

Annex 2b

Climate Rationale

to the GCF Funding Proposal

Climate-resilient Landscapes in Central Asia

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Table of Contents

List of Tables	3
List of Figures.....	4
Abbreviations and Acronyms	7
1. Introduction	8
2. Scope of the Assessment	10
2.1 Programme Region	10
2.2 Programme Areas	12
2.3 Land-use Systems	15
3. Methodological Approach	18
3.1 IPCC Concepts and Definitions	18
3.2 Climate Risk Assessment Approach	19
3.3 Key Sources of Information.....	21
3.4 Climate Modelling Methodology	22
Quantitative data sources	22
Treatment for local conditions.....	23
Periods and scenarios	23
Treatment of uncertainty	23
Indicators and indices	23
Limitations.....	25
4. Problem Statement: Climate Risk	26
5. Exposure	28
Spatial Distribution of Key Land-use Systems.....	30
Social Dimensions of Exposure and Livelihood Dependence	34
6. Climate Hazards.....	37
6.1 Selected Indices.....	39
6.2 Mean Temperature.....	40
6.3 Extreme Heat	43
6.4 Hot Dry Wind	47
6.5 Seasonal Precipitation Patterns	51
6.6 Drought Conditions	58
6.7 Heavy Rain.....	62
6.8 Upstream run-off shift.....	66
7. Climate Impacts	69
7.1 Impacts on Irrigated Annual Cropland	75
7.2 Impacts on Irrigated Perennial Cropland	78
7.3 Impacts on Rainfed Cropland	81
7.4 Impacts on Forests and Pasture Land	84

7.5	Cross-cutting and Systemic Impacts across Land-use Systems	87
7.6	Conclusion	89
8.	Vulnerabilities	90
	Cross-cutting vulnerability architecture	90
	Vulnerabilities of land-use systems	91
9.	Adaptation Measures	100
9.1	Overall Adaptation Approach of the Programme	100
9.2	Individual Adaptation Measures	102
10.	References	113

List of Tables

Table 1: Programme Intervention Areas	12
Table 2: Focus Land-Use Systems and Value Chains	16
Table 3: Problem Statement	26
Table 4: Area and share of land-use systems by elevation (below/above 1,500m) in the programme areas	33
Table 5: Selected State Forest Enterprises (SFEs) in the programme areas	33
Table 6: Synthesis of key projected climate hazards across the programme areas	37
Table 7: Summary of main hazard-to-impact pathways across focus land-use systems, including geographic differentiation and examples of key crops, pasture, and forest systems	69
Table 8: Key cross-cutting findings from the impact assessment	89
Table 9: Major vulnerabilities of systems of each key land-use system, as well as cross-cutting vulnerabilities	92
Table 10: List of individual adaptation measures for the key land-use systems promoted by the programme (full barrier titles are provided in Table 11 below)	104
Table 11: Barriers addressed by the programme and referenced in Table 10	111

List of Figures

Figure 1: Population density (panel a; estimation for 2020), topography/elevation (panel b), and climatology based on Köppen-Geiger classification (panel c) for the surroundings of the Kyrgyz Republic, Tajikistan, and Uzbekistan	11
Figure 2: Programme intervention areas: Districts around Fergana Valley (top right) and Southern Border Region between Uzbekistan and Tajikistan (bottom left); total of 39 labelled districts; colours according to elevation (30m x 30m grid).....	13
Figure 3: Climate classification of the programme areas (Fergana Valley and Southern Border Region), illustrating the spatial distribution of major climate zones and their variation across elevation gradients	14
Figure 4: Meteograms for the programme areas in Fergana Valley (top row) and the Southern Border Region (bottom row) by elevation level (below and above 1500m in left and right column, respectively) (mean of 1991-2010, ensemble median of the 20 selected climate models). Numbers in the top right corner are total annual precipitation and annual mean temperature, respectively. Whiskers are “likely range” (IPCC) of model ensemble. Shades are temperature daily minimum/maximum.	15
Figure 5: Core concepts of the IPCC’s Working Group II AR6	19
Figure 6: Conceptual Climate Impact Chain framework applied across the Climate Rationale	20
Figure 7: Conceptual Climate Impact Chain framework applied across the Climate Rationale - resulting risks and problem statement	27
Figure 8: Conceptual Climate Impact Chain framework applied across the Climate Rationale - exposure	28
Figure 9: Exposed Elements from the Climate Impact Chains (cf. Chapters 7 and 8)	29
Figure 10: Vertical geography scheme typical for the programme area (exemplarily for the area around Nookat, Kyrgyz Republic; land use data has been smoothed for presentation).....	30
Figure 11: Land use distribution in the programme areas (Top: Fergana Valley; Bottom: Southern Border Area). (Note that the dataset is based on satellite observations and differentiation between irrigated and rainfed schemes for cropland are only historic estimates.)	31
Figure 12: Distribution of major land-use systems across elevation gradients in the Fergana Valley and Southern Border Region (share of area for each 250m elevation bin)	32
Figure 13: Conceptual Climate Impact Chain framework applied across the Climate Rationale - climate hazards.....	38
Figure 14: Hazard-side components of the land-use-specific Climate Impact Chains	39
Figure 15: Historical and projected mean annual temperature in the programme areas	41
Figure 16: Mean annual temperature over time by elevation zone in the Fergana Valley (only programme districts)	42
Figure 17: Mean annual temperature over time by elevation zone in the Southern Border Region.....	42
Figure 18: Historical and projected annual number of days with maximum temperature above 35°C.....	44
Figure 19: Annual number of days with maximum temperature above 35°C over time by elevation zone in the Fergana Valley (only programme districts)	45
Figure 20: Annual number of days with maximum temperature above 35°C over time by elevation zone in the Southern Border Region	45
Figure 21: Change in monthly heat days (days in maximum temperature above 35°C) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts).....	46
Figure 22: Change in monthly heat days (days in maximum temperature above 35°C) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region	46
Figure 23: Historical and projected annual number of hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) in the programme areas.....	48

