CLIMAAX
climate ready regions

Deliverable Phase 2 – Climate Risk Assessment

Climate Resilience of Lodzkie Region (CliRes-LR)

Poland, Lodzkie

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Abbreviations and acronyms

Skróty / akronimy	Opis
ARIMR	Agency for Restructuring and Modernisation of Agriculture
AWC	Available Water Capacity
AWRA	Aqueduct Water Risk Atlas
BDL	Local Data Bank
CDD	Consecutive Dry Days
HDHI	Hydrological Drought Hazard Index
IMGW-PIB	Institute of Meteorology and Water Management
KPEiK	National Energy and Climate Plan till 2030, with an outlook to 2040
LAI	Leaf Area Index
MPA	Urban Climate Change Adaptation Plans
NDRE	Normalized Difference Red Edge Index
NDVI	Normalized Difference Vegetation Index
OSP	Volunary Fire Service
POLSA	Polish Space Agency
PET	Potential evapotranspiration
PGWWP	State Water Management Authority - Polish Waters
PSP	State Fire Service
RCP	Representative Concentration Pathways
RDOŚ	Regional Directorate for Environmental Protection
RSO	Regional Warning System
RX1day	Maximum 1-day Precipitatin
RX5day	Maximum 5-day Precipitatin
SMSR	Agricultural Drought Monitoring System
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathways
WFOŚiGW	Regional Fund of Environmental Protection and Water Management in Łódź
WŁ	Lodzkie Region
SRWŁ	Regional Development Strategy of the Lodzkie Region 2030
ZPKWŁ	Lodzkie Region Landscape Park Group

Executive summary (1-2 pages)

Phase 2 of the CliRes-LR project develops the analysis of the Climate Risk Assessment carried out in Phase 1 of the project. Its primary objective was to proceed from the initial identification of climate hazards to a more detailed risk assessment in the Lodzkie Region, taking into account spatial variation, local exposure and vulnerability, as well as potential future changes. To this end, CLIMAAX methods and tools were applied, adapting them to the regional context through the use of additional local and regional data.

The results of Phase 1 served as a starting point, with hydrological drought, agricultural drought and heavy rainfall identified as the most significant issues for the Lodzkie Region. In Phase 2, each of these risks was subject to an in-depth analysis, combining information on climate hazards with the data on the elements at risk and their vulnerability. The use of data that is more detailed in both spatial and thematic terms made it possible to depart from the general characteristics of risks and to identify specific areas, sectors and resources of particular importance in terms of resilience of the region.

Another key element of Phase 2 was the work related to the acquisition, preparation and integration of regional and local data, which allowed for further refinement of the standard CLIMAAX analyses and their better adaptation to the conditions of the Lodzkie Region. Among others, data on the distribution of crops, the condition of vegetation, urban areas and historical impacts of extreme events was acquired. Satellite data was also used, as well as information provided by institutions and organisations holding resources significant for individual analyses. The work involved not only data collection itself, but also its verification, harmonisation, processing and adaptation to the requirements of spatial analysis. This allowed for linking climate information with the actual distribution of vulnerable assets and the locally observed impacts of hazards, thereby enhancing the usefulness of the results for regional risk assessment and subsequent planning of adaptation measures.

In the case of hydrological drought, the analysis revealed a marked spatial variation in terms of relative risk and a possibility of deteriorating water conditions in the future. The findings indicate both the significance of current water deficits and the need to consider projected changes in runoff and availability of water resources in long-term planning of the region's development.

The analysis of agricultural drought made it possible to translate changes in climatic conditions into potential effects for agricultural production. Combining climate projections with information on crop distribution and vegetation condition made it possible to assess the potential reduction in crop yields, as well as the production and economic consequences for two crops significant to the region, i.e. maize and apple trees. The results indicate that increasing the resilience of agricultural production to water shortages may be particularly important.

In the case of heavy rainfall, the analysis revealed a projected increase in the intensity of heavy rainfall and a significant exposure of urban areas to these changes. A comparison of the model results with the data on past flood interventions allowed for linking future changes in hazards to the problems already observed in the region. The results indicate the need to improve the resilience of urban areas and drainage systems, as well as the capacity to retain and manage rainwater.

A comprehensive interpretation of the results leads to the key conclusion for the Lodzkie Region: adaptation measures must address both the effects of water shortage and water surplus. On the one hand, climate change may exacerbate problems relating to the availability of water resources and agricultural production conditions; on the other hand, it may increase the intensity of rainfall and the pressure on urban areas and the drainage systems. This means that water management, water retention, the resilience of agriculture and the resilience of urban areas must be treated as interlinked elements of regional adaptation to climate change.

Phase 2 was not only concluded with the presentation of results of individual analyses. In accordance with the CLIMAAX approach, the results were subject to the Key Risk Assessment comprising the evaluation of severity, urgency and resilience capacity of the region. Hydrological drought, agricultural drought and

intensive rainfall have been identified as high-priority risks requiring further action. The overall regional resilience capacity has been assessed as moderate - the existing monitoring and response systems, institutional capacity and the availability of financial instruments provide the basis for implementing adaptation measures; however, projected changes in risks and the identified vulnerabilities indicate the need for further strengthening of the region's resilience.

Therefore, the outcome of Phase 2 provides not only a deeper understanding of climate risk, but above all a basis for decision-making regarding the management of that risk. The results allow for identifying where and for which sectors action is necessary, and which issues should be treated as a priority. In Phase 3, the focus will shift from diagnosis to climate risk management, including the setting of risk management objectives, the identification and assessment of potential adaptation measures, the conditions for their implementation, and the way of incorporating the results of Climate Risk Assessment into regional planning and decision-making processes.

1 Introduction

1.1 Background

The Lodzkie Region was described in detail in the Phase 1 Report of the project.
In Phase 2, these characteristics were adopted as a benchmark, focusing further work on the hazards previously identified as particularly significant for the region: hydrological drought, agricultural drought and heavy rainfall. Their importance stems, amongst others, from the significant role of agriculture in economy of the region, issues relating to the availability of water resources, and the occurrence of local flooding and other effects of heavy rainfall.

1.2 Main objectives of the project

Phase 2 of the project builds on the assessment carried out in Phase 1. Its main objective is to refine the analysis of climate risk by using regional and local data and adapting the available methods and models to the conditions of the Lodzkie Region.

Compared with Phase 1, the scope of the analyses was expanded to include more detailed information on, among others, hydrological conditions, distribution of selected crops, condition of vegetation, historical impacts of heavy rainfall and spatial distribution of areas at risk. This allowed for linking the results of climate models more effectively to the actual conditions prevailing in the region.

The expected benefit of using the CLIMAAX Handbook and incorporating local data in Phase 2 is to obtain a more detailed and regionally adapted picture of the risks, enabling better understanding of their spatial variability and potential impacts on selected sectors and areas of the region.

1.3 Project team

Phase 2 of the project is carried out by the Team for the implementation of the project entitled: „Climate Resilience of Lodzkie Region" (CliRes-LR), with the participation of employees of the Marshal's Office of the Lodzkie Region and the Office for Regional Planning for the Lodzkie Region. In-depth climate risk analyses are carried out with the support of a third-party contractor responsible for data processing and integration, as well as for preparing expertise for Phase 2.

1.4 Outline of the document's structure

This document presents the results of Phase 2 of the Climate Risk Assessment for the Lodzkie Region, prepared in accordance with the CLIMAAX framework. The report covers the definition of the scope and context of the analysis, risk exploration, the selection of scenarios, the regional analysis of three major hazards, findings regarding the key risk assessment, monitoring and evaluation, as well as a plan for further work.

2 Climate risk assessment – phase 2 (15-25 pages)

2.1 Scoping

2.1.1 Objectives

The objective of the Climate Risk Assessment is to provide knowledge enabling the identification of the areas and sectors most vulnerable to the effects of hydrological drought, agricultural drought and heavy rainfall, as well as to determine the significance of these risks for the development of the Lodzkie Region.

The expected result is to establish the basis for information supporting the planning of adaptation measures and the integration of climate risk into regional strategic and decision-making processes. The results may be used for setting priorities of intervention, updating strategic and planning documents, and developing measures to enhance the region's resilience to climate change effects.

The results of Phase 2 will also form the basis for further assessment of risk priorities and the formulation of recommendations in the next phase of the project, involving stakeholders representing key sectors and institutions of the region.

A major limitation is the availability of data at a level of detail required to assess the impacts of climate change. The analysis was based on available spatial, climate, environmental and socio-economic data, as well as the data provided by the Polish Space Agency (POLSA), which enabled to take into account local conditions and reduce the information gap. However, the availability of data did not pose a significant barrier to carrying out the overall analysis.

The availability of sufficiently detailed data regarding the risk of heavy rainfall was a particular limitation. It required data that would enable determining of reference values and their comparison with the forecast conditions. This limitation was taken into account at the stage of selection of the methodology and interpretation of the results.

An additional challenge was the time needed for POLSA to prepare and make the data available, which required taking this constraint into account in the work schedule.

One of the challenges was to ensure the consistency and comparability of the results obtained from different data sources and analytical methods. This was mitigated by the adoption of standardised methodological principles, the verification of the results and consultations with the project team.

2.1.2 Context

In the Lodzkie Region, climate hazards, impacts and risks have so far been identified primarily on the basis of meteorological and hydrological analyses compiled using data from the Institute of Meteorology and Water Management (IMGW) and the State Water Management Authority - Polish Waters (PGWWP). The results of these analyses form the basis for drafting numerous documents on climate change adaptation, prepared at the national, regional and local level, including, among others, urban climate change adaptation plans (MPA), such as the Climate change adaptation plan for the city of Łódź (MPA, 2030), as well as in the Regional Development Strategy of the Lodzkie Region 2030 (SRWŁ 2030). These documents enable to identify the key climate risks, assess their potential impacts and define the directions of action aimed at enhancing the region's resilience to climate change.

On the basis of conclusions drawn from these analyses and strategic documents, institutions operating at various levels of public administration implemented numerous measures aimed at both adapting to climate change and reducing its impacts (mitigation). These activities were identified and described in the Report of project Phase 1 (CliRes-LR). The scope of programmes and support instruments currently in place demonstrates that funding is available for measures aimed at climate change adaptation and mitigation of its effects. It provides an opportunity to raise external funding for projects that enhance the region's resilience to climate risks.

The project addresses the growing challenges associated with climate change, exerting an increasingly significant impact on the social, economic and environmental development of the regions. The Lodzkie Region is one of the areas particularly vulnerable to the effects of extreme weather events, including hydrological drought, agricultural drought and heavy rainfall, as highlighted and described in the Deliverable of Phase 1. These phenomena result in losses in agriculture, reduce the availability of water resources, increase the risk of flooding and flash floods, as well as affect the functioning of technical infrastructure, the economy and residents' quality of life (SRWŁ 2030).

A significant problem is the lack of a comprehensive and reliable climate risk assessment dedicated to the Lodzkie Region, hidering the identification of the areas and sectors most vulnerable to risks and the assessment of their level of vulnerability. The deficit of regional analyses and research limits a possibility of adequate planning of adaptation measures, setting investment priorities and making effective use of public funds earmarked for counteracting the effects of climate change.

This problem is exacerbated by the lack of a planned and coordinated response at the regional level, which also stems from the dispersion of competence and responsibilities of individual units and institutions in the scope of climate change adaptation. Consequently, adaptation measures are implemented in an inconsistent and fragmented manner, which limits their effectiveness and makes it difficult to achieve synergy between the initiatives undertaken.

Both of these deficits - the lack of reliable, regional climate risk analyses, and the insufficient coordination of actions coupled with dispersed responsibilities - reinforce one another, limiting the capacity of the Lodzkie Region to adapt to progressing climate change.

The issue addressed by the project is a part of the broader context of climate and development policy of the European Union, Poland and the region. At the European level, these measures support the implementation of the objectives of the European Green Deal and the EU Climate Change Adaptation Strategy. At the national level, the project contributes to the achievement of the objectives of the Strategic Adaptation Plan for sectors and areas vulnerable to climate change, and strengthens the implementation of policies relating to water security and the resilience of infrastructure and economic sectors. From the regional perspective, the project deliverables will form the basis for updating and refining the provisions on interventions set out in the strategic documents for the Lodzkie Region, thereby supporting the region's sustainable development, increasing its resilience to climate-related risks, as well as protecting its residents, the environment and the economy against the adverse effects of climate change.

The governance context is a key component of regional climate risk assessment. Regulatory and strategic measures reflect a growing awareness that the level of climate risk in Poland is increasing on a national scale. An update of the Development Strategy of the Lodzkie Region 2030 (SRWŁ 2030) and the National Energy and Climate Plan till 2030, with an outlook to 2040, have recently been adopted (KPEiK). Both documents emphasise the importance of measures to counteract the effects of climate change. In particular, KPEiK highlights Objective 1.6.1, "Striving to adapt to climate change", which includes, among others, increasing the energy sector's resilience to extreme weather events, ensuring adequate water resources and increasing water retention, as well as adapting agriculture and agricultural production to climate change.

In addition, local government units in the Lodzkie Region were granted financial assistance from the Lodzkie Region budget for 2026, earmarked for subsiding projects in the scope of development of green infrastructure, "Łódź for the Climate" (Łódzkie dla klimatu).

The Lodzkie Region adopted a resolution on the allocation of financial aid to local government units in the Lodzkie Region from the Lodzkie Region budget for 2026, for the implementation of measures to prevent the adverse effects of drought through retention and rational management of rainwater, "Łódź catches the rain".

In the report on Deliverable Phase 1 - Climate Risk Assessment for the project entitled Climate Resilience of the Lodzkie Region (CliRes-LR) (SRWŁ 2030), the most vulnerable sectors of the economy have been

identified and described, particularly those dependent on natural resources, stable weather conditions and technical infrastructure quality. For the purposes of this stage of the work, the analysis has focused on identifying the key sectors characteristic for the Lodzkie Region. Taking into account the results of Phase 1 and the socio-economic characteristics of the region, the following sectors of particular importance for further assessment of climate risk have been identified: agriculture, including agri-food processing; the energy sector; and the medical, pharmaceutical and public health sectors.

Agriculture is one of the underlying pillars of the Lodzkie Region's economy. The region is one of the country's leading producers of many agricultural crops, in particular wheat, maize, potatoes, sugar beet and rapeseed. Vegetable production is also significant, particularly cabbage and onions. Horticulture also plays an important role - the region has a significant area of apple orchards, reached approximately 20.3 thousand hectares in 2023. (Rocznik Statystyczny Rolnictwa, 2024 GUS) and specialises in growing strawberries and red currant. Well-developed raw material facilities form the foundation for the regional agri-food processing sector, which plays a significant role in the region's economy and provides jobs in rural areas. Water shortage leads to a decrease in groundwater levels and soil degradation, whilst extreme weather events cause yield losses. It results in a decline in agricultural productivity, a rise in food prices and a reduction in farmers' income. This is confirmed by the findings of the Agricultural Drought Monitoring System, according to which a drought is defined as a fall in yields of at least 20 % compared with average conditions.

In 2023, the Lodzkie Region was one of the worst-affected regions in the country - agricultural drought was recorded in all 177 municipalities for many crops monitored, and it affected approximately 86-88% of the cultivated area.

The energy sector is one of the pillars of the Lodzkie Region's economy. The Bełchatów Lignite Mine, together with the Bełchatów Power Plant are particularly important, which belong the largest facilities of this type in Europe and play a key role in the national power system. The power plant accounts for approximately 20% of Poland's electricity generation and the energy sector remains one of the region's largest employers. At the same time, climate change - in particular, increasingly frequent heatwaves - leads to a rise in demand for electricity for cooling purposes, which increases the load of the power system and increases the risk of disruptions to energy supplies. For this reason, ensuring the energy infrastructure resilience to the effects of climate change is of vital importance to the energy security of the region and the country.

The medical, pharmaceutical and public health sector is also very important in the context of climate change. The region is one of the fastest ageing in Poland - according to the data from the GUS Local Data Bank, by the end of 2024, people aged 60 and over accounted for nearly 45% of the region's population (BDL, 2024 GUS).

Climate change exerts an increasing impact on public health and the functioning of the healthcare system. Rising temperatures and changes in environmental conditions are conducive to the emergence of new pathogens and the spread of diseases transmitted by organisms that are shifting their geographical ranges. Increasingly frequent heatwaves lead to a higher risk of hyperthermia, dehydration and exacerbations of cardiovascular and respiratory conditions, as well as intensify allergic reactions. The elderly and children are particularly exposed, which is of major importance given the ageing population of the Lodzkie Region.

The lack of a comprehensive assessment of climate-related risks remains a challenge, taking into account both droughts and heavy rainfall. The occurrence of these phenomena in the Łódź region is affected by factors of both a local and external nature.

In the case of drought, both global factors, including changes in atmospheric circulation, and greenhouse gas emissions, as well as the structure of the fossil fuel energy sector, play a significant role (IPCC, 2021). Furthermore, the hydrological situation in neighbouring regions affects the region's water balance, in terms of both surface water and groundwater. At the local level, spatial conditions are also significant, including

continuing urbanisation, surface sealing and limited water retention, which exacerbate the water deficit((SRWŁ 2030).

Analogically, in the case of heavy rainfall, climate change which leads to an increase in terms of frequency and intensity of extreme weather events, is of key importance. Furthermore, urbanisation and the increase in sealed surfaces limit the natural infiltration of rainwater, contributing to rapid surface runoff and increases the risk of flooding. This problem is further exacerbated by insufficient capacity and outdated sewage systems which are not adjusted to discharge large volumes of rainwater within a short period of time (SRWŁ 2030).

Consequently, both drought and heavy rainfall pose significant climate threats to the Lodzkie Region, affecting the functioning of the environment, the economy and the infrastructure.

At this stage of the work, it is worth focusing on specific measures already identified in the applicable strategic documents, such as the Urban Climate Change Adaptation Plans for cities of the Lodzkie Region. These include, among others, the development of blue and green infrastructure, increasing rainwater retention, making hard surfaces permeable, planting trees and creating green spaces, protecting residents from the effects of heatwaves, as well as adapting infrastructure to cope with increasingly frequent torrential downpours (MPA, 2030). Similar initiatives are supported under programmes operated by the Regional Fund of Environmental Protection and Water Management in Łódź (WFOŚiGW), such as "Adaptation to climate change - small-scale blue and green infrastructure", funding, among others, rainwater management systems, rain gardens, permeable surfaces and the expansion of green spaces; or the "Lodzkie region in green" programme, which aims to reduce the urban heat island effect, enhance biodiversity and create publicly accessible green spaces using elements of blue and green infrastructure (Adaptation to Climate Change (WFOSiGW)). In addition, educational and community initiatives, such as the "Making the Lodzkie Region Greener" project run by the Lodzkie Region Landscape Park Group, promote planting of trees and shrubs and raise residents' awareness of climate change adaptation and biodiversity conservation (Zazieleniamy łódzkie, 2026). This approach will enable better integration of the planned interventions with the existing financial and strategic instruments and enhance their coherence and the effectiveness of their implementation.

2.1.3 Participation and risk ownership

Responsibility for climate risk management in the region is dispersed among many institutions, each of which is responsible for a specific area - water management, environmental protection, spatial planning, crisis management or regional development. Successful adaptation requires efficient cooperation, better coordination of activities and effective exchange of data and information between these entities.

Responsibility for risk management in the region is decentralised and relies on cooperation between different levels of public administration and specialised institutions.

At the regional level, the local government plays the key role in formulating mitigation and adaptation measures in documents such as development strategies and operational programmes (taking climate risks into account). Institutions such as IMGW-PIB (Institute of Meteorology and Water Management - National Research Institute), RDOŚ (Regional Directorate for Environmental Protection), PGWWP (State Water Management Authority "Polish Waters"), government administration bodies responsible for specific areas (e.g. water management, environment, infrastructure) and the Lodzkie Region Provincial Governor (Crisis Management) are also responsible for more detailed identification and assessment of risks. At the local level, municipality and city councils, county councils, the State Fire Service and forestry services play the key role, as authorities are responsible for implementing specific risk mitigation measures, including adaptation investment projects and solutions enhancing resilience.

At this stage of the project, special attention should be paid to sectors identified as most exposed to climate change effects, i.e. agriculture and the agri-food sector, the medical, pharmaceutical and public health sectors, as well as the electricity sector.

In the agricultural sector, the priority group consists primarily of farmers, plant producers and livestock farmers, particularly those operating in areas vulnerable to agricultural drought, water shortages and extreme weather events.

In the medical, pharmaceutical and public health sectors, the elderly, people with chronic conditions and residents of urban areas exposed to heatwaves and the urban heat island effect are particularly vulnerable.

In the power sector, the priority group comprises operators and owners of energy infrastructure, in particular those responsible for the generation, transmission and distribution of energy, who are vulnerable to, among others, the effects of heatwaves, droughts and extreme rainfall.

Involving representatives of these groups in the CLIMAAX process will allow for better identification of local risk factors and planning of adaptation measures responding to the actual needs of the most vulnerable sectors.

A significant element of climate change risk management is the hazard monitoring and early warning system in case of dangerous meteorological and hydrological phenomena. It provides current assessment of the situation, enables adequate early response of the services and mitigation of the impact of extreme events on the population, infrastructure and the environment.

IMGW-PIB continuously monitors the situation and issues meteorological and hydrological warnings. Meteorological warnings are categorised on a three-tier scale and indicate the occurrence of a dangerous weather phenomenon that may pose threat to human health or life. It ensures that emergency services and crisis management centres are ready for action. Hydrological warnings, on the other hand, provide information about a phenomenon.

In the event of heavy rainfall, a 3-level warning is issued (https://meteo.imgw.pl/dyn):

1. Precipitation: 30 mm ≤ R < 40 mm within 12 hours or 40 mm ≤ R < 60 mm within 24 hours,

2. Precipitation: 60 mm ≤ R < 90 mm within 24 hours,

3. Precipitation: R ≥ 90 mm within 24 hours.

Official alerts concerning hydrological drought (low water level), as well as warnings and forecasts of weather conditions conducive to the development of drought, are issued and updated on an ongoing basis by IMGW-PIB (IMGW-PIB).

This information is used by the crisis management system, including the Provincial Crisis Management Centre in Łódź, which coordinates the activities of emergency services and the administration in the event of threat. Warnings and announcements are also communicated to residents, among others, via the Regional Warning System (RSO) and other information channels. This system enables taking measures adequate to the scale of the threat and helps to mitigate the effects of extreme events.

2.1.4 Application of principles

The analysis took into account the spatial variation in exposure and vulnerability to the hazards analysed, including the social and economic conditions of individual areas of the region. This allowed for identification of areas and groups/sectors that are potentially more exposed to the effects of hydrological drought, agricultural drought and heavy rainfall.

The analysis was carried out based on the CLIMAAX methodology and assumptions, using the data derived from the specified sources and local data, including the data provided by PAK. The assumptions adopted, the data sources, the indicators used and the limitations of the analysis are documented, which enables tracing how the results were obtained and verifying them at a later date. Where possible, the results were consulted and verified as part of the work with the project team and stakeholders.

A precautionary approach was adopted by taking into account the uncertainty associated with future climate change and using climate scenarios to assess potential future conditions. The results are not

treated as a definitive forecast of future events, but rather as an indication of potential trends and the scale of risk changes. The conclusions were drawn whilst taking into account the limitations of the data and the methods applied, and the results are intended primarily to serve as a basis for further risk prioritisation and for planning measures enhancing the resilience of the region.

2.1.5 Stakeholder engagement

In Phase 2 of the project, collaboration with stakeholders focused primarily on acquiring data and information enabling a deeper analysis of the work carried out in Phase 1. The key organisations involved at this stage included the Polish Space Agency (POLSA), the Łódź Provincial Office (Crisis Management Department), the Agency for Restructuring and Modernisation of Agriculture (ARiMR) and the Lodzkie Region Landscape Park Group (ZPKWŁ).

The collaboration with POLSA was particularly important, with Agreement No. P/2025/64 concluded with the Lodzkie Region on cooperation in the scope of promotion and use of satellite data.

As part of the collaboration, POLSA provided access to satellite data used in the analyses of agricultural drought. This enabled to supplement the model climate data with information on the actual condition of the vegetation and, consequently, to refer the results of the analysis more precisely to the conditions prevailing in the region.

The Agency for Restructuring and Modernisation of Agriculture also made a significant contribution to the project, providing data on the distribution of crops. This data was used to identify more precisely the areas exposed to agricultural drought and to assess potential production and economic losses.

Data from the ZPKWŁ, derived from the survey of fruit orchards, was used to provide more detailed information on the location of apple orchards. This made it possible to establish a better link between the results of climate analyses and the actual distribution of one of the region's key crop groups.

In the event of heavy rainfall risk, data obtained from the Łódź Provincial Office regarding interventions by the State Fire Service (PSP) and Voluntary Fire Service (OSP) in response to flooding following heavy rainfall in 2015-2025 proved to be the key source of information. This data allowed for comparing the projections of climate-related risks with historically observed impacts of events at a county level, and enabled a more accurate identification of particularly vulnerable areas.

Another important element of the stakeholder engagement process was the presentation and discussion of the results of Phase 1 of the project. The stakeholder group established did not raise any substantive comments regarding the results of Phase 1 - the feedback indicated that the results of Phase 2 were of the greatest interest in the context of hydrological drought.

However, stakeholders are expected to play the most significant role in Phase 3 of the project, during which the results of the in-depth climate risk assessment will be subject to further interpretation and discussion with entities responsible for managing individual risk areas. Stakeholder engagement will be particularly important when assessing the significance of the results for the region, identifying priorities and formulating recommendations on adaptation measures and possibilities of using the project results in strategic planning and decision-making processes. The composition of the group concerned is described in detail in Deliverable Phase 1_CLIMAAX.

2.2 Risk Exploration

2.2.2 Screen risks (selection of main hazards)

The findings of the work carried out so far as part of the project indicate that the Lodzkie Region is exposed to a number of risks arising from climate change. Over the recent years, the region has seen increasingly frequent occurrence of prolonged periods without rainfall, heatwaves, heavy rainfall causing local flooding, as well as an increased risk of fires. The examples include the heatwaves reported in 2026. In the Lodzkie

Region, Level 2 weather warnings were in force due to the forecast heatwave, with maximum temperatures at the peak of the event reaching 35-39°C. High temperatures were accompanied by increased evaporation and deterioration of the soil moisture deficit, which elevated the risk for public health, agriculture and ecosystems (IMGW-PIB, Report No. 135 of 24 June 2026).

The analysis of hazards, exposure and vulnerabilities carried out as part of Phase 1 indicated that, among all the climate hazards analysed, agricultural drought, hydrological drought and heavy rainfall pose the highest level of risk to the Lodzkie Region. These risks have been selected for further analysis due to their significant impact on the region's functioning and due to forecasts indicating an increase in the frequency and intensity of their occurrence in the successive decades.

The risk assessment took into account not only the projected changes in climate hazards, but also the level of exposure and vulnerability of individual environmental components and socio-economic sectors. Agricultural land, urban areas and ecosystems dependent on the availability of water resources demonstrate the highest exposure. High vulnerability primarily refers to agricultural production, water management, municipal infrastructure and areas with limited natural water retention capacity. Consequently, even a moderate rise in the intensity of climate phenomena may lead to a significant increase in environmental, social and economic losses (PGWWP, Retencja dla rolnictwa). Although the risks under analysis occur across the region, their spatial intensity is not uniform.

Agricultural drought poses a significant threat to farmland, leading to the reduction in soil moisture, the deterioration in plant growth conditions and lower crop yields. Areas with low water retention capacity are particularly exposed, which may result in increased production and economic losses of agricultural holdings (SMSR, Prognoza oddziaływania na środowisko dla projektu planu przeciwdziałania skutkom suszy, Rozporządzenie ministra infrastruktury z dnia 15 lipca 2021 r. w sprawie przyjęcia Planu przeciwdziałania skutkom suszy).

