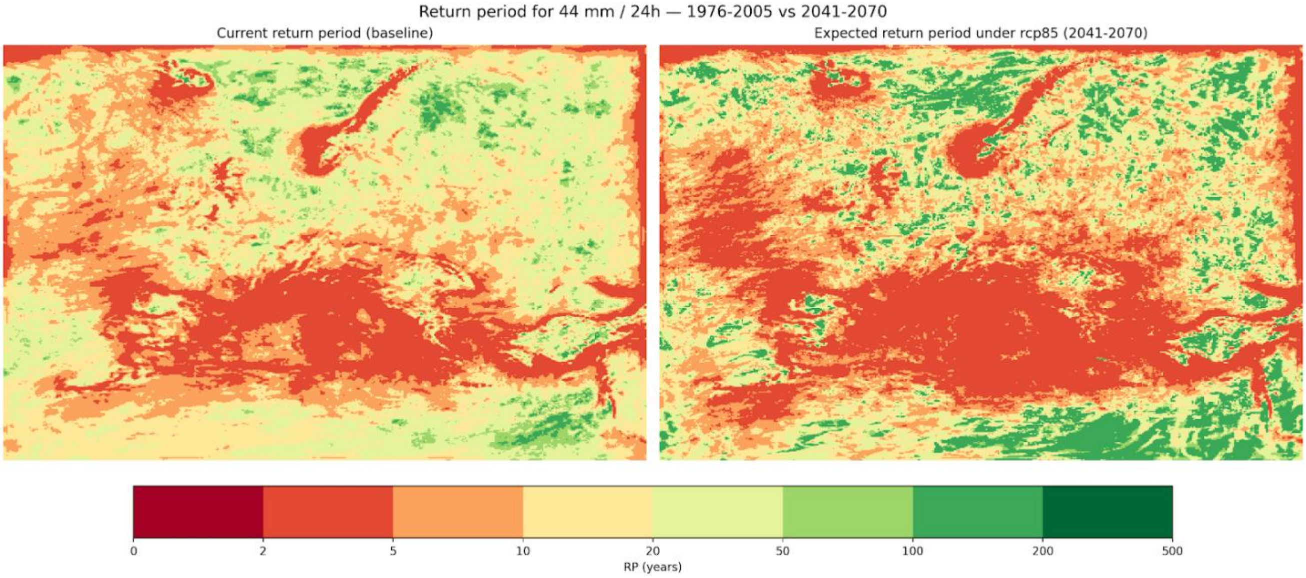

Figure 10 Comparison of extreme 24-hour precipitation return periods in the Lodzkie region: historical period 1976–2005 (left) and future projection 2041–2070 under the RCP8.5 scenario (right).

The risk analysis as part of **Path B (hazard-driven)** enabled the assessment of spatial changes in the frequency and intensity of daily extreme precipitation in the region. Two indicators were calculated: **Return Period shift** for the threshold of 44.4 mm/ 4 and **Magnitude shift** for the fixed return period RP = 10 years. The results indicate a **spatially diverse distribution of frequency** of precipitation with intensity of 44.4 mm / 24 h. In the base period, classes of RP = 5–20 years dominate, which corresponds to an average frequency of approximately 10 years, with locally occurring areas of rare events (50–200 years). In the period 2041–2070, the RP distribution is extended: the share of areas with shorter return periods (<10 years) increases, and new zones with very long return periods (≥100 years) appear, where 44.4 mm events remain rare. This means the simultaneous occurrence of trends toward both increasing and decreasing event frequency, showing differences in local extreme characteristics.

The supplementary **Magnitude shift** analysis for RP = 10 years confirms an increase of precipitation intensity on most of the region. Changes range from –20 % (in central part of the region) to +40–50 % (in the western and northern districts), and a median increase of approximately **+12 %**. Such diversity means that future precipitation with the same frequency (10-year) will be stronger than in the base period in most of the areas.

The results of the analyses on heavy rainfalls hazards and risk used in this section have been complied as the **“Charts and data for heavy rainfalls hazards and risk” package** and made available in the Zenodo repository. See Chapter 5 “Supporting Documentation”. Combination of the two indicators shows that the risk of extreme precipitation in the Lodzkie Region is expected to increase. The highest potential hazard regards the western and northern parts of the region, where a decrease in Return Period and increase in rainfall intensity occur simultaneously. The central part of the region also remains vulnerable due to dense urban development and low soil permeability.

