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Report on the local scenarios

Vransko lake catchment pilot site

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Index

Abstract

This report analyses the exposure and vulnerability of the Vransko lake catchment pilot site to climate change across four key sectors: biodiversity, tourism, agriculture, and fisheries/aquaculture. For each sector, adaptation strategies and their feasibility and applicability within the environmental, socio-economic, and governance context are discussed. The assessment considers two IPCC scenarios, SSP2-4.5 and SSP5-8.5. Results reveal that biodiversity, tourism, agriculture and fisheries are critically exposed to hydraulic/hydrogeological and thermal risks while under the two IPCC scenarios, SSP2-4.5 and SSP5-8.5 also wind and weather storm risks become very relevant. Under SSP5-8.5, adaptation capacity is ineffective, and all sectors shift to high vulnerability values. Overall, the pilot site emerges as a climate hotspot with high exposure, which suggest need of critical intervention, where urgent, cross-sectoral adaptation measures are required to protect ecosystems, infrastructure, and livelihoods.

1. Introduction

This report presents a structured methodology for assessing climate vulnerability and resilience in the Vransko lake catchment pilot site, within the framework of the ACTION – Increasing coastal ecosystem resilience to climate change project.

The area of Lake Vrana and its catchment, due to the mosaic of wetland and agricultural habitats and the species associated with them, particularly the avifauna, is part of the ecological network, while the narrower lake area is designated as a Nature Park and is listed under the Ramsar Convention as a wetland of international importance. The area's exceptional biodiversity has already been partly degraded due to the combination of natural vulnerability, increasing anthropogenic pressures, and climate change, and is under further long-term threat. As in other parts of the Mediterranean, climate change is expected to amplify existing natural and anthropogenic pressures. Ravni Kotari belong to the most fertile region of northern Dalmatia, so it is not surprising that agriculture is the main activity of this region. The exceptional richness of the agrobiodiversity of Ravni Kotari is part of the historical tradition and cultural heritage, but also the most important tool for preserving existing landscapes, habitats and associated biodiversity. The whole area is located in the coastal zone, well-known tourist destination, with extreme seasonal activity. Even if only recreational fishing is allowed in the lake, it is considered very relevant for specific groups of tourists. The region is highly vulnerable to climate change, facing increasing hazards and threats such as increased temperatures and heatwaves, prolonged dry periods and saltwater intrusion, as detailed described in the project deliverables D.1.2.1. and D.1.3.1.

The study adopts a common assessment matrix, agreed upon by project partners, which combines sensitivity, exposure, and adaptive capacity across relevant sectors - biodiversity, tourism, agriculture, fisheries and aquaculture. Two climate scenarios are considered: SSP2-4.5, which represents a moderate mitigation pathway, and SSP5-8.5, describing a high-emission trajectory where adaptation capacity becomes ineffective.

This integrated approach allows identifying the most critical risks for each sector, thus providing evidence for prioritizing adaptation strategies at the local scale.

2. Methodology

The methodology adopted in this study is based on a framework provided by the European Commission's *Technical Guidance on Sustainability Verification for the InvestEU Fund* (EU, 2021) and it is adapted to a local scale by integrating ecological, socio-economic, and governance dimensions.
The assessment combines:

- **Qualitative Sensitivity analysis** (Sheet 1 of attached file): evaluating how system components respond to climate threats.
- **Exposure analysis** (Sheet 2 of attached file): assessing expected impacts under climate projections.
- **Adaptation analysis** (Sheet 3 of attached file): identifying the capacity to mitigate risks through available measures.
- **Residual vulnerability assessment** (Sheet 4 of attached file): integrating the above to provide risk-based prioritization.

This multi-layered approach ensures a structured and transparent methodology for identifying climate-related risks and adaptation needs. Hazards and threats are identified based on the probability of occurrence (low, medium, high); expected severity of impact on ecological and socio-economic systems, and relevance at seasonal and long-term scales.

To ensure a more robust and representative assessment of the levels of environmental sensitivity/criticality, it was foreseen that for each pilot area the matrix would be compiled in at least three separate versions, each by a subject with a complementary perspective:

- A research organization, to ensure a scientific and technical analysis.
- A local government/public administration to integrate aspects of planning, governance and political feasibility.
- A representative from a protected area or environmental management body, to bring the operational and territorial point of view, rooted in concrete knowledge of the natural context.

A final matrix will be put together merging the three different contributions. This triangulation of inputs mitigated bias, enabled cross-sectoral comparisons, and ensured legitimacy of the results.
For the analysis of hazards and threats and local scenarios of the Po Delta and Lamone River pilot site the following stakeholders were involved: i) PP3 UNIBO, as research organization; ii) the LM Ravenna Municipality, as local public administration; and iii) the PP2 PDP, as environmental management body.

2.1. Sheet 1 – Qualitative Sensitivity analysis

The goal of this evaluation is to identify how climate threats affect the components of each thematic area based on their inherent characteristics and role in the socio-ecological system.

The assessment is applied to four selected sectors that characterize the context of the pilot areas, each broken down into three key components (Fig. 1):

1. **Biodiversity** (protected habitats, species richness, ecosystem services).
2. **Tourism** (infrastructure and services, economic development and employment, cultural/natural attractions).
3. **Agriculture** (land use and landscape, agricultural income and employment; agricultural biodiversity).
4. **Fishing & Aquaculture** (resource use, income and employment, multifunctionality).

These four selected sectors represent both ecological and socio-economic pillars of coastal systems. They were selected for their high exposure to climate threats and their relevance for local communities.

Each component is assessed against four climate factors:

- **Temperature** (increase, heat/cold waves, wildfires),
- **Wind** (changes in the wind regime, storms; whirlwinds),
- **Water** (change in the hydrological regime and type of precipitation; sea acidification; saltwater intrusion; sea level rise; flooding.),
- **Solid Mass** (coastal erosion; soil degradation/erosion; landslide; subsidence.

These four climate factors allow for a comprehensive capture of different stressors. These categories encompass both gradual processes (e.g., sea level rise, acidification) and extreme events (e.g., storms, heat waves, floods).

Each key component is assigned a sensitivity level for each threat, ranging from 'low sensitivity' (score 1) to 'high sensitivity' (score 3).

EVALUATION OF SENSITIVITY

OUTPUT: inviduating the sensitivity of the components of each area to climatic factors

This analysis aims to:
* Analyse how climate factors translate into climate threats and hazards.
* Identify the impacts of these threats for the area of reference.

Guide for compilation:
* Do not add rows, insert the info in the rows provided
* Select the level of sensitivity from the drop-down menu in the respective cell

AREA: BIODIVERSITY			Area of protected habitats	Species richness	Ecosystem services
CLIMATE FACTORS	*THREATS*	*IMPACTS*	*SENSITIVITY*	*SENSITIVITY*	*SENSITIVITY*
TEMPERATURE	Temperature increase, heat waves				
	Cold waves, frost				
	Wildfires				
WIND	Changes in the wind regime, storms (rain-snow and wind)				
	Whirlwinds				
WATER	Change in the hydrological regime (water stress, drougth) and type of precipitation				
	Sea acidification				
	Saltwater intrusion				
	Sea level rise				
	Flooding (coastal, fluvial, pluvial, groundwater)				
SOLID MASS	Coastal erosion				
	Soil degradation/erosion				
	Landslide				
	Subsidence				

AREA: TOURISM			Tourism infrastructure and services	Economic development and employmen	Preservation of tourist attractions
CLIMATE FACTORS	*THREATS*	*IMPACTS*	*SENSITIVITY*	*SENSITIVITY*	*SENSITIVITY*
TEMPERATURE	Temperature increase, heat waves				
	Cold waves, frost				
	Wildfires				
WIND	Changes in the wind regime, storms (rain-snow and wind)				
	Whirlwinds				
WATER	Change in the hydrological regime (water stress, drougth) and type of precipitation				
	Sea acidification				
	Saltwater intrusion				
	Sea level rise				
	Flooding (coastal, fluvial, pluvial, groundwater)				
SOLID MASS	Coastal erosion				
	Soil degradation/erosion				
	Landslide				
	Subsidence				