Hydrological drought results from limited availability of water resources and the occurrence of periodic rainfall deficits. It may affect the availability of water for the population, agriculture and industry, lead to decreased surface and groundwater levels, and increase pressure on local water resources and ecosystems (Prognoza oddziaływania na środowisko dla projektu planu przeciwdziałania skutkom suszy, Rozporządzenie ministra infrastruktury z dnia 15 lipca 2021 r. w sprawie przyjęcia Planu przeciwdziałania skutkom suszy).

Heavy rainfall poses threat due to huge quantities of water falling within a short period of time. Torrential rain can cause local flooding, overload stormwater drainage systems, result in soil erosion, damage infrastructure and cause losses to the agricultural sector. Urbanised areas are particularly vulnerable, as limited water infiltration increases the risk of rapid surface runoff and the formation of waterlogged areas (SRWŁ, 2030).

In order to identify and visualise spatially climate hazards in the Lodzkie Region that may lead to specific risks, data from the Copernicus database was used (Baza Copernicus), as well as data from the Aqueduct Water Risk Atlas (AWRA).

During the second phase of the project, a detailed analysis of selected climate risks was carried out using data of significantly higher spatial resolution, compiled specifically for the Lodzkie Region. It builds on the initial risk selection stage carried out in Phase 1 of the project, which was a screening exercise based on the analysis of, among others, data available in the IPCC Interactive Atlas (IPCC, 2021). Due to the limited spatial resolution of the atlas, this analysis was carried out for the area of Western and Central Europe, including the Lodzkie Region. Based on the results obtained, the following climate indicators were selected for further analysis: the maximum 1-day precipitation (Rx1day index), the maximum 5-day precipitation (Rx5day index) and the number of consecutive dry days (CDD). These indicators were analysed on the basis of CMIP6 climate projections for the SSP2-4.5 and SSP5-8.5 emission scenarios for the period 2031-2100. Moreover, the assessment of risks relating to the availability of water resources has been supplemented with the water stress indicator from the AWRA, which defines the ratio of total water demand to available

renewable surface and groundwater resources (this indicator is only available until 2050). Its analysis over time enables to assess whether water availability issues are likely to deteriorate in the future, which is a key element of climate risk assessment. This is particularly important in the context of the Lodzkie Region, whose economy relies considerably on agriculture. The region is one of the country's leading fruit-producing areas, particularly for apples, and it also demonstrates a significant share of maize cultivation. Both fruit orchards and maize crops are sensitive to water shortages during the growing season.

Maximum 1-day Precipitation - RX1day

Climate forecasts suggest that increasingly frequent and intensive episodes of extreme precipitation, including rain, hail and snow may occur. In the climate change scenarios analysed, the trend values are as follows: +0.15/10 years for the SSP2-4.5 scenario, and +0.58/10 years for the SSP5-8.5 scenario. Although an increase in the indicator under analysis is recorded in both scenarios, the trend is more pronounced in the SSP5-8.5 scenario. In both cases, forecasts indicate a continuing risk of years characterised by high intensity and frequency of extreme rainfall, which may lead to local flooding, infrastructure overload and losses in agriculture.

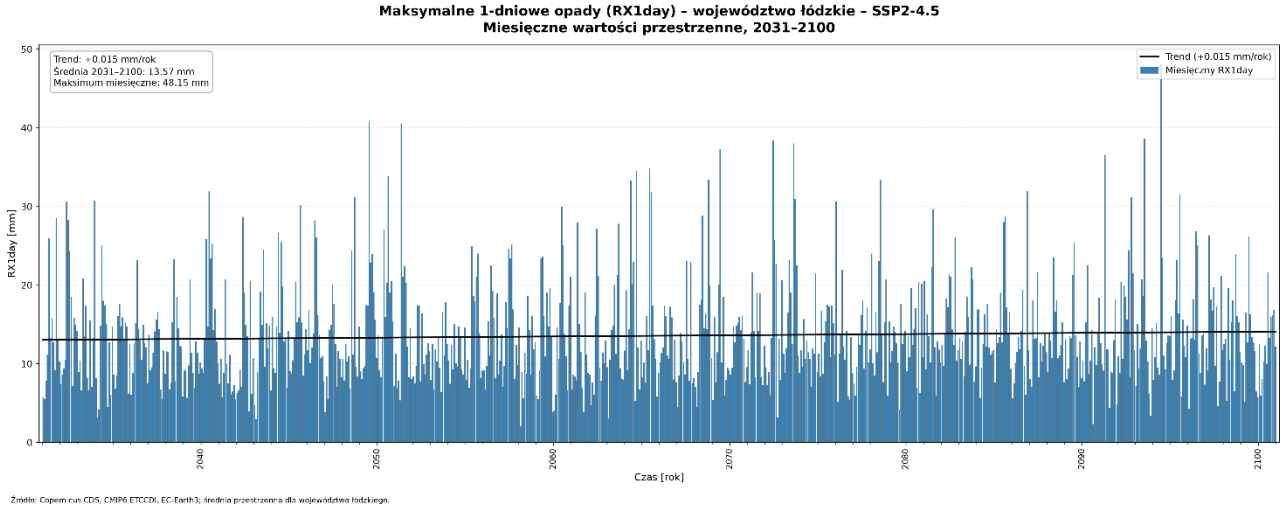


Figure 1 : Projected changes in maximum 1-day rainfall (Rx1day) - according to the SSP2-4.5 scenario - in the Lodzkie Region in 2031-2100 (own elaboration based on the Copernicus Climate Data Store)

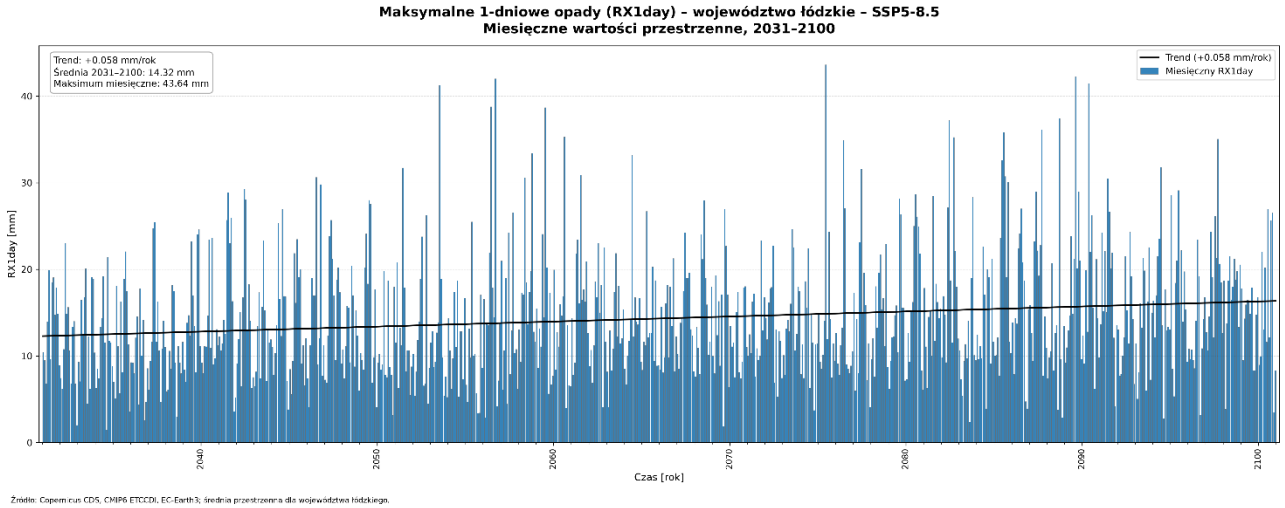


Figure 2 : Projected changes in maximum 1-day rainfall (Rx1day) - according to the SSP5-8.5 scenario - in the Lodzkie Region in 2031-2100 (own elaboration based on the Copernicus Climate Data Store)

Maximum 5-day precipitation - RX5day

In the climate change scenarios analysed, the trend values are as follows: +0.37/10 years for the SSP2-4.5 scenario, and +0.90/10 years for the SSP5-8.5 scenario. In the case of the SSP5-8.5 scenario, a more pronounced increase in the indicator under analysis is recorded compared with the SSP2-4.5 scenario, which indicates a more pronounced intensification of changes under the conditions of higher emission forcing. Forecasts indicate that the risk of years with high intensity and frequency of extreme rainfall is likely to persist and may increase in the longer term. These phenomena may contribute to an increased risk of localised flooding and losses in the agricultural sector.

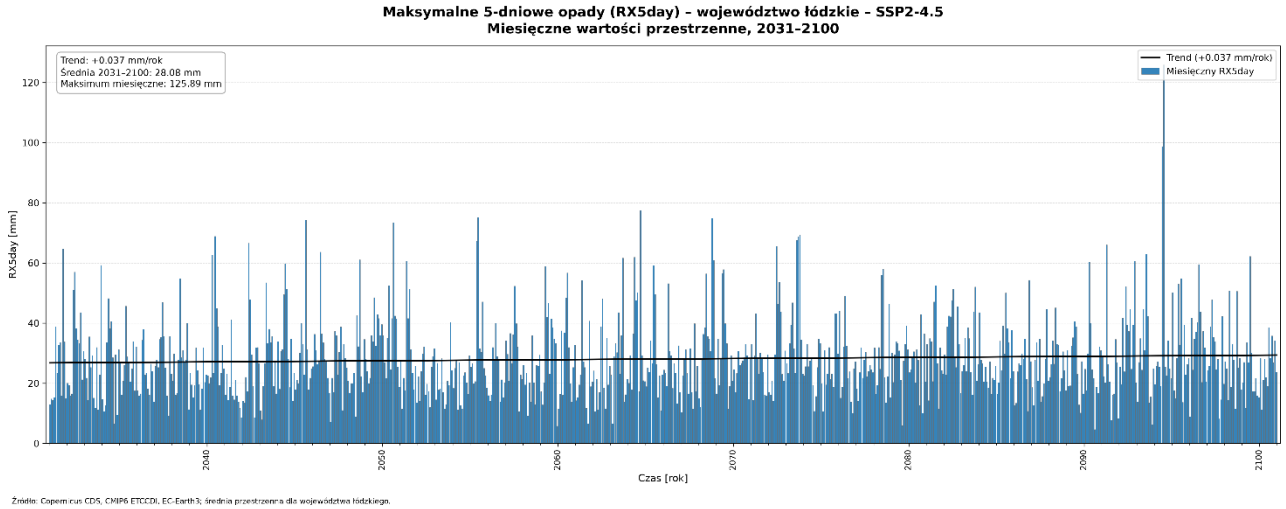


Figure 3 : Projected changes in maximum 5-day rainfall (Rx1day) - according to the SSP2-4.5 scenario - in the Lodzkie Region in 2031-2100 (own elaboration based on the Copernicus Climate Data Store)

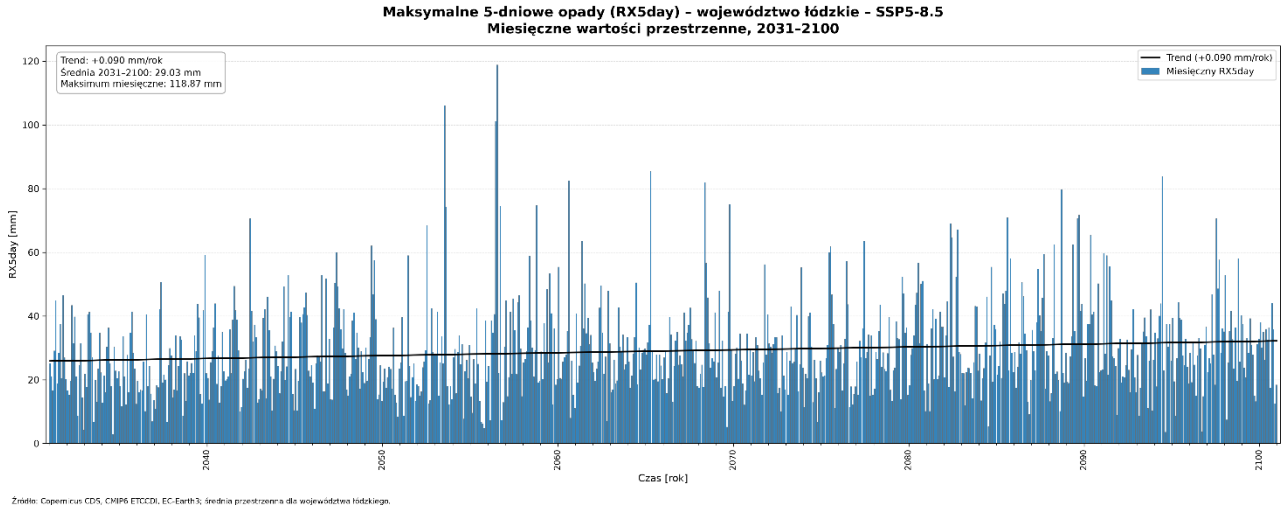


Figure 4 : Projected changes in maximum 5-day rainfall (Rx1day) - according to the SSP5-8.5 scenario - in the Lodzkie Region in 2031-2100 (own elaboration based on the Copernicus Climate Data Store)

Consecutive Dry Days - CDD

Climate forecasts also indicate a possibility of increasingly prolonged periods without precipitation, which may increase the risk of drought, particularly agricultural and hydrological drought. In the climate change scenarios analysed, the trend of the number of dry days is -0.19 days/10 years for the SSP2-4.5 scenario and -0.53 days/10 years for the SSP5-8.5 scenario. It means that, in the SSP2-4.5 scenario, a gradual decrease in the number of periods without rainfall is predicted. In the case of the SSP5-8.5 scenario, the average trend indicates a decrease in the number of dry days. However, this does not mean that the risk of

long-lasting periods of drought has been completely eliminated. In individual years, longer periods without precipitation may still appear, the effects of which may be further exacerbated by rising air temperatures and increased evaporation, leading to more severe droughts. Accordingly, it remains essential to implement adaptation measures, particularly with regard to increasing water retention and the rational management of water resources.

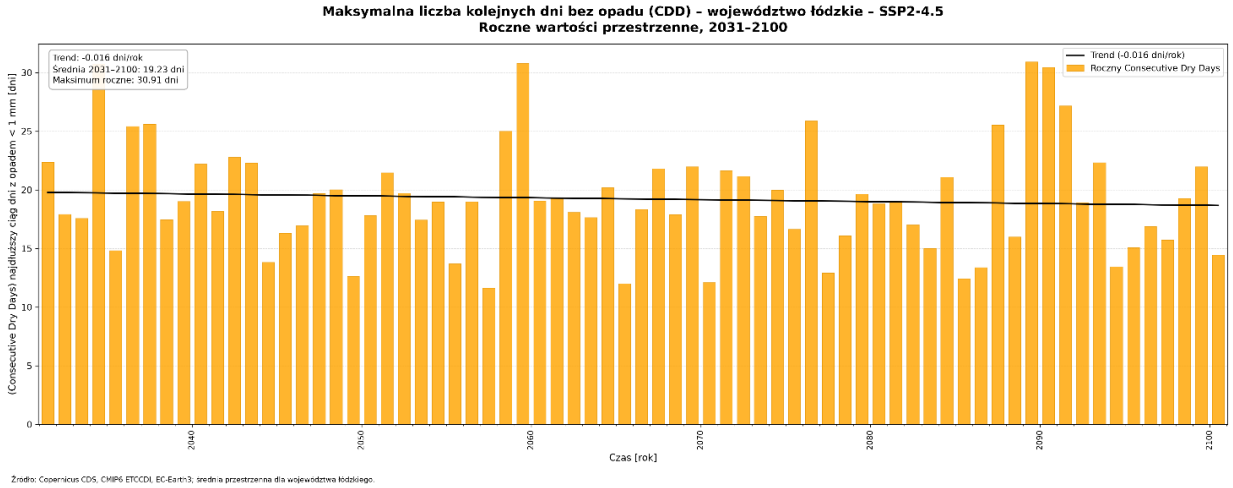


Figure 5 : Projected changes in Consecutive Dry Days (CDD) - according to the SSP2-4.5 scenario in the Lodzkie Region in 2031-2100 (own elaboration based on the Copernicus Climate Data Store)

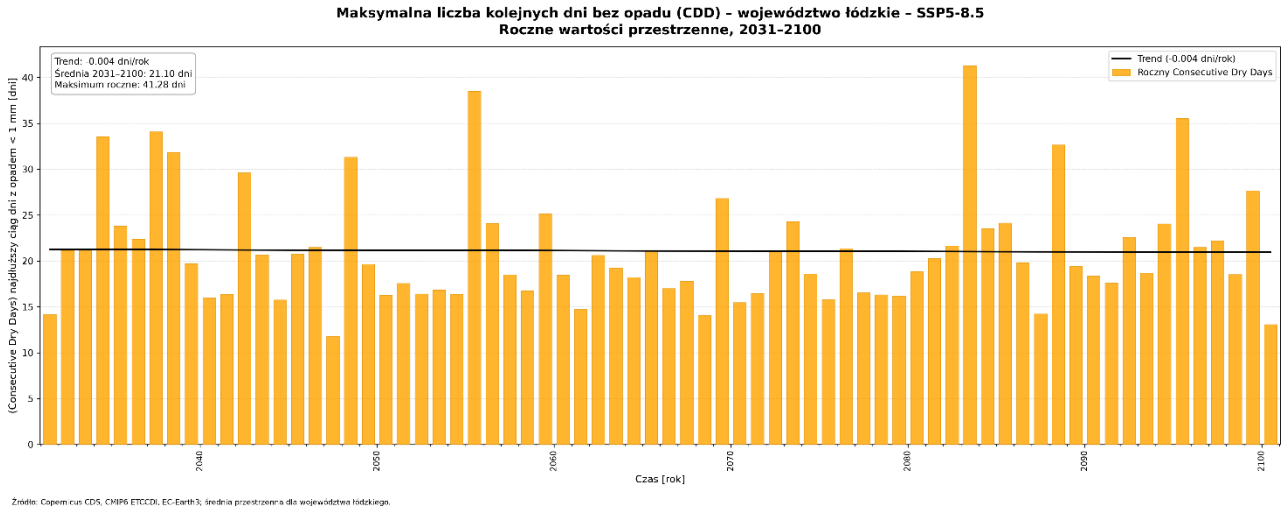


Figure 6 : Projected changes in Consecutive Dry Days (CDD) - according to the SSP5-8.5 scenario in the Lodzkie Region in 2031-2100 (own elaboration based on the Copernicus Climate Data Store)

Water stress

The water stress index for the analysed area of the Lodzkie Region was classified as moderately high (20-40%) both in the SSP2-4.5 (business asusual) and SSP5-8.5 (pessimistic) scenario. Persistent water stress may increase the vulnerability of the Lodzkie Region to agricultural and hydrological droughts. Rising air temperatures, heatwaves, changes in rainfall patterns and increased demand for water may further exacerbate the pressure on local water resources, affecting the agriculture, the economy and the availability of water for residents.

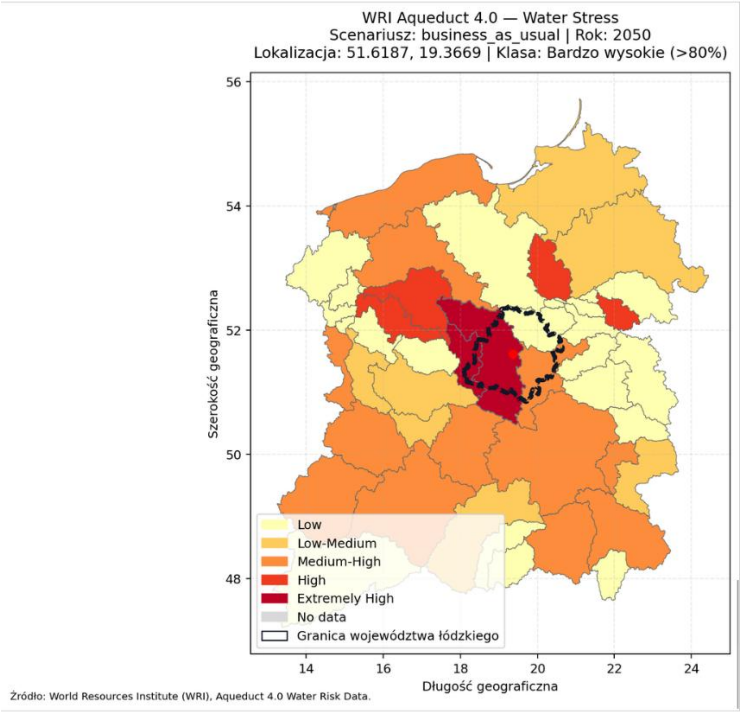


Figure 7 : Projected changes in the occurrence of water stress according to the SSP2-4.5 scenario in the Lodzkie Region in 2050 (own elaboration based on the Aqueduct Water Risk Atlas)

WRI risk class - SSP2-4.5 scenario: Extremely high (the western part, covering most of the region), medium high (the south-eastern part of the region) and low (the north-eastern part of the region).

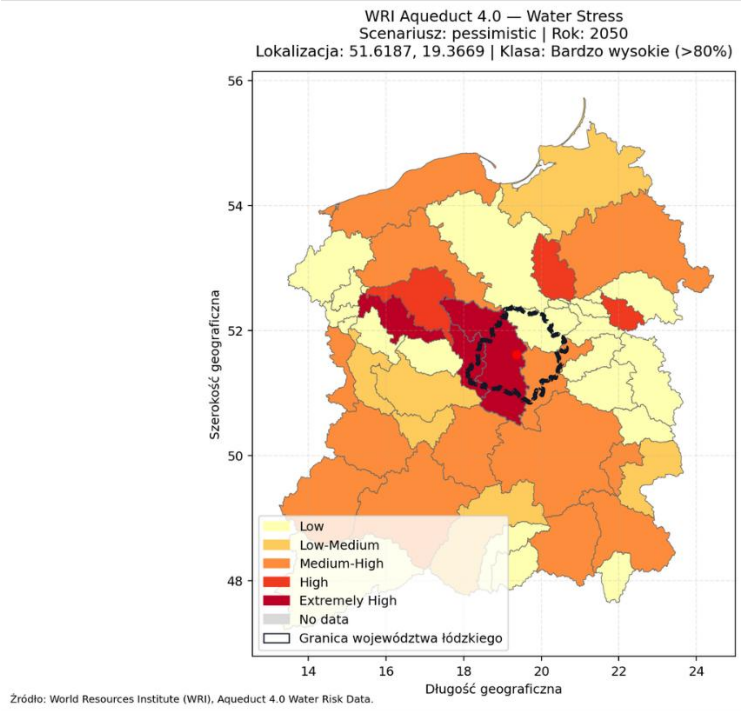


Figure 8 : Projected changes in the occurrence of water stress according to the SSP2-4.5 scenario in the Lodzkie Region in 2050 (own elaboration based on the Aqueduct Water Risk Atlas)

WRI risk class - SSP5-8.5 scenario: Extremely high (the western part, prevailing), medium high (the south-eastern part) and low (the north-eastern part).

The significance of the hazards indicated will increase in the coming years. Despite the forecast decline in the number of dry days, the risk of drought remains significant. Longer periods without rainfall may occur in individual years, and their effects may be further exacerbated by rising air temperatures and increased evaporation. At the same time, forecasts indicate an increase in the number of days with heavy rainfall, which means increased variability of rainfall patterns. This pattern of rainfall fosters rapid water runoff, limits its infiltration into the soil and reduces the potential for natural replenishment of water resources.

The available knowledge on climate hazards in the Lodzkie Region is based on climate, hydrological and spatial data derived from the national and international data sources. The analysis used, among others, CMIP6 climate projections for the SSP2-4.5 and SSP5-8.5 scenarios, comprising indicators related to the occurrence of extreme precipitation (RX1day, RX5day) and periods without precipitation (CDD), as well as the Water Stress indicator from the Aqueduct Water Risk Atlas (AWRA). This data allows for the assessment of the potential increase in risks associated with drought, water deficit and heavy rainfall.

2.2.3 Choose Scenario

The following analysis takes into account future climate conditions forecast until the end of the 21st century, based on the latest CMIP6 climate projections developed as part of the sixth phase of the Coupled Model Intercomparison Project. Special attention was paid to the projected changes of climate factors relevant to the Lodzkie Region, including, above all, a rise in air temperature, an increase in the frequency and intensity of heatwaves, changes in precipitation patterns, the occurrence of periods without precipitation, and an increased risk of extreme weather events, such as droughts and heavy rainfall causing local flooding.

Taking future climate conditions into account allows for determining the extent of potential changes in climate risks and assessing the extent of the Lodzkie Region's exposure to their consequences in the long term.

The following analysis takes into account potential future trends in socio-economic development, including demographic, economic and environmental changes that may affect the level of exposure and the region's capacity to adapt to climate change. Factors considered included, among others, changes in population size, urbanisation processes, economic development, changes in the structure of using energy and natural resources, technological development, as well as the potential for implementing measures to reduce greenhouse gas emissions and enhance the resilience of society and the economy. Further depopulation processes are anticipated in the region, associated with a decline in the population and the progressive ageing of society, which may affect the structure of demand for public services and the adaptability of local communities. At the same time, it is anticipated that urban areas will continue to expand, that low-carbon technologies will become increasingly important and that the energy sector will undergo gradual transformation towards more extensive use of renewable energy sources and improved energy efficiency.

Potential changes in water and food demand are also a significant element of the analysis. The economic growth, changes in lifestyle and evolving consumption patterns may affect the level of demand for agricultural products, thereby increasing pressure on the agricultural sector and water resources. In the case of the Lodzkie Region, this is of particular importance given the significant role of agriculture, including fruit growing and arable farming, in the region's economy.

Account has also been taken of the possibility of changes in the costs of running business resulting from rises in the prices of energy, water, agricultural inputs and food. These factors may affect the vulnerability of individual sectors to the effects of climate change and their ability to implement adaptation measures.

The socio-economic development scenarios adopted do not constitute a forecast of the future development of the Lodzkie Region, but represent potential global growth paths developed by the IPCC, are used to assess the potential consequences of climate change. Hereinafter in the analysis, depending on data availability and the specific nature of the risk under analysis, the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios were taken into account, representing moderate, high and very high emission paths and associated climate change, respectively.

Combining future climate conditions with potential socio-economic development paths using the IPCC integrated scenarios based on the SSP pathways.

Three scenarios were used in the analysis: SSP2-4.5, SSP3-7 and SSP5-8.5, representing diverse scenarios of the future socio-economic development and the associated climate change. The SSP2-4.5 scenario presents an intermediate variant, assuming moderate socio-economic development, gradual demographic changes, continuation of current development trends, and limited measures to reduce emissions. SSP3-7.0 describes a world featuring growing social and economic divisions, limited international cooperation, a strong emphasis on security and self-sufficiency, and a slower economic and technological development. Under such conditions, efforts to mitigate climate change are less effective, leading to high levels of greenhouse gas emissions. The SSP5-8.5 scenario presents a high economic growth variant based on intensive use of resources and energy, in particular fossil fuel, leading to high levels of greenhouse gas emissions and more severe climate changes (IPCC, 2021).

Projections of changes in selected climate hazards were analysed for the scenarios identified. This approach enables to assess how different levels of future climate change and varying socio-economic development pathways may affect the level of climate risk, the vulnerability of individual sectors, as well as the scope of required adaptation measures in the Lodzkie Region.

The analysis took into account the following time horizons: medium-term (up to 2050) and long-term (up to 2070), considering both a realistic and a pessimistic outlook. The timeframes adopted in that way allow for identification of both current threats and long-term challenges associated with the Lodzkie Region's adaptation to climate change.

2.3 Regionalized Risk Analysis

The selection of scenarios has been tailored to the data and scenarios available in individual workflows. In the Relative Drought analysis, SSP3-7.0 was adopted as the main future scenario, whereas SSP5-8.5 was retained as a high-forcing variant and a benchmarking scenario. The Agriculture Drought and Heavy Rainfall workflows, based on EURO-CORDEX data, used the RCP4.5 and RCP8.5 scenarios in accordance with the availability of products and the structure of the CLIMAAX workflow.
All the analyses relied on the CLIMAAX conceptual framework comprising hazard, exposure, vulnerability and risk or potential impacts. The method used to combine these elements quantitatively was adapted to the relevant workflow and the available data. The direct product of the standardised components, Risk = dH × dE × dV, was used in the official CLIMAAX Relative Drought product. In the Agricultural Drought and Heavy Rainfall analyses, the H-E-V components were used as an interpretation framework, whereas the final results were determined in accordance with the impact chains specific to these hazards.