Figure 24: Annual number of hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) over time by elevation zone in the Fergana Valley (only programme districts)	49
Figure 25: Annual number of hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) over time by elevation zone in the Southern Border Region.....	49
Figure 26: Change in monthly hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts).....	50
Figure 27: Change in monthly hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region	50
Figure 28: Historical and projected precipitation during the wetter season (October to May)	52
Figure 29: Historical and projected precipitation during the drier season (June to September).....	53
Figure 30: Seasonal precipitation over time by elevation zone in the Fergana Valley (only programme districts)	54
Figure 31: Seasonal precipitation over time by elevation zone in the Southern Border Region	55
Figure 32: Precipitation for drier months (June to September) over time by elevation zone in the Fergana Valley (only programme districts).....	56
Figure 33: Precipitation for drier months (June to September) over time by elevation zone in the Southern Border Region	56
Figure 34: Change in total monthly precipitation for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts).....	57
Figure 35: Change in total monthly precipitation for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region	57
Figure 36: Historical and projected annual minimum SPEI-3 in the programme areas.....	59
Figure 37: Seasonal minimum SPEI-3 over time by elevation zone in the Fergana Valley (only programme districts)	60
Figure 38: Seasonal minimum SPEI-3 over time by elevation zone in the Southern Border Region ...	61
Figure 39: Historical and projected annual number of days with precipitation above 20mm	63
Figure 40: Annual number of days with precipitation above 20mm over time by elevation zone in the Fergana Valley (only programme districts)	64
Figure 41: Annual number of days with precipitation above 20mm over time by elevation zone in the Southern Border Region	64
Figure 42: Change in monthly heavy rain days (days with precipitation above 20mm) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts).....	65
Figure 43: Change in monthly heavy rain days (days with precipitation above 20mm) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region	65
Figure 44: Upstream-basin systems relevant to the programme areas (Syr Darya upstream basin in relation to the Fergana Valley programme districts; Amu Darya upstream basin in relation to the Southern Border Region programme districts)	66
Figure 45: Annual mean temperature (top left), annual snowfall-condition precipitation (top right), annual snow share (bottom left), and mid-century monthly change in snow share relative to 1991–2010 (bottom right) for the Syr Darya upstream basin relevant to the Fergana Valley programme districts	67
Figure 46: Annual mean temperature (top left), annual snowfall-condition precipitation (top right), annual snow share (bottom left), and mid-century monthly change in snow share relative to 1991–2010 (bottom right) for the Amu Darya upstream basin relevant to the Southern Border Region programme districts	68

Figure 47: Conceptual Climate Impact Chain framework applied across the Climate Rationale - climate impacts	69
Figure 48: Climate impact chain for irrigated annual cropland in the programme areas	76
Figure 49: Climate impact chain for irrigated perennial cropland in the programme areas	79
Figure 50: Climate impact chain for rainfed cropland in the programme areas	82
Figure 51: Climate impact chain for forests and pastureland in the programme areas	85
Figure 52: Conceptual Climate Impact Chain framework applied across the Climate Rationale - vulnerabilities	90
Figure 53: Climate impact chain for irrigated annual cropland in the programme areas including vulnerabilities	96
Figure 54: Climate impact chain for irrigated perennial cropland in the programme areas, including vulnerabilities	97
Figure 55: Climate impact chain for rainfed cropland in the programme areas, including vulnerabilities	98
Figure 56: Climate impact chain for forests and pastureland in the programme areas, including vulnerabilities	99
Figure 57: Conceptual Climate Impact Chain framework applied across the Climate Rationale - adaptation measures and programme outputs to address the identified vulnerabilities	100

Abbreviations and Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
AR6	Sixth Assessment Report
CRLE	Climate-resilient low-emission
CMIP6	Coupled Model Intercomparison Project Phase 6
DEM	Digital Elevation Model
GCF	Green Climate Fund
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für internationale Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change
iTAP	Independent Technical Advisory Panel
NEX-GDDP-CMIP6	NASA Earth Exchange Global Daily Downscaled Projections based on CMIP6
SFE	State Forest Enterprise
SPEI	Standardized Precipitation Evapotranspiration Index
SPEI-3	Standardized Precipitation Evapotranspiration Index, 3-month timescale
SSP2-4.5	Shared Socioeconomic Pathway 2 – 4.5 W/m ² forcing scenario – optimistic scenario
SSP5-8.5	Shared Socioeconomic Pathway 5 – 8.5 W/m ² forcing scenario – business-as-usual scenario
ND-GAIN	Notre Dame Global Adaptation Initiative
INFORM	Index for Risk Management
EC	European Commission
JRC	Joint Research Centre
GADM	Global Administrative Areas (Database of Global Administrative Areas)
FAO	Food and Agriculture Organization (of the United Nations)
FAO AQUASTAT	FAO's global water information system
UNECE	United Nations Economic Commission for Europe
ISO	International Organization for Standardization
NASA	National Aeronautics and Space Administration
GLO-30	Copernicus Global Land Cover / Global DEM (30 m resolution dataset)
HydroBASINS	Hydrological data and maps based on elevation data
ETCCDI	Expert Team on Climate Change Detection and Indices
FAO-56	FAO Irrigation and Drainage Paper No. 56 (reference for evapotranspiration calculation)
cf.	compare (academic reference)
Pm	Monthly precipitation
PETm	Monthly potential evapotranspiration
Dm(3)	3-month climatic water balance
FLL	Frequency of Low Levels
Φ^{-1}	Inverse cumulative distribution function (inverse normal function)
R20mm	Number of days with precipitation ≥ 20 mm (standard ETCCDI index)
UNCCD	United Nations Convention to Combat Desertification
UNICEF	United Nations Children's Fund
NDC	National Designated Contribution
LFIs	Local Financial Institutions
MFIs	Microfinance Institutions
Uni. Bonn	University of Bonn

1. Introduction

This Climate Rationale has been prepared for the programme “Climate resilient landscapes in Central Asia”, which aims to enhance the climate resilience of vulnerable populations and the transboundary Agriculture, Forestry and Other Land Uses (AFOLU) systems on which they depend in the Kyrgyz Republic, Tajikistan, and Uzbekistan. The programme responds to increasing climate risks by promoting climate-resilient and low-emission land-use systems across interconnected landscapes, while also strengthening enabling environments, improving access to finance, and fostering regional cooperation. By targeting key vulnerabilities in agriculture, pasture, and forest systems, the programme contributes to more sustainable land management, improved livelihoods, and enhanced ecosystem resilience in the face of climate change.