AREA: AGRICULTURE			Land use and landscape	Agricultural income and employment	Agricultural biodiversity
CLIMATE FACTORS	*THREATS*	*IMPACTS*	*SENSITIVITY*	*SENSITIVITY*	*SENSITIVITY*
TEMPERATURE	Temperature increase, heat waves				
	Cold waves, frost				
	Wildfires				
WIND	Changes in the wind regime, storms (rain-snow and wind)				
	Whirlwinds				
WATER	Change in the hydrological regime (water stress, drougth) and type of precipitation				
	Sea acidification				
	Saltwater intrusion				
	Sea level rise				
	Flooding (coastal, fluvial, pluvial, groundwater)				
SOLID MASS	Coastal erosion				
	Soil degradation/erosion				
	Landslide				
	Subsidence				

AREA: FISHING AND AQUACULTURE			Use of resources	Income and employment	Multifunctionality
CLIMATE FACTORS	*THREATS*	*IMPACTS*	*SENSITIVITY*	*SENSITIVITY*	*SENSITIVITY*
TEMPERATURE	Temperature increase, heat waves				
	Cold waves, frost				
	Wildfires				
WIND	Changes in the wind regime, storms (rain-snow and wind)				
	Whirlwinds				
WATER	Change in the hydrological regime (water stress, drougth) and type of precipitation				
	Sea acidification				
	Saltwater intrusion				
	Sea level rise				
	Flooding (coastal, fluvial, pluvial, groundwater)				
SOLID MASS	Coastal erosion				
	Soil degradation/erosion				
	Landslide				
	Subsidence				

Fig. 1 – Structure and input fields for the qualitative sensitivity analysis.

2.1. Sheet 2 – Exposure analysis

The goal is to assess how climate risks are expected to affect the pilot site over time, based on global scenarios, local projections and seasonal variability.

Two IPCC Shared Socio-economic development Pathways (SSPs) were selected (Calvin et al., 2023):

- SSP2-4.5 ("Middle of the Road"): an intermediate scenario where socio-economic and technological trends follow historical trajectories, without major shifts in development, leading to medium-level warming. CO_2 emissions remain roughly stable until mid-century before declining, but they do not reach net zero by 2100. This pathway results in a projected global warming of about 2.7 °C by 2100 (relative to 1850–1900), with a likely exceedance of 1.5 °C between 2021 and 2040.
- SSP5-8.5 ("Fossil-Fueled Development"): a high-emission pathway characterized by energy-intensive growth driven by intensive fossil fuel use and reliance on technological progress, resulting in severe warming and associated impacts. Under this pathway, CO_2 emissions roughly triple by 2075, leading to a projected global warming of about 4.4 °C by 2100 (range 3.3–5.7 °C). In this scenario, exceeding 1.5 °C of warming in 2021–2040 is very likely, with severe consequences for ecosystems, societies, and economies.

These scenarios enable comparison of vulnerabilities under both realistic and extreme climate futures, highlighting the range of possible risks and adaptation needs.

The four climate factors from sheet 1 are converted into risk factors (Fig. 2):

- **Thermal risk and climate extremes** ← Temperature
- **Hydraulic and hydrogeological risk** ← Water
- **Wind and weather storm risk** ← Wind
- **Geological and land degradation risk** ← Solid Mass

For each season (spring, summer, autumn, winter) and for each risk factor, an exposure level is assigned, ranging from 'low exposure' (score 1) to 'high exposure' (score 3).

Each risk is assessed for its probability and expected impact, establishing a baseline (current state) and projected future conditions under 2 selected IPCC climate (SSP2-4.5 and SSP5-8.5).

EVALUATION OF EXPOSURE

OUTPUT: Identification of the climate risk factors of the location/area under consideration at present and in the two scenarios

This analysis assesses future exposure to climate risks with reference to the location of the pilot action (macro-climatic area), using the climate projections available according to the latest IPCC Report, choosing scenarios SSP2-4.5 and SSP5-8.5.
The expected seasonal climate variations and the resulting impacts in terms of risks for the pilot area are qualitatively assessed.

Current climate exposure				
Season	*Thermal risk and climate extremes*	*Hydraulic and hydrogeological risk*	*Wind and weather storm risk*	*Geological and land degradation risk*
Spring				
Summer				
Autumn				
Winter				

Future climate exposure: SSP2-4.5 scenario - "Middle of the Road" world where trends largely follow their historical patterns				
Season	*Thermal risk and climate extremes*	*Hydraulic and hydrogeological risk*	*Wind and weather storm risk*	*Geological and land degradation risk*
Spring				
Summer				
Autumn				
Winter				

Future Climate Exposure: Scenario SSP5-8.5 - Fossil-fueled Development "Taking the Highway", a world characterised by rapid and unlimited growth in economic production and energy use				
Season	*Thermal risk and climate extremes*	*Hydraulic and hydrogeological risk*	*Wind and weather storm risk*	*Geological and land degradation risk*
Spring				
Summer				
Autumn				
Winter				

LEGEND
HIGH: High probability of occurrence with potential significant impacts
MODERATE-HIGH
MODERATE: Medium probability of occurrence with manageable impac
MODERATE-LOW
LOW: Limited probability and low impacts

Fig. 2 – Structure and input fields for the exposure analysis.

2.2. Sheet 3 – Adaptation analysis

This sheet evaluates the adaptive capacity of each area, focusing on strategies to mitigate or buffer impacts from the exposure risks (Fig. 3), such as:

- **Infrastructural** (e.g., barriers, drainage),
- **Managerial** (e.g., land use planning, irrigation solutions),
- **Formative** (e.g., awareness and training campaigns),
- **Ecosystemic** (e.g., wetland restoration, green infrastructure).

Capacity is scored qualitatively as High (robust systems in place, good governance, financial/technical resources - score 3), Medium (partial coverage, possibility for improvement - score 2), or Low (limited or no capacity, lack of awareness/tools/resources - score 1), reflecting governance, resources, and technical feasibility.

Adaptation analysis
OUTPUT: Adaptation strategies of the components examined for each area in relation to climate risks

Overall objective: Compile a vulnerability assessment for the future for each thematic area, identifying:
1. The adaptation measures needed for each component of the scope.
2. The level of adaptive capacity (High, Medium, Low) with respect to different types of climate risks.

For each component and type of risk, identify specific and concrete mitigation/prevention actions, e.g.:
* Infrastructural (e.g. barriers, shelters, drainage)
* Managerial (e.g. planning, monitoring, soil/water management)
* Formative (e.g. capacity building, vocational training)
* Ecosystemic (e.g. nature-based solutions)

Assign a level of adaptive capacity for each combination.
LEGEND:
* High: if effective measures already exist or the context is favourable (resources, governance, awareness).
* Medium: if supportive actions are needed but there is some operational scope.
* Low: if tools, resources, knowledge or political will are lacking.

AREA: BIODIVERSITY					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Area of protected habitats	**Measures**	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*
	Adaptive Capacity				
Species richness	**Measures**	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*
	Adaptive Capacity				
Ecosystem services	**Measures**	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*	*List potential adaptation/prevention measures and their level*
	Adaptive Capacity				

AREA: TOURISM					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Tourism infrastructure and services	**Measures**				
	Adaptive Capacity				
Economic development and employment	**Measures**				
	Adaptive Capacity				
Preservation of tourist attractions	**Measures**				
	Adaptive Capacity				

AREA: AGRICULTURE					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Land use and landscape	**Measures**				
	Adaptive Capacity				
Agricultural income and employment	**Measures**				
	Adaptive Capacity				
Agricultural biodiversity	**Measures**				
	Adaptive Capacity				

AREA: FISHING AND AQUACULTURE					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Use of resources	**Measures**				
	Adaptive Capacity				
Income and employment	**Measures**				
	Adaptive Capacity				
Multifunctionality	**Measures**				
	Adaptive Capacity				

Fig. 3 - Structure and input fields for the adaptation analysis.