2.3.1 Hazard #1 – Relative drought

Table 1 : Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Historical overview (2015–2025): Soil Moisture – soil moisture [m^3/m^3], monthly values for 2015-2025 (a variable used as a regional diagnostic indicator of drought conditions; it is not a component of the official dH CLIMAAX risk assessment based on WASP) Surface Runoff – surface	Supplementary regional information: AWC - Available Water Capacity, the maximum quantity of water available to plants, expressed in mm of water in the soil profile (~10 km resolution) Source: FAO/IIASA GAEZ v4 (res06/LR/awc/)	The current distribution of maize crops (High Resolution Layer Crop Types) and apple orchards Maize: the CLMS HRL Crop Types location layer, reference year - 2023, supplemented with ARiMR data for 2021-2025 Apple orchards: a survey carried out by the Lodzkie Region Landscape Park Group, "Fruits of Memory", for 2020-2024, supplemented with	Hydrological Drought Hazard Index (HDHI) – a regional, dimensionless diagnostic index on a 0-1 scale, combining normalised and deficit-oriented values for Surface Runoff, Subsurface Runoff, Water Balance and SPEI (layers processed

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
runoff [mm/month], monthly runoff totals for 2015-2025 Surface Runoff – subsurface runoff [mm/month], monthly runoff totals for 2015-2025 Water Balance – water balance (P-PET) (mm/month), water availability in the environment (regional diagnostic indicator of water conditions) SPEI (Standardised Precipitation Evapotranspiration Index) - a standardised index of precipitation and evapotranspiration, Source: Copernicus Climate Change Service (C3S), ECMWF, ERA5-Land.		ARiMR data for 2021-2025. Source: CLMS High Resolution Layer Crop Types (CTY 2023), ARiMR data for 2021–2025; the resulting land use survey layer made available by the Lodzkie Region Geoportal via the ArcGIS REST FeatureServer service, layer 0: https://geoportal.lodzkie.pl/server/rest/services/Hosted/survey123_74c9731df834427f9b45238d09e0eb91_results/FeatureServer/0. The data has been converted to the GeoJSON format and restricted to the Lodzkie Region	using the min-max method, i.e. values were rescaled to the 0-1 range according to the formula: N(x) = (x - min) / (max - min). The components were directed to the deficit by reversing the scale: Nd(x) = 1 - N(x). Consequently, a higher normalised value indicates a greater deficit, and therefore a higher risk of drought (*Surface Runoff, Subsurface Runoff, Water Balance and SPEI). The layers were combined into a dimensionless HDHI index, with a greater weighting given to runoff components (a higher weighting was assigned to direct runoff components - Surface Runoff and Subsurface Runoff); the index is intended as an auxiliary tool and does not replace the official dH CLIMAAX hazard rating. CLIMAAX Relative Drought Risk - the relative risk of hydrological drought calculated as dH (hazard: the probability of a severe rainfall deficit as determined by WASP) × dE (exposure: aggregated data on agricultural land, livestock, water stress and population) × dV (vulnerability: aggregated information on GDP per capita and the proportion of the rural population) on a
Scenario analysis: Total Runoff [mm/month] - comprises the total of surface and subsurface runoff; the raw variable mrro [$kg \cdot m^{-2} \cdot s^{-1}$ ≈ mm/s], converted to monthly runoff totals; the change is presented as the percentage difference in average runoff between the future and reference periods (2031-2060) relative to the period of 2015-2025 scenario: SSP3-7.0 was adopted as the main interpretation scenario, while SSP5-8.5 was retained as a high-forcing variant and a reference point The Total Runoff analysis is an additional regional diagnostic extension and does not replace the official dH CLIMAAX hazard component based on WASP. Source: Copernicus Climate Data Store (CDS), CMIP6 climate projections, the mrro variable (Total Runoff), the MPI-ESM1-2-LR model, and the SSP3-7.0 and SSP5-8.5 scenarios.	Per capita GDP and the share of the rural population, using the standardised vulnerability value (*vulnerability_raw*) for NUTS-3 units, which forms part of the official Relative Drought Risk indicator. In addition, in order to characterise the current water conditions in the Lodzkie Region, data on soil moisture, water balance and soil water-holding capacity was used. The data is supplementary and interpretative - it is not taken into account in the calculation of dV or in the final climate risk result dH × dE × dV. Source: ERA5-Land / Copernicus Climate Data Store (CDS) - Soil Moisture, Water Balance indicators, 2015-2025; FAO/IIASA GAEZ v4 - Available Water Capacity (AWC) indicator.	Determined on the basis of the official CLIMAAX Relative Drought Risk component for NUTS-3 units. The indicator covers information on agricultural land, water stress, population and livestock density, and is presented as a standardised value on a 0-1 scale. Pre-calculated exposure_raw value was used for 73 NUTS-3 units in Poland, from which five units covering the Lodzkie Region (PL711–PL715) were selected. The current distribution of maize crops (High Resolution Layer Crop Types) and apple orchards Maize: the CLMS HRL Crop Types location layer, reference year - 2023, supplemented with ARiMR data for 2021-2025 Apple orchards: inventory for 2020-2024, supplemented with ARiMR data for 2021-2025. Source: CLMS High Resolution Layer Crop Types (CTY 2023), ARiMR data for 2021–2025; the resulting land use survey layer made available by the Lodzkie Region Geoportal via the ArcGIS REST FeatureServer service, layer 0: https://geoportal.lodzkie.pl/server/rest/services/Hosted/survey123_74c9731df834427f9b45238d09e0eb91_results/FeatureServer/0. The data has	

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
		been converted to the GeoJSON format and restricted to the Lodzkie Region The current distribution of maize crops and apple orchards was used as a supplementary spatial context, independent of the dE values. These layers are used to identify the locations of agricultural areas of particular significance in the context of projected changes in Total Runoff, as well as to interpret the results at the regional and county level (they are not included in the dE calculations and do not change the values of exposure_raw or the official CLIMAAX Relative Drought Risk result)	0-1 scale for NUTS-3 units. The analysis covers the historical period of 1981-2015, as well as SSP3-7.0 and SSP5-8.5 for 2031-2060. Risk output: Relative Drought Risk CLIMAAX dH × dE × dV The dH, dE and dV values, as well as the final risk_raw value, were calculated using the official CLIMAAX workflow. As part of the regional analysis, pre-compiled results for the NUTS-3 units of the Lodzkie Region were used, and these were visualised and interpreted. Regional diagnostic result - scenario-based change in Total Runoff [%], spatial extent of the change in runoff, and changes in runoff in maize-growing areas and apple orchards. The results are presented in section 2.3.1.1, Scenario-based changes in total runoff. The results were used to identify agricultural areas at risk of a projected decline in runoff and to provide a regional interpretative framework. This analysis serves as a regional supplement; it is not the official CLIMAAX Relative Drought Risk and does not alter the dH × dE × dV value.

2.3.1.1 Hazard assessment

The assessment of the hydrological drought risk was carried out on the basis of an analysis of hydrological conditions in the Lodzkie Region for the period of 2015-2025. Data relating to Surface Runoff, Subsurface Runoff, Water Balance and SPEI, as well as Soil Moisture was used as a supplementary diagnostic indicator of drought conditions. A comprehensive analysis of the indicators makes it possible to identify periods and areas demonstrating an increased hydrological stress.

Monthly total of Subsurface Runoff and Surface Runoff (July 2020)

a) b)

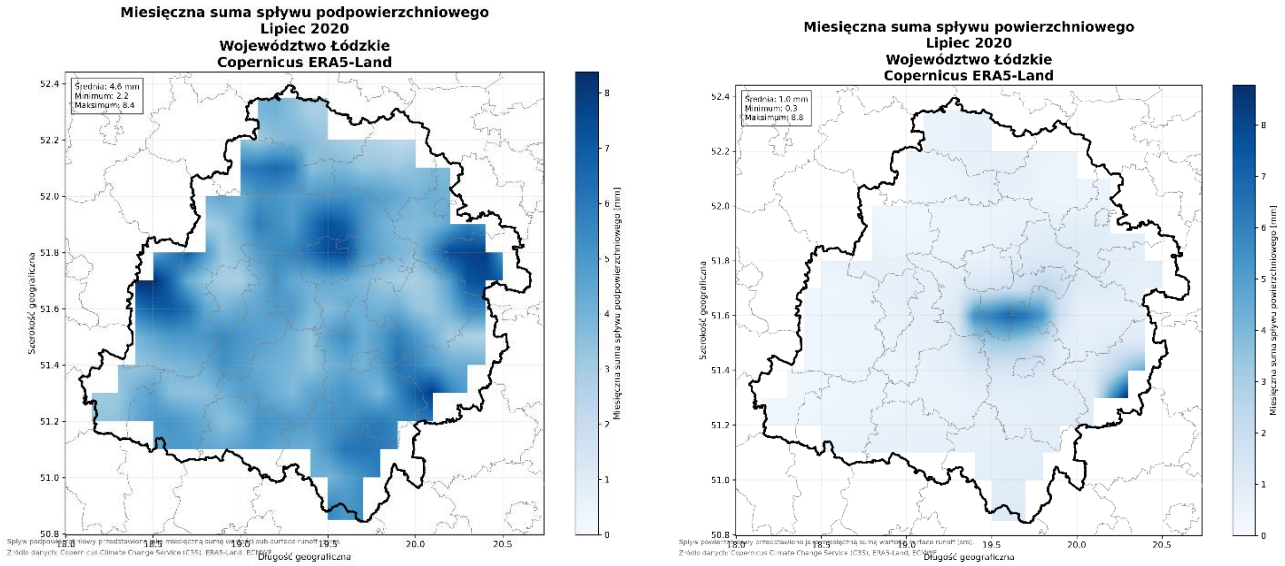


Figure 9 Hydrological conditions in July 2020: (a) subsurface runoff, (b) surface runoff. Source: ERA5-Land/CDS; own elaboration.

As an example of the spatial variation in hydrological conditions, the situation of July 2020 is presented. In that month, the average value for Surface Runoff was 0.966 mm, whilst that for Subsurface Runoff was 4.599 mm. With regard to the average values for all July months in the period 2015-2025, which amounted to 2.84 mm and 15.04 mm, respectively. Compared with these long-term averages, the figures recorded in July 2020 were approximately 66.0% lower for surface runoff and approximately 69.4% lower for subsurface runoff. July 2020 also recorded the highest average value for the regional HDHI index for the period of 2015-2025 (0.711; 1st place amongst the months analysed following relative spatial analysis).

The spatial analysis of the Surface Runoff and Subsurface Runoff values for July 2020 indicates that runoff patterns were not uniform across the region. The lowest Surface Runoff values were recorded, among others, in the counties of Wieruszów, Sieradz and Poddębice, whilst the lowest Subsurface Runoff values were recorded, among others, in the counties of Łowicz, Kutno and Łódź East. The Wieruszów county was one of the areas demonstrating low values for both components of the runoff. However, the results for Surface Runoff and Subsurface Runoff should be interpreted in conjunction with the other indicators used in the HDHI regional assessment. The maps therefore supplement the regional average values with information on the spatial variation in runoff conditions.

Monthly water balance (July, August 2015)

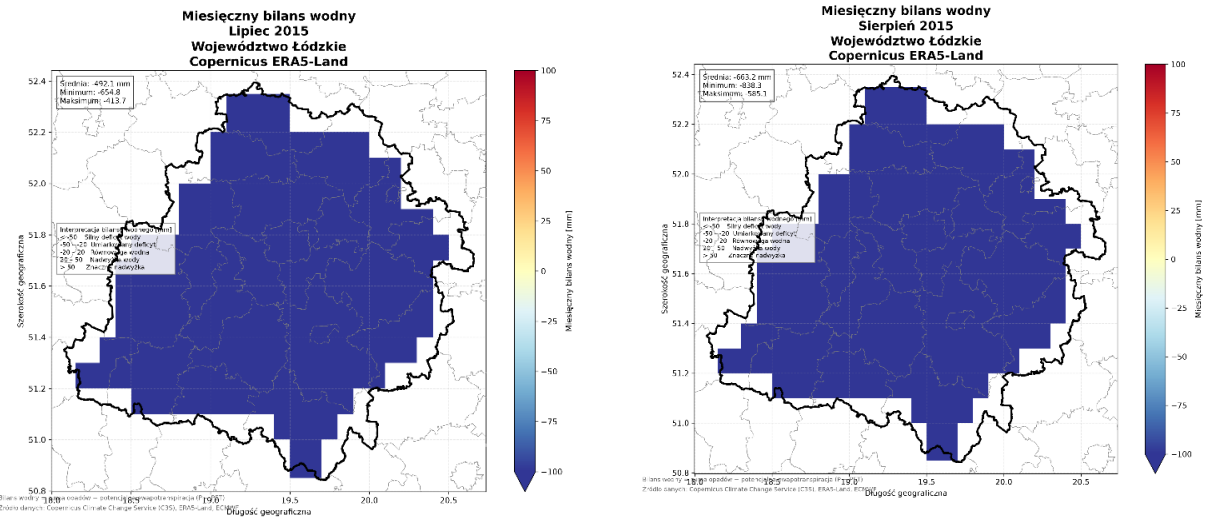


Figure 10 : Water balance in the Lodzkie Region in July and August 2015. Source: ERA5-Land/CDS; own elaboration.

The analysis is supplemented by the assessment of the water balance for each month of the 2015-2025 period.

In July 2015, the average water balance was recorded as -492.13 mm. On the other hand, the lowest average water balance was recorded in August 2015, when it stood at -663.21 mm. Adverse conditions affected a significant part of the region, indicating the presence of conditions conducive to drought. Negative values indicate that potential evapotranspiration exceeds precipitation, resulting in water deficit. The risk assessment also took into account the scenario-based evaluation of changes in runoff, carried out on the basis of monthly projections of Total Runoff (the combined surface and subsurface runoff) and the raw mrro variable [$kg \cdot m^{-2} \cdot s^{-1} \approx$ mm/s], converted into monthly runoff totals.

Projected change in Total Runoff according to SSP scenarios (2031-2060)

b) b)

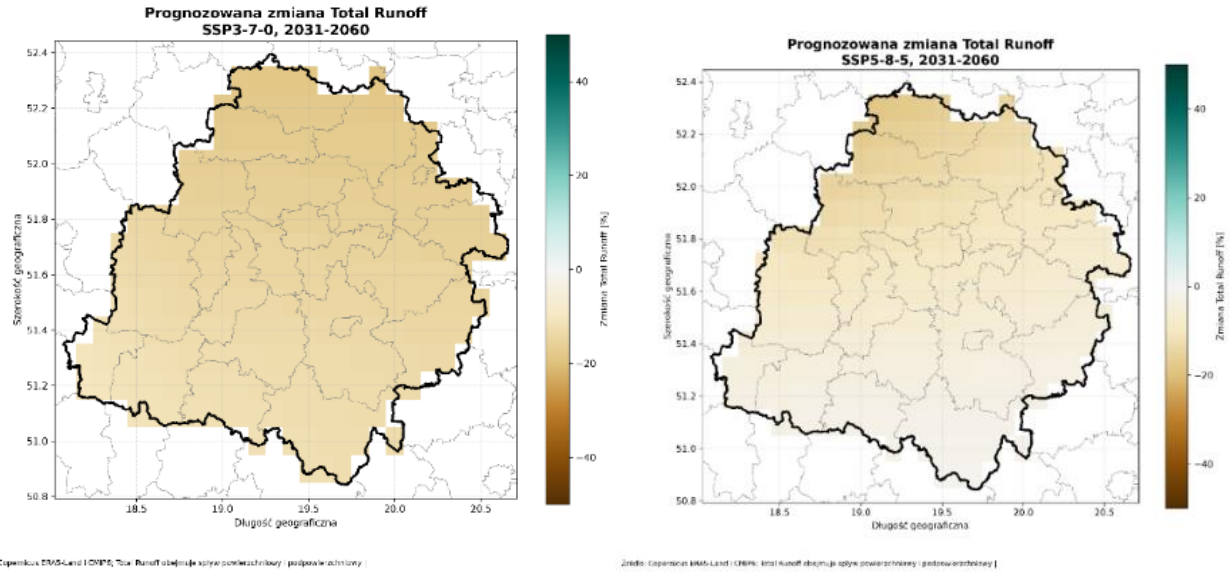


Figure 11 Projected change in total runoff in the Lodzkie Region for scenario (a) SSP3-7.0 and (b) SSP-8-5 over the period of 2031-2060 compared with 2015-2025. Source: CMIP6, MPI-ESM1-2-LR model, Copernicus Climate Data Store

Table 2 Summary of scenario-based changes in Total Runoff in the years 2031-2060

Scenario	Average change [%]	Minimum [%]	Maximum [%]	Interpretation
SSP3-7.0	-14.64	-18.49	-10.50	higher average decline in the project under analysis
SSP5-8.5	-7.87	-18.19	-1.47	lower average decline, but locally values close to SSP3-7.0

Source: CMIP6/CDS, MPI-ESM1-2-LR model; own elaboration.

For the SSP3-7.0 scenario, the average change in Total Runoff for the Lodzkie Region was -14.64%, and the spatial range of changes ranged between -18.49% and -10.50%. For the SSP5-8.5 scenario, the average change in Total Runoff for the Lodzkie Region was -7.87%, and the spatial range of changes ranged between -18.19% and -1.47%. In the model simulation analysed, the decline in the runoff was, on average, higher in the SSP3-7.0 scenario than in the SSP5-8.5 scenario. This result should not be interpreted as a general rule applicable to all climate models. The difference relates to a single run of the MPI-ESM1-2-LR model and may be due to the model's internal variability, as well as the spatial and seasonal distribution of precipitation and evapotranspiration. Negative values in the analysed area indicate a projected decrease in the average Total Runoff for the period of 2031-2060 compared with the reference period of 2015-2025. This may increase the pressure on water resources, particularly during periods of low rainfall and high evapotranspiration. This result should be interpreted in conjunction with the other climatic and hydrological indicators describing the region's water conditions.

Exposure of maize crops and apple orchards to a decline in Total Runoff according to SSP scenarios (2031-2060)

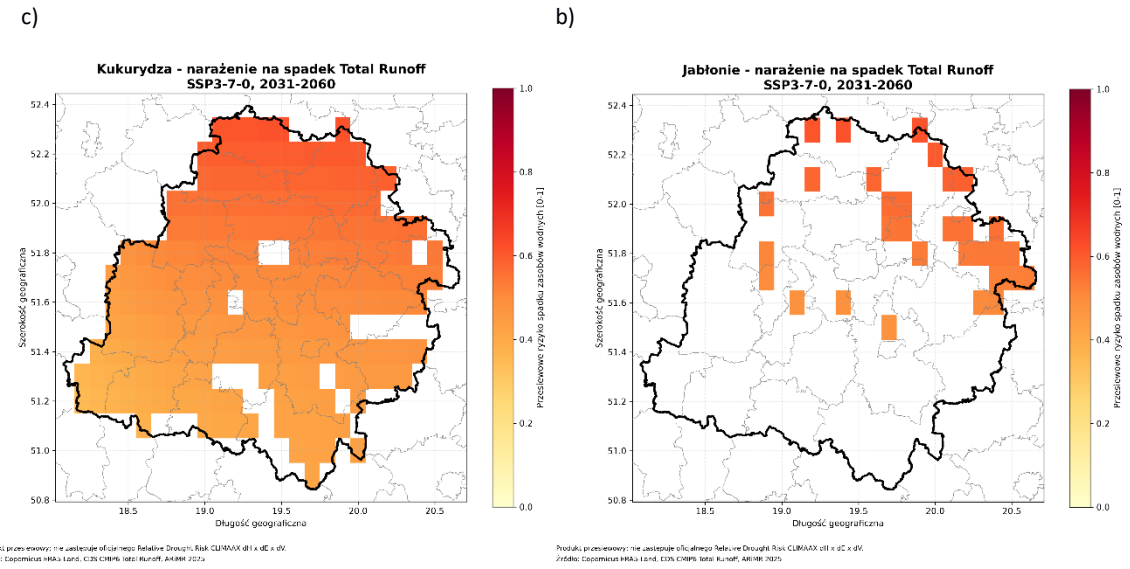


Figure 12 Vulnerability of (a) maize and (b) apple orchard cultivation to the projected change in total runoff under the SSP3-7.0 scenario, 2031-2060. Sources: CMIP6/CDS, CLMS HRL Crop Types, ARiMR; own elaboration.

Overlaying the projected changes in Total Runoff to the current distribution of crops enables to identify agricultural areas where the projected changes in total runoff may be of greatest significance in terms of availability of water resources. The analysis of crop exposure showed that the greatest reductions in Total Runoff in maize-growing areas were recorded in the Kutno county: -18.05% for SSP3-7.0 and -15.92% for SSP5-8.5. For apple orchards, the highest rates of decline were also recorded in the Kutno county: -18.39% for SSP3-7.0 and -17.12% for SSP5-8.5. The results indicate that the northern part of the region, particularly

the Kutno County, may require greater attention in terms of water retention, water management and the adaptation of agriculture.

The absence of the result for some counties in the orchard analysis indicates that no orchard exposure has been identified in the reference layer used, rather than a lack of climate data.

In the supplementary local classification of the magnitude of the decline in Total Runoff, the following intervals were used: 0-10 %, 10-20 %, 20-30 % and ≥30 %. The classification relates to the percentage reduction in the average Total Runoff during the period of 2031-2060 compared with the 2015-2025 reference period in the reference crop areas. The maximum decline in the analysed results was lower than 20% and there were no areas of cultivation falling within the ≥20% range. This classification is auxiliary and does not constitute the official CLIMAAX Relative Drought Risk classification.

2.3.1.2 Risk assessment

The assessment of hydrological drought risk was carried out using two complementary approaches. The first one comprises a regional analysis of historical hydrological conditions for 2015-2025, under which the Hydrological Drought Hazard Index (HDHI) was developed - a regional, dimensionless diagnostic index on a 0-1 scale, based on normalised and deficit-oriented values of Surface Runoff, Subsurface Runoff, Water Balance and SPEI which differs from the official CLIMAAX Relative Drought Risk method. The individual monthly layers for Surface Runoff, Subsurface Runoff, Water Balance and SPEI were spatially normalised using the min-max method, directed to the deficit, and then combined into a single dimensionless index, imposing greater weight to the direct runoff components, i.e. Surface Runoff and Subsurface Runoff. The second approach is the CLIMAAX Relative Drought Risk, which constitutes the official assessment of relative drought risk within the CLIMAAX methodology, based on the combination of the hazard (dH), exposure (dE) and vulnerability (dV) components.

Hydrological Drought Hazard Index (July 2020)

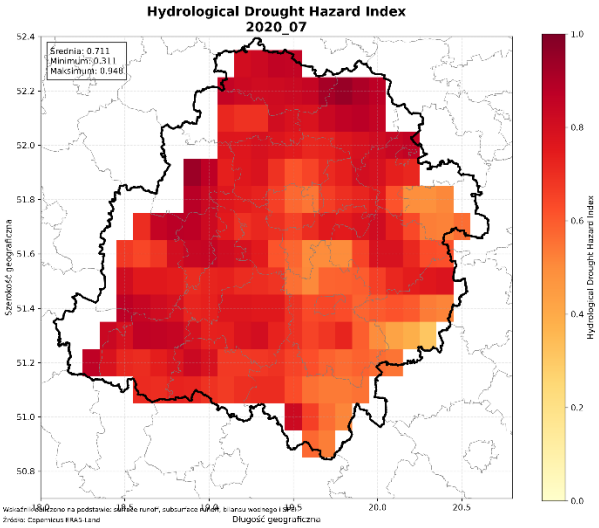


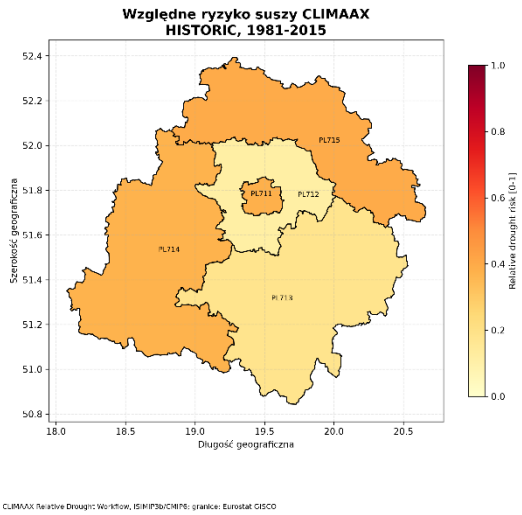
Figure 13 Hydrological Drought Hazard Index - July 2020. Source: ERA5-Land/CDS; own elaboration.

In the years 2015-2025, the highest average HDHI value was recorded in July 2020, -0.711. This result was additionally interpreted in the context of the decrease in Surface Runoff and Subsurface Runoff observed this month compared with typical July values. HDHI enables the identification of periods and areas of increased hydrological stress. This indicator is of regional and diagnostic nature and does not replace the official dH component.

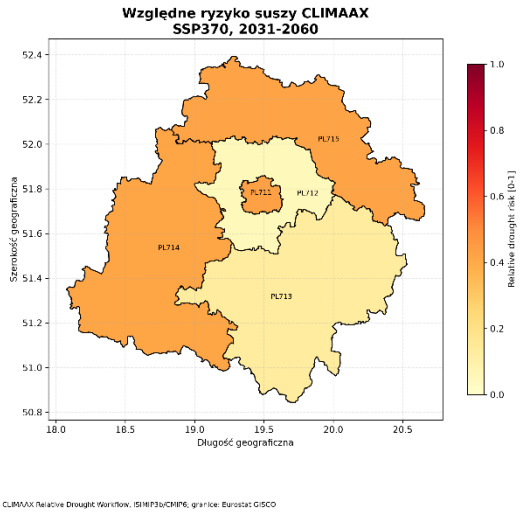
Relative Drought Risk, on the other hand, is presented on a 0-1 scale for the NUTS-3 subregions of the Lodzkie Region. The analysis was carried out for the historical period of 1981-2015 and for the SSP3-7.0 and SSP5-8.5 scenarios for the 2031-2060 period.

Relative risk of drought determined on the basis of historical data (1981-2015) and scenario analyses (2031-2060)

a)



b)



c)

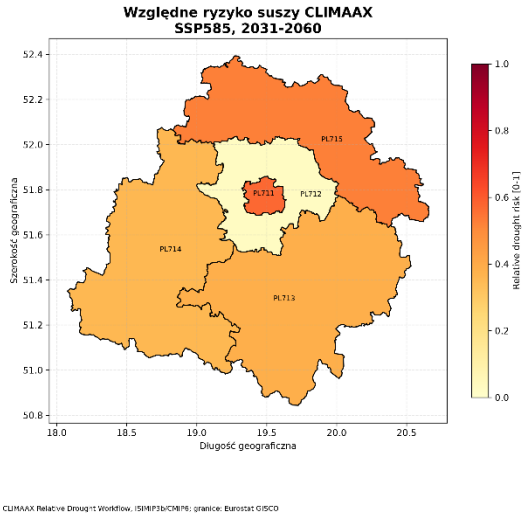


Figure 14 Relative risk of hydrological drought in the (a) historical period and for (b) SSP3-7.0 and (c) SSP5-8.5 in the years 2031-2060 at the NUTS-3 level. Source: CLIMAAX; own elaboration.

Table 3 Relative drought risk for NUTS-3 subregions, historical period, SSP3-7.0 2031-2060, SSP5-8.5 2031-2060

NUTS-3 subregion	Historical period	SSP3-7.0	SSP5-8.5
Sieradz	0.373	0.421	0.359
Piotrków	0.182	0.131	0.386
Łódź	0.117	0.049	0.028
City of Łódź	0.382	0.430	0.574
Skierniewice	0.400	0.425	0.526

The results indicate spatial variation in the relative risk of hydrological drought between the subregions of the Lodzkie Region. In the SSP3-7.0 scenario, the highest Relative Drought Risk values were recorded for the City of Łódź (0.430), the Skierniewice subregion (0.425) and the Sieradz subregion (0.421), whilst the lowest value was recorded for the Łódź subregion (0.049). In the SSP5-8.5 scenario, the highest values were recorded in the City of Łódź (0.574) and in the Skierniewice subregion (0.526), followed by the Piotrków subregion (0.386). The lowest figure was recorded in the Łódź subregion (0.028).