The Climate Rationale is a core analytical element of a Green Climate Fund (GCF) funding proposal. It provides the climate-change perspective underpinning the proposal and forms the overarching narrative through which the programme demonstrates how it addresses climate change and contributes to the GCF Investment Framework, including the criterion of climate-related impact (GCF, 2022a; GCF, 2014). In the case of adaptation, this requires an evidence-based analysis of observed and projected climate hazards, exposure, vulnerability, and resulting impacts, as well as an assessment of whether and how far the proposed measures constitute plausible and effective adaptive responses in the programme context (GCF, 2022b). Socio-economic and implementation aspects are addressed in greater detail in the Feasibility Study (Annex 2a), while this Climate Rationale focuses specifically on the climate-risk logic required to justify the proposed adaptation measures under the GCF framework.

Building on concepts and definitions of the Intergovernmental Panel on Climate Change (IPCC) and specific requirements and guidance from the GCF as well as the Independent Technical Advisory Panel (iTAP), this report analyses exposure, climate hazards, and vulnerability factors related to five land-use systems in two transboundary intervention areas and presents the resulting risks of specific impacts.

The analysis is conceptualised by means of Climate Impact Chains, which provide a framework for understanding and visualising the causal relationships between changes in the climate and their impacts (GIZ, 2023). These Climate Impact Chains function as the analytical backbone of the assessment and are presented in the Appendix for key land-use systems in the programme area. The analysis is based on a variety of primary and secondary sources, including both quantitative climate projection results as well as the perceptions and expertise of local stakeholders.

This Climate Rationale is structured according to a stepwise climate risk logic, which distinguishes hazards, impacts, and vulnerabilities as analytically distinct but closely connected components of climate risk:

- Chapter 2 “**Scope of the Assessment**”, defines the programme context, intervention areas, and relevant land-use systems.
- Chapter 3 “**Methodological Approach**”, introduces the concepts and definitions applied in the assessment and sets out the data basis, climate analyses, and Climate Impact Chains used as the central analytical instruments.
- Chapter 4 “**Problem Statement: Climate Risk**”, formulates the overarching climate risk that the programme is intended to address.
- Chapter 5 “**Exposure**”, identifies the geographic distribution of the land-use systems exposed to climate-related hazards.
- Chapter 6 “**Climate Hazards**”, assesses the observed and projected climatic changes relevant to the programme areas.
- Chapter 7 “**Climate Impacts**”, examines how these hazards translate into effects on land-use systems and, where relevant, on climate-sensitive livelihoods.
- Chapter 8 “**Vulnerabilities**”, analyses the factors that increase susceptibility to harm, reduce adaptive capacity, and thereby aggravate the severity of climate impacts.
- Chapter 9 “**Adaptation Measures**”, links the measures proposed under the programme to the identified vulnerabilities that aggravate climate impacts and justifies them as targeted adaptation responses to the assessed climate risks.