2.3. Sheet 4 – Residual vulnerability assessment

The goal is to quantify residual vulnerability after adaptation is considered, allowing for risk-based planning. Residual vulnerability provides a prioritization tool for identifying critical areas requiring urgent adaptation measures.
Residual vulnerability is automatically calculated using the formula:

*Residual Vulnerability = Sensitivity * Exposure / Adaptation Capacity*

Under SSP2-4.5, adaptation capacity is considered active, while under SSP5-8.5 it is fixed at 1, reflecting the nullification of adaptation in extreme scenarios. Final residual vulnerability (Fig. 4) is scaled from 1 to 9, where higher values indicate greater climate risk, based on the following categories:

- 1–2: Low residual vulnerability
- 3–5: Moderate vulnerability
- 6–9: High residual vulnerability which suggest need od critical intervention.

Residual vulnerability analysis

OUTPUT: weighted assessment of sensitivity and exposure and how adaptation measures can reduce the impacts of risks

On the basis of the matrices in the previous sheets, a summary is made to allow verification of the impact of the different types of risks for each area. If every part is compiled correctly, the table below will automatically upload and it will not be necessary to insert any input

AREA: BIODIVERSITY	Scenario	Sensitivity	Exposure	Adaptation	Residual vulnerability
Thermal risk and climate extremes	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Hydraulic and hydrogeological risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Wind and weather storm risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Geological and land degradation risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**

AREA: AGRICULTURE	Scenario	Sensitivity	Exposure	Adaptation	Residual vulnerability
Thermal risk and climate extremes	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Hydraulic and hydrogeological risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Wind and weather storm risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Geological and land degradation risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**

AREA: TOURISM	Scenario	Sensitivity	Exposure	Adaptation	Residual vulnerability
Thermal risk and climate extremes	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Hydraulic and hydrogeological risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Wind and weather storm risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Geological and land degradation risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**

AREA: FISHING AND AQUACULTURE	Scenario	Sensitivity	Exposure	Adaptation	Residual vulnerability
Thermal risk and climate extremes	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Hydraulic and hydrogeological risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Wind and weather storm risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**
Geological and land degradation risk	SSP2-4.5	#N/D	#N/D	#N/D	**#N/D**
	SSP5-8.5	#N/D	#N/D	1.00	**#N/D**

Sensitivity: the sensitivity to climate factors is averaged for each area, evaluated as a number from 1 (low sensitivity) to 3 (high sensitivity)
Exposure: the exposure to the individual risks in the case of SSP2-4.5 and SSP5-8 is evaluated as a number from 1 (low exposure) to 3 (high exposure)
Adaptation: averaged over the effectiveness of the adaptive capacity of the measures that can be implemented in the SSP2-4.5 scenario (=1, i.e. null, in case of SSP5-8.5), evaluated as a number from 1 (low mitigation/adaptation capacity) to 3 (high capacity)
Residual vulnerability: calculated as the product of sensitivity and exposure, divided by the effectiveness of adaptation

Fig. 4 - Structure and input fields for residual vulnerability assessment.

3. Results and discussion

3.1. Exposure

As described in the deliverable D.1.3.1, the Vransko lake catchment pilot site is a fragile area where the main challenges in preserving the natural values of the area partly arise from its natural characteristics and partly from anthropogenic pressures in the region, while climate change intensifies risks associated with both factors. Due to its shallowness (with depths ranging from 0.5-1 m in the northwest part to 4-6 m in the southeast part), and the fact that the lake is a cryptodepression (with the lakebed at -3.47 m above sea level), separated from the sea by a narrow permeable karst barrier through which — depending on the lake's water level — fresh water flows into the sea or seawater penetrates the lake, Vransko Lake is a very sensitive coastal freshwater ecosystem. Even without additional anthropogenic influences, it is susceptible to salinity changes, which can have catastrophic consequences for its living organisms. Anthropogenic impacts have made it even more vulnerable. The most significant was the excavation of the Prosika canal as a direct outlet for high lake waters into the sea, along with the associated hydromelioration of the formerly vast swamp area in what is today the Vransko polje (Vrana field). This has resulted in a multiple reduction of the floodplain wetland habitat area and the loss of the wetland's function as a natural buffer against extreme water level fluctuations and habitat conditions in the lake. This land-use change has also caused the current most significant anthropogenic pressure on the lake: agricultural activities in the catchment area, which are mostly conventional and dependent on the input of chemicals (fertilizers and pesticides), which, through erosion and leaching, end up in the lake causing its eutrophication and pollution. An additional challenge is the use of water from the catchment for irrigating arable land, which reduces the inflow of fresh water and increases the risk of salinization, especially during the summer months when tributaries and the lake's water level are at their lowest, and irrigation demands are highest. Climate change — primarily hotter and drier summers with increased evaporation, reduced precipitation, and decreased water inflow from the catchment to the lake, combined with increased irrigation demands and rising sea level — increases the risk of episodes with extreme salinity rises and catastrophic consequences for the lake's freshwater ecosystem. Another significant negative impact on the lake's ecosystem comes from the ichthyofauna dominated by allochthonous (non-native) species, which, by feeding, disturb the sediment and thus add to the eutrophication pressure. These combined pressures cumulatively cause the currently unsatisfactory conservation status of the lake ecosystem and many target habitat types associated with it.

Changes in the hydrological regime including prolonged droughts (especially relevant when there is the occurrence of two consecutive dry years as in 2008/2009, 2011/2012) and altered precipitation patterns and seasonal cycles affect habitat suitability, alter aquatic ecosystems and cause water salinisation. Being a very shallow lake, lower availability of freshwater and lower stream discharge cause higher water temperatures and higher evapotranspiration which again influences salt water intrusions and salt accumulation. Habitats, species richness and ecosystem services exhibit high sensitivity due to reduced water availability, and decreased buffering against salinization.

Over time, these combined pressures can intensify water and soil salinization, compromise groundwater quality, and undermine the sustainability of local water management systems.

The analysis of the climate characteristics of the study area is based on the processing of long-term meteorological data collected at the Biograd na Moru meteorological station (data from the Croatian Meteorological and Hydrological Service, DHMZ). The dataset includes 34 years (1990–2023) of average monthly and annual values for air temperature (°C), precipitation (mm), and climate extreme indicators. The normality of data distribution was tested using the Jarque-Bera test for all variables. Linear regression was used to assess long-term trends, with results expressed as annual changes in values.
Analysis of the average monthly air temperature and precipitation for the period 1990–2023 confirms distinct Mediterranean climate features for Vransko lake catchment (Figure 5), while linear trends in annual values show a rise in temperature (Figure 6). The winter months (January, February) are characterized by the lowest air temperatures, averaging around 7–9 °C, with temperatures gradually rising from the onset of spring. The highest values are recorded in July and August, when the average temperature reaches 25–27 °C. This is followed by a decrease in autumn and winter, with values around 8 °C in December. Such a seasonal temperature regime indicates typical Mediterranean climate patterns, with warm, dry summers and mild winters.

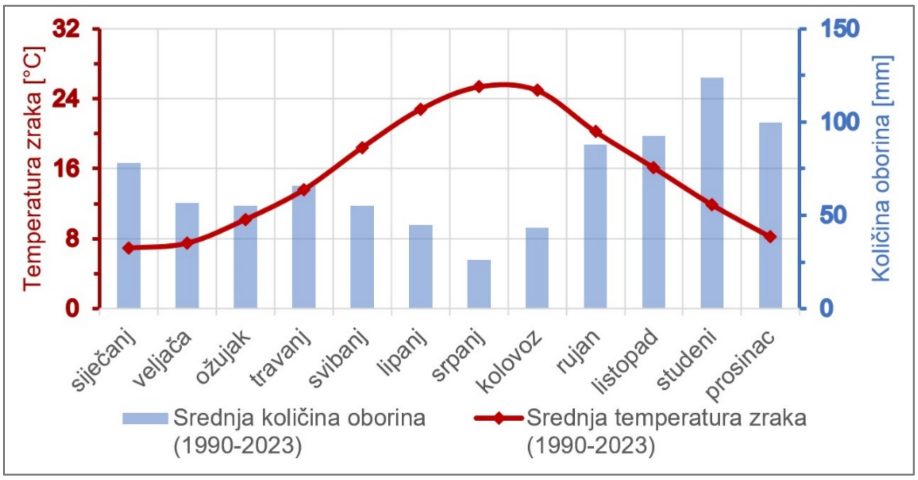

Figure 5. Monthly progression of average air temperature and precipitation (1990–2023) for Biograd na Moru station (source: DHMZ)

Precipitation patterns show the opposite trend to temperature. Most precipitation occurs in the autumn-winter period, especially in November and December, when monthly values reach 100–120 mm. The summer months, particularly July and August, are the driest part of the year, averaging just 20–40 mm of precipitation. Spring and early autumn record intermediate values (60–90 mm), further confirming the seasonal unevenness in rainfall distribution.