2.4 Preliminary key Risk Assessment Findings

2.4.1 Severity

Climate-related hazards (droughts, heavy rainfalls, floods, fires, declining snowfalls), in interaction with non-climate risk factors (such as water management, ecosystem fragmentation, spatial planning model and urban development, as well as social inequality) pose threats to European food security, public health, ecosystem, infrastructure and economy (EEA, 2024), including the Lodzkie Region.

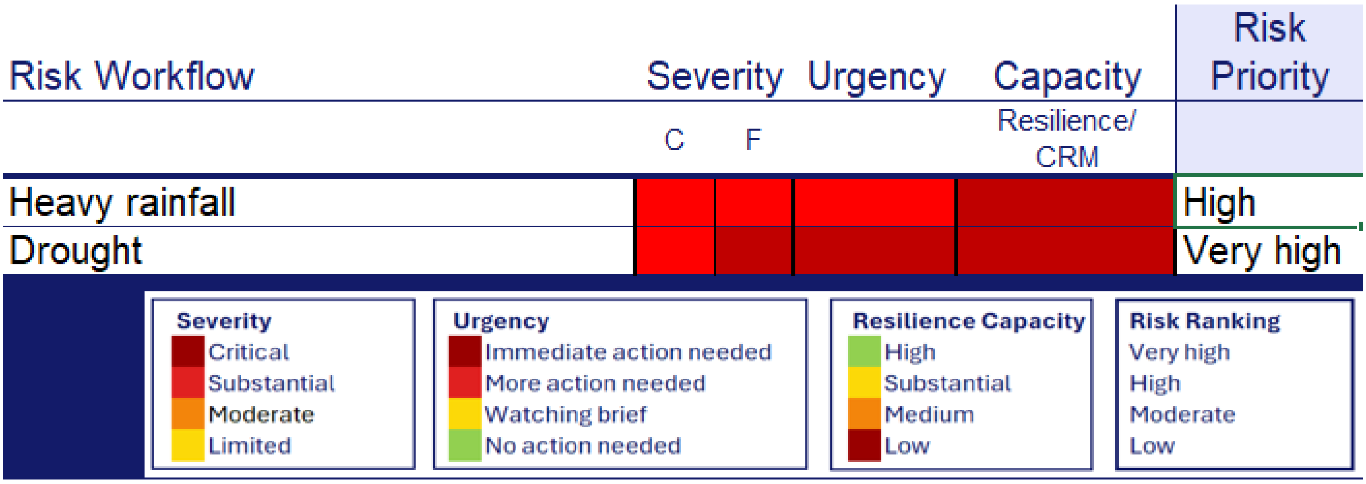

Figure 11 Assessment of key risks by ranking risks, taking into account severity (current – C risk and future – F risk), urgency, and resilience (Source: DRMKC Risk Data Hub, IPCC, Copernicus Program, Risk Analysis)

A risk assessment was conducted to identify, analyze and evaluate the main types of climate-related risk for the Lodzkie Region (Figure 11). The analysis included the assessment of the risk effect severity in four categories (catastrophic, critical, significant and limited - EEA, 2024) in relation to two periods (present and future). The comparison indicates that the greatest hazards to the Lodzkie Region are drought and heavy rainfall. Prolonged periods without precipitation and low soil moisture lead to agricultural losses, declining groundwater levels and hazards to ecosystems. Intense rainfall, on the other hand, cause localized flooding, overloaded drainage systems and infrastructure damage (particularly in the urban areas). The highest climate risk for the Lodzkie Region is posed by drought and heavy rainfalls.

2.4.2 Urgency

In relation to types of climate-related risks (Figure 11), an assessment of action urgency was carried out using the following categories: urgent action required, further action needed, situation monitoring and maintaining current measures. The urgency is determined based on the severity of the risk impacts, the level of confidence over time and the readiness of existing policies.

The presented climate risks are increasingly affecting the functioning of the Lodzkie Region. Analyses from Copernicus, DRMKC and IPCC clearly showed that the specified climate risks, i.e. drought and heavy rainfall, are likely to persist and even intensify in the near future in the Lodzkie Region. This results in the need for urgent action in the region to manage climate-related risks effectively.

As the Lodzkie Region experiences extreme weather fluctuations – drought periods alternating with intense rainfall – climate risks must be addressed urgently and adaptation measures should be implemented primarily in water management, spatial planning and agriculture.