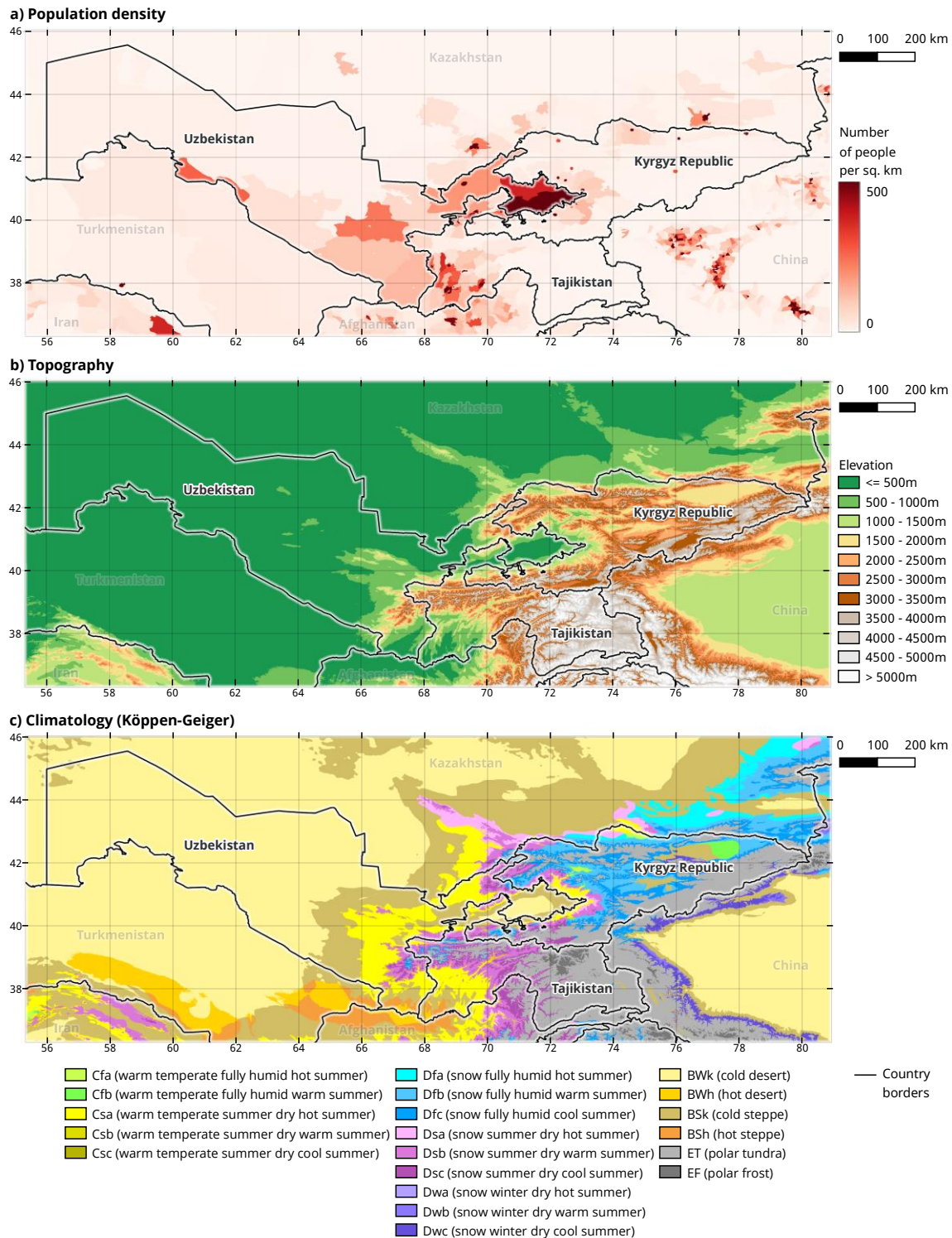
2. Scope of the Assessment

2.1 Programme Region

Within Central Asia, the **Kyrgyz Republic, Tajikistan, and Uzbekistan** are among the most vulnerable to climate change and its impacts, with rankings of 65th, 102nd, and 72nd, respectively, in the ND-GAIN country index, reflecting their high vulnerability and low adaptive capacity (Notre Dame Global Adaptation Initiative, 2021). These results are also confirmed by the INFORM risk index (EC/JRC/INFORM, 2024), which is based on a set of indicators across hazard and exposure, vulnerability, and lack of coping capacity. The INFORM index also shows that the combination of hazards, vulnerabilities, and exposures is predicted to be highest in the regions where these three countries converge, particularly in and around the Fergana Valley and in the south, where Uzbekistan borders Tajikistan (cf. the Climate Rationale Annex G.2b of the Concept Note).

Building on this, Figure 1 illustrates how population distribution, topography, and climate zones interact across the Kyrgyz Republic, Tajikistan, and Uzbekistan, shaping patterns of exposure to climate risks. Population density (panel a) is concentrated in lowland and valley areas - most prominently in the Fergana Valley - where favourable conditions for settlement and agriculture coincide. In contrast, large parts of the Kyrgyz Republic and Tajikistan remain sparsely populated due to their predominantly mountainous terrain (panel b), with extensive areas at higher elevations. The climatological patterns (panel c) mirror this topographic gradient: arid and semi-arid desert and steppe climates dominate the lowlands, particularly in Uzbekistan, while cooler continental and alpine climates prevail in the mountainous regions. Together, these patterns highlight how populations and economic activities are concentrated in accessible and climatically favourable zones, including transboundary hotspots such as the Fergana Valley, where high exposure intersects with underlying vulnerability and limited adaptive capacity.

Figure 1: Population density (panel a; estimation for 2020), topography/elevation (panel b), and climatology based on Köppen-Geiger classification (panel c) for the surroundings of the Kyrgyz Republic, Tajikistan, and Uzbekistan



Source: Own illustration based on GADM, 2022, Copernicus Programme, 2021, Brun et al., 2022, and CIESIN, 2018

2.2 Programme Areas

Building on the analysis of population distribution, topography, and climate zones in Central Asia (2.1), which highlights strong spatial concentrations of population and economic activity in lowland and valley systems alongside extensive mountainous areas with distinct climatic conditions, priority intervention areas were identified through a multi-criteria assessment and stakeholder consultations (cf. Section 2.7 of the Annex 2a Feasibility Study). As a result, two programme areas were selected (cf. Figure 2 below), which stand out due to the convergence of high population density, climate-sensitive land-use systems, and pronounced transboundary dynamics.