There is also a clear increase in the relative level of risk in selected subregions in the SSP5-8.5 scenario compared with the SSP3-7.0 scenario, particularly in the City of Łódź and the Skierniewice subregion. The higher level of relative risk in the City of Łódź stems primarily from the high exposure of the population and socio-economic activities to the effects of limited access to water resources, whilst taking into account the projected increase in the risk of hydrological drought. At the same time, the values of the indicator should be interpreted as relative, serving to compare risk levels between NUTS-3 units within the scenario under analysis. They do not mean a percentage loss, the probability of loss, or the projected value of economic losses.

2.3.2 Hazard #2 - Agriculture drought

Table 4 : Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Historical characteristics (2015-2025): monthly air temperature (°C), total precipitation (mm), PET - potential evapotranspiration, SPI - Standardised Precipitation Index, SPEI - Standardised Precipitation Evapotranspiration Index Source: Copernicus Climate Change Service (C3S), ECMWF, ERA5-Land. Supplementary impact indicators - contemporary regional diagnostics (2015-2025) (used to assess the response of vegetationcondition to periods of adverse meteorological and hydrological conditions): NDVI (Normalized Difference Vegetation Index) - 300 m 10-daily V3; Sentinel-2 L2A; NSIS: NDRE (Normalised Difference Red Edge Index) Sentinel-2 L2A as a median value for July of each year from 2015 to 2025, at a resolution of 20 m and in the EPSG:2180 system. NDRE was calculated using the formula: (B8A − B05)/ (B8A + B05)	Soil Moisture - soil moisture [m^3/m^3], monthly values for 2015-2025 Water Balance – water balance (P-PET) (mm/month), water availability in the environment (regional diagnostic indicator of water conditions) Source: Copernicus Climate Change Service (C3S), ECMWF, ERA5-Land. AWC - Available Water Capacity expressed in mm of water in the soil profile (~10 km resolution) - the maximum amount of water available to plants Source: FAO/IIASA GAEZ v4 (res06/LR/awc/)	The current distribution of maize crops (High Resolution Layer Crop Types) and apple orchards Maize: the CLMS HRL Crop Types location layer, reference year - 2023, supplemented with ARiMR data for 2021-2025 Apple orchards: a survey carried out by the Lodzkie Region Landscape Park Group, “Fruits of Memory”, for 2020-2024, supplemented with ARiMR data for 2021-2025. Source: CLMS High Resolution Layer Crop Types (CTY 2023), ARiMR data for 2021–2025; the resulting land use survey layer made available by the Lodzkie Region Geoportal via the ArcGIS REST FeatureServer service, layer 0: https://geoportal.lodzkie.pl/server/rest/services/Hosted/survey123_74c9731df834427f9b45238d09e0eb91_results/FeatureServer/0. The data has been converted to the GeoJSON format and restricted to the Lodzkie Region	Current satellite impact indicators and the results of the diagnostic analysis (2015-2025): (NDVI, NDRE, LAI) in maize-growing areas and apple orchards - these factors affect the descriptive context of the risk output, together with historical model data **Risk/Impact = f(H,E,V):** **dH / hazard characteristics:** temperature, precipitation, PET/Water Balance, SPI and SPEI used in the regional historical analysis for 2015-2025; the model for future yield reduction directly utilised precipitation and the Penman-Monteith ET0 calculated from temperature and other EURO-CORDEX climate data. **dE / exposure:** the distribution and area of maize crops and apple orchards, as well as their associated reference production. **dV / vulnerability:** AWC and crop parameters determining plant response to water deficit; Soil Moisture and Water Balance were used as supplementary data in the historical analysis. **Result:** potential reduction in

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
LAI (Leaf Area Index 2014-present (300 m raster), global, 10-day - version 2; WEkEO: Leaf area index and fraction absorbed of photosynthetically active radiation 10-daily gridded data from 1981 to present) Source: C3S/ECMWF ERA5-Land; CLMS NDVI 300 m 10-daily V3; Sentinel-2 L2A/POLSA - NDRE 20 m; CLMS - LAI 300 m.			yield → loss of production → potential loss of revenue.
Scenario analysis: RCP4.5 and RCP8.5 (a combination of the MPI-M-MPI-ESM-LR/SMHI-RCA4 models, spatial resolution 0.11). air temperature (°C), precipitation (mm), relative humidity (%), solar radiation (MJ/m²/day) and wind speed (m/s). On this basis, the following parameters were determined: ET0 - reference evapotranspiration [mm/day], FAO-56 Penman-Monteith method based on temperature, relative humidity, solar radiation, wind speed and elevation. ETc - crop evapotranspiration [mm/day], crop water requirement: ETc = Kc × ET0, where Kc is the crop coefficient, which varies between the initial phase, the full growth phase and the final phase of the season. Water balance in the root zone [mm] - water availability in the root zone. The balance was calculated in accordance with the updated CLIMAAX PR #34 model. ETa - actual evapotranspiration [mm/day], calculated as:	Irrigation availability - [% of arable land] - the indicator measuring the share of arable land equipped with irrigation systems. source: FAO/IIASA GAEZ v4 (GLCSv11_12_5m.tif) AWC - Available Water Capacity expressed in mm of water in the soil profile (~10 km resolution) - the maximum amount of water available to plants source: FAO/IIASA GAEZ v4 (res06/LR/awc/)	**Geographical and economic exposure of crops:** Maize: the CLMS HRL Crop Types location layer, reference year - 2023, supplemented with ARiMR data for 2021-2025 Apple orchards: inventory for 2020-2024, supplemented with ARiMR data for 2021-2025. Source: CLMS High Resolution Layer Crop Types (CTY 2023), ARiMR data for 2021–2025; the resulting land use survey layer made available by the Lodzkie Region Geoportal via the ArcGIS REST FeatureServer service, layer 0: https://geoportal.lodzkie.pl/server/rest/services/Hosted/survey123_74c9731df834427f9b45238d09e0eb91_results/FeatureServer/0. The data has been converted to the GeoJSON format and restricted to the Lodzkie Region **Exposed production:** area under cultivation [ha] × reference yield [t/ha]. For maize, a yield of 7.26 t/ha was used, according to the Statistical Office in Łódź (data for 2023), and for apple trees, a yield of 25.951 t/ha was used, according to Eurostat (data for Poland for 2023; a substitute value applied to the ARiMR area in the Lodzkie Region). Eurostat prices for 2023 were used to estimate the potential loss of revenue: EUR 166.40/t for maize and EUR 190.50/t for apples. Sources: ARiMR 2021–2025,	Potential yield reduction [%] for maize and apple trees in the RCP4.5 and RCP8.5 scenarios for the years 2041-2070, compared with the historical reference period of 1976-2005. Potential loss of production [t] = potential reduction in yield [%] × exposed production [t]. Potential loss of revenue [EUR] = potential loss of production [t] × reference price of the product [EUR/t]. Risk = dH (risk) × dV (irrigation availability, AWC) × dE (crop distribution, exposed production) → yield reduction [%] → production loss [t] →revenue loss [EUR]

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
ETa = Ks × ETc, where Ks is the water stress coefficient, ranging from 0 to 1. Elevation [m above sea level] - static terrain characteristics used in the FAO-56 Penman-Monteith method to correct for atmospheric pressure, the psychrometric constant and clear-sky radiation when calculating ET0 Source: EURO-CORDEX/CDS, MPI-M-MPI-ESM-LR/SMHI-RCA4, r1i1p1, EUR-11 (0,11°). The historical model period of 1976-2005 was compared with the RCP4.5 and RCP8.5 projections for the years 2041-2070. ET0 was calculated using the FAO-56 Penman-Monteith method. RCP4.5.0 was adopted as the main interpretation scenario, while RCP8.5.5 was retained as a high-forcing variant and a sensitivity test.		CLMS HRL Crop Types 2023, the Geoportal of the Lodzkie Region, the Statistical Office in Łódź and Eurostat (apri_ap_crpouta, apro_cpsh1). References: MapSPAM 2010 - spatial data on global crop production [t]; FAO/IIASA GAEZ v4 - aggregate crop value [GK$, equivalent to USD]. The sources were analysed as methodological materials, but were not used directly in the final calculation of regional output and revenue losses.	

2.3.2.1 Hazard assessment

The assessment of the historical risk of agricultural drought in the Lodzkie Region was carried out on the basis of an analysis of satellite indicators for areas under maize cultivation and apple orchards:

NDVI (Normalized Difference Vegetation Index) is defined as a normalised differential vegetation index, used to assess the condition of plants based on their activity. It is indirectly related to chlorophyll content, as chlorophyll strongly absorbs red radiation, whilst the structure of the leaves strongly reflects radiation in the NIR range.

NDRE (Normalized Difference Red Edge Index) j is a parameter that is more sensitive to chlorophyll content and the physiological state of plants; therefore, it can be used to assess plant condition more accurately, particularly where biomass density is high.

LAI (Leaf Area Index) it is an indicator that measures leaf area; it determines the ratio of the total leaf area of the vegetation to the area of land it occupies.

Anomalies in the NDVI, NDRE and LAI values for the years 2015-2025 were used to identify periods of deterioration in the condition and activity of vegetation.

The results were compared with data characterising the meteorological and hydrological conditions, namely air temperature, total precipitation, potential evapotranspiration (PET), SPI (Standardized Precipitation Index), SPEI (Standardized Precipitation Evapotranspiration Index), soil moisture (Soil Moisture) and the water balance (Water Balance). Soil Moisture and Water Balance were used for the

characteristics of historical water conditions, while AWC describes the soil capacity to store water available to plants. In the scenario section, vulnerability to water shortage was also taken into account through the AWC and irrigation availability. The NDVI, NDRE and LAI indices fulfil a diagnostic function and show the observed response of vegetation, but they are not direct components of the model for future yield reduction. The assumptions adopted enabled to illustrate changes in the condition of vegetation in relation to adverse temperature and precipitation conditions, as well as water deficit.

As part of the historical analysis covering the period of 2015-2025, the temporal and spatial variability of agricultural drought conditions and the response of vegetation were analysed. The results were used to identify the periods and areas where the condition of the crops deteriorated, and to determine the relationship between these changes and the hydrological and meteorological conditions. July was selected for the analysis because it coincides with the growing season, when vegetation is in a phase of intensive growth and development, and its condition is particularly sensitive to water shortages.

NDVI anomaly in maize-growing areas and apple orchards (July 2019)

a) b)

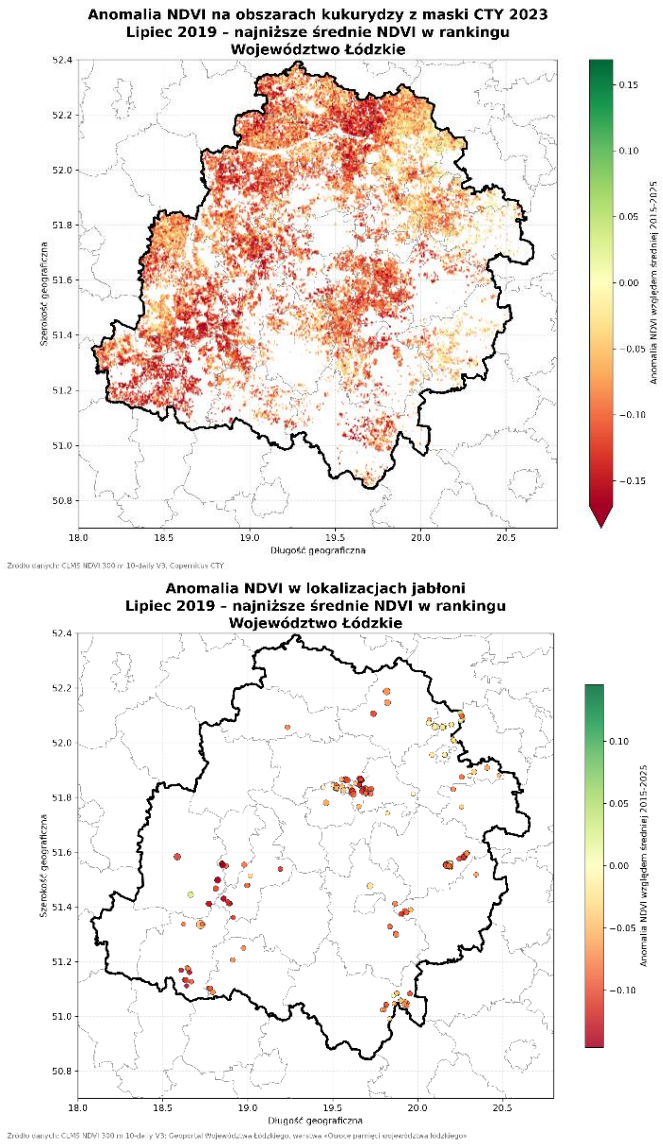
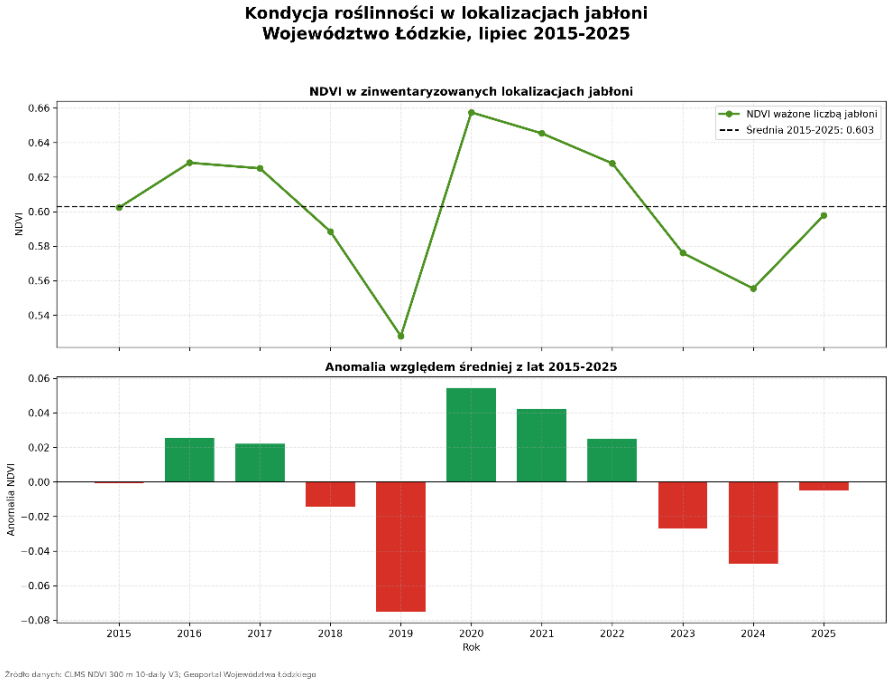


Figure 15 NDVI anomaly in July 2019 in (a) maize crops and (b) apple orchards relative to the 2015-2025 average. Source: CLMS NDVI 300 m 10-daily V3, Copernicus CTY 2023, the Geoportal of the Lodzkie Region; own elaboration.

Satellite analysis showed that in 2019, both maize-growing areas and apple orchards predominantly recorded negative NDVI anomalies, which indicates that the crops under analysis were in poorer vegetative condition. Negative NDVI anomalies indicate limited vegetation activity. This information was used to assess how vegetation had responded to prevailing water conditions in the past.

Historical analysis of vegetation condition based on satellite indices (NDVI, LAI, SPI, SPEI 2015-2025)

a)



b)

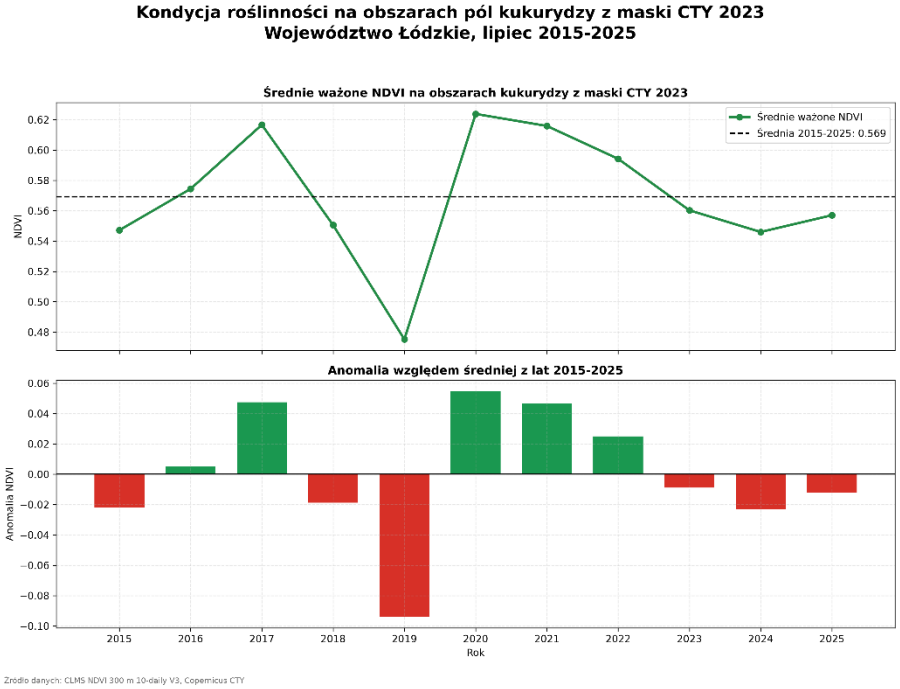


Figure 16 Variability of the NDVI index and anomalies relative to the 2015-2025 average for (a) the location of apple orchards and (b) maize crops. Source: CLMS NDVI 300 m V3, CTY 2023, the Geoportal of the Lodzkie Region; own elaboration

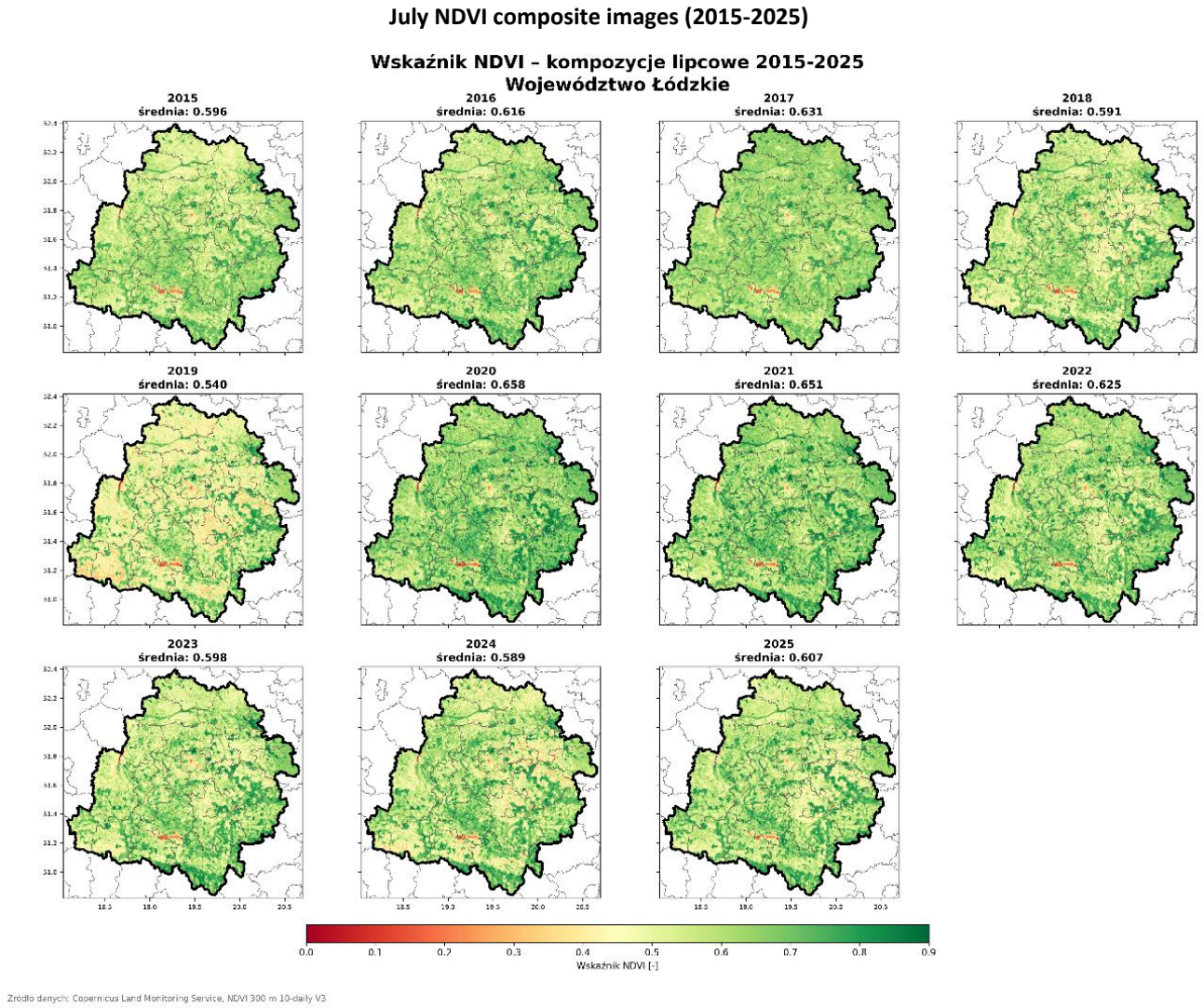


Figure 17 July NDVI composite images for the years 2015-2025; Source: Sentinel-2 L2A Copernicus Browser NDVI, own elaboration

Based on the results presented in Figures 16 and 17, it was found that in 2019 and in 2023-2025 a marked decrease in the NDVI value was recorded, indicating lower photosynthetic activity in plants and, consequently, their poorer condition. Changes in this parameter were observed in both maize and apple crops, suggesting the impact of wider-ranging external factors, including weather conditions and drought.

The statistics were calculated separately for the maize reference areas and for the surveyed apple orchard sites. The mean, median, range, standard deviation, deviation from the mean for the period of 2015-2025 and the z-score were calculated. The negative anomaly indicates that the condition of the vegetation is below average for the period under analysis. In Phase 2, NDRE serves to provide historical data and to perform a partial verification of vegetation responses. It does not replace the EURO-CORDEX model baseline period, is not extrapolated to the future projection period of 2041-2070, and has not been directly incorporated into the equation for potential yield reduction or into the Relative Drought Risk.
The reference locations of the maize fields used in the analysis correspond to the CLMS HRL Cro Types 2023 layer, whilst the locations of the apple orchards are derived from the 2020-2024 survey, supplemented with the ARiMR data for 2021-2025. These layers were used as contemporary exposure data. They do not represent a reconstruction of the distribution of crops in each year between 2015 and 2025. The results of the analyses using the NDRE ratio are presented below:

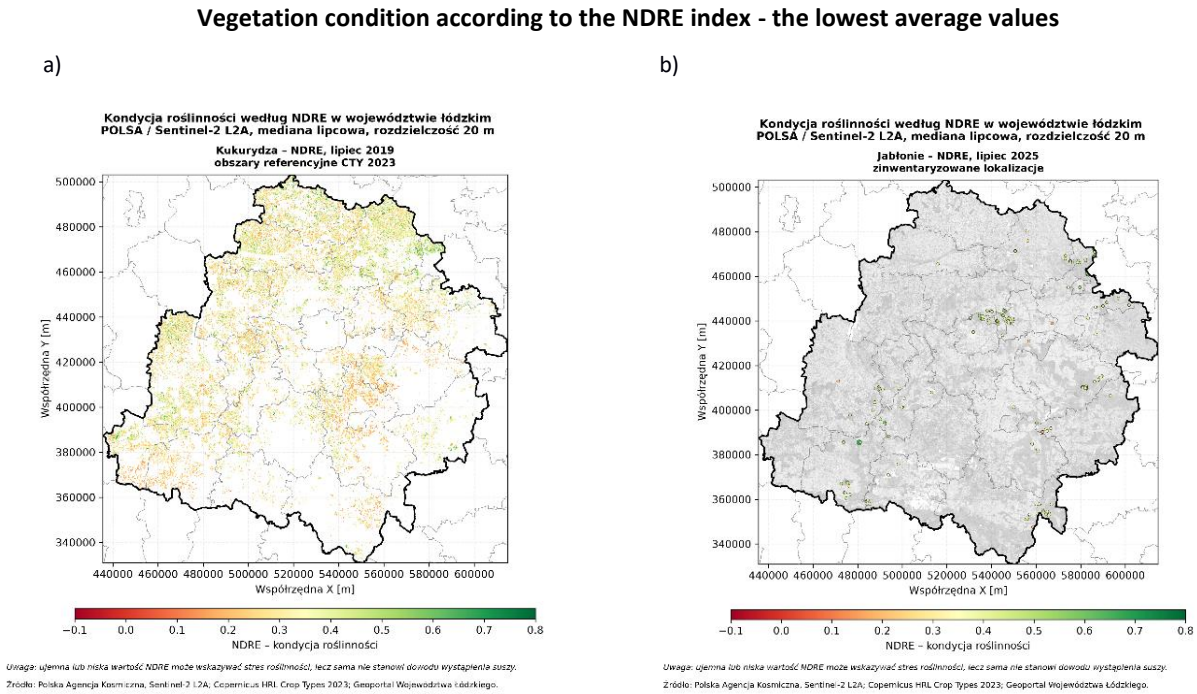


Figure 18 (a) Spatial distribution of NDRE in July 2019 across maize reference areas; (b) NDRE values in July 2025 at surveyed apple orchard sites. The years were selected on the basis of the lowest average NDRE values obtained separately for both crops. Figures 18a and 18b do not provide a direct comparison of 2019 and 2025. The maps do not provide a direct comparison between the years, nor do they offer a complete inventory of all crops in the region. Source: POLSA, Sentinel-2 L2A; Copernicus HRL Crop Types 2023; the Geoportal of the Lodzkie Region; own elaboration.

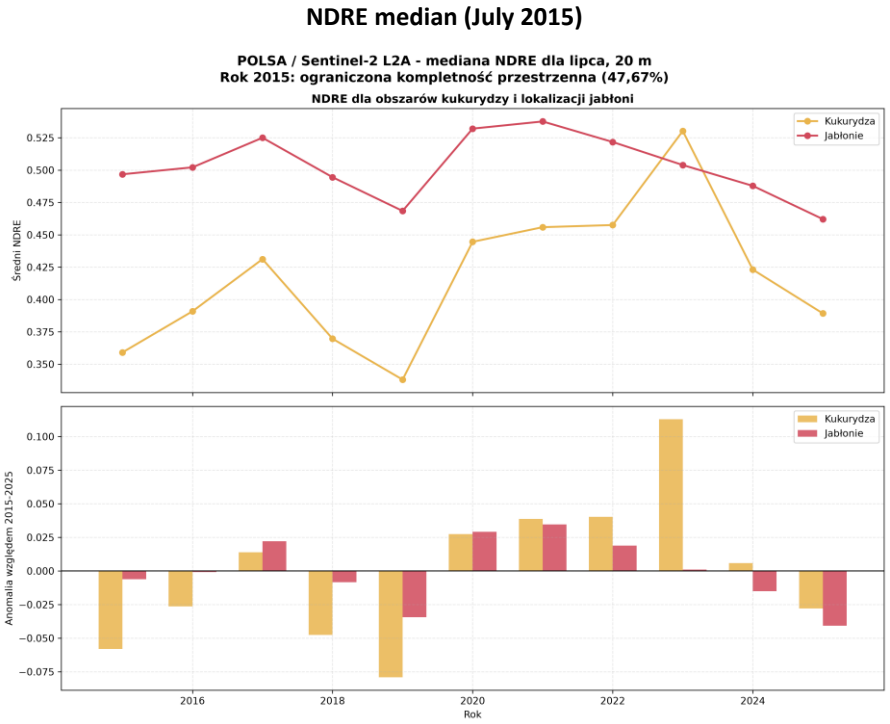


Figure 19 Average NDRE indices and anomalies relative to the period of 2015-2025 in reference areas for maize and apple cultivation. Source: POLSA, Sentinel-2 L2A; Copernicus HRL Crop Types 2023; the Geoportal of the Lodzkie Region; own elaboration.