The combination of high summer temperatures and low precipitation creates pronounced drought conditions and significantly increases fire risk. On the other hand, periods of intense rainfall in autumn and winter, when temperatures are still relatively high, boost vegetation productivity but also raise the risk of flash floods and soil erosion. These climate patterns have direct impacts on agriculture, water resource management, and the conservation of natural habitats in Vransko lake catchment, making the seasonal climate dynamics a key factor for planning and implementing nature protection measures.

Average annual air temperatures have shown an upward trend over the past several decades, consistent with global and regional climate patterns. From 1990 to 2023, the average air temperature increased by about 1.5–2 °C, corresponding to an average annual rise of 0.05 °C (Figure 6). Of particular note is the increase in average summer temperatures, reflected in more frequent heatwaves and prolonged drought periods.

The total annual precipitation displays significant variability. Although the long-term average does not show a substantial decrease, there has been a redistribution of rainfall: most of the annual total is concentrated in a few intense episodes, while summers have become increasingly dry. Examples of extremely dry years (e.g., 2007, 2011) are clearly evident, as are years with heavy rainfall that have caused local flooding (Figure 6). Such patterns increase the risk of soil erosion and flood events in the lowland parts of Ravni Kotari, while also reducing water availability during the growing season. Trend analysis also shows that increased precipitation amounts and their seasonality impact the area’s hydrological characteristics, including water regimes of Lake Vrana and lowland areas of Ravni Kotari.

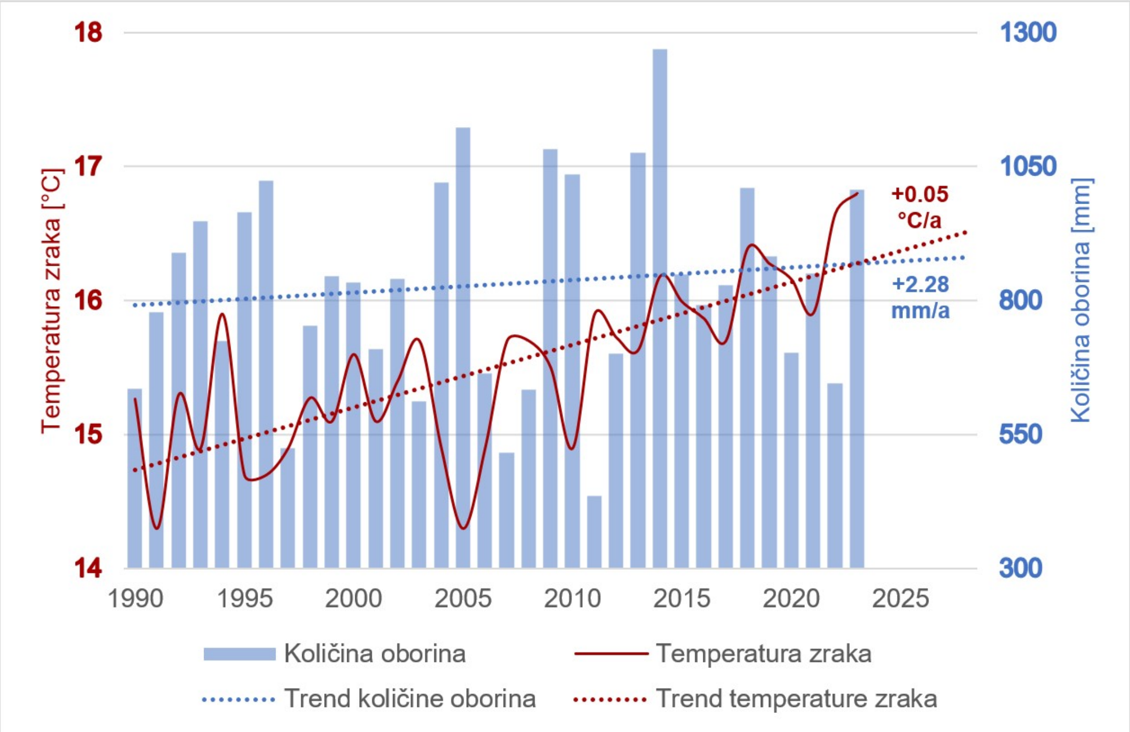

Figure 6. Annual average values of air temperature and total precipitation and related trends (1990–2023) for Biograd na Moru station (source: DHMZ)

The obtained results confirm the globally observed patterns of climate change—increasing average temperatures and the growing frequency of extreme climate events (IPCC, 2023). In Vransko lake catchment, this has multiple consequences:

- Natural habitats—greater susceptibility to forest and shrubland fires, and accelerated overgrowth of grasslands due to changed moisture and heat conditions.
- Agriculture—greater exposure to drought during the growing season and increased need for irrigation, alongside the risk of flood damage after heavy precipitation.
- Water resources—changes in groundwater and surface water levels linked to the redistribution of precipitation and increased evapotranspiration.

These results emphasize the importance of systematic meteorological monitoring and integration of such data into land use monitoring protocols, ensuring timely assessment of climate change impacts and the adoption of adaptation measures. Climate trends in Vransko lake catchment therefore require adaptive management measures focused on agriculture, habitat conservation, water management, and the incorporation of meteorological parameters into planning (Batina, 2025.).

The SSP2-4.5 -the "middle-of-the-road" scenario - assumes the continuation of current policies, without substantial intensification of mitigation or a dramatic increase in emissions :

- CO_2 emissions stabilize around current levels and begin to decline by mid-century, but do not reach net zero by 2100,
- projected global warming reaches about 2.7°C by 2100 compared to pre-industrial levels (uncertainty range: 2.1–3.5°C),
- this pathway involves “moderate” challenges for mitigation and adaptation, with steady but limited technological and demographic changes (https://www.sustain.life/blog/ipcc-warming-scenarios) .

Projected impacts under SSP2-4.5 include more frequent heatwaves, changing rainfall patterns, sea level rise (about 30–65 cm by 2100), as well as increasing health, agricultural, biodiversity, and infrastructure risks worldwide. SSP2-4.5 ("middle of the road" scenario) predicts moderate warming due to stabilization of emissions by mid-century. (https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-du-climat/en/4-climate-scenarios-and-projections)
For the Croatian Adriatic, this means a projected temperature increase of 2–3°C by 2100, more frequent and severe heatwaves, longer dry periods, and a steadily rising Adriatic sea level (by 30–65 cm). Seasonal precipitation changes are likely, with drier summers and wetter autumns and winters. These trends risk increased drought stress, reduced river flows, greater need for irrigation, coastal flooding, and saltwater intrusion affecting agriculture, tourism, human health, and infrastructure. Although adaptation challenges are significant, they are less severe than those of high-emission scenarios (MINGOR, 2020).

The SSP5-8.5 - the "high emissions" scenario - represents continued, rapid economic growth dominated by fossil fuels, with steadily rising emissions:

- CO_2 emissions double by mid-century and triple by 2100 compared to present-day levels,
- projected global warming under SSP5-8.5 reaches about 4.4°C by 2100 (uncertainty range: 3.3–5.7°C),
- this pathway brings the greatest risks: extremely high temperature increases, rapid sea level rise (63 to >80 cm by 2100), more frequent and intense extreme weather events (droughts, floods), and substantial ecosystem disruptions (https://www.sustain.life/blog/ipcc-warming-scenarios).