2.4.3 Capacity

The Lodzkie Region is characterised by low capacity to cope with climate risks. Although regional and even local policies introduce a broad set of measures, their implementation remains highly localized and is carried out by a limited number of entities (e.g. State Forests, ERCE PAN). Growing awareness among decision-makers is reflected in regional management strategies, however these strategies have not yet translated into large-scale investments that could achieve significant, region-wide impact.

This is still insufficient to effectively manage climate risks. To speak of the capacity of the Lodzkie Region to cope with climate risk, it is essential that local governments ensure critical infrastructure and services, invest in forecasting and early-warning systems for extreme events, and foster a climate-engaged society, along with equity and supportive political conditions.

2.5 Preliminary Monitoring and Evaluation

Phase 1 of the climate risk assessment enabled the identification of the most vulnerable sectors (agriculture, water infrastructure, public health, spatial planning) as well as the main hazards (droughts, floods, dry periods). Available environmental data were collected and verified, however, difficulties were encountered due to the inconsistency, varying timeliness and scale of spatial data, and their processing at the NUTS2–NUTS3 level. Stakeholder reactions in the first phase were very positive. They appreciated the practical application of the CLIMAAX project and the possibilities for using the developed data for further utilization and identifying areas requiring a reduction of climate risks. In the next round of analysis, it is recommended to include a broader group of entities, including institutions responsible for agriculture such as the Agency for Restructuring and Modernization of Agriculture, the Institute of Soil Science and Plant Cultivation – State Research Institute, representatives of the private sector (e.g., farms, insurance companies), and non-governmental organizations dealing with climate change adaptation. Their practical knowledge and operational data could significantly improve the quality and representativeness of the risk analysis results. In terms of monitoring, it is possible to use indicators that have been designated for monitoring the implementation of planning and strategic documents at the regional level, such as: CO_2 emissions from particularly burdensome plants [t/year], forest coverage [%], the share of green areas in cities in the total area [%], total capacity of small retention facilities [dam3]. Nevertheless, to better understand climate risks, more precise and up-to-date data on agricultural production, water infrastructure, and soil conditions are necessary, taking into account the development of agricultural and urbanized areas. Additional financial resources are also needed to launch local measurements, modernize models, and provide training for local administration in the interpretation of climate data. Research collaboration with meteorological, agricultural, and scientific institutes is also recommended to develop analytical tools and validate results.

2.6 Work Plan

In the next phase, it is planned to conduct a public procurement for the provision of expert services to carry out a "multi-risk" analysis for three selected workflows. Additionally, the participation of Project Team representatives in local climate-themed events is planned, promoting the CliRes-LR project and the CLIMAAX initiative itself.

Heavy rainfall: in the next phase, an update of the risk assessment is planned by incorporating local data and possibly extending the historical period used in the hazard analysis (currently 1976–2005) in order to more accurately reflect contemporary precipitation trends. At the same time, it is planned to take into account local data on exposure and vulnerability (e.g. land cover, population density), as well as an analysis of historical incidents through the examination of data obtained from the Lodz Voivodeship Office regarding floods and damages.

Agricultural drought: it is planned to incorporate satellite data from the Polish Space Agency - POLSA for wheat and maize crops, which will enable the combination of climate analyses with agricultural observations. It is also planned to obtain material for analysis concerning agricultural soil suitability complexes from the Geoportal of the Lodzkie Region (https://mapy.lodzkie.pl/).

Relative drought: in the second phase of the project, it is planned to expand the analysis of relative drought to include the seasonal aspect, in order to better capture the region's characteristic variability – higher precipitation in the winter-spring season and more frequent drought episodes in the summer period. The use of available observational data (including from European EDO databases) will allow for a more precise assessment of the seasonal course of the phenomenon and its impact on local climate risk. It is planned to obtain data on surface water levels and river flow rates. This data will provide an additional perspective on the actual risk of hydrological drought in the region, showing current values.

3 Conclusion Phase 1 – Climate risk assessment

Phase 1 of the CLIMAAX project involved a comprehensive review of climate hazards in the Lodzkie Region, conducted based on data from European reference databases (IPCC Interactive Atlas, Copernicus Climate Atlas, DRMKC Risk Data Hub) and the CLIMAAX Workflow tools. Within this phase, key risk phenomena were identified, their spatial and temporal variability was analyzed, and the most vulnerable sectors and areas of the region were determined.