In the 2015-2025 period under review, a marked difference in the NDRE index values between maize and apple trees is visible. Apple trees generally demonstrate higher and more stable NDRE values, while in the case of maize, greater variability is observed in year-on-year terms.

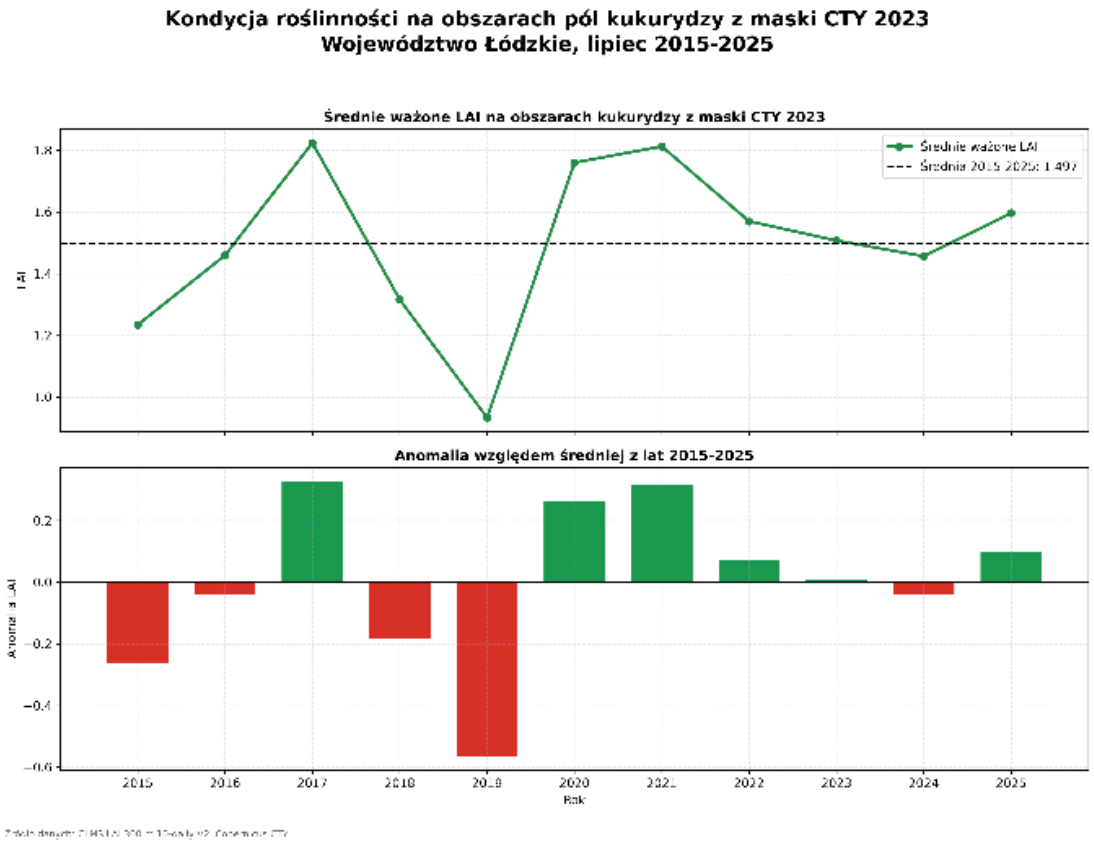
In the case of apple trees, NDRE values have remained at a relatively high and consistent level in most of the years analysed. Following a period of relative stability from around 2022, a downward trend has become apparent, particularly marked in the recent years of the series. Maize, on the other hand, shows greater year-on-year fluctuations. Periods of lower NDRE values are particularly visible (especially in 2019).

Following the increase observed in the first half of 2020s, a further decline of the value takes place in 2024-2025. The analysis of deviations from the reference value confirms that maize is more variable. In its case, both clear negative and positive anomalies occur, while the variations are more moderate for apple trees. In the recent years, a trend towards negative NDRE anomalies has been observed for both crops under analysis, which may indicate a deterioration in vegetation condition compared with the reference period.

The lowest average NDRE value for maize crops was recorded in 2019 (0.338; z-score -1.51), whilst for apple trees it was recorded in 2025 (0.462; z-score -1.73). 2015 has been included in the time series; however, its results should be interpreted with caution due to the limited spatial completeness of the data. For July 2015, five independent Sentinel-2 time series were available, and at least one valid NDRE value was obtained for 47.67% of the region's area. In the years 2016-2025, spatial coverage ranged from 90.87% to 99.68%.

The condition of vegetation in maize fields and apple orchards and LAI anomalies

a)



b)

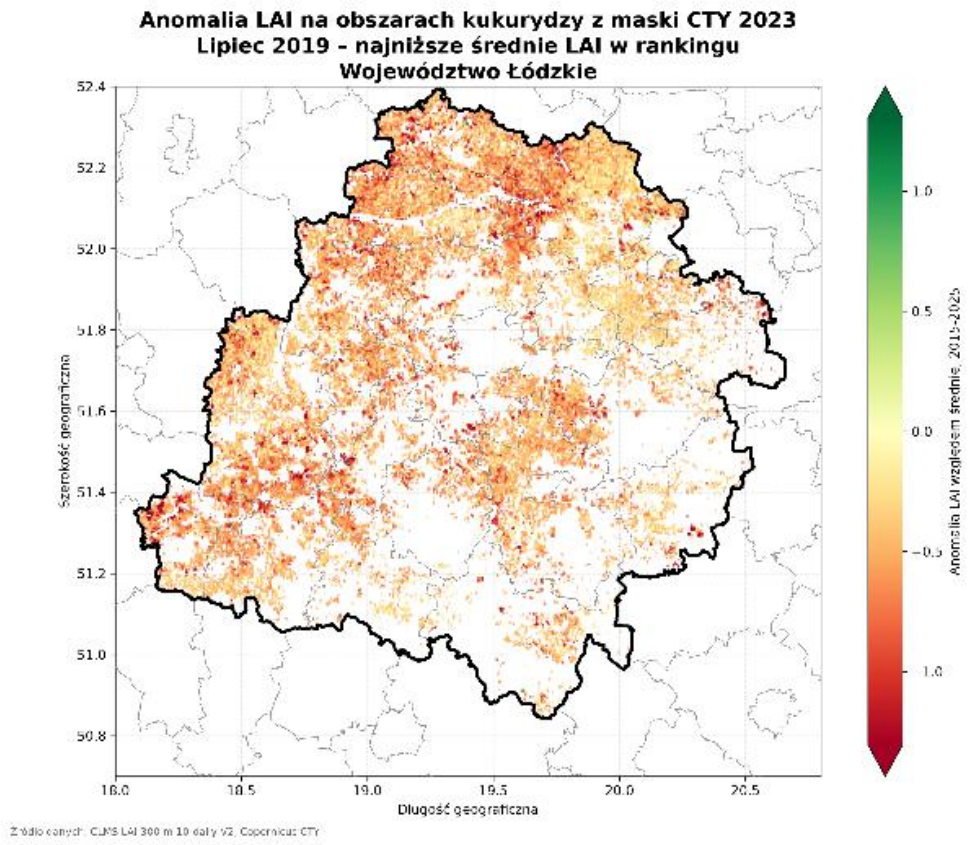
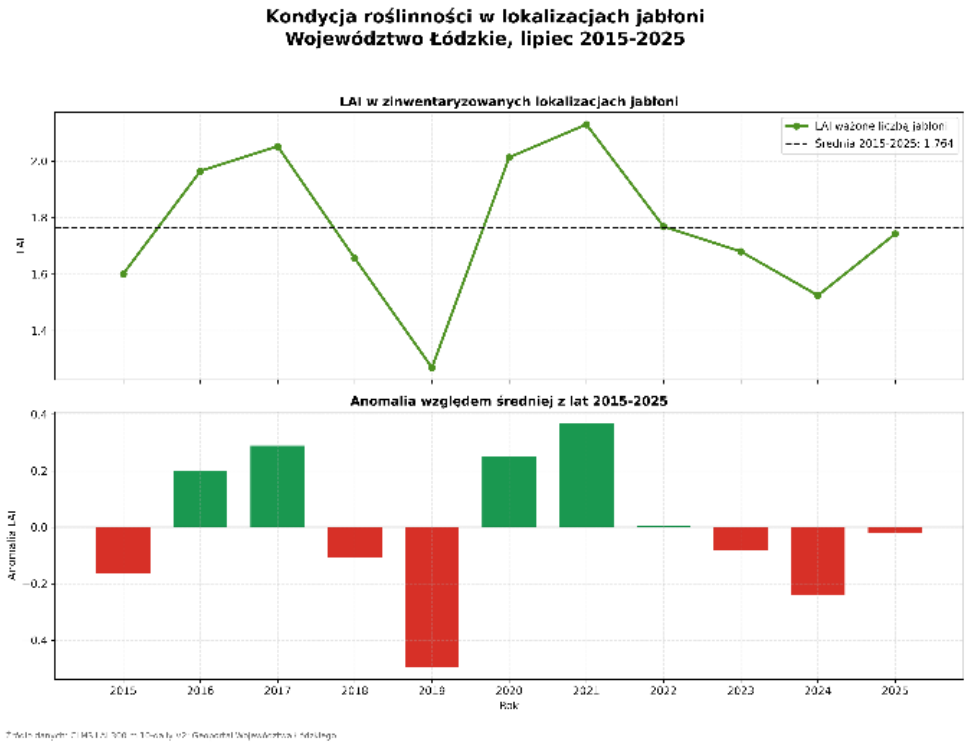


Figure 20 (a) LAI anomaly for 2015-2025 for maize crops in 2023; (b) maize LAI, July 2019 - the lowest average LAI in the regional ranking for 2015-2025

a)



b)

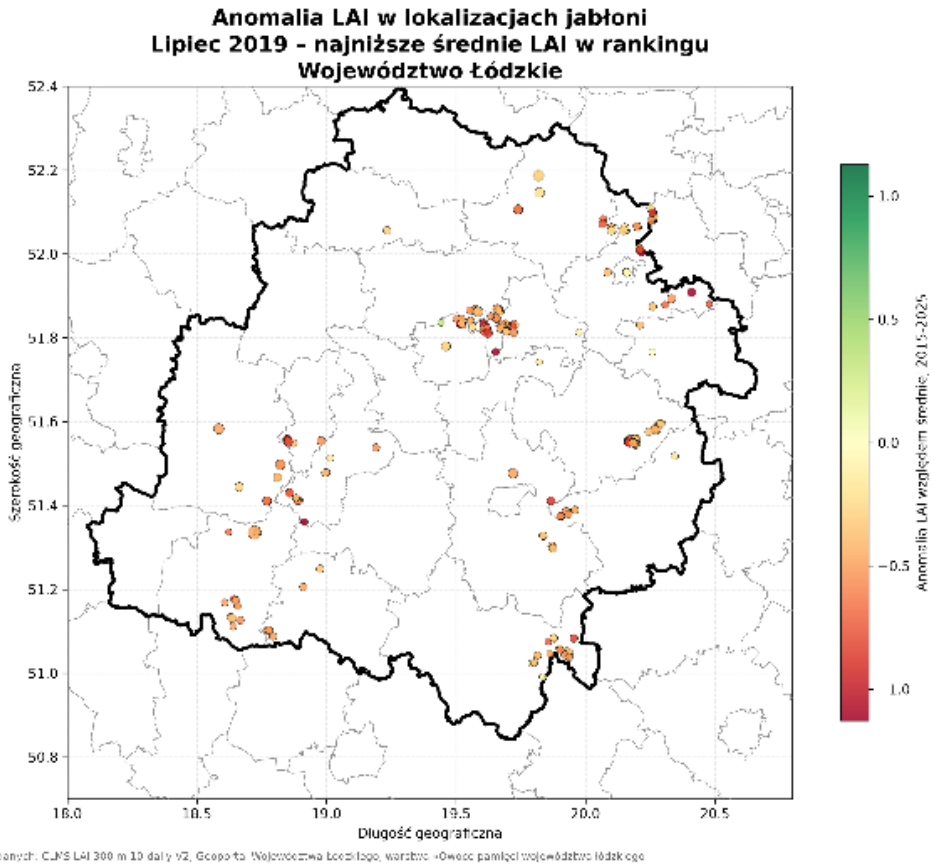


Figure 21 (a) LAI anomalies for 2015-2025 for apple orchards at the 2023 reference site; (b) LAI - apple trees, July 2019: the lowest average LAI in the regional ranking

In the analysis, the LAI parameter was also applied, which is a key parameter used in assessing the condition of vegetation. The analysis of LAI values for 2015-2025 indicates that the condition of vegetation is variable, both for maize and for apple trees. The lowest LAI values and the greatest negative anomalies relative to the average were recorded in July 2019 both for maize and for apple trees. The results therefore indicate a reduction in leaf area compared with the average conditions for the period of 2015-2025.

The analysis of the NDVI, LAI and NDRE indices allowed for identification of periods and areas of poor crop condition in the Lodzkie Region in the years 2015-2025. Given the complementary nature of the indicators, combining them provides a more comprehensive assessment of vegetation response. The following section of the analysis therefore presents a summary of the NDRE, LAI and LAI indices for July 2019 (July 2019 was selected for analysis as the period in which a marked deterioration in vegetation condition was recorded, based on the data shown in Figures 19 and 20). At the same time, July 2019 demonstrated other anomalies indicating unfavourable water and drought conditions. A comparison of the meteorological and environmental conditions observed during this period with changes in the NDVI, LAI and NDRE values suggests that these indices may serve as a useful supplement to the assessment of occurrence and spatial variation of drought effects in relation to vegetation condition. This analysis makes allows for identification of areas where water scarcity may be reflected by the deterioration in the condition and activity of vegetation.

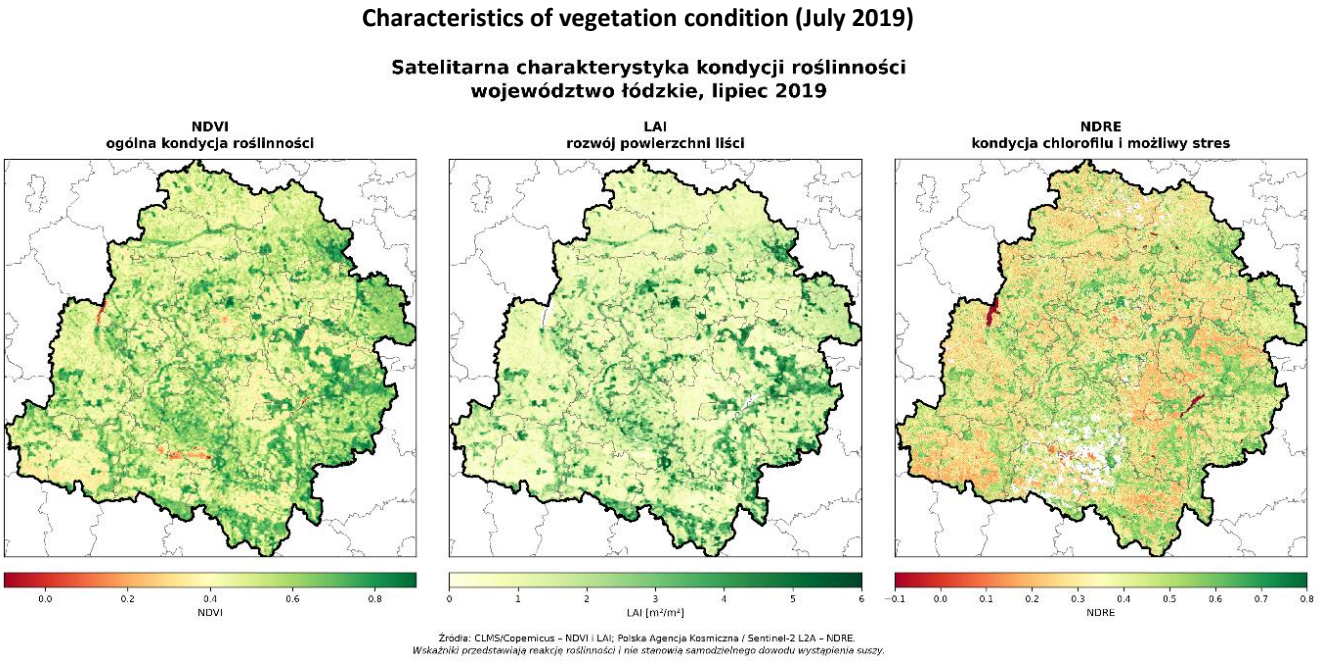


Figure 22 Satellite characteristics of vegetation conditions in the Lodzkie Region in July 2019: NDVI - overall vegetation condition, LAI - leaf area index and NDRE - chlorophyll condition and potential plant stress. Sources: CLMS/Copernicus – NDVI I LAI; Polish Space Agency/Sentinel-2 L2A – NDRE; own elaboration

The figure above shows the spatial variation in vegetation condition in the Lodzkie Region in July 2019, based on three complementary satellite indices: NDVI, LAI and NDRE. A combined interpretation of all three indicators provides a more comprehensive picture of vegetation response than the use of a single satellite product.

The map shows the spatial variation in NDVI values. According to the interpretation of the NDVI index, lower values are found, among others, in areas with sparser vegetation and in parts of agricultural and urban areas, whereas higher values are concentrated primarily in areas with dense and well-developed vegetation, including forest complexes. Lower values of this indicator also suggest poorer condition of the plants. The data presented in Figure 22 show that NDVI values varied in spatial terms within the Lodzkie Region. In the major part of the region, intermediate values were recorded, whilst locally there were areas with significantly lower NDVI values.

In the case of LAI, the highest values of this index are recorded in forested areas and dense vegetation complexes, whilst lower values predominate in agricultural and urban areas and in areas with limited vegetation. The data presented on the map show that the spatial distribution of LAI is similar to that of NDVI in the Lodzkie Region, which confirms that both indices are consistent in identifying areas with more and less developed vegetation. Considering the NDRE index, it can be concluded that it shows considerably greater variation. Extensive areas with low and moderate values may indicate poorer vegetation health or possible stress, particularly in the central and southern parts of the region. The visible white areas indicate the lack of appropriate observation, rather than a zero NDRE value.

Satellite data analysis was used to assess the condition of vegetation in 2015-2025 and to determine whether the observed periods of deterioration coincided with adverse water conditions indicative of agricultural drought. The NDVI, NDRE and LAI indices were used in the analysis for maize crops and apple orchards.

Reduced values and negative anomalies in the NDVI, NDRE and LAI indices indicate a deterioration in the condition of the vegetation; however, as such, they do not constitute proof of a drought. The values of these indicators may also be related to the stage of plant growth, the harvest date and other physiological

and environmental factors. For this reason, the results of the satellite analysis were interpreted in conjunction with information on water and meteorological conditions.

The analysis revealed significant variability in the condition of the vegetation in the years 2015-2025. July 2019 stood out particularly clearly when, in maize-growing areas, reduced values of NDVI, LAI and NDRE coincided with the lowest soil moisture levels in the period analysed, the most negative monthly water balance and very low Surface Runoff values. It indicates that the deterioration in the condition of the vegetation coincided with adverse water conditions during the period of agricultural drought.

The results obtained indicate that the NDVI, NDRE and LAI indices may be useful for assessing changes in vegetation health and identifying periods of potential plant stress associated with water shortages. However, their interpretation requires reference to water and meteorological conditions, as well as taking into account the natural variability resulting from the vegetation cycle. Satellite analysis therefore complements the characteristics of drought conditions and enables an assessment of vegetation response to prevailing environmental conditions.

2.3.2.2 Risk assessment

Regional data for 2015-2025 were used to characterise current meteorological and hydrological conditions, assess current exposure and analyse the observed response of vegetation.

As part of the diagnostic analysis, maps and statistics on meteorological and hydrological anomalies were used, accompanied by vegetation health indices (NDVI, NDRE and LAI) for maize-growing areas and apple orchards. However, this data does not constitute the climate dataset for the EURO-CORDEX projections.

The assessment of the potential future impacts of agricultural drought was performed on the basis of the EURO-CORDEX model data. The period of 1976-2005 was adopted as the historical benchmark period, whereas future conditions were assessed for the period of 2041-2070 under the RCP4.5 and RCP8.5 scenarios.

Based on changes in climatic conditions between the historical period and the future projections, the following parameters were estimated:

- potential yield reduction [%] for maize and apple trees,
- potential loss in production [t],
- potential loss in revenue [EUR].

Accordingly, data for 2015-2025 is used to characterise current conditions and vegetation responses, whereas the model period of 1976-2005 and the projections for 2041-2070 form the basis for the quantitative assessment of the potential future impacts of agricultural drought.

Table 5 Potential yield reduction [%] and its change relative to the historical period [p.p.] in the model historical period of 1976-2005 and the EURO-CORDEX projections for 2041-2070

Cultivation	Historical [%]	RCP4.5 [%]	Change [p.p.]	RCP8.5 [%]	Change [p.p.]
Corn	4.83	13.75	+8.92	11.89	+7.06
Apple trees	2.96	4.54	+1.58	4.11	+1.15

Changes in the potential reduction in maize yields according to RCP scenarios (2041-2070, compared to 1976-2005)

a) b)

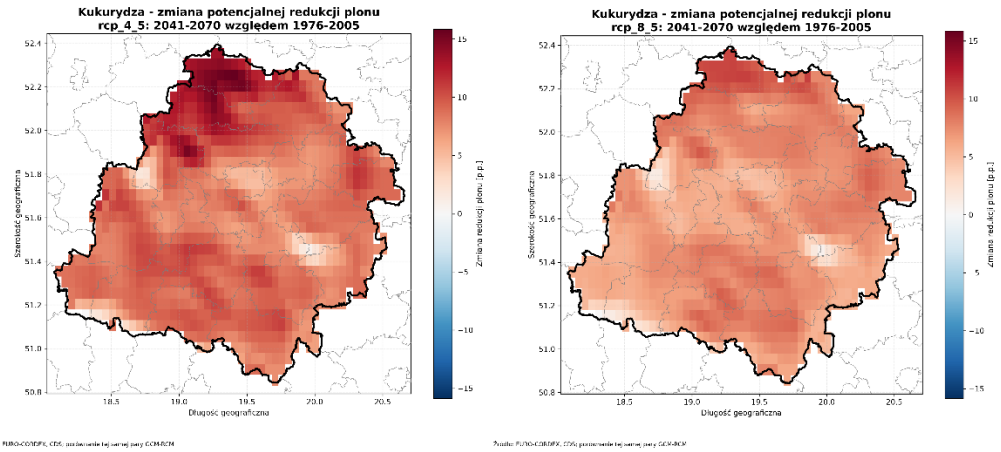


Figure 23 Change in the potential yield reduction (p.p.) of maize under the RCP4.5 scenario (a) the RCP8.5 scenario (for comparison) for in the years 2041-2070 (b), relative to the model historical period of 1976-2005. Source: EURO-CORDEX/CDS, MPI-M-MPI-ESM-LR/SMHI-RCA4, r1i1p1; own elaboration.

Change in the potential reduction in apple orchard yields according to RCP scenarios (2041-2070, compared to 1976-2005)

a) b)

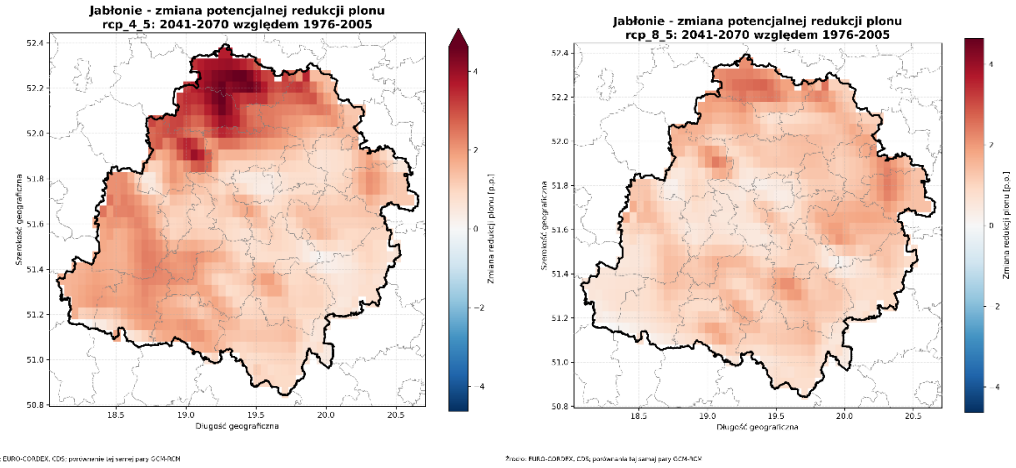


Figure 24 (a) Change in the potential yield reduction (p.p.) of apple trees under the RCP4.5 scenario (b) RCP8.5 in the years 2041-2070 relative to the model historical period of 1976-2005. Source: EURO-CORDEX/CDS, MPI-M-MPI-ESM-LR/SMHI-RCA4, r1i1p1; own elaboration.

The results indicate an increase in the potential yield reduction for both crops analysed compared with the historical reference period of 1976-2005. The greatest change was observed for maize - the average yield reduction has increased from 4.83% in the historical period to 13.75% in the RCP4.5 scenario and 11.89% in the RCP8.5 scenario, representing an increase of 8.92 and 7.06 percentage points, respectively. In the case of apple trees, the changes are significantly smaller - the reduction in yield increases from 2.96% to 4.54% for RCP4.5 and to 4.11% for RCP8.5, i.e. by 1.58 and 1.15 percentage points, respectively. This means that maize is significantly more sensitive to the climatic conditions under consideration than apple orchards. At the same time, the higher reduction in maize yield in the RCP4.5 scenario compared with the RCP8.5 scenario stems from the specific characteristics of the GCM-RCM model run used and should not be interpreted as a general trend indicating a greater impact of the RCP4.5 scenario.

Table 6 Potential production losses and revenue losses for climate projections in 2041-2070.

Cultivation	Potential loss in production* [t]	Potential loss in revenue* [EUR million]	Estimated reference production value **2023 [EUR million
RCP 4.5			
Maize	149,835	24.93	112.45
Apple trees	5,937	1.13	116.25
RCP 8.5			
Maize	126,300	21.02	112.45
Apple trees	6,361	1.21	116.25

*Source of current prices: Eurostat. **The estimated production value for 2023 is calculated using data from the Statistical Office in Łódź and Eurostat prices at current values*

Converting potential yield reductions into production volumes allows for determining the scale of potential economic consequences of climate change. Under the RCP4.5 scenario, the potential loss of production amounts to approximately 149,800 tonnes of maize and 5,900 tonnes of apples, which corresponds to the potential loss in revenue of EUR 24.93 million and EUR 1.13 million, respectively. Under the RCP8.5 scenario, the potential loss of maize production is lower, at around 126,300 tonnes, whilst the associated loss in revenue stands EUR 21.02 million. In the case of apple trees, however, the potential loss of production rises to approximately 6.4 thousand tonnes, while the loss of revenue amounts to EUR 1.21 million.

To illustrate the scale of potential losses, these values have been compared with the estimated value of maize and apple production in the Lodzkie Region in 2023. The value of production was calculated as the product of the harvest volume [t] and the reference price [EUR/t] for the same year. For maize, the yield of 675,771 tonnes was estimated, based on data from the Statistical Office in Łódź, and a price of EUR 166.40/tonne according to Eurostat (apri_ap_crpouta, Poland, 2023), which corresponds to the value of approximately EUR 112.45 million. For apples, the yield of 610,247.7 tonnes was estimated, based on the publication “Agriculture in the Lodzkie Region in 2023” and a price of EUR 190.50/tonne according to Eurostat (apri_ap_crpouta, Poland, 2023), which corresponds to the value of approximately EUR 116.25 million. These figures serve for comparison purposes only and do not constitute a forecast of future prices or actual farm income.