SSP5-8.5 ("fossil-fueled development" scenario) envisions much greater warming (over 4°C), far more frequent and intense extreme events (heatwaves, floods, wildfires), and a more dramatic rise in sea level (up to 83 cm). (https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-du-climat/en/4-climate-scenarios-and-projections) For the Croatian coast, this scenario brings coastal erosion, frequent flooding of low-lying areas, losses in agricultural productivity, near-certain damage to vital infrastructure, and impacts on biodiversity, fisheries, and tourism. Some impacts—like saltwater intrusion, water supply vulnerability, and ecosystem change—would be severe and possibly irreversible without strong adaptation (MINGOR, 2020).

According to IPCC AR6 (2023) policy recommendations SSP2-4.5 is considered broadly plausible under current policies, whereas SSP5-8.5 is unlikely given global mitigation efforts, but it cannot be ruled out if current trends reverse. Both scenarios indicate the 1.5°C threshold could be reached by the mid-2030s. SSP2-4.5 leads to significant risks at around 2°C, while SSP5-8.5 results in far more severe impacts. Rapid, systemic transformations are essential across all scenarios to mitigate and adapt to the risks of climate change. SSP2-4.5 remains the commonly used “central” scenario for local and national climate policy planning.

Expected climate risk impacts on the Vransko lake catchment pilot site considering both SSP2-4.5 and SSP5-8.5 scenarios are derived from IPCC projections and local seasonal variability and include thermal risk and climate extremes (related to temperature increases and heat waves), hydraulic and hydrogeological risk (water stress, drought, precipitation changes, saltwater intrusion), wind and weather storm risk (storms, wind regime changes, whirlwinds) and geological and land degradation risk (soil erosion, sediment deposition). Their exposure levels vary seasonally in a way that summer shows the highest exposure to thermal, hydraulic, and some geological risks, reflecting peak heat, drought, and water stress conditions typical of the Mediterranean climate. Winter and spring have moderate to high exposure to hydraulic and storm risks due to increased precipitation and storm activity. Autumn exhibits moderate exposure levels across most risks, often associated with transitional climate conditions.
In the SSP2-4.5 ("Middle of the Road") Scenario projections are that the climate risks intensify moderately over time, with thermal risks remaining high in summer and also notable in spring and

autumn. Hydraulic risks increase, especially in summer and winter, highlighting challenges linked to droughts and altered precipitation patterns. Wind and storm risks show moderate to high exposure particularly in spring, summer, and autumn. Geological and land degradation risks maintain moderate levels throughout the year, increasing slightly in summer and autumn. This scenario reflects gradual warming and water cycle changes linked to moderate emissions stabilization, resulting in manageable but significant challenges requiring adaptive management.

In the SSP5-8.5 ("Fossil-Fueled Development") scenario projections all risk factors show pronounced increases in exposure across all seasons. Thermal risk is significantly higher, with more frequent and intense heat waves, driving elevated physiological stress on ecosystems and human activities. Hydraulic and hydrogeological risk sharply intensify, further stressing water availability and quality. Wind and storm risks escalate, leading to more severe and frequent extreme weather events. Geological and land degradation risks peak, exacerbating soil erosion and habitat loss. This high-emission pathway presents severe systemic vulnerabilities, demanding urgent comprehensive adaptation and mitigation measures.

The analysis highlights the growing exposure of the Vransko lake catchment to multiple climate risks under both scenarios, with seasonal variability influencing the timing and intensity of these risks. The SSP2-4.5 scenario foresees notable but comparatively moderate increases in these exposures, offering a potential window for enhanced adaptive management. Conversely, the SSP5-8.5 pathway signals severe amplification of risks, underlying an urgent need for intensified mitigation to prevent catastrophic impacts. Effective adaptation strategies must therefore prioritize addressing high thermal and water stress risks in summer, pivotal for biodiversity, agriculture, and water resource sectors, enhancing resilience to hydraulic variability and storm events during wetter seasons and implementing soil conservation and ecological restoration to mitigate geological and land degradation risks across all seasons.

3.2. Adaptation strategies and adaptive capacity

The analysis of adaptation strategies for the Vransko lake catchment pilot site reflects both the ecological fragility of the area and the heterogeneous level of preparedness to face climate risks. Across all thematic areas, adaptive capacity under the SSP2-4.5 scenario is uneven: measures exist and in some cases are already implemented, but gaps remain in financial resources, institutional coordination, and public awareness.

3.2.1. Biodiversity

The adaptation strategies for biodiversity in the Vransko lake catchment emphasize multifunctional approaches that integrate ecosystem restoration with climate risk management. Key multifunctional strategies include:

- Planting trees along watercourses, which serves multiple purposes such as providing shade to reduce water temperature, creating windbreaks, purifying water through buffer zones, offering habitats for diverse species, and reducing erosion. This intervention supports thermal regulation, storm protection, water quality, and land stability simultaneously.
- Restoration of riparian zones and degraded wetland habitats strengthens ecosystem resilience by improving species habitats, supporting water purification, regulating water levels, and stabilizing soils. It also mitigates hydrological and geological risks while enhancing biodiversity richness and ecosystem services.
- Regulating water levels using movable dams and creating retention zones upstream are hydrological management measures that balance flood control, water availability, and habitat maintenance, thereby supporting multiple climate risk adaptations.
- Monitoring climatic parameters and species stress responses supports adaptive management across several risk categories by providing data to guide restoration, invasive species control, and ecosystem health.
- Integrated sediment trapping and erosion control measures protect land and water quality, contributing to both geological risk mitigation and ecosystem function.

Adaptive capacity varies between components and risk types, with the highest capacity observed in adaptation to hydraulic and hydrogeological risk hydrological and wind and weather storm risk for protected habitats, and high capacity for adaptation to thermal risk and climate extremes in ecosystem services. Species richness adaptation capacity is generally medium, indicating a need for ongoing support.
These multifunctional strategies demonstrate an ecosystem-based approach that enhances biodiversity protection, water resource management, and climate resilience in the Vransko catchment area, making them central to effective, integrated adaptation planning.
Adaptive capacity under SSP2-4.5 in this domain is generally assessed as medium, reflecting the availability of technical know-how and management instruments, but also the dependence on financial and institutional resources for effective implementation.

3.2.2. Tourism

The adaptation strategies for tourism in the Vransko lake catchment under the SSP2-4.5 scenario focus on enhancing resilience to multiple climatic risks while supporting sustainable development. Key multifunctional strategies include:

- Planting trees along watercourses and nature trails to provide shading, create habitat, and serve as windbreaks. This measure reduces thermal stress, supports biodiversity, protects against wind and storm damage, and improves the visual and recreational appeal of tourist areas.
- Adjusting timing and tourist offerings based on seasonal climatic conditions helps maintain economic viability during hotter or wetter periods, while ensuring tourist safety and comfort.
- Implementing rapid alert systems and monitoring climatic parameters to provide real-time information on natural hazards, enhancing safety and preparedness for visitors and service providers.
- Restoration of wetlands as natural buffers which not only mitigate hydraulic and flood risks but also improve water quality and contribute to the preservation of key tourist attractions.
- Ensuring sustainable water consumption and quality by declaring water sanitary zones and providing drinking water spots, critical for visitor satisfaction and health.
- Energy-efficient and natural building practices support adaptation to thermal extremes while reducing environmental impact.

Adaptive capacity is generally rated high across all components exept hydraulic and hydrogeological risk for tourism infrastructure and services, high to medium for economic development and employment, and mostly medium and a high (thermal risk and climate extremes) for preservation of tourist attractions. The multifunctional strategies integrate ecosystem restoration, hazard management, and visitor services, highlighting their effectiveness in addressing intertwined climate risks and sustaining tourism's economic, social, and environmental functions in the region. Some of the measures are long term focused and include various levels of decision making and stakeholders involvement which makes their adaptive capacity lower. Very interesting are the measures that are highly adaptive and effective, while some of them also low-cost (tree planting) and would give results in the short term.