CMIP6 and EURO-CORDEX climate indicators showed clear changes in the region's precipitation and temperature regimes. The comparison of Rx1day, Rx5day, and CDD reveals increasing contrasts in the region's water balance – increasingly frequent episodes of intense rainfall alternate with prolonged dry periods. This phenomenon reflects the observed greater variability in precipitation and seasonal shifts in moisture distribution in Central Europe, as confirmed in the IPCC AR6 analyses (2021, sections B.3 and C.2).

The analysis of changes in CDD (+4–8 days in the SSP5-8.5 scenario) indicates a systematic increase in drought, while the simultaneous rise in Rx1day and Rx5day (up to +6 mm/24 h and +9 mm/5 days) implies a higher risk of localized pluvial floods. As a result, the Lodzkie Region is experiencing highly seasonally variable hydrological extremes, which from an adaptation perspective, creates a situation of increasing instability in water resources.

Soil moisture and available water capacity (Mean soil moisture, AWC) indicators confirm that the area of the region is among the driest in Poland. Soils with low retention capacity (100–150 mm) dominate in the central and southeastern parts of the region, which, combined with increasing evapotranspiration (ET_0), raises the risk of agricultural drought. Meanwhile, the WASP (Weighted Anomaly Standardized Precipitation) analysis for NUTS-3 subregions showed the highest precipitation deficit values in the Skierniewice and Piotrków subregions – consistent with Copernicus data on decreasing soil moisture and increasing CDD.

DRMKC models confirm these relationships – areas with high drought exposure partially overlap with locations facing increasing forest fire risk (FWI 30y) and water deficit. This spatial correlation between drought and fire hazard (particularly in the agricultural-forest zones of the southwestern parts of the Lodzkie Region indicates the need to treat them as cascading risks rather than separate phenomena.

In the Heavy Rainfall (EURO-CORDEX) workflow, it was estimated that 24-hour extreme rainfall with a 10-year return period will increase on average by +12%, and locally even by 60–70%. Importantly, the spatial distribution of these changes is not random: areas with increasing rainfall intensity are concentrated in the northeastern and southwestern parts of the region, whereas the central zone of the region – characterized by dense development and low soil permeability – remains vulnerable due to its limited infiltration capacity and the potential overloading of drainage systems. This means an increased risk of flooding and water accumulation in areas with the lowest retention capacity.

An integrated analysis of indicators allows several patterns to be identified:

- Northern and southern zones: northeastern counties (skierniewicki, rawski, łowicki) are characterized by the highest risk of agricultural drought, while southwestern counties (sieradzki, wieruszowski) face the greatest risk of intense rainfall.
- Central zone with a large share of impervious surfaces shows a relatively lower increase in rainfall intensity but remains highly vulnerable to the effects of urban flash floods.
- Sectoral dependence: agriculture primarily responds to water deficits (wheat and corn yield losses of up to 30–35%), whereas the infrastructure sector is affected by temperature variability and the intensity of rainfall. Both phenomena interact – dried-out soil reduces infiltration, increasing surface runoff and susceptibility to flooding.

During the implementation of the CRA, additional limitations related to the availability and consistency of climate data were revealed. The sources used differed in terms of spatial resolution, emission scenarios (RCP, SSP), and time horizons, which hindered the full integration of results between risk analyses. Most of the indicators applied (e.g., WASP, P–ET_0, Rx5day) were averaged on an annual or multi-year basis (in some cases, only trend visualizations of precipitation intensity changes were available), which limited the ability to capture short-term, seasonal episodes of droughts and heavy rainfall. The lack of a national monitoring system for the effects of extreme events also hindered the validation of model results against observational data.

4 Progress evaluation and contribution to future phases

Table 5 Overview key performance indicators

Key performance indicators	*Progress*
2 workflows completed as part of the Phase 1 Report of the project	*completed*

Table 6 Overview milestones

Milestones	*Progress*
Participation in workshops for beneficiaries of the CLIMAAX initiative in Barcelona in June 2025.	*completed*
Risk assessment completed in Phase 1	*completed*

5 Supporting documentation

- Package „DRMKC – Lodzkie (atlas, hazard/exposure/vulnerability/losses layers)”;
- Package „IPCC – Lodzkie”;
- Package „Copernicus – Lodzkie”;
- Package „Charts and data for relative drought hazards and risk”;
- Package „Charts and data for agricultural drought hazards and risk”;
- Package „Charts and data for heavy rainfall hazards and risks”;
- Package „meetings with project stakeholders”.

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