Comparing potential losses with the value of production in 2023 indicates markedly greater economic exposure of maize production. The potential loss in revenue corresponds to approximately 22.2% of the value of production in 2023 under the RCP4.5 scenario, and approximately 18.7% under the RCP8.5 scenario. In the case of apples, this figure stood at around 1.0% in both scenarios. This means that, under the model conditions adopted, the potential scale of economic losses in maize production is more than twenty times higher than in the case of apples.

The higher potential losses for maize in the RCP4.5 scenario compared with the RCP8.5 scenario result from greater yield reduction estimated for that scenario, as well as from the specific characteristics of the GCM-RCM modelling implementation used and the methodology adopted. However, this difference should not be interpreted as a general pattern suggesting that a scenario with higher radiation exposure always leads to greater economic losses. The results should be regarded as a projection of potential losses and the cost of lost opportunities under specific climatic conditions and based on the model assumptions made. They do not constitute a forecast of actual losses or future revenues, but rather an indicator enabling an assessment of the potential scale of climate risk to the agricultural production under analysis.

Over the analysed period of 2041-2070, the maize production sector therefore requires particular attention in terms of adaptation measures, due to the combination of a relatively high reduction in yields, the large scale of production and the high economic value of the production that could potentially be lost. In the case of apple orchards, the scale of potential losses is smaller, although it also highlights the need to take climate risks into account when planning adaptation measures.

Potential loss in revenues for maize crops according to RCP scenarios (2041-2070, compared to 1976-2005)

a) b)

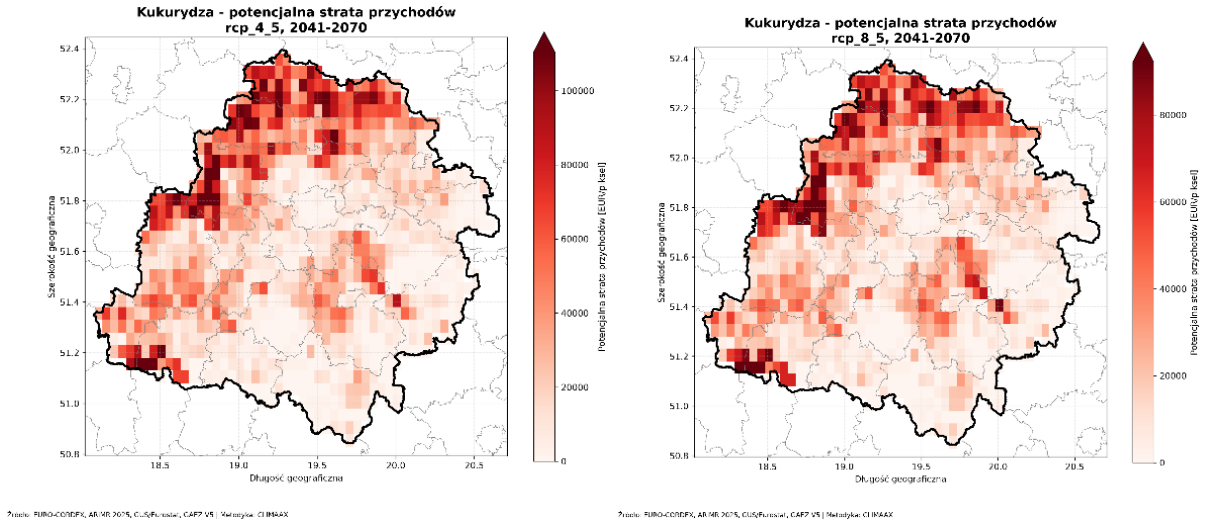


Figure 25 (a) Potential loss in revenue [EUR/pixel] for maize in 2041-2070 for RCP4.5; (b) RCP8.5 (for comparison); Sources: EURO-CORDEX/CDS, MPI-M-MPI-ESM-LR/SMHI-RCA4, r1i1p1; ARiMR/CLMS/Geoportal; Eurostat; own elaboration.

Potential loss in revenues for apple orchards according to RCP scenarios (2041-2070, compared to 1976-2005)

a) b)

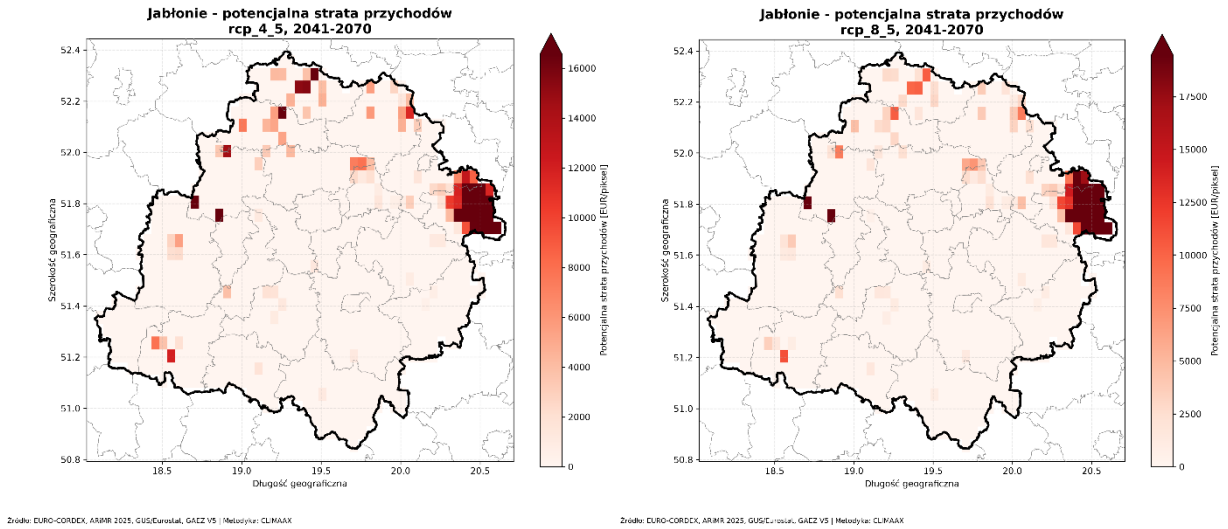


Figure 26 (a) Potential loss in revenue [EUR/pixel] for apples in 2041-2070 for RCP4.5; (b) RCP8.5 (for comparison); Sources: EURO-CORDEX/CDS, MPI-M-MPI-ESM-LR/SMHI-RCA4, r1i1p1; ARiMR/CLMS/Geoportal; Eurostat; own elaboration.

The figure above shows the spatial distribution of potential revenue losses for maize and apple trees in the years 2041-2070. The results were calculated on the basis of changes in potential yield reduction relative to

the EURO-CORDEX historical model period (1976-2005), the current distribution of crops, and reference production and price parameters.

Spatial variation results from overlapping of modelled yield reduction onto the current distribution and extent of crop exposure.

2.3.3 Hazard #3 – Heavy rainfall

Table 7 : Data overview workflow #3

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Climate data: ready-to-use, statistically adjusted IDF products for maximum 24-hour rainfall, compiled on the basis of EURO-CORDEX data (scenario: RCP 4.5, RCP 8.5, the MPI model chain MPI-ESM- LR/RCA4 at a resolution of 0.11° (~12 km). Analysis: changes in the precipitation intensity while maintaining constant return periods, and the future frequency of precipitation corresponding to the historical RP10 level, i.e. precipitation that is statistically reached or exceeded once every 10 years for the periods of 1976-2005 (baseline) and 2041-2070 (projected). The data was elaborated using *Path B*. Source: CLIMAAX Heavy Rainfall Workflow; bias-corrected EURO-CORDEX, chain. MPI-ESM-LR / RCA4	Vulnerability assessed indirectly, in accordance with the CLIMAAX methodology (Extreme Precipitation Critical Thresholds), and relative to the 24-hour precipitation threshold associated with the occurrence of local impacts. A standard level of vulnerability of infrastructure and ecosystems to 24-hour heavy rainfall was assumed; this was assessed, in part, on the basis of interventions by the PSP/OSP in 2015-2025 (data on historical impacts and service interventions were used to establish the local hazard-impact context) In addition, the following supplementary sources were used: AWC - Available Water Capacity expressed in mm of water in the soil profile (~10 km resolution) - the maximum amount of water available to plants The following parameters were used to interpret the water retention capacity of soil. source: FAO/IIASA GAEZ v4 (res06/LR/awc/) Elevation [m above sea level] – the static layer of mn30_grd, cropped to the boundaries of the Lodzkie Region. Used to interpret runoff directions and the potential for local water accumulation; it is not a component of the weighted vulnerability index. Source of the layer: GMTED2010 (30”), supplied as part of the CLIMAAX Agriculture Drought reference package.	Spatial exposure - the Lodzkie Region – BDOT10k buildings, class OT_BUBD_A, SHP packages, merged and limited to the boundaries of the Lodzkie Region. Exposure, understood as the potential range of impact of extreme rainfall in the region, covering urban areas and infrastructure vulnerable to flooding Source: Regionalny System Informacji Przestrzennej Województwa Łódzkiego - provision of geodetic and cartographic data (https://rsip.lodzkie.pl/udostepnianie-zasobu-geodezyjnego-i-kartografi, znego/) Apple orchards: inventory for 2020-2024, supplemented with ARiMR data for 2021-2025.	Screening risk assessment: precipitation hazard + building exposure + qualitative vulnerability context. (The Hazard-Exposure-Vulnerability framework was retained in the Heavy Rainfall analysis. The hazard and building exposure was quantified, whereas vulnerability was assessed qualitatively on the basis of the regional context of the consequences of heavy rainfall. The result is a screening risk assessment: Risk = f(H,E,V)) and is not the direct product of the normalised values dH × dE × dV.) Indicators analysed: Return Period shift and Magnitude shift determined for extreme 24-hour rainfall. Baseline variable: daily precipitation totals (pr) from the EURO-CORDEX regional climate models (ICHEC-EC-EARTH / KNMI-RACMO22E model chain, RCP 4.5 and RCP 8.5 scenarios). The IDF product range covers return periods of 2-200 years; the historical RP10 rainfall has been adopted as the main interpretative threshold. Risk assessment based on changes in rainfall hazard and the exposure of BDOT10k buildings. It covers the number and share of buildings located in areas where rainfall intensity is increasing and where the historical RP10 is becoming more frequent. Data from the PSP/OSP for the period of 2015-2025 was used to provide the local context of the historical consequences. The result

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
			indicates a potential increase in the risk of localised flooding and flash floods, but does not constitute a forecast of the actual number of buildings flooded. Results of the building exposure - 1,295,810 buildings were identified, with a total outline area of approximately 18,586 ha. Spatial mapping of changes in precipitation hazard in relation to the location of BDOT10k buildings and determining of the number and proportion of buildings located in areas where precipitation intensity has increased and the RP10 historical return period has shortened.

2.3.3.1 Hazard assessment

Change in intensity of 24-hour extreme rainfall according to the RCP scenarios (2041-2070)

a) b)

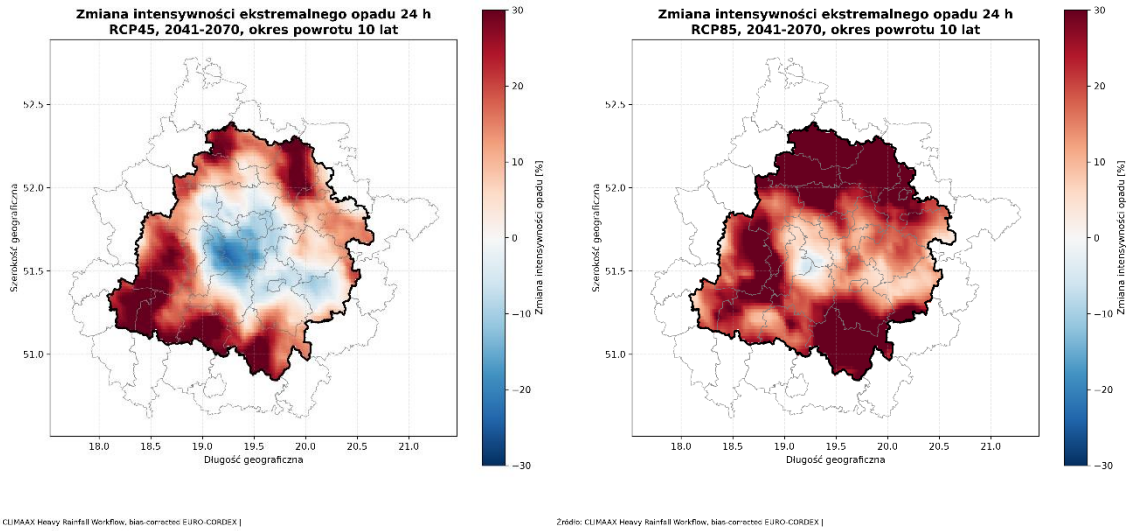


Figure 27 Change in the intensity of the 24-hour extreme rainfall event RP10 in the years 2041-2070 compared with the historical period of 1976-2005: (a) RCP4.5, (b) RCP8.5. Source: CLIMAAX Heavy Rainfall / EURO-CORDEX; own elaboration.

Table 8 Summary of changes in 24-hour RP10 precipitation intensity and the future historical RP10 return period under the RCP4.5 and RCP8.5 scenarios. Source: CLIMAAX Heavy Rainfall / EURO-CORDEX; own elaboration.

Scenario	Average change in RP10	Median of change in RP10	Future mean return period for rainfall corresponding to the historical RP10
RCP4.5	+10.8%	+11.4%	approx. 8.1 years
RCP8.5	+26.3%	+22.8%	approx. 5.6 years

The change in the intensity of the 24-hour extreme rainfall (RP10) shows its increase in both scenarios analysed. Under the RCP4.5 scenario, the average change in intensity is +10.8%, and a 10-year historical rainfall event may, on average, occur approximately every 8.1 years in the future. Under the RCP8.5 scenario, the change is significantly higher – +26.3% on average, with the historical return period for RP10 reduced to approximately 5.6 years. The spatial distribution of the changes indicates that the increase in risk is not uniform across the region. This means a simultaneous increase in both the intensity and frequency of rainfall events corresponding to the historical RP10, which may place greater pressure on drainage systems, urban areas and areas prone to localised flooding.

In the next step, the risk analysis was supplemented with data on 5,960 interventions by the PSP/OSP relating to flooding caused by torrential rain between 2015 and 2025. The data was used to characterise the temporal and spatial patterns of the historical consequences of heavy rainfall in the Lodzkie Region. Incidents were aggregated to county level according to the agency carrying out the response, which made it possible to identify the areas where the effects of heavy rainfall were most frequent. Data on interventions provide the local context for interpreting the scenario results. However, they should not be interpreted as a record of the buildings that were actually flooded, the extent of the flooding or the scale of the losses incurred.

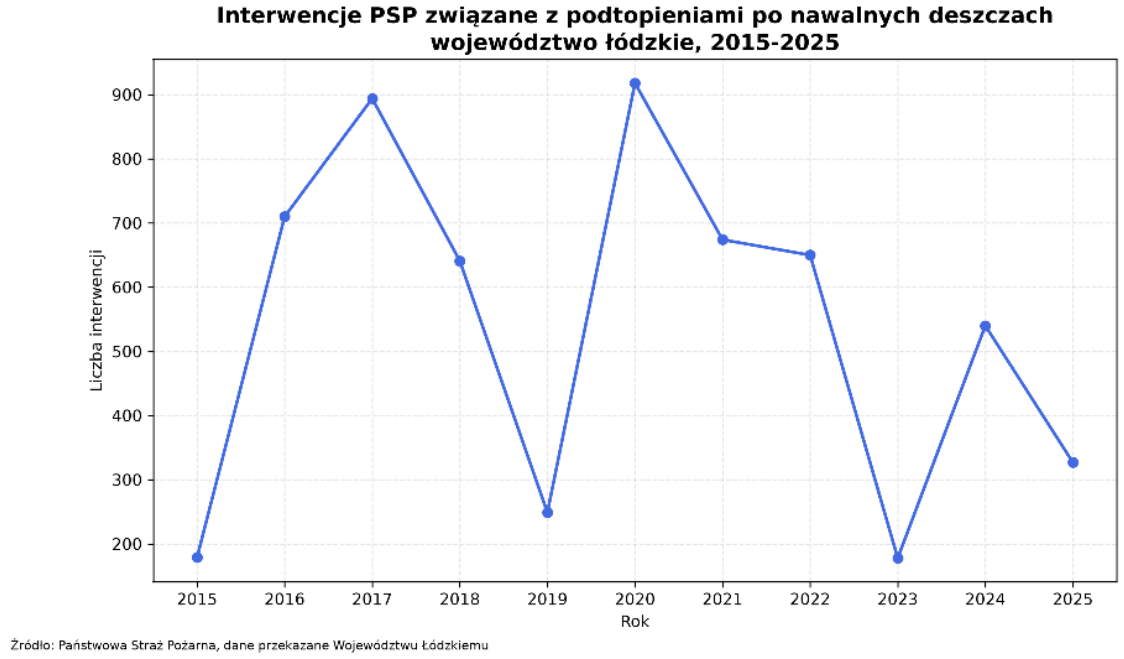
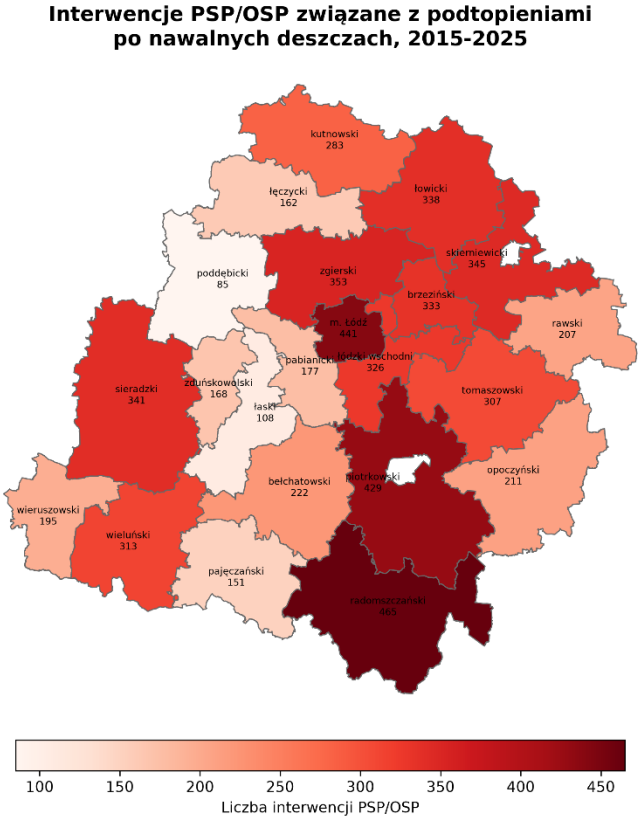


Figure 28 Number of interventions by the PSP/OSP relating to flooding following heavy rainfall in the Lodzkie Region in 2015-2025. Source: PSP/OSP data; own elaboration.

In the period under review, the number of interventions showed significant year-on-year variation. The highest number of incidents was recorded in 2020 - over 900 interventions and in 2017 - approximately 890. The lowest number of incidents was recorded in 2015 and 2023, with approximately 180 incidents in each year. Significant fluctuations have also been observed in recent years - following a rise in the number of interventions to approximately 540 in 2024, a decline to around 330 in 2025 was recorded. No clear upward trend was observed over the entire period analysed, which indicates significant variation in the frequency of the effects of heavy rainfall year-on-year.

The temporal analysis was supplemented with spatial characteristics. The summary map shows the number of incidents relating to flooding following torrential rain in 2015-2025 in the individual counties of the Lodzkie Region. It enables us to identify the areas where the historical consequences of heavy rainfall have occurred most frequently.



Źródło: PSP/OSP, dane przekazane Województwu Łódzkiemu. Agregacja według jednostki prowadzącej interwencję.

Figure 29 Number of interventions by the PSP/OSP relating to flooding following heavy rainfall by counties of the Lodzkie Region in 2015-2025. Source: PSP/OSP data; own elaboration.

These results are also presented in the table below:

Table 9 Ranking of counties by number of interventions

Location	County	Interventions	Share [%]	Towns/villages	Years
1	Radomsko	465	7.8	72	11
2	Łódź	441	7.4	1	11
3	Piotrków	429	7.2	84	11
4	Zgierz	353	5.9	58	11
5	Skierniewice	345	5.8	65	11
6	Sieradz	341	5.7	81	11
7	Łowicz	338	5.7	65	11
8	Brzeziny	333	5.6	43	11
9	Łódź East	326	5.5	43	10
10	Wieluń	313	5.3	45	11

Assignment method: the county was determined on the basis of the PSP/JRG unit conducting the operation. In the case of the towns with county status, Piotrków Trybunalski and Skierniewice, the events are compared together with the relevant rural county.

The highest number of interventions in 2015-2025 was recorded in the Radomsko County, the City of Łódź and the Piotrków County. These results highlight the spatial variation in the occurrence of historical consequences of heavy rainfall and complement the analysis based on climatic data.

In the next stage, the analysis of historical events was compared with the results concerning future exposure to changes in rainfall risk. The tables below supplement the spatial analysis with a ranking of counties, information on the area of vulnerable zones, and changes in the frequency of RP10 extreme rainfall events. The ranking shows the order of the counties according to the score calculated in the relevant analytical module and does not represent a ranking of the actual damage incurred.

Table 10 Five counties with the highest number of buildings situated in areas where the intensity of 24-hour extreme rainfall (RP10) is projected to increase under the RCP4.5 and RCP8.5 scenarios. Source: CLIMAAX Heavy Rainfall / EURO-CORDEX; BDOT10k; own elaboration.

County	Buildings in the growth area	Share [%]	Change in intensity [%]	Future return period [years]
		RCP 4.5		
Sieradz	83,161	99.9	+23.2	5.5
Radomsko	82,589	99.5	+20.9	5.5
Łowicz	61,547	100.0	+26.5	4.7
Wieluń	60,062	100.0	+27.0	5.4
Kutno	46,731	100.0	+18.0	5.9
		RCP 8.5		
City of Łódź	97,518	100.0	+16.7	6.5
Zgierz	94,290	100.0	+30.7	5.2
Piotrków	85,365	100.0	+21.8	5.9
Sieradz	83,040	99.8	+27.3	5.0
Radomsko	83,008	100.0	+45.0	3.8

A significant part of the buildings analysed are located in areas where an increase in the intensity of RP10 extreme rainfall is forecast. The highest number of buildings situated in areas at increased risk was recorded, among others, in the City of Łódź and in the counties of Zgierz, Piotrków, Sieradz and Radomsko, although the ranking of these areas varies depending on the climate scenario considered.

It should be emphasised that these results describe the exposure of facilities to the projected change in rainfall risk. They do not indicate the actual area flooded, the number of buildings that have been flooded, or the projected economic losses. Comparing historical data from the PSP/OSP with scenario-based results, on the other hand, allows for a broader interpretation of the risk by combining information on the consequences of heavy rainfall observed to date with forecast changes in its intensity in the future.

2.3.3.2 Risk assessment

Buildings exposed to changes in 24-hour extreme rainfall according to the RCP scenarios (2041-2070)

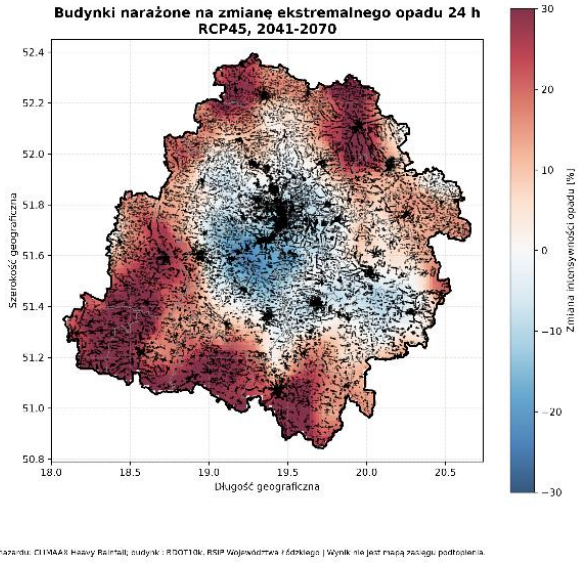


Figure 30 RCP4.5 - buildings against the backdrop of changes in the risk of extreme 24-hour rainfall, RCP4.5, 2041-2070

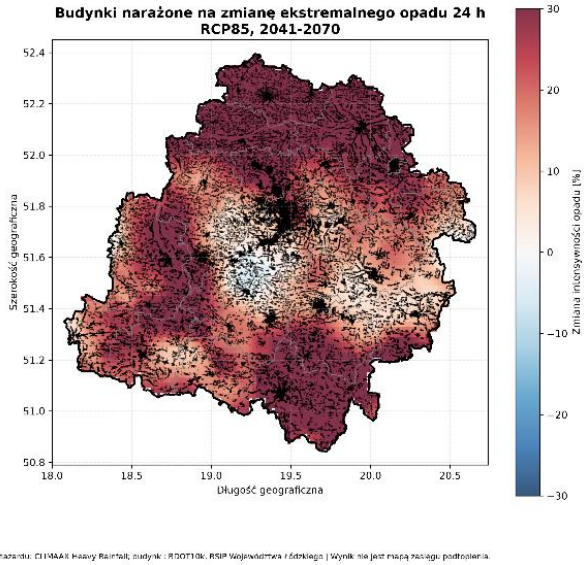


Figure 31 RCP8.5 - buildings against the backdrop of changes in the risk of extreme 24-hour rainfall, RCP8.5, 2041-2070

Table 11 Exposure of BDOT10k buildings to the projected change in the intensity of 24-hour extreme rainfall (RP10) under the RCP4.5 and RCP8.5 scenarios. Source: CLIMAAX Heavy Rainfall / EURO-CORDEX; BDOT10k; own elaboration.

Scenario	Buildings with data	Buildings in the growth area	Share	Average change weighted by buildings	Average future payback period
RCP4.5	1,291,179	802,507	62.2%	+7.7%	approx. 9.1 years
RCP8.5	1,291,179	1,276,340	98.9%	+24.4%	approx. 5.8 years

The increased risk of extreme precipitation may have significant implications for the urban environment of the Lodzkie Region, as shown in Figures 30 and 31; however, the extent of the exposure depends heavily on the climate scenario, as set out in Table 11. Under RCP4.5, approximately 62.2% of buildings for which data is available are located in areas where RP10 precipitation intensity is projected to increase, whilst under RCP8.5 this proportion rises to approximately 98.9%. The average change in intensity, weighted by the location of the buildings, is +7.7% and +24.4%, respectively. At the same time, the average future return period for precipitation corresponding to the historical RP10 is reduced to approximately 9.1 and 5.8 years, respectively. This means that, under the RCP8.5 scenario, almost all urban areas analysed are located in regions where the model predicts an increase in the intensity of extreme rainfall and a higher frequency of events corresponding to the historical RP10. Historical PSP/OSP data confirm that the effects of heavy rainfall have already affected many parts of the region, particularly in the counties of Radomsko, Piotrków and Zgierz, as well as in Łódź. A comparison of the scenario results with historical events thus highlights areas where an increase in future risk may coincide with existing functional vulnerability and previous cases of flooding.