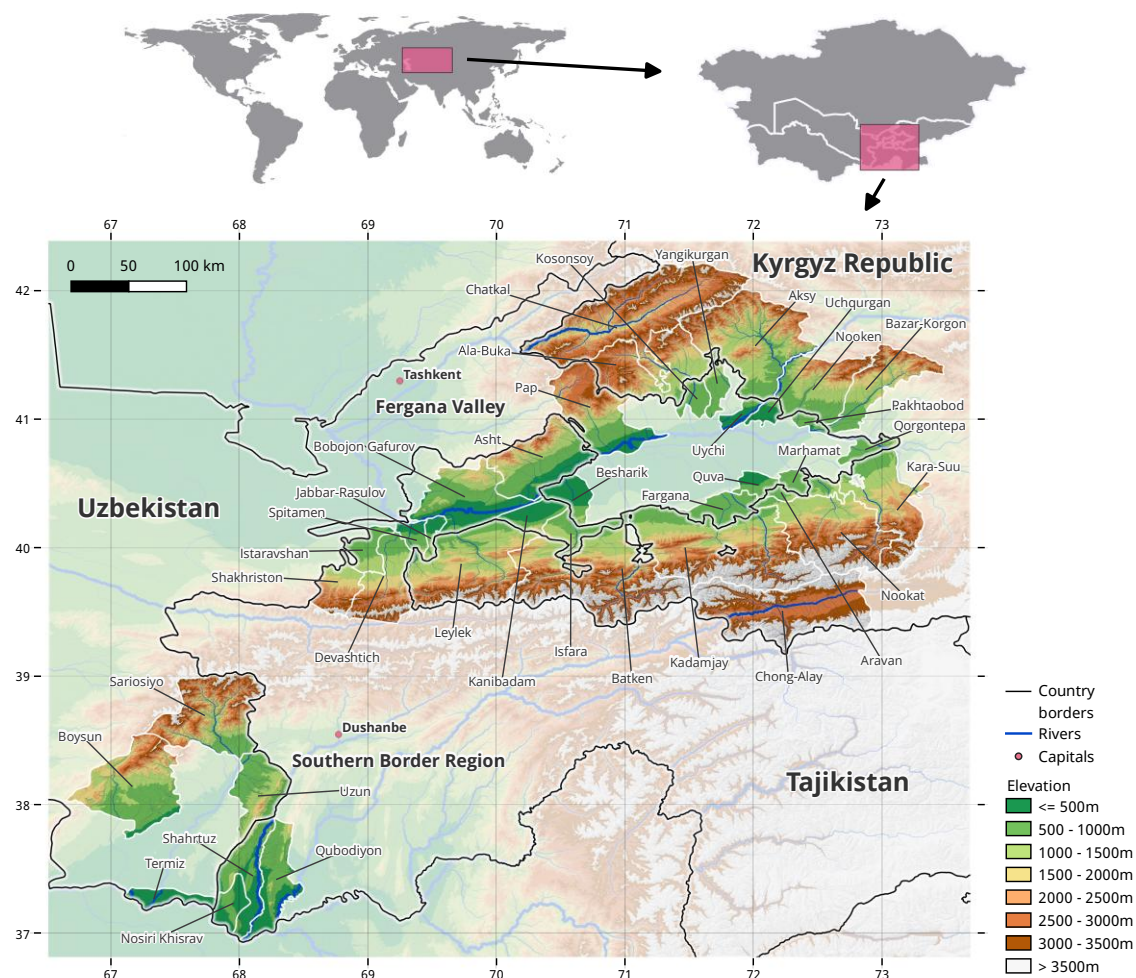
Table 1: Programme Intervention Areas

Programme Intervention Areas	
Name	Countries / Description
Fergana Valley	Kyrgyz Republic, Tajikistan, Uzbekistan Focus on the surrounding hilly and mountainous zones, including parts of the Alay Valley
Southern Border Region	Tajikistan, Uzbekistan Covering parts of the Khatlon and Surkhandarya regions

Both regions are characterized by vertically interconnected mountain–valley landscapes, where irrigated and rainfed cropland, pastures, and forests are closely linked through shared water resources and ecological processes. These interconnections contribute to high exposure to climate hazards and enable cascading impacts across elevation zones and land-use systems. At the same time, rural livelihoods depend heavily on agriculture, livestock, and forest resources, underlining the socio-economic relevance of these systems and the need for coordinated adaptation measures in transboundary landscapes.

Figure 2 is important not only as a location map, but because it shows that the selected districts span connected lowland, foothill, and mountain areas across national borders. The relevance of the programme areas lies precisely in this vertical and transboundary structure: climate pressures arising in upper catchments and middle-elevation slopes are transmitted into lower agricultural systems through shared water resources, runoff processes, and land-use interdependence.

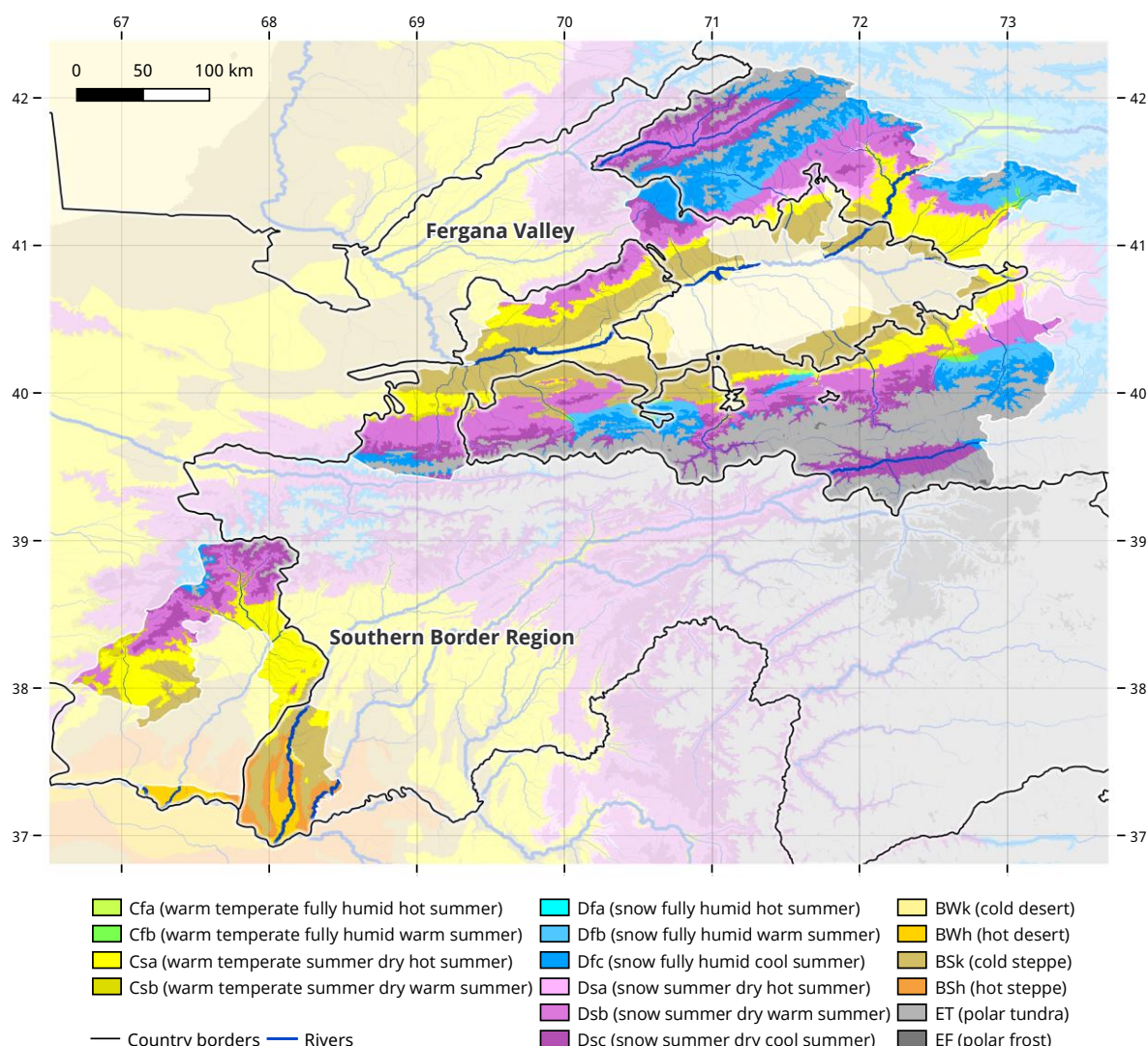
Figure 2: Programme intervention areas: Districts around Fergana Valley (top right) and Southern Border Region between Uzbekistan and Tajikistan (bottom left); total of 39 labelled districts; colours according to elevation (30m x 30m grid)



Source: Own illustration based on GADM, 2022, and Copernicus Programme, 2021

The programme landscapes are located in a predominantly arid to semi-arid climate, characterized by strong intra-annual variability in temperature and precipitation (Figure 3). Lower-lying areas depend heavily on water resources originating from upper catchments, particularly during the typically dry summer months when water demand peaks for irrigation and pasture use. The pronounced alternation between wet and dry seasons also increases climate-related risks: higher elevation areas are more susceptible to landslides and flooding during wetter months, while drought conditions commonly occur during summer.