Overall, the strategy emphasizes multifunctional approaches combining ecosystem restoration, hazard preparedness, and sustainable resource management to secure tourism's long-term viability in the catchment under climate change.

3.2.3. Agriculture

The agriculture sector in the Vransko lake catchment faces significant climate risks across thermal, hydraulic, wind, and geological categories, with generally low adaptive capacity. This indicates a critical need for focused support and implementation of adaptation measures.
Multifunctional adaptation measures recommended across these risks include:

- Promoting agroforestry and shaded cropping systems, which lower crop stress from heat while enhancing biodiversity and soil moisture retention.
- Land use changes such as plowing to pastures improve soil health, reduce erosion, and support water cycle regulation.
- Restoration and conservation of wetlands and riparian zones regulate water cycles, mitigate flooding, and serve as habitats supporting agricultural biodiversity.
- Enhancing drainage infrastructure and implementing flood-tolerant cropping zones reduce hydraulic risks, while buffer zones near water bodies help manage runoff.
- Shelterbelts and windbreaks mitigate wind damage, reduce pesticide drift, and support microclimatic stability.
- Soil stabilization and reforestation projects address land degradation, protect soil fertility, and contribute to carbon sequestration.

Despite the broad range of measures, the sector's overall adaptive capacity is currently limited by resource availability, governance, and technical capacity. Therefore, coordinated programs encompassing farmer education, technical assistance, financial incentives, and ecosystem-based practices are vital to strengthen resilience and ensure sustained agricultural productivity under climate change.

This analysis demonstrates the critical importance of multifunctional nature-based solutions that simultaneously improve climate resilience, biodiversity conservation, and agricultural sustainability in the region.

Overall, agriculture remains one of the most exposed sectors under SSP2-4.5, with adaptive capacity unevenly distributed between medium and low across risks and components. Many measures, such as restoring wetlands, constructing movable dams, enhancing drainage, and implementing agroecological practices, require substantial financial investment and ongoing resource allocation. Limited funding restricts the scale and continuity of these interventions. Also, effective implementation depends on monitoring climatic and ecological parameters, managing water systems, and controlling invasive species which require technical expertise, scientific knowledge, and capacity-building among local stakeholders, which may be insufficient. As the land paraticles are small an there are many privat owners of the land coordinated multi-sectoral management is necessary due to the interconnected nature of risks and sectors. Fragmented governance or unclear responsibilities can hinder adaptive planning, enforcement of regulations, and landscape-level restoration. Some adaptation measures face natural environment constraints, such as complex karst hydrology affecting water management. Overall, these constraints highlight the need for integrated governance, capacity building, financial support, community involvement, and adaptive management frameworks tailored to the specific environmental and socioeconomic context of the Vransko lake catchment.

3.2.4. Fishing and Aquaculture

The fishing and aquaculture sector in the Vransko lake catchment demonstrates moderate adaptive capacity to thermal and hydraulic risks, reflecting the availability of practical ecosystem-based and technical solutions such as invasive species control and water-level management. However, limited adaptive capacity exists for risks from wind storms and geological degradation, primarily due to localized impacts, limited infrastructure, and fewer economic incentives.

Multifunctional measures included in the adaptation strategies for the fishing component of the Vransko lake catchment serve multiple purposes such as ecological restoration, economic benefits, and social/recreational uses simultaneously. These multifunctional measures increase resilience by addressing climate risks while simultaneously supporting multiple sector goals, making them highly valuable in integrated adaptation planning.
Examples include:

- Restoration of submerged vegetation and natural aquatic habitats helps stabilize habitats for fish, enhances water quality, and supports broader ecosystem services including recreational fishing and biodiversity conservation.
- Development of natural filtration ecosystems and multipurpose infrastructure is integrating aquaculture with wetland conservation and creating facilities that serve fishing, tourism, and monitoring.

The adaptive capacity for the fishing and aquaculture component for the Vransko lake catchment under scenario SSP2-4.5 is medium across all three evaluated components (resource use, income and employment, multifunctionality) for the thermal risk and climate extremes. Hydraulic and hydrogeological risk adaptive capacity is medium for resource use but low for income/employment and multifunctionality
Adaptive capacity is medium for resource use but low for income and multifunctionality on wind and weather storm risk. Geological and land degradation risk have low to medium adaptive capacity. The fishing and aquaculture sector in the Vransko lake catchment demonstrates moderate adaptive capacity to thermal and hydraulic risks, reflecting the availability of practical ecosystem-based and technical solutions such as invasive species control and water-level management. However, limited adaptive capacity exists for risks from wind storms and geological degradation, primarily due to localized impacts, limited infrastructure, and fewer economic incentives. Overall, strengthening governance, increasing financial support, and enhancing local technical capacity will be vital to improve the sector's adaptability under projected climate challenges. It is also worth mentioning that commercial fishing or fish farming no longer takes place on Lake Vrana, instead, only sport fishing is allowed, for which the lake is internationally renowned and rated as a highly attractive destination. Ichthyofauna includes several species attractive to sport anglers, which often yield trophy-sized fish - primarily the non-native species carp, catfish, and pike. Nevertheless, the condition of the ichthyofauna in Lake Vrana is alarming, with a real threat that some native fish species could become

extinct in the near future. The introduction of non-native species has significantly altered community structure by displacing native species, and it is also assumed that carp species, which feed by rooting in the sediment, contribute to silting and accelerate the processes of eutrophication and lake aging. The Public Institution of Vransko Jezero Nature Park holds the fishing right and is responsible for management within the park's fishing zone so the loss of income would only seriously affect the institution managing the protected area.

3.3. Residual vulnerability assessment

The residual vulnerability assessment and the summary of scores highlights sector-specific criticalities under the 2 selected climate scenarios SSP2-4.5 and SSP5-8.5.

Highest residual vulnerability (score >5) is associated with thermal risk and climate extremes (7.33) and hydraulic and hydrogeological risk (7.15) under SSP5-8.5. This is due to high exposure (droughts, salinization, climate extremes and higher temperatures) combined with limited adaptive capacity, particularly regarding biodiversity and agriculture. This indicates extreme fragility of ecosystems in the pilot site, where adaptation capacity collapses under high-emission scenarios.

Biodiversity shows to be highly vulnerable to thermal risk and climate extremes (6.42) and hydraulic and hydrogeological risks (7.15), while moderately vulnerable to wind and weather storm risk (4.25) under SSP5-8.5 due to high exposures and limited adaptive capacity. Biodiversity is also moderately vulnerable to hydraulic and hydrogeological risk (2.65) under SSP2-4.5.

Tourism shows to be highly vulnerable to thermal risk and climate extremes (5.50) moderately vulnerable to hydraulic and hydrogeological risks (4.77) and wind and weather storm risk (3.90) under SSP5-8.5 but with not very high and significant sensitivity to climate change impacts the risks are not significantly highlighted.

Agriculture is highly exposed to thermal risk and climate extremes (7.33) and hydraulic and hydrogeological risks (5.50) and moderately vulnerable to wind and weather storm risk (3.19) under SSP5-8.5 but it is also moderately vulnerable to thermal risk and climate extremes (3.40) under SSP2-4.5. In this sector adaptive strategies exist but remain fragmented, with uneven access to resources and limited protection for small farms.

Also fishing and aquaculture are highly vulnerable to hydraulic and hydrogeological risks (5.87) associated with salinization and eutrophication that favours invasive and allochtonous species and moderately vulnerable to thermal risk and climate extremes (4.28) and wind and weather storm risk (3.19) under SSP5-8.5.

4. Conclusions

The residual vulnerability assessment for the Vransko lake catchment underlines significant sector-specific fragilities in light of projected climate change, especially when contrasting the SSP2-4.5 and SSP5-8.5 scenarios. The highest residual vulnerability scores are associated with thermal risk and climate extremes and hydraulic and hydrogeological risk under SSP5-8.5. These results reflect the combined effects of increased exposure to drought, salinization, and more frequent climate extremes with a concurrent lack of adaptive capacity, particularly within biodiversity and agriculture sectors. Under such high-emission scenarios, the site's ecosystems demonstrate acute vulnerability, as adaptation capacity fails to keep pace with intensifying climate pressures.