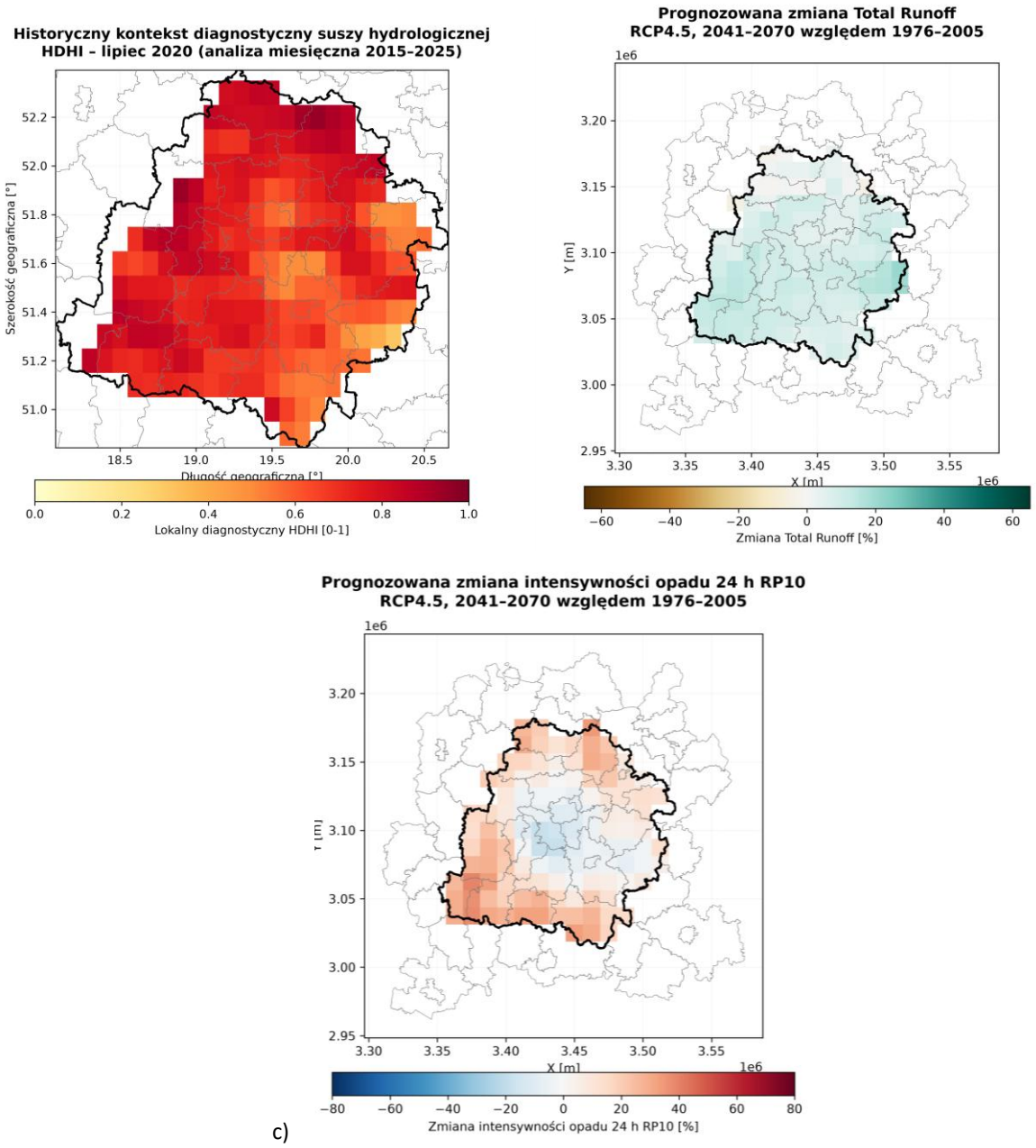
2.3.4 Additional assessments based on local models and data

Additional analysis of the historical context of hydrological drought and of projected changes in hydrological conditions and extreme rainfall.

2.3.4.1 Hazard assessment

As part of an additional risk assessment, the historical context of hydrological drought was compared with projected changes in hydrological conditions and the intensity of extreme rainfall. The historical context was presented using the local diagnostic HDHI for July 2020, while for the period of 2041-2070, the change in average Total Runoff relative to 1976-2005 and the change in 24-hour RP10 precipitation intensity were used. The analysis was carried out separately for the RCP4.5 and RCP8.5 scenarios.

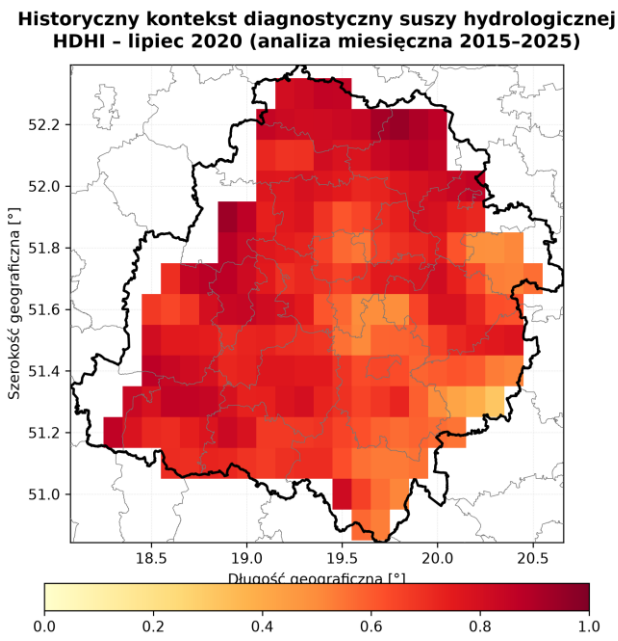
a) b)



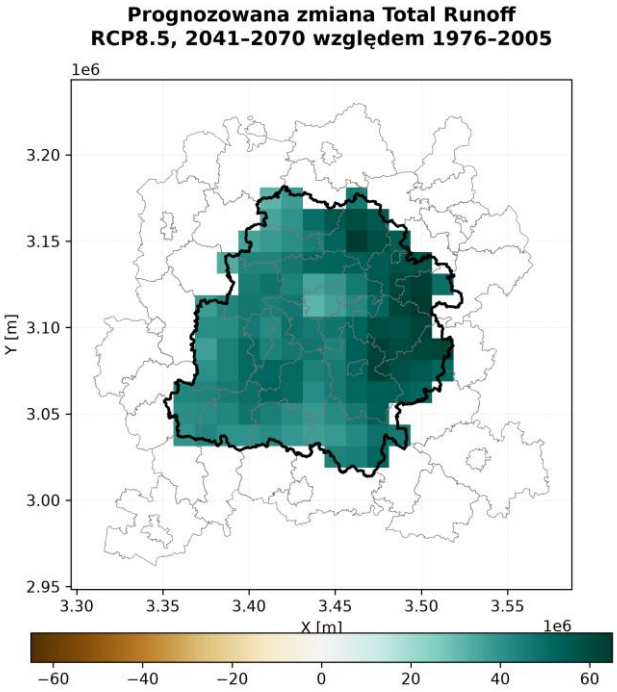
c)

Figure 32 Historical diagnostic context of hydrological drought and projected changes in Total Runoff and 24-hour RP10 rainfall intensity in the Lodzkie Region: (a) the local diagnostic HDHI for July 2020, compared with analyses for 2015-2025, (b) the change in the average Total Runoff for the period of 2041-2070 compared with 1976-2005, and (c) the change in 24-hour RP10 rainfall intensity for the period of 2041-2070 compared with 1976-2005, for the RCP4.5 scenario.

a)



b)



c)

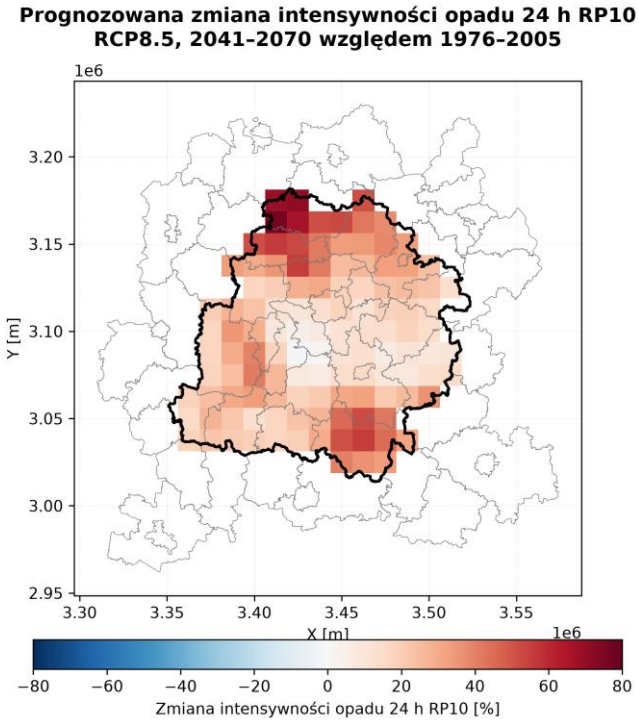


Figure 33 Historical diagnostic context of hydrological drought and projected changes in Total Runoff and 24-hour RP10 rainfall intensity in the Lodzkie Region: (a) the local diagnostic HDHI for July 2020, compared with analyses for 2015-2025, (b) the change in the average Total Runoff for the period of 2041-2070 compared with 1976-2005, and (c) the change in 24-hour RP10 rainfall intensity for the period of 2041-2070 compared with 1976-2005, for the RCP8.5 scenario.

This compilation is of interpretative nature; the layers are drawn from various sources and model chains, do not form a single index, and do not indicate the simultaneous occurrence of hydrological drought and extreme precipitation.

2.3.4.2 Risk assessment

As part of the analysis, a spatial comparison was presented of two projected variables relevant to water management in the Lodzkie Region: changes in the average Total Runoff and changes in the intensity of 24-hour rainfall with a 10-year return period (RP10).

For the hydrological component, the percentage change in the average total runoff for the period of 2041-2070 relative to the 1976-2005 reference period was used. The negative change in Total Runoff was treated as an indication of deterioration in hydrological conditions, rather than as a direct classification of a hydrological drought. A change of ≤ −10% was adopted as the local threshold for classifying a marked decline in the runoff. This threshold is not a formal threshold for defining a hydrological drought.

For the Heavy Rainfall component, the 24-hour RP10 rasters showing the percentage change in rainfall intensity - previously prepared as part of Phase II - were used for the RCP4.5 and RCP8.5 scenarios. A positive change signal was defined as an increase in the RP10 intensity of > 0 %. A limitation of the analysis is the omission of the years 2006-2025 from the model reference period. It results from the structure of the EURO-CORDEX data, in which the historical data ends in 2005, whilst the period from 2006 onwards is represented by RCP scenario projections. The results therefore show the projected change in 24-hour RP10 precipitation intensity for the period of 2041-2070 relative to the model period of 1976-2005, rather than relative to conditions observed over the last two decades. The analysis is not intended to assess the historical trend in the frequency of extreme rainfall in the years 2006-2025.

The analysis was carried out exclusively for the Lodzkie Region, separately for RCP4.5 and RCP8.5. The percentage shares of the area were calculated relative to the area of the region for which valid values for both signals were available after the layers had been projected onto a common grid. The areas of the cells were calculated on the basis of their precise intersection with the region's boundary.

Under the RCP4.5 scenario, the positive trend in 24-hour RP10 precipitation intensity covers approximately 73.1% of the analysed area of the region, while under the RCP8.5 scenario it covers approximately 99.1%. Using the adopted threshold for a significant decrease in Total Runoff (≤ −10%), no areas meeting this criterion were identified in any of the scenarios analysed. Consequently, there were no areas that met both classification criteria at the same time.

The absence of the spatial co-occurrence class should be interpreted in the context of the threshold adopted and the methodology used. The analysis compares the increase in the intensity of short-term extreme rainfall with the change in the long-term average runoff. These are various characteristics of the water cycle, which may respond to climate change in a different way. The fact that the average Total Runoff has not dropped below the −10 % threshold does not mean that there are no periodic water shortages, nor does it rule out the occurrence of hydrological drought conditions. However, an increase in the intensity of RP10 does not automatically imply a sustainable improvement in the availability of water resources.

Furthermore, Total Runoff and Heavy Rainfall are derived from two different model chains. The CNRM-CM5 / CNRM-ALADIN63 chain was used for Total Runoff, while the RP10 - MPI-ESM-LR / RCA4 chain was used for the intensity change. The result should not be interpreted as a single, consistent model simulation, the probability of a complex event, or an assessment of the temporal co-occurrence of drought and extreme rainfall. This is an exploratory analysis of the spatial co-occurrence of predicted signals.

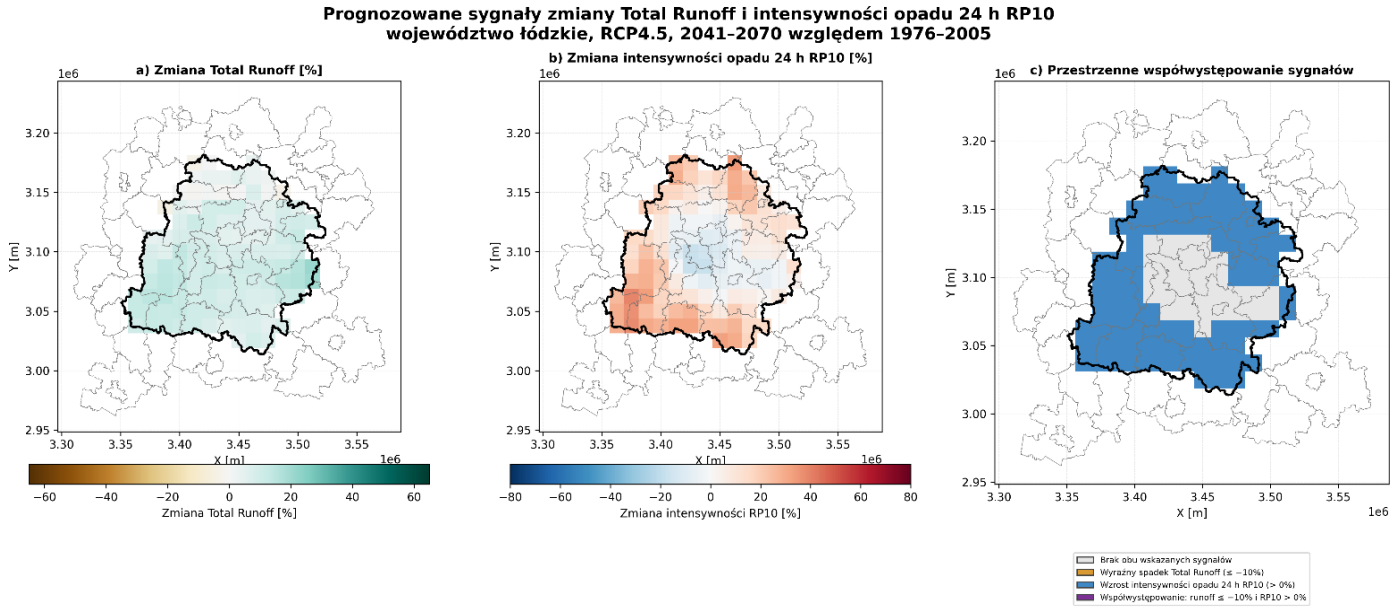


Figure 34 Projected changes in Total Runoff, 24-hour RP10 rainfall intensity and the spatial co-occurrence of both signals in the Lodzkie Region for the RCP4.5 scenario, 2041-2070 compared with 1976-2005

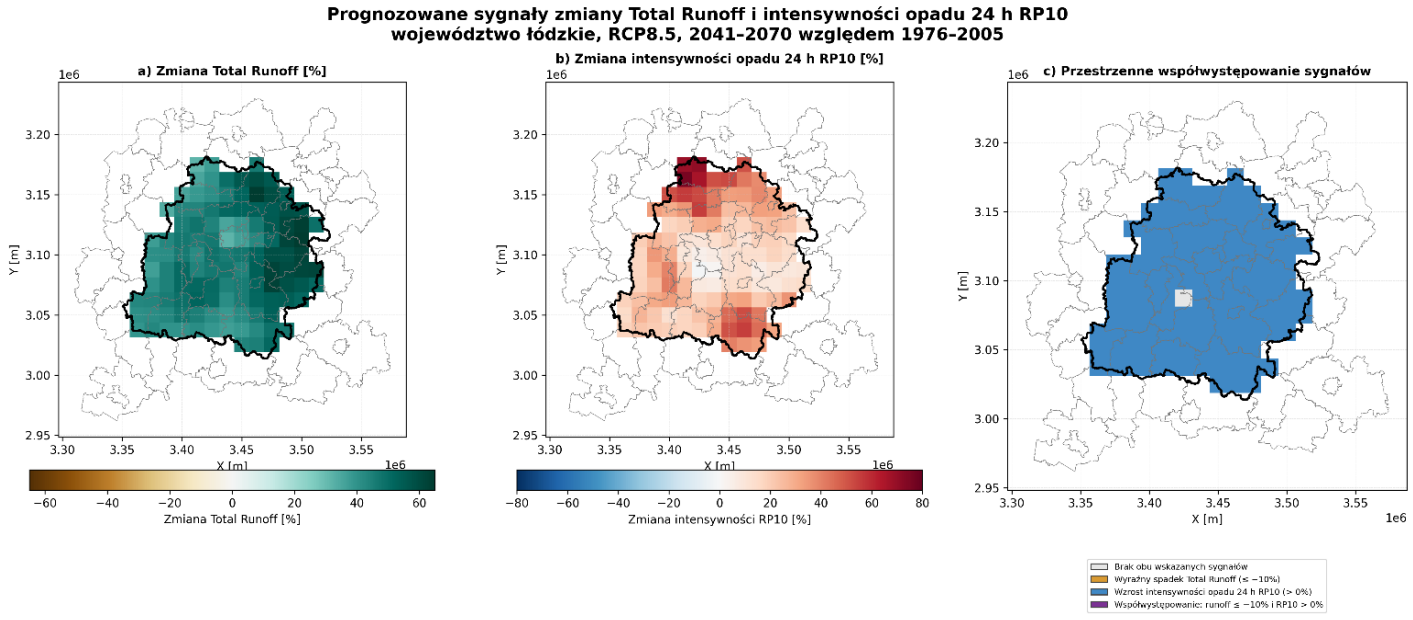


Figure 35 Projected changes in Total Runoff, 24-hour RP10 rainfall intensity and the spatial co-occurrence of both signals in the Lodzkie Region for the RCP8.5 scenario, 2041-2070 compared with 1976-2005

Figure 12 Projected changes in Total Runoff, 24-hour RP10 rainfall intensity and the spatial co-occurrence of both signals in the Lodzkie Region for the RCP4.5 scenario, 2041-2070 compared with 1976-2005, own elaboration.

Scenario	Area with RP10 > 0%	Area with runoff ≤ −10 %	Both criteria
RCP4.5	73.1%	0.0%	0.0%
RCP8.5	99.1%	0.0%	0.0%

Note: the Total Runoff threshold of ≤ −10% is a local classification threshold adopted for the purposes of additional analysis and does not constitute a formal definition of hydrological drought. The percentages refer to the area where both signals have valid values.

From an adaptation perspective, the findings justify taking a two-pronged approach to addressing water shortages and heavy rainfall. The widespread positive signal from the RP10 change indicates a need to increase water retention, reduce rapid surface runoff, and adapt drainage systems and infrastructure to cope with heavier rainfall. At the same time, the absence of areas meeting the Total Runoff threshold of ≤ −10 % does not justify abandoning measures to enhance the region's resilience to periodic water shortages, including the protection of water resources, rational water management and the development of water retention facilities.

The HDHI historical analysis for July 2020, carried out against the backdrop of the 2015-2025 period, indicates spatial variation in hydrological stress conditions in the Lodzkie Region. However, the HDHI provides a historical diagnostic context rather than the projection for the years 2041-2070. The indicator includes components dependent on precipitation and the water balance, but it is not an indicator of extreme precipitation and should not be directly compared with RP10.

The co-occurrence analysis does not comprise the Agricultural Drought results relating to potential reductions in maize and apple yields. It is therefore not possible to determine whether the spatial pattern of agricultural drought overlaps with the increase in RP10 precipitation intensity or not. The results of the Agricultural Drought analysis, the BDOT10k building exposure analysis and the historical PSP/OSP interventions remain separate outputs of the relevant Phase II workflows.

While applying the local threshold of Total Runoff ≤ −10%, no spatial correlation was found between a marked decrease in mean runoff and an increase in the intensity of 24-hour RP10 rainfall. However, this result does not mean that there is no risk of hydrological drought, nor that problems relating to water shortages and heavy rainfall cannot occur in the Lodzkie Region. The analysis does not assess the chronological sequence of these phenomena or the probability of their simultaneous occurrence.

The results obtained indicate, above all, a widespread positive trend in the 24-hour RP10 precipitation intensity, particularly under the RCP8.5 scenario. It justifies an integrated approach to water management, combining the development of water retention, the reduction of rapid runoff, the adaptation of drainage systems, and the protection of water resources during periods of scarcity.

2.4 Key Risk Assessment Findings

2.4.1 Mode of engagement for participation

The stakeholder engagement process in Phase 2 was the key element in refining the Climate Risk Assessment. The collaboration was mainly aimed at acquiring expert knowledge, regional and local data, and information that would enable better reference of the results of the analyses to the actual circumstances of the Lodzkie Region. This engagement took various forms and included both direct working meetings and the collection and consultation of data subsequently used in analyses of hydrological drought, agricultural drought and heavy rainfall.

A particularly extensive partnership has been established with the Polish Space Agency. On 15 July 2026, a special meeting was held between the CliRes-LR Project Implementation Team, the contractor responsible for the in-depth analysis and representatives of POLSA, focusing on the potential use of satellite data in regional analyses. Representatives from POLSA presented the satellite products available via the NSIS portal and OGC web services; subsequently arrangements were made for further cooperation on identifying and making available the data required for the analyses. The contractor was expected to analyse the available resources and identify specific needs, whilst POLSA declared that it would gradually make available data not contained in the Copernicus resources already in use, and provide support regarding the access to NSIS products.

The collaboration with POLSA was primarily aimed at development of the analysis of agricultural drought. The range of the data analysed included, among others, the NDVI, NDRE, EVI, LAI and FAPAR indices, as well as data on evapotranspiration, soil and root-zone moisture, ground surface temperature, the condition of orchards and water balance. In practice, the analysis made use of, among others, NDRE Sentinel-2/POLSA data, which supplemented the model-derived information on the observed condition of the vegetation.

Cooperation with the Agency for the Restructuring and Modernisation of Agriculture was also significant. ARiMR provided data on the distribution of maize crops and apple orchards, which were used to provide a more detailed spatial picture of the agricultural sector's exposure to the effects of drought. Data from the ARiMR for 2021-2025 was used to supplement information on the location of maize crops and apple orchards and to estimate the potential production and economic impacts of agricultural drought.

Data from the Lodzkie Region Landscape Park Group, derived from the survey of fruit orchards, provided further insight. These findings allowed for more specific determining of the location of apple orchards and better correlation of the results of climate analyses with the actual distribution of one of the region's key crop groups.

In the case of heavy rainfall, the key aspect of stakeholder engagement was the collection, via the Łódź Provincial Office, of the data on interventions by the State Fire Service and Volunteer Fire Departments in relation to flooding following heavy rainfall in 2015-2025. This data allowed for comparing the projections of changes in climate-related risks with historically observed effects of events and identification of counties where consequences of intensive rainfall occurred most frequently.

Stakeholder engagement was therefore not limited to consultations of informative nature, but had a direct impact on the scope and level of detail of the analyses performed. The data provided made it possible to characterise exposure more accurately, verify the spatial variation in the effects of the analysed hazards, and supplement the results of climate models with information derived from actual conditions and events observed in the region. The information gathered confirmed the practical significance of hydrological drought, agricultural drought and heavy rainfall, and supported the assessment of their severity, urgency and priority. Stakeholder involvement is expected to play the greatest role in Phase 3 of the project.

2.4.2 Gather output from Risk Analysis step

Table 13 Data used in Phase 2

CLIMAAX/Copernicus standard data	**Role in the assessment**
ERA5-Land, Copernicus Climate Change Service / ECMWF, 2015–2025	*Characteristics of historical meteorological and hydrological conditions: precipitation, temperature, soil moisture, water balance, SPI/SPEI and runoff.*
Bias-corrected EURO-CORDEX / CLIMAAX Heavy Rainfall, 1976-2005 and 2041-2070	*Assessment of changes in 24-hour extreme rainfall, RP10 and the future return period of historical RP10 rainfall*
EURO-CORDEX, 1976-2005 and 2041-2070	*Scenario-based assessment of agricultural drought: ET0, water balance, potential yield reduction.*

AWC, irrigation, mn30_grd - CLIMAAX Agriculture Drought reference package	*Input and supporting data for the vulnerability assessment / ET0 calculations*
CMIP6 Total Runoff, 2015-2025 and 2031-2060	*Scenario-based analysis of changes in total runoff*

Table 14 Data used in Phase 2

Additional data used in Phase 2	Role in the assessment
ARiMR 2021-2025: maize and apple tree declarations	Current crop distribution and reference area of 2015, used to calculate production and potential losses
Geoportal of the Lodzkie Region: locations of orchards 2020-2024	Location of the orchard exposure and analysis of satellite indicators
BDOT10k RSIP of the Lodzkie Region	*Exposure of buildings to changes in extreme rainfall*
PSP 2015–2025	*Context and qualitative validation of the historical consequences of torrential rain*
CLMS Crop Types 2023	*Reference location of maize*
NDVI, LAI i NDRE Sentinel-2/POLSA, 2015-2025	*Diagnosis of vegetation condition and partial historical validation (satellite data)*
GUS/Statistical Office in Łódź, Eurostat, 2023	*Reference yields and prices for estimating production and potential revenue losses*
Boundaries of the region and counties	*Cropping of analyses, and aggregation and presentation of spatial results*

The results of the Climate Risk Assessment form the basis for further evaluation of climate risk within the Lodzkie Region, in particular for identifying areas, sectors and groups that are particularly vulnerable to the effects of climate change, and for setting priorities of adaptation measures. The following results are mainly used:

- the results of risk assessment for hydrological drought, agricultural drought and heavy rainfall, including the spatial variation in risk levels and exposure;
- the results of scenario analyses, indicating potential changes in the intensity and frequency of hazards and their potential consequences for water resources, agriculture and urban areas;
- data on the exposure of infrastructure, urban areas and selected economic sectors, used to identify particularly vulnerable areas;
- estimates of the potential production and economic impacts of agricultural drought, used to assess the significance of the risk to the agricultural sector;
- historical data on the occurrence of hazards and their consequences, including data on interventions by the PSP/OSP, as well as meteorological, hydrological and satellite indicators, used to assess the current risk context and verify its spatial variation.

The results gathered are used collectively to assess the significance of individual risks, identify areas and sectors requiring in-depth analysis, and determine the direction of further adaptation measures.

2.4.3 Assess Severity

The assessment of the level of threat posed by current and future climate risks was carried out using four categories set out in the risk assessment: low, moderate, high and critical. The classification covered both the scale and frequency of the phenomena to date, as well as the anticipated changes in their intensity and

the potential impacts on residents, the environment, infrastructure and key sectors of the region's economy. The assessment also took into account the geographical range of the risk, the likelihood of direct and indirect losses, potential long-term consequences, and the possibility of knock-on effects.

The analysis of historical and current conditions indicates that the risks associated with drought and heavy rainfall belong to the most significant threats facing the Lodzkie Region. Their significance stems not only from the occurrence of extreme events themselves, but also from their impact on functioning of the region. Droughts can lead to the reduction in the availability of water resources, the deterioration in agricultural production conditions and lower crop yields. Heavy rainfall, on the other hand, can result in flooding, overwhelm drainage systems and damage infrastructure within a short space of time.

The level of risk was also assessed in terms of the frequency and extent of the phenomena. Risks associated with drought can affect large areas of the region and have a simultaneous impact on many sectors, in particular agriculture, water management and the environment. Heavy rainfall is often more localised, but its effects can be very sudden and concentrated in urban areas, where a high share of sealed surfaces increases the risk of flooding. In the event of high-intensity incidents, economic losses, disruption to transport and temporary restrictions on the operation of critical infrastructure are also possible.

The assessment also covered a possibility of long-term, irreversible or cascading effects. A long-lasting drought can lead to soil degradation, a deterioration in the condition of ecosystems, a decline in agricultural productivity and reduced water availability for various users. Heavy rainfall, on the other hand, can cause damage to infrastructure, soil erosion and degradation, as well as losses in agricultural production. The effects of individual hazards may also reinforce one another - for example, periods of drought can increase the vulnerability of soils to rapid surface runoff during subsequent heavy rainfall. This means that the assessment of the severity of the risk should not be limited solely to a single event, but should also take into account its potential long-term consequences.