Figure 3: Climate classification of the programme areas (Fergana Valley and Southern Border Region), illustrating the spatial distribution of major climate zones and their variation across elevation gradients



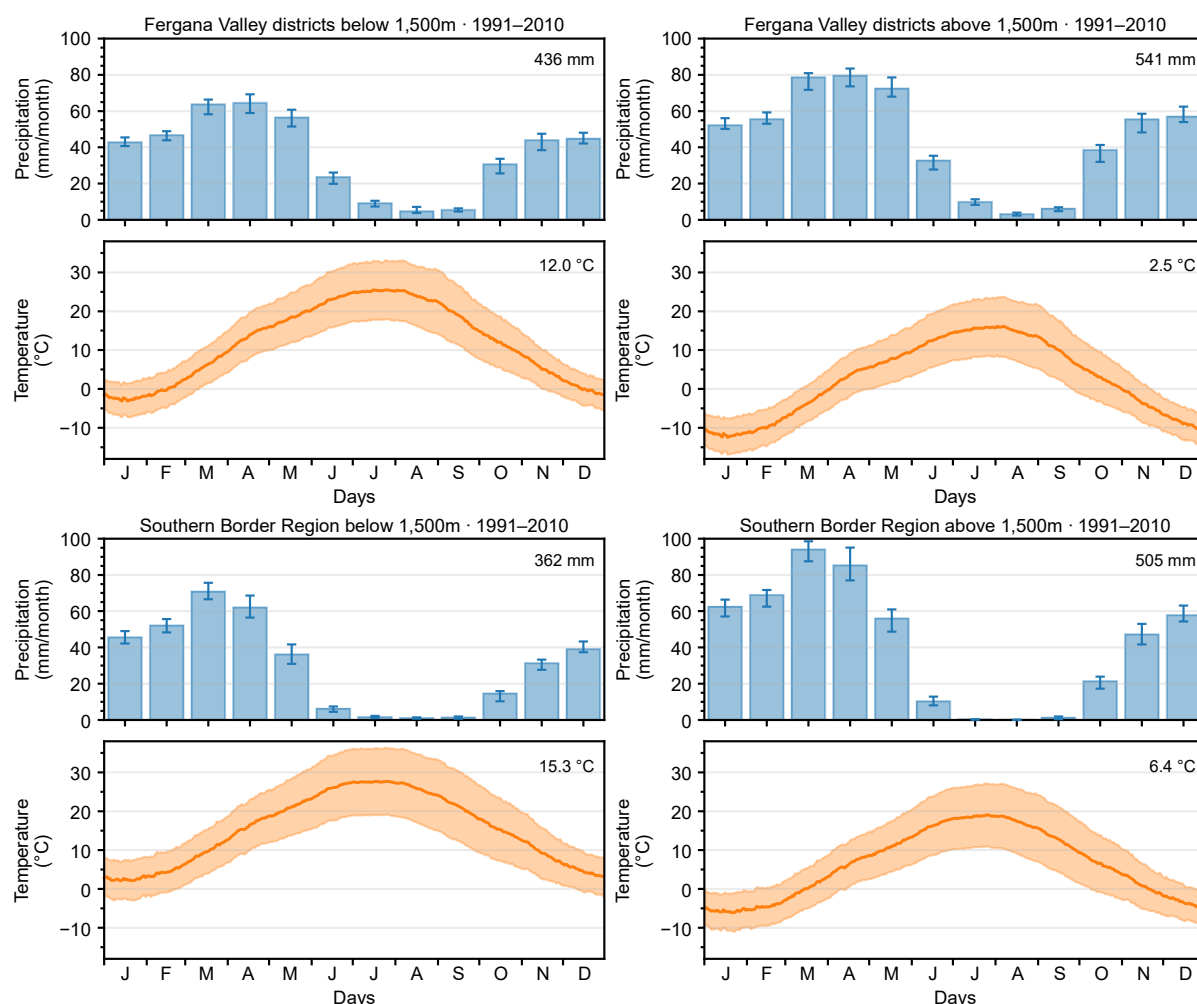
Source: Own illustration based on GADM, 2022, and Brun et al., 2022

To better understand the climatic conditions in the selected programme areas, Figure 4 presents meteograms illustrating the seasonal distribution of temperature and precipitation across regions (Fergana Valley and Southern Border Area) and elevation zones (below and above 1,500m). Based on the historical baseline period 1991–2010 and derived from an ensemble of climate models, the data show pronounced intra-annual variability in both temperature and precipitation. Across all locations, precipitation is concentrated in the spring months, while summers are consistently dry, highlighting the strong seasonality of rainfall and water availability throughout the year. Temperature patterns follow a typical continental profile, with cold winters and hot summers, and a clear altitudinal gradient: higher elevations experience lower mean annual temperatures and slightly higher annual precipitation compared to lowland areas. Figure 4 also illustrates the range of model variability through whiskers and shaded areas. Overall, the meteograms provide important context for understanding the climatic conditions that shape water availability, agricultural cycles, and ecosystem dynamics across the programme landscapes.

Figure 4 is particularly important for the later hazard analysis because it already shows the basic climatic asymmetry that structures climate risk in the programme areas: a large share of water availability is concentrated in the cooler part of the year, while the warm season is hot and dry, especially in lower

elevations. Many of the hazards assessed in Chapter 6 should therefore be read not as isolated extremes, but as intensifications of an already strongly seasonal mountain–valley climate regime.

Figure 4: Meteograms for the programme areas in Fergana Valley (top row) and the Southern Border Region (bottom row) by elevation level (below and above 1500m in left and right column, respectively) (mean of 1991–2010, ensemble median of the 20 selected climate models). Numbers in the top right corner are total annual precipitation and annual mean temperature, respectively. Whiskers are “likely range” (IPCC) of model ensemble. Shades are temperature daily minimum/maximum.