Biodiversity is most at risk, showing very high vulnerability to both thermal and hydraulic risks under SSP5-8.5, and remaining moderately vulnerable to wind and weather storm risk. Even in the SSP2-4.5 scenario, biodiversity retains moderate vulnerability to hydraulic and hydrogeological threats, indicating persistent concern.

Tourism, while sensitive to climate change, registers its highest vulnerability to thermal extremes and more moderate scores to hydraulic and wind/storm risks under SSP5-8.5, but overall does not display the same critical sensitivity as biodiversity or agriculture.

Agriculture shares very high vulnerability to thermal extremes and considerable vulnerability to hydraulic risks under SSP5-8.5, with only moderate vulnerability persisting for wind/storm risk and under intermediate warming (SSP2-4.5). Adaptation in agriculture exists but is characterized as fragmented, with limited resources and uneven sectoral protection, especially for small farms.

Fishing and aquaculture are also highly vulnerable to hydraulic and hydrogeological risks, largely due to risks of salinization and eutrophication that favor invasive species, and show moderate vulnerability to both thermal and storm risks under SSP5-8.5.

In summary, the assessment highlights the acute vulnerability of biodiversity and agriculture to climate extremes and water-related risks, especially under scenarios of unmitigated emissions, while also signalling significant but lesser risks for tourism and fishing. This underscores the pressing need for comprehensive adaptation strategies—strengthening adaptive capacity, improving resource allocation, and reducing exposure—to maintain the ecological and socio-economic stability of the Vransko lake catchment in a warming climate.

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Annexes

Compiled matrix (final version resulting from the analysis of three different stakeholders (.xls file)

1 - The working Excel file used to perform Exposure, Adaptation and Risk assessments for the different local climate scenarios.

2 - The Exposure, Adaptation and risk assessments, resulting from the integration of the analyses completed by PP5 for the Vransko lake catchment pilot site.

Current climate exposure				
Season	*Thermal risk and climate extremes*	*Hydraulic and hydrogeological risk*	*Wind and weather storm risk*	*Geological and land degradation risk*
Spring	Moderate	Moderate	Moderate	Moderate-Low
Summer	High	Moderate-High	Moderate-Low	Low
Autumn	Moderate	Moderate-High	Moderate	Moderate-Low
Winter	Moderate-Low	Moderate	Moderate-Low	Low

Future climate exposure: SSP2-4.5 scenario - "Middle of the Road" world where trends largely follow their historical patterns				
Season	*Thermal risk and climate extremes*	*Hydraulic and hydrogeological risk*	*Wind and weather storm risk*	*Geological and land degradation risk*
Spring	Moderate-High	Moderate-High	Moderate-High	Moderate-Low
Summer	Moderate-High	Moderate-High	Moderate	Low
Autumn	Moderate-High	Moderate-High	Moderate	Moderate-Low
Winter	Low	Moderate	Moderate-Low	Low

Future Climate Exposure: Scenario SSP5-8.5 - Fossil-fueled Development "Taking the Highway", a world characterised by rapid and unlimited growth in economic production and energy use				
Season	*Thermal risk and climate extremes*	*Hydraulic and hydrogeological risk*	*Wind and weather storm risk*	*Geological and land degradation risk*
Spring	High	High	High	Moderate
Summer	High	High	Moderate	Low
Autumn	High	High	Moderate	Moderate
Winter	Moderate	Moderate	Moderate-Low	Moderate-Low

AREA: BIODIVERSITY					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Area of protected habitats	**Measures**	Planting of trees along watercourses (shades reducing water temperature, water purification buffer zones, habitat, windbreaks) Restoration of riparian zones Monitor climatic parameters Regulate water level by movable dam Ensure alternative habitats and refuges by restoring degraded wetland habitats Fire protection measures	Regulate water level by movable dam on channel Prosika Reduce melioration water pumping in winter months Contol illegal extraction of water Define the hydraulic elements that can be managed (small dams on channels) Create retention zones upstream to slow runoff and collect water	Planting of trees along watercourses (windbreaks, shades reducing water temperature, water purification buffer zones, habitat) Restoration of the riparian vegetation	Planting of trees along watercourses (windbreaks, shades reducing water temperature, water purification buffer zones, habitat, erosion reduction) Restoration of the riparian vegetation for erosion reduction Promote sediment trapping measures
	Adaptive Capacity	*Medium*	*High*	*High*	*Medium*

Species richness	**Measures**	Planting of trees along watercourses (shades reducing water temperature, water purification buffer zones, habitat, windbreaks) Restoration of riparian zones Monitor indicator species' stress responses Remove invasive and allochtonous species (fish, crab) Ensure alternative habitats and refuges by restoring connectivity between channels and wetland and restoring degraded wetland habitats	Manage the water level in accordance with breeding timing Restore water connectivity between channels and wetland units Create habitats suitable for birds in different water levels Ensure alternative habitats and refuges by restoring degraded wetland habitats	Monitor vulnerable nesting sites Remove invasive and allochtonous benthivore fish species that are degrading submerged vegetation Restore submerged vegetation	Planting of trees along watercourses (windbreaks, shades reducing water temperature, water purification buffer zones, habitat, erosion reduction) Restoration of the riparian vegetation for erosion reduction Create refuges or corridors for species migration Restore degraded habitats to support ecosystem resilience
	Adaptive Capacity	*Medium*	*Medium*	*Medium*	*Medium*
Ecosystem services	**Measures**	Planting of trees along watercourses (shades reducing water	Planting of trees along watercourses (shades reducing water	Grow natural windbreaks and vegetative buffers to	Prevent soil compaction and erosion in agricultural and wetland

		temperature, water purification buffer zones, habitat, windbreaks) Restoration of riparian zones Protect wetland buffer vegetation Avoid land change and consumption Encourage agroecological practices in buffer areas	temperature, water purification buffer zones, habitat, windbreaks) Restoration of riparian zones Improvement of drainage systems Widening of the channels and impelmentation of two-stage channels for high waters purification Enhance water storage capacity during wet seasons Apply water-sensitive agriculture	reduce storm damage Diversify agroecosystem functions including long rotation crops Promote land use change (plowing to pastures)	areas Apply conservation tillage and native vegetation cover, especially in wetland habitat to sequester carbon efficiently Promote land use change (plowing to pastures) Planting of trees along watercourses (windbreaks, shades reducing water temperature, water purification buffer zones, habitat, erosion reduction) Restoration of riparian vegetation for erosion reduction
	Adaptive Capacity	*High*	*Medium*	*Medium*	*Medium*

AREA: BIODIVERSITY	*Scenario*	*Sensitivity*	*Exposure*	*Adaptation*	***Residual vulnerability***
Thermal risk and climate extremes	**SSP2-4.5**	2,33	2,13	2,33	**2,13**
	SSP5-8.5	2,33	2,75	1,00	**6,42**
Hydraulic and hydrogeological risk	**SSP2-4.5**	2,60	2,38	2,33	**2,65**
	SSP5-8.5	2,60	2,75	1,00	**7,15**
Wind and weather storm risk	**SSP2-4.5**	2,00	2,00	2,33	**1,71**
	SSP5-8.5	2,00	2,13	1,00	**4,25**
Geological and land degradation risk	**SSP2-4.5**	1,25	1,25	2,00	**0,78**
	SSP5-8.5	1,25	1,63	1,00	**2,03**