In the case of future risks, the assessment of the level of risk was also based on the results of scenario analyses. Taking future climatic conditions into account allowed for determining whether the current level of risk is likely to persist, increase or change in nature. It is particularly important to identify areas where an increased risk may occur simultaneously to an increase in exposure or vulnerability. Such a combination could lead to the risk level rising from moderate to significant, and in the most vulnerable locations, to critical.

The assessment has been supplemented to include the perspectives of stakeholders, experts and groups particularly vulnerable to the effects of climate change. Their experience enables better assessment of the actual scale of the impacts of these phenomena, including localised flooding, water supply issues, losses in agriculture and disruptions to infrastructure. This information significantly supplements the quantitative analyses and helps to identify impacts that cannot always be fully captured using the available spatial and statistical data. At the same time, consultations with stakeholders may highlight areas where existing adaptation measures are insufficient or need to be strengthened.

Another key element of the assessment is the level of knowledge and preparedness of decision-makers. The analysis performed enhances our understanding of climate risks by presenting them in spatial, quantitative and scenario-based terms. At the same time, further educational and awareness-raising activities are needed to ensure that the results of the analyses are correctly interpreted and utilised in decision-making processes. It is particularly important to develop the ability to interpret climate scenarios, understand the uncertainty in forecasts, and translate information on risks into specific adaptation measures.

2.4.4 Assess Urgency

With regard to the identified types of climate risks, the urgency of the actions was assessed by classifying each risk into one of four categories: "no action required", "monitoring", "further action required" and "requires immediate response". The assessment focused primarily on the severity of the potential consequences of the risk in the present and future periods, as well as the anticipated direction of change in

the risk, the time horizon for the occurrence of significant consequences, and the possibility of mitigating losses by taking adaptive measures at a sufficiently early stage. The analysis also took into account the nature of the threat - whether it was sudden or progressive - as well as information obtained from stakeholders and experts with knowledge of the region's local conditions.

As part of the assessment, the severity of the impacts was classified into four categories: catastrophic, critical, significant and limited (EEA, 2024). The results indicate that hydrological drought, agricultural drought and heavy rainfall pose significant threats to the Lodzkie Region and have been classified as high-priority risks. All three threats were assigned the highest priority category - "requires immediate response". This means that the measures to mitigate risk should be taken now, rather than only when the more severe effects of climate change become apparent.

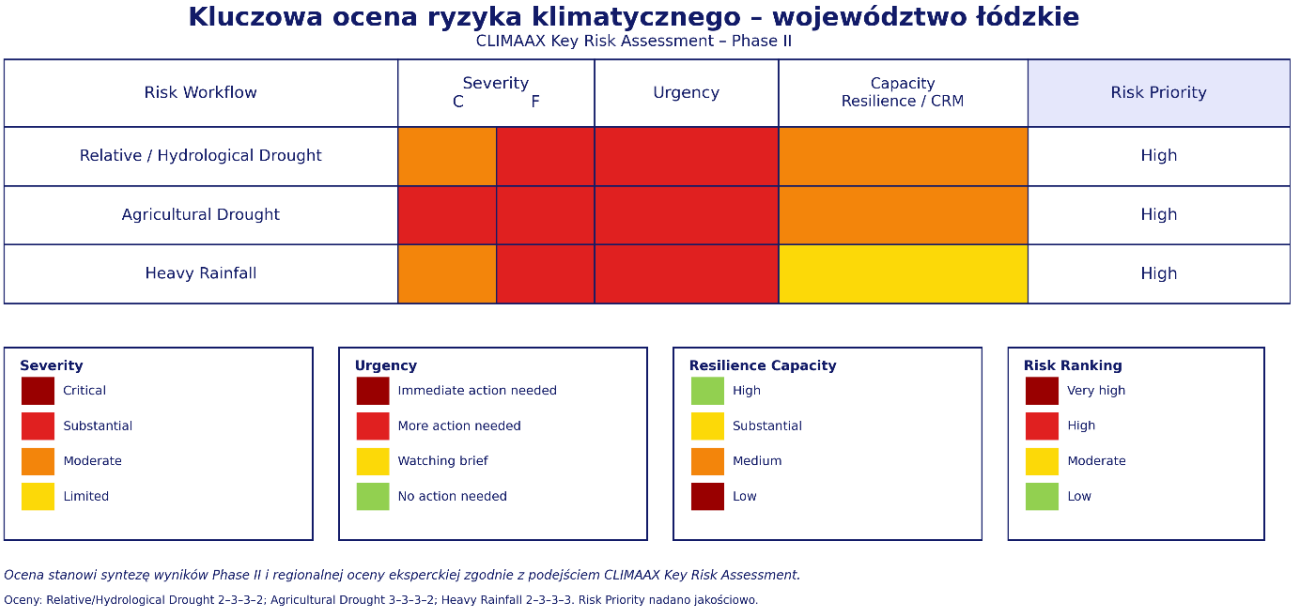


Figure 36 Assessment of key risks by prioritising them, taking into account risk severity (current - C and future - F), urgency and resilience

The analysis indicates that the significance of the risks identified may increase in the future; however, their urgency is not solely due to the forecast deterioration in climatic conditions. It is also important to note that these threats are already present in the region and may have tangible consequences. In the case of hydrological and agricultural drought, the possibility of a persistent water deficit and its consequences for water resources, agricultural production and the functioning of ecosystems is of particular importance. Heavy rainfall, on the other hand, can cause sudden flooding, overload drainage systems and damage infrastructure. Adaptation measures should therefore be taken in advance to limit potential losses and reduce the region's vulnerability to future changes.

The timeframe within which the effects occur is also relevant to the assessment of urgency. In the event of heavy rainfall, the effects may become apparent immediately during or shortly after the event, and the time available to respond is limited. For this reason, it is important to take measures to improve preparedness, including the development of monitoring and early warning systems, ensuring that infrastructure is adequately prepared, and increasing the capacity for rainwater retention and drainage. Droughts, on the other hand, tend to be more progressive in nature. Their effects may build up gradually as the shortfall in rainfall and runoff persists, which provides greater opportunities for early detection of the risk, but at the same time requires long-term measures to reduce vulnerability to water shortages.

In the case of all three threats, it should be assumed that they may persist under future climatic conditions. These are therefore not merely isolated, one-off incidents, but risks that should be taken into account in

the long-term management of the region. At the same time, their actual scale and location may vary depending on future climatic conditions, as well as local exposure and vulnerability. For this reason, the assessment of urgency should be updated periodically as new data and observations become available.

The possibility of limiting future losses through measures taken at a sufficiently early stage is of particular importance for determining the urgency of a matter. In the event of a drought, measures such as increasing water retention, managing water resources sustainably and adapting agricultural production take time to prepare and implement. In the event of heavy rainfall, however, mitigating the effects requires appropriate preparation of infrastructure, drainage systems, stormwater management and emergency response procedures. Delaying action until the effects become more severe may limit the scope for effectively minimising losses.

The urgency assessment was supplemented with information obtained from stakeholders with knowledge of the local conditions in the Lodzkie Region. In Phase 2 of the project, collaboration with stakeholders focused primarily on acquiring data and information enabling a deeper analysis of the work carried out in Phase 1. The information provided allowed for better consideration of local conditions relating to hydrological drought, agricultural drought and heavy rainfall, as well as for the results of the analyses to be linked to the phenomena observed in the region and their potential impacts.

The information and data provided by stakeholders complemented the quantitative analyses and supported the interpretation of the results obtained. At the same time, this collaboration highlighted the importance of further developing knowledge and awareness of climate risks, particularly with regard to their spatial variation, potential consequences and the need to take proactive measures. Local and expert knowledge can also be utilised at subsequent stages of risk management, including the implementation of adaptation measures and the monitoring of changes in risk levels.

Consequently, hydrological drought, agricultural drought and heavy rainfall should be treated as risks requiring an immediate response, in accordance with the findings of the assessment performed. Priority should be given to adaptation measures in the areas of water management, agriculture, spatial planning, infrastructure protection and increasing water retention, supplemented by the development of capacity to monitor and respond to sudden extreme events. At the same time, the ongoing monitoring of climatic conditions, water resources and risk levels should enable the assessment of urgency to be updated periodically and the scope of measures to be adapted to changing conditions.

2.4.5 Understand Resilience Capacity

The resilience of the Lodzkie Region to the climate hazards under analysis was assessed, taking into account existing risk management instruments, institutional and financial capacities, monitoring and early-warning systems, human and social capacity, and the environment's natural ability to mitigate the effects of these hazards.

Mechanisms are already in place in the region to mitigate the effects of hydrological drought, agricultural drought and heavy rainfall. These include, amongst other things, meteorological and hydrological monitoring, early warning systems, the activities of emergency services, projects relating to water retention and management, and adaptation measures set out in various strategic documents and Local Adaptation Plans (which have already been drawn up for, amongst others, Łódź, Tomaszów Mazowiecki and Łask, whilst other towns in the region are currently in the process of preparing such documents). Another key element of resilience is the ability to raise national and European funding for the implementation of adaptation measures.

The region has the institutional, human and technical resources to monitor risks and respond to their consequences. At the same time, the results of the analyses performed indicate the occurrence of vulnerabilities. In the case of drought, these relate primarily to the limited availability of water resources and the vulnerability of agriculture and ecosystems to water scarcity. In the event of heavy rainfall, however, key factors include the vulnerability of buildings and infrastructure, the capacity of drainage systems, and the potential for local flooding. Knowledge and skills relating to the interpretation of climate

information and its use in planning adaptation measures also need to be further strengthened. The results of Phase 2 indicate the need to continue and build on the interventions already undertaken. With regard to the hydrological and agricultural drought, increasing water retention, protecting water resources and improving the resilience of agriculture to water shortages are of particular importance. In the event of heavy rainfall, it is important to increase the capacity for rainwater retention and management, to reduce rapid surface runoff, and to adapt drainage systems and infrastructure to the increasing load.
Based on the analysis performed, the overall resilience potential of the Lodzkie Region can be described as **moderate**. The existing monitoring and response systems, institutional capacity and the availability of financial instruments provide the basis for implementing adaptation measures; however, projected changes in risks and the identified vulnerabilities indicate the need for further strengthening of the region's resilience.
At the same time, measures relating to climate change adaptation are currently scattered across various strategic and sectoral documents, programmes, plans and actions carried out by individual institutions and local government units. There is a lack of a single document at a regional level that would bring together the available information on climate risks, set out common priorities and coordinate adaptation measures across the entire region. Drawing up a regional climate change adaptation plan would make it possible to organise and link existing measures, identify areas requiring further action, and establish a coherent framework for planning, funding and monitoring adaptation. The results of the climate risk assessment performed as part of the CLIMAAX project could provide an important analytical basis for the preparation of such a document.

2.4.6 Decide on Risk Priority

The priority of climate risks was determined on the basis of the results of a risk assessment, taking into account the level of hazard, exposure and the vulnerability of the area or sector to its effects.

In the first instance, the level of risk associated with individual climate hazards was determined; the results were then compared with their potential impacts on the region's residents, infrastructure, environment and key economic sectors.

To determine the priorities, the risk assessment panel was used, illustrating the relationship between the likelihood of hazard occurrence and the scale of its potential consequences. The positioning of a given risk within the panel allows for its assigning to the adequate priority level and indicating whether it primarily requires monitoring, further adaptive measures or urgent action. Risks demonstrating both a high probability of occurrence and significant consequences were identified as priorities, whereas it was recognised that risks with a lower likelihood and limited consequences require, above all, monitoring.

The risk assessment panel is therefore a tool that supports the prioritisation of identified risks and helps to identify those for which adaptation measures should be treated as a priority. The time horizon was also taken into account when setting priorities - risks whose significance may increase in the future were assessed not only in terms of their current level of threat, but also in terms of the anticipated change in their extent. This allows for identification of risks that require proactive measures to be taken before their effects reach a level that would cause significant losses.

The results of the prioritisation assessment should be used to target adaptation measures in the areas and sectors most vulnerable to the effects of climate change. In the case of the Lodzkie Region, the risks associated with drought and heavy rainfall and their consequences are of particular significance, given their potential impact on water management, agriculture, infrastructure and the socio-economic functioning of the region.

2.5 Monitoring and Evaluation

Phase 2 of the project enabled a deeper understanding of the spatial variation in risks, exposure and vulnerability within the Lodzkie Region, and allowed for establishing a better link between the results of climate analyses and the potential impacts on individual sectors. The use of more detailed regional and local data, scenario analyses and additional exposure layers has enabled a more precise identification of the areas where the risk may be most significant. The availability, completeness and comparability of data remained the greatest challenge, including the integration of datasets with varied spatial and temporal resolution and the translation of climate indicators into actual socio-economic impacts.

Stakeholders play the key role in monitoring and assessing risk, in particular local authorities, emergency response services, infrastructure managers and representatives of sectors vulnerable to climate change. Their local knowledge enables them to verify the results of analyses and supplement information that is not fully apparent in spatial or statistical data. Consultations also enable to assess whether the results are consistent with the region's experience to date and the measures taken. The results of Phase 2 were well received and were recognised as useful for planning adaptation measures.

The monitoring and evaluation process should be a continuous learning process. The results should be updated as new climate data, information on the impacts of extreme events, and changes in exposure and vulnerability become available. It will be particularly important in future to compare forecast changes with observed conditions and to use lessons learnt from actual events to improve risk assessment.

In the subsequent stages, up-to-date data on extreme rainfall, drought, river flows and the availability of water resources, as well as the exposure and vulnerability of individual sectors, will be particularly important. It is important to improve the resolution and frequency of data updates and to develop expertise in climate modelling, spatial analysis and the interpretation of projections. It is also worth developing local systems for gathering information on the impacts of extreme events.

The final results of the risk assessment should be presented in the form of a report, maps and visual materials, as well as a presentation for stakeholders and decision-makers. The results should be used not only to provide information on the level of risk, but also to prioritise adaptation measures and to support further strategic and spatial planning.

At present, the monitoring of the risks under analysis is based on available meteorological, hydrological, environmental and spatial data, as well as information on extreme events. Phase 2 provides the basis for further development of the monitoring system, which should enable regular data updates, tracking of changes in risks and the actual impacts of events, and assessment of the effectiveness of adaptation measures.

The integration of climate and spatial data, the use of scenario analysis and the application of GIS tools proved effective, enabling the detailed identification of areas and sectors vulnerable to the effects of climate change. The difficulties were mainly related to the availability and quality of the data, as well as the need to process and harmonise it. A significant part of the resources was allocated to the preparation and verification of data, which highlights the need for such data to be standardised in advance in future assessments.

The efficiency of the process was enhanced by the integration of existing data and tools, the automation of certain analyses, and the use of GIS. This made allowed for expansion of the scope of the analysis within the constraints of the available time and resources. At the same time, the restrictions on the data increased the workload involved in preparing and verifying it. The experience of Phase 2 therefore indicates the need for further automation and streamlining of the data update process.

The analysis performed has contributed to better understanding of climate-related risks in the region, identifying areas that are particularly vulnerable and potential changes in the level of risk in the future. The findings may help to raise climate awareness and strengthen institutional capacity, as well as to channel

funding and investment towards measures that enhance the region's resilience, particularly in the areas of water management, agriculture, infrastructure and spatial planning.

2.6 Work plan Phase 3

Phase 3 of the project will focus on the transition from Climate Risk Assessment to climate risk management. The starting point will be based on the results of Phase 2 concerning hydrological drought, agricultural drought and heavy rainfall, including the determined risk priorities, the identified areas and sectors that are particularly vulnerable, and the assessment of the region's resilience potential.

As part of Phase 3, climate risk management objectives will be defined and potential measures will be identified to mitigate the impacts of the analysed risks and strengthen the region's resilience. The measures to be taken will include, among others, infrastructure and technical, environmental, organisational, planning and social measures. The measures will be assessed in terms of their effectiveness, feasibility, timeframe for implementation, potential additional benefits, responsibilities of the relevant bodies, as well as organisational and financial considerations.

Meetings with a group of stakeholders will be the key part of the work. These will be used to discuss the results of Phase 2, assess their significance in a regional context, identify possible adaptation measures and prioritise them. Consideration will also be given to the options for financing and implementing the measures, as well as their links to existing strategic, planning and investment documents.

The monitoring will involve both continued tracking of changes in risk levels and the assessment of the progress and effectiveness of adaptation measures. To this end, available climate, hydrological, environmental and spatial data, information on the impacts of actual events, and the expertise of stakeholders will be utilised. Potential indicators will also be identified to monitor the achievement of risk management objectives and changes in the region's adaptive capacity.

Phase 3 will not involve repeating the full Climate Risk Assessment or the modelling analyses carried out in Phase 2. The work will focus on using the findings to select, assess and prioritise potential adaptation measures, and to define the conditions for their implementation and monitoring.

3 Conclusions Phase 2- Climate risk assessment

The results indicate marked spatial variation in the relative risk of hydrological drought in the Lodzkie Region. The highest values are reported in the City of Łódź and the Skierniewice and Sieradz subregions under the SSP3-7.0 scenario, whilst under the SSP5-8.5 scenario they are found primarily in the City of Łódź and the Skierniewice subregion. Compared with SSP3-7.0, SSP5-8.5 shows an increase in relative risk, particularly in the City of Łódź and the Skierniewice subregion. This indicates the need to take into account the risk of water shortages and its potential increase in water management planning and regional development.

The assessment of hydrological drought was supplemented by regional diagnostic analyses of hydrological conditions and the analysis of scenario-based changes in total runoff. For the SSP3-7.0 scenario, the average change in total runoff for the Lodzkie Region was approximately -14.6%, which indicates a potential deterioration in the availability of surface and groundwater over the projection period analysed. This finding confirms the potential of deterioration in water conditions in the future and highlights the importance of considering changes in water resources in long-term regional development planning.

Agricultural drought

The results indicate an increase in the potential reduction in maize and apple yields in the future climatic conditions. The major change relates to maize, for which the yield reduction rises from 4.83% in the historical period to 13.75% in RCP4.5 and 11.89% in RCP8.5. In the case of apple trees, the increase is smaller - 4.54% and 4.11%, respectively. Maize is therefore subject to a greater potential reduction of yield, and the associated potential consequences for production and the economy are significantly greater than

in the case of apple trees. In the adaptation measures, the maize production sector requires special attention.

The results obtained also indicate the need to increase the resilience of agricultural production to periodic water shortages, in particular by improving the management of water resources, increasing water retention and implementing measures to reduce water losses in crops. At the same time, the scenario results should be regarded as an indication of the potential scale of change, rather than a forecast of actual yield losses, as production levels are also affected by factors other than directly related to climatic conditions, including farming practices, the choice of varieties and the adaptation measures implemented.

Heavy rainfall

The results indicate an increase in intensity and frequency of extreme rainfall in the future climatic conditions. Under RCP4.5, approximately 62.2% of the buildings analysed are located in areas where RP10 precipitation intensity is projected to increase, whilst under RCP8.5 this share rises to approximately 98.9%. At the same time, the average rainfall intensity, weighted by building location, increases by 7.7% and 24.4%, respectively, whereas the return period for rainfall corresponding to the historical RP10 is reduced to approximately 9.1 and 5.8 years. In particular, under the RCP8.5 scenario, almost all urban areas analysed are located in regions where extreme rainfall intensity is forecast to increase, which highlights the need to strengthen the resilience of the infrastructure and the drainage systems. At the same time, past interventions by the PSP/OSP confirm that the effects of heavy rainfall already affect many parts of the region.

The findings also highlight the need to take account of the increasing burden on drainage systems when planning and modernising infrastructure, and to increase the capacity for rainwater retention and management. Measures to reduce rapid surface runoff may be of particular importance, especially in heavily urbanised and sealed areas.

General conclusion

The results of Phase 2 indicate that the Lodzkie Region must be prepared for both water shortages and surpluses. On the one hand, the findings regarding hydrological and agricultural drought indicate a possibility of increased water stress, reduced runoff and a deterioration in agricultural production conditions. On the other hand, the analysis of heavy rainfall indicates an increase in the intensity and frequency of extreme events, as well as significant exposure of urban areas and parts of the fruit-growing sector. This means that there is a need to combine adaptation measures aimed at increasing water retention, improving the resilience of agriculture to water scarcity, developing local drainage systems and mitigating the effects of flooding in urban areas.

Outstanding limitations and challenges

The analyses performed are primarily regional and serve as a screening tool. In the case of Heavy Rainfall, no hydrodynamic modelling of the extent and depth of flooding was carried out; consequently, the results do not allow for determining of the number of buildings actually flooded or the extent of the economic losses. The PSP/OSP data provide information on past incidents, rather than a complete record of damages. In the Agriculture Drought analysis, a single EURO-CORDEX model run was used; therefore, the differences between RCP4.5 and RCP8.5 should not be interpreted as a probabilistic hierarchy of scenarios. Regional diagnostic indicators used in the analysis of hydrological drought, as well as historical satellite and meteorological data, fulfil a supporting role and do not replace the official CLIMAAX risk components.

The findings of Phase 2 provide the basis for the next stage of the project, in particular for identifying priority areas and sectors for adaptation measures, and linking the results of the Climate Risk Assessment to the analysis of the adaptive capacity and planning of measures in subsequent phases of the project.

4 Progress evaluation

Table 4-1 Summary of Key Performance Indicators

Key performance indicators	*Progress*
1 website with information on project implementation and results	*completed*
2 risk assessment made using the Handbook	*completed*

Table 4-2 Summary of milestones

Milestones	*Progress*
Refinement of the multi-risk assessment carried out in Phase 2	*completed*
Presenting information about the project at a public event in the region	*completed*

5 Supporting documentation

Data and results developed as part of Phase II of the project have been organised and published in the GeoNode service within the regional group **„lodzkie”**. Within this group, the data have been assigned to the following workflow subgroups:

- droughts
- agri_droughts
- heavy_rain
- multiple

Within the individual workflow layers, the data are organised according to the CRA categories:

- hazard
- exposure
- vulnerability
- risk

The final spatial layers used in the Phase II analyses have been published in GeoNode as separate datasets, including in GeoTIFF, GeoPackage and GeoJSON formats, together with metadata and SLD styles, where unique reproduction of the symbology applied in the analyses and reports was possible.

Additional materials, such as figure series, tables, supplementary documents and scripts, are treated as supporting materials and do not alter the basic structure of the workflow groups in GeoNode. **A total of 41 main spatial datasets** have been published in GeoNode, organised according to the workflows and CRA categories. Their list is presented below:

I DATASETS

1. lodzkie_droughts_hazard_trun_chg_ssp370_2031_2060_raster
2. lodzkie_droughts_hazard_trun_chg_ssp585_2031_2060_raster
3. lodzkie_heavy_rain_hazard_rp10_intchg_rcp45_2041_2070_raster
4. lodzkie_heavy_rain_hazard_rp10_intchg_rcp85_2041_2070_raster
5. lodzkie_heavy_rain_hazard_rp10_futrp_rcp45_2041_2070_raster
6. lodzkie_heavy_rain_hazard_rp10_futrp_rcp85_2041_2070_raster
7. lodzkie_multiple_hazard_trun_chg_rcp45_2041_2070_raster
8. lodzkie_multiple_hazard_trun_chg_rcp85_2041_2070_raster
9. lodzkie_multiple_risk_runoff_rp10_rcp45_2041_2070_raster
10. lodzkie_multiple_risk_runoff_rp10_rcp85_2041_2070_raster
11. lodzkie_agri_droughts_risk_apple_run_ssp370_2031_2060_raster
12. lodzkie_agri_droughts_risk_maize_run_ssp370_2031_2060_raster
13. lodzkie_agri_droughts_risk_apple_yloss_rcp45_2041_2070_mpi_rca4_raster
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17. lodzkie_agri_droughts_hazard_maize_ndvi_anom_hist_2019_raster
18. lodzkie_agri_droughts_hazard_maize_lai_anom_hist_2019_raster
19. lodzkie_agri_droughts_hazard_ndvi_reg_hist_2019_raster

20. lodzkie_agri_droughts_hazard_lai_hist_2019_raster
21. lodzkie_droughts_hazard_reldrt_hist_1981_2015_vector
22. lodzkie_droughts_hazard_reldrt_ssp370_2031_2060_vector
23. lodzkie_droughts_hazard_reldrt_ssp585_2031_2060_vector
24. lodzkie_agri_droughts_exposure_maize_hist_2023_vector
25. lodzkie_agri_droughts_exposure_orchards_hist_2020_2024_vector
26. lodzkie_agri_droughts_risk_apple_run_ssp585_2031_2060_raster
27. lodzkie_agri_droughts_risk_maize_run_ssp585_2031_2060_raster
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31. lodzkie_agri_droughts_risk_maize_rcp85_2041_2070_mpi_rca4_raster
32. lodzkie_droughts_hazard_total_runoff_historical_2015_2025_raster
33. lodzkie_droughts_hazard_total_runoff_ssp370_2031_2060_raster
34. lodzkie_droughts_hazard_total_runoff_ssp585_2031_2060_raster
35. lodzkie_heavy_rain_hazard_idf_24h_rp10_historical_1976_2005_raster
36. lodzkie_heavy_rain_hazard_idf_24h_rp10_rcp45_2041_2070_raster
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39. lodzkie_multiple_hazard_total_runoff_rcp45_2041_2070_epsg4326
40. lodzkie_multiple_hazard_total_runoff_rcp85_2041_2070_epsg4326
41. lodzkie_agri_droughts_hazard_maize_historical_2015_2025_raster

II. DOCUMENTS

DOCUMENTS

1. lodzkie_heavy_rain_hazard_psp_osp_interventions_by_powiat_historical_2015_2025_table
2. lodzkie_heavy_rain_exposure_buildings_statistics_rcp45_rcp85_2041_2070_table
3. lodzkie_heavy_rain_exposure_buildings_validation_rcp45_rcp85_2041_2070_table
4. lodzkie_heavy_rain_hazard_psp_osp_interventions_annual_historical_2015_2025_table
5. lodzkie_agri_droughts_risk_economic_results_rcp45_rcp85_2041_2070_table
6. lodzkie_heavy_rain_exposure_buildings_by_powiat_rcp45_rcp85_2041_2070_table
7. lodzkie_agri_droughts_hazard_ndre_drought_ranking_historical_2015_2025_table
8. lodzkie_agri_droughts_hazard_ndre_statistics_historical_2015_2025_table
9. lodzkie_agri_droughts_exposure_apple_ndre_locations_historical_2015_2025_table
10. lodzkie_agri_droughts_lai_full_series_figures.zip
11. lodzkie_agri_droughts_ndre_full_series_figures.zip
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13. lodzkie_droughts_cdd_full_series_figures.zip
14. lodzkie_droughts_precipitation_full_series_figures.zip

15. lodzkie_droughts_relative_drought_full_series_figures.zip
16. lodzkie_droughts_soil_moisture_full_series_figures.zip
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21. lodzkie_droughts_water_balance_full_series_figures.zip
22. lodzkie_heavy_rain_psp_osp_full_series_figures
23. lodzkie_heavy_rain_rx1day_full_series_figures
24. lodzkie_heavy_rain_rx5day_full_series_figures
25. lodzkie_agri_droughts_exposure_core_figures
26. lodzkie_agri_droughts_hazard_core_figures
27. lodzkie_agri_droughts_risk_core_figures
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33. lodzkie_heavy_rain_supporting_core_materials
34. lodzkie_multiple_hazard_core_figures
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36. lodzkie_multiple_supporting_core_materials
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38. lodzkie_agri_droughts_hazard_ndre_july_median_historical_2016_raster.tif
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41. lodzkie_agri_droughts_hazard_ndre_july_median_historical_2019_raster.tif
42. lodzkie_agri_droughts_hazard_ndre_july_median_historical_2020_raster.tif
43. lodzkie_agri_droughts_hazard_ndre_july_median_historical_2021_raster.tif
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55. lodzkie_droughts_relative_drought_full_figure_series.zip
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58. lodzkie_droughts_spi_full_figure_series.zip
59. lodzkie_droughts_subsurface_runoff_full_figure_series.zip
60. lodzkie_droughts_surface_runoff_full_figure_series.zip
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