Source: Own illustration based on analyses of NASA, 2025

2.3 Land-use Systems

Transboundary AFOLU systems dominate land use in the programme areas and underpin rural livelihoods, with settlement patterns and incomes closely tied to climate-sensitive agriculture, pasture use, and forest ecosystem services. These systems are increasingly under pressure from land degradation, particularly soil erosion across large parts of the Fergana Valley and the Southern Border Area, as well as the widespread deterioration of pasture lands over recent decades, driven by unsustainable grazing practices. The policy relevance of these areas is further shaped by the high exposure of livelihoods to hydro-climatic variability, especially shifts in precipitation patterns, river flows, and water availability, as well as the growing frequency of droughts and extreme rainfall events (6), combined with cross-border dependencies and the transboundary propagation of climate-related hazards.

Outside of cities, these areas are shaped by following key interconnected land-use systems, which together underpin rural livelihoods, agricultural production, and key ecosystem functions across the target regions and in which the programme's focus value chains are embedded.

Table 2: Focus Land-Use Systems and Value Chains

Focus Land-Use Systems and Value Chains	
Land-Use System	Focus Value Chains
Irrigated Annual Cropland	Annual Horticulture (field-grown onions, field-grown and greenhouse tomatoes, field-grown garlic, and greenhouse strawberries); Seed Potatoes
Irrigated Perennial Cropland	Orchard-based fruit production
Rainfed Cropland	Wheat
Pasture	--
Forests	Non-timber Forest Products (Walnuts and Pistachios)

The following paragraphs provide a brief overview of the land-use system characteristics in the programme areas. Further details on the socio-economic context of these land-use systems and value chains are presented in the Feasibility Study (Annex 2a) and the Value Chain Analysis (Annex 2c), respectively. The climatic conditions, associated impacts, and vulnerabilities affecting these landscapes are analysed in the subsequent chapters of this Climate Rationale.

Agriculture remains a key economic sector in the region, employing a substantial share of the workforce across countries in Central Asia (World Bank, n.d.). Irrigated agricultural systems accounted for a large share of arable and permanent cropland in 2020, representing 75% in the Kyrgyz Republic, 72% in Tajikistan, and 83% in Uzbekistan (FAO, 2020). Irrigation also contributes the majority of agricultural production value, with irrigated systems generating an estimated 85% of agricultural gross value added in the Kyrgyz Republic, 82% in Tajikistan, and 98% in Uzbekistan. In addition, more than 60% of each country's grain production is derived from irrigated agriculture (FAO AQUASTAT, 2020). This high dependence underscores the economic significance of irrigation, indicating that the combined impacts of agricultural and hydrological droughts can have substantial consequences for national economies.

Annual irrigated cropland forms the backbone of agricultural production systems in the programme areas and is concentrated in valley floors and irrigated lowlands. Major crops include wheat, cotton, potatoes, vegetables, and fodder crops, with cotton and wheat historically dominating production systems. Irrigated agriculture is the principal form of crop production in Central Asia, reflecting the arid climatic conditions and the strong dependence on managed water supply (Hamidov et al., 2016). These systems are supported by extensive irrigation networks drawing on river systems originating in high mountain regions, which sustain agricultural production across densely populated areas such as the Fergana Valley. Within annual irrigated cropland, the programme focuses in particular on the annual **horticulture** and **potato** value chains (horticultural crops including field-grown onions, field-grown and greenhouse tomatoes, field-grown garlic, and greenhouse strawberries).

Perennial irrigated cropland, including orchards and vineyards, are an important component of agricultural land use in the programme areas, particularly in the Fergana Valley and the lowland regions of Khatlon and Surkhandarya. These systems are typically located in irrigated plains and foothill zones, where favourable climatic conditions and established irrigation infrastructure support fruit and nut production. Common crops include apricot, apple, grape, and pomegranate. Perennial systems are often managed by smallholder farmers and contribute significantly to household incomes due to the higher value of horticultural produce such as grapes. Within perennial irrigated cropland, the programme focuses in particular on the **orchard-based fruit** value chain.

Rainfed cropland is present across both lower and higher elevations, particularly in foothill and upland areas where irrigation infrastructure is limited. These systems rely on seasonal precipitation and are primarily used for cereal production (e.g. wheat), while also contributing to fodder production. However, fodder supply is more predominantly derived from pasture systems, with rainfed cropland playing a supplementary role, particularly in years or areas with favourable rainfall. Across Central Asia, approximately 90% of the land area receives less than 400mm of annual precipitation, which constrains the extent and productivity of rainfed agriculture (Hamidov et al., 2016). As a result, rainfed systems generally play a complementary role to irrigated agriculture, supporting subsistence production and livestock feed in more marginal areas. Within rainfed cropland, the programme focuses in particular on the **wheat** value chain.

Pasture and grassland systems dominate land use across Central Asia, covering approximately 69% of the total land area (Measho et al., 2022). These systems are primarily located in foothill and mountainous zones and form the basis of livestock production, including sheep, cattle, and goats. Livestock-based livelihoods are particularly important in rural areas, where a large share of the population depends on pasture resources. In the Kyrgyz Republic, for example, more than 60% of the overall population relies directly on natural grasslands for their livelihoods (Khazieva et al., 2022). Pastures also provide key ecosystem services, including forage production, carbon storage, and soil stabilization.

Forests cover a relatively small share of land in Central Asia but play an important role in providing ecosystem services and supporting rural livelihoods. Forests are mainly located in mountainous areas and include a range of forest types such as mountain forests and riparian woodlands. In Uzbekistan, forest area accounts for approximately 3.68 million hectares, or about 8.6% of the national territory (FAO, 2024a), while in the Kyrgyz Republic forests cover around 4.6% of the land area (Park et al., 2021). In Tajikistan, where over 90% of the territory is mountainous, forest cover is comparatively low, accounting for less than 3% of the land area, or approximately 563,000ha of forest and other wooded lands (UNECE, 2019). These ecosystems provide goods such as fuelwood and non-timber forest products (walnuts and pistachios, and contribute to soil protection and water regulation, particularly in steep and erosion-prone terrain. Within forest systems, the programme focuses in particular on the **walnut** and **pistachio non-timber forest product** value chains.