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AREA: TOURISM					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Tourism infrastructure and services	**Measures**	Planting of trees along watercourses and nature trails (shades, habitat, windbreaks) Adjust timing and tourist offer based on seasonal conditions Monitor climatic parameters Implement rapid alert systems to inform tourists of real-time natural hazards Energy sustainable and natural building Ensure drinking water spots Fire protection measures	Adjust timing and tourist offer based on seasonal conditions Restore wetlands as natural buffers Ensure proclamation of water sanitary zones Ensure sustainable water consumption Ensure drinking water quality Implement rapid alert systems to inform tourists of real-time natural hazards	Adjust timing and tourist offer based on seasonal conditions Planting of trees along watercourses and nature trails (shades, habitat, windbreaks) Implement rapid alert systems to inform tourists of real-time natural hazards.	Promote land use change (plowing to pastures) Planting of trees along watercourses (windbreaks, shades reducing water temperature, water purification buffer zones, habitat, erosion reduction) Restoration of riparian vegetation for erosion reduction
	Adaptive Capacity	*High*	*Medium*	*High*	*High*
Economic development and employment	**Measures**	Regulate tourist access based on forecasts of extreme weather events Educate visitors about newly	Increase connectivity of habitats to preserve migratory species (e.g., birds, fish, amphibians)	Implement rapid alert systems to inform tourists of real-time natural	Rehabilitate degraded tourist natural sites and mantain the existing one to

		introduced or dangerous species, and increase the availability of portable water sources.	Restore and mantain small freshwater bodies Implement rapid alert systems to inform tourists of real-time natural hazards	hazards Develop resilient infrastructure in tourist areas to protect both visitors and employees from major storms and extreme weather events	increase attractivity Monitor and manage human impact on ecosystems
	Adaptive Capacity	*High*	*Medium*	*Medium*	*High*
Preservation of tourist attractions	**Measures**	Introduce heat-resilient vegetation in visitation zones Planting of trees along watercourses and nature trails (shades, habitat, windbreaks) Monitor climatic parameters	Restore wetlands as natural buffers Ensure proclamation of water sanitary zones Ensure sustainable water consumption Ensure drinking water quality	Use wind-resistant barriers and shelters to protect open-air attractions	Restore eroded landscapes and features
	Adaptive Capacity	*High*	*Medium*	*Medium*	*Medium*

AREA: TOURISM	*Scenario*	*Sensitivity*	*Exposure*	*Adaptation*	***Residual vulnerability***
Thermal risk and climate extremes	**SSP2-4.5**	2,00	2,13	3,00	**1,42**
	SSP5-8.5	2,00	2,75	1,00	**5,50**
Hydraulic and hydrogeological risk	**SSP2-4.5**	1,73	2,38	2,00	**2,06**
	SSP5-8.5	1,73	2,75	1,00	**4,77**
Wind and weather storm risk	**SSP2-4.5**	1,83	2,00	2,33	**1,57**
	SSP5-8.5	1,83	2,13	1,00	**3,90**
Geological and land degradation risk	**SSP2-4.5**	1,17	1,25	2,67	**0,55**
	SSP5-8.5	1,17	1,63	1,00	**1,90**

AREA: AGRICULTURE					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Land use and landscape	**Measures**	Promote agroforestry and shaded cropping systems Promote land use change (plowing to pastures) Shift sowing and harvesting calendars Introduce heat-resilient crops Expand use of mulching and precision irrigation	Restore and conserve wetlands to regulate water cycles Promote land use change (plowing to pastures) Design flood-tolerant cropping zones Create buffer zones near water bodies as flooding areas Manage drainage infrastructures	Use shelterbelts and windbreaks Apply storm-resilient land zoning practices Reinforce protective field infrastructure like greenhouses and fencing	Enforce zoning in erosion-prone areas Promote land use change (plowing to pastures) Implement soil stabilization and reforestation projects Increase the carbon storage against soil erosion.
	Adaptive Capacity	*Low*	*Medium*	*Medium*	*Medium*
Agricultural income and employment	**Measures**	Provide subsidies for climate-resilient farming Support income diversification (e.g., agritourism) Develop early warning	Promote insurance for flood-related crop loss Promote land use change (plowing to pastures) Offer financial aid for	Strengthen access to social safety nets post-storm events Provide infrastructure	Invest in land restoration programs with labor components Encourage sustainable farming to prevent land degradation

		systems for heatwaves and crop loss	farm recovery Train farmers on adaptive irrigation methods and water conservation	protection grants Support local cooperatives for emergency response	Promote land use change (plowing to pastures) Fund educational programs for soil health practices
	Adaptive Capacity	*Medium*	*Medium*	*Low*	*Medium*
Agricultural biodiversity	**Measures**	Conserve and promote drought- and heat-tolerant crop varieties Enhance seed banks with local species Support mixed cropping and polyculture systems	Protect wetland and riparian habitats for wild species Maintain genetic diversity of flood-tolerant crops Promote landscape connectivity for agro-ecosystems	Establish emergency seed reserves post-storm events Enhance resilience through crop diversification Design biodiversity corridors protected from storm damage	Prevent monoculture in erosion-prone areas Promote land use change (plowing to pastures) Encourage crop rotation to maintain soil structure and species richness Restore degraded agro-ecosystems with native species Encourage the use of shelterbelts as biodiversity hot spot
	Adaptive Capacity	*Medium*	*Medium*	*Medium*	*Medium*

AREA: AGRICULTURE	*Scenario*	*Sensitivity*	*Exposure*	*Adaptation*	***Residual vulnerability***
Thermal risk and climate extremes	**SSP2-4.5**	2,67	2,13	1,67	**3,40**
	SSP5-8.5	2,67	2,75	1,00	**7,33**
Hydraulic and hydrogeological risk	**SSP2-4.5**	2,00	2,38	2,00	**2,38**
	SSP5-8.5	2,00	2,75	1,00	**5,50**
Wind and weather storm risk	**SSP2-4.5**	1,50	2,00	1,67	**1,80**
	SSP5-8.5	1,50	2,13	1,00	**3,19**
Geological and land degradation risk	**SSP2-4.5**	1,25	1,25	2,00	**0,78**
	SSP5-8.5	1,25	1,63	1,00	**2,03**

AREA: FISHING AND AQUACULTURE					
Component	***Scenario SSP2-4.5***	*Adaptation to thermal risk and climate extremes*	*Adaptation to hydraulic and hydrogeological risk*	*Adaptation to wind and weather storm risk*	*Adaptation to geological and land degradation risk*
Use of resources	**Measures**	Promote removal of allochtonous and invasive species Monitor oxygen levels and harmful algal blooms	Improve water management to prevent salinity intrusion Install water-level regulation systems (movable gate at channel Prosika)	Restore submerged macrophytes	Restore submerged macrophytes Monitor sediment erosion and resuspension
	Adaptive Capacity	*High*	*High*	*Medium*	*Medium*
Income and employment	**Measures**	Provide financial incentives for removal of allochtonous and invasive species	Diversify livelihoods linked to wetland-related processing	Implement rapid alert systems to inform anglers of real-time natural hazards	Support circular economy initiatives to reduce resource pressure
	Adaptive Capacity	*Medium*	*Medium*	*Medium*	*Low*
Multifunctionality	**Measures**	Promote recreational and educational fishing practices	Develop nature-based solutions (e.g., aquaculture-wetland integration) Create natural filtration ecosystems	Create multipurpose docks and floating hubs that combine fishing, tourism, and monitoring	Integrate aquaculture with dune or sediment stabilization efforts; Use multifunctional coastal zones to reduce degradation pressure.

	Adaptive Capacity	*Medium*	*Medium*	*Medium*	*Medium*

AREA: FISHING AND AQUACULTURE	*Scenario*	*Sensitivity*	*Exposure*	*Adaptation*	***Residual vulnerability***
Thermal risk and climate extremes	**SSP2-4.5**	1,56	2,13	2,33	**1,42**
	SSP5-8.5	1,56	2,75	1,00	**4,28**
Hydraulic and hydrogeological risk	**SSP2-4.5**	2,13	2,38	2,33	**2,17**
	SSP5-8.5	2,13	2,75	1,00	**5,87**
Wind and weather storm risk	**SSP2-4.5**	1,50	2,00	2,00	**1,50**
	SSP5-8.5	1,50	2,13	1,00	**3,19**
Geological and land degradation risk	**SSP2-4.5**	1,08	1,25	1,67	**0,81**
	SSP5-8.5	1,08	1,63	1,00	**1,76**