Where the analysis later in this climate rationale refers to four land-use-specific Climate Impact Chains, pasture and forest are represented jointly because they function as an interconnected socio-ecological system and climate pressures often propagate directly between them. This distinction does not change the overall land-use logic of the assessment but reflects the way climate impacts and adaptation needs are analysed in the subsequent chapters.

All of these value chains were selected through a multi-criteria analysis based on their economic importance and broad relevance in the programme areas (cf. Value Chain Analysis Annex 2c). This Climate Rationale accordingly takes land-use systems as its primary unit of analysis, as climate hazards and their effects manifest across spatial, ecological, and resource-use systems rather than only within individual crops or products. The selected value chains are addressed within this framework where greater specificity is required for the analysis of vulnerabilities and the presentation of targeted adaptation measures.

3. Methodological Approach

This chapter describes the methodological approach underpinning the Climate Rationale. The assessment combines the IPCC risk framework with qualitative Climate Impact Chains, quantitative climate hazard analysis, geospatial evidence, and stakeholder-based primary information in order to assess how climate hazards translate into impacts and risks across the land-use systems covered by the proposal and to identify corresponding adaptation needs.

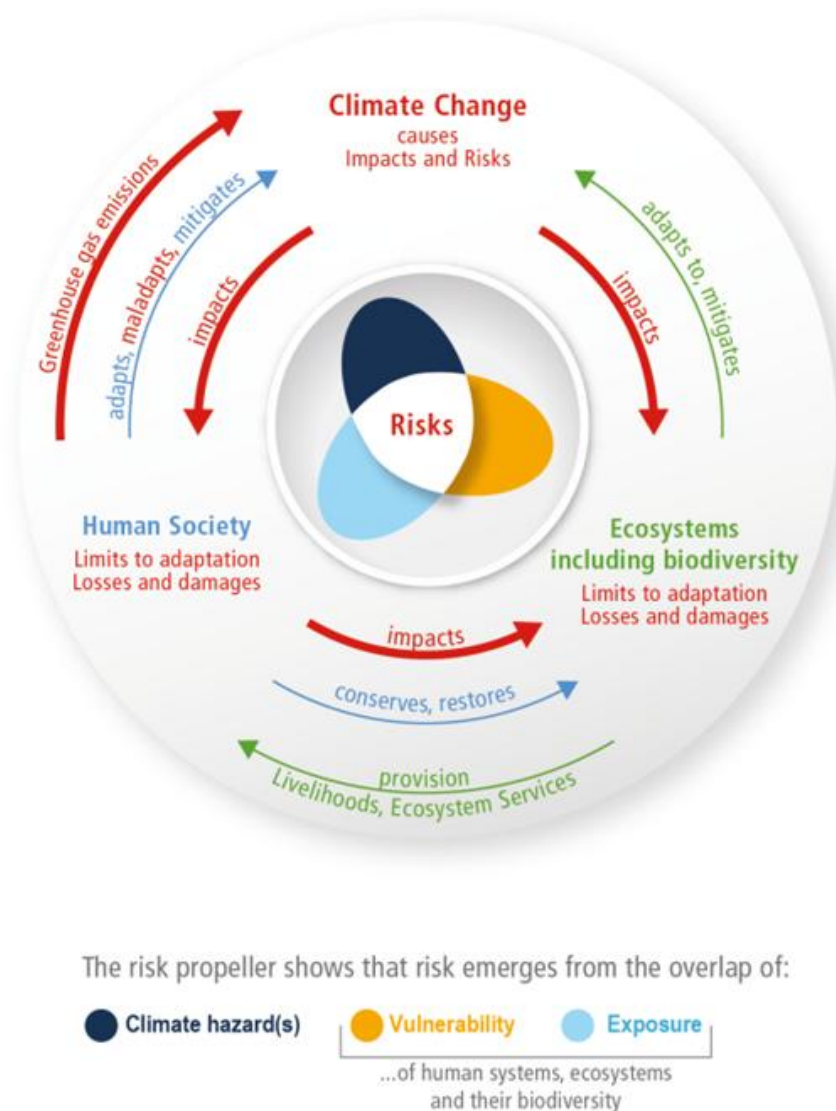
3.1 IPCC Concepts and Definitions

The methodological concepts and definitions applied in this Climate Rationale follow the framing of the Sixth Assessment Report (AR6) of the IPCC Working Group II, as illustrated in Figure 5. As per this conceptual framework, the risk of climate-related impacts is understood as resulting from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems. These concepts are defined as follows (IPCC, 2022):

- **Hazard:** natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- **Vulnerability:** propensity or predisposition to be adversely affected. It encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
- **Exposure:** presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
- **Impacts:** the effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate change or hazardous climate events occurring within a specific period and the vulnerability of an exposed society or system.
- **Risk:** Refers to the possible outcome of the interaction of climate hazards on exposed elements with particular vulnerability. 'The potential for consequences where something of value is at stake and where the outcome is uncertain (...). Risk results from the interaction of vulnerability, exposure and hazard (...).' Higher hazard, exposure and/or vulnerability will lead to higher risk.

As reflected in the figure, risks and their three components are influenced by the climate system, human society and ecosystems, as well as their interactions. Therefore, these aspects need to be considered when assessing the climate risks of a given region, sector, or population.

Figure 5: Core concepts of the IPCC's Working Group II AR6



Source: IPCC, 2022

3.2 Climate Risk Assessment Approach

The assessment of the climate risks for the selected land-use systems and the associated adaptation measures has been carried out with proven and established methodologies. Specifically, GIZ's *Climate Risk Sourcebook* was used to inform the development of **Climate Impact Chains** as a fit-for-purpose tool to understand how cropland, pasture, and forest systems in the programme landscapes are impacted by climate change and how specific adaptation measures would contribute to reducing the resulting climate risk (GIZ, 2023).

The *Climate Risk Sourcebook* delivers a conceptual framework for a comprehensive climate risk assessment together with modular instructions on how it can be conducted. It is an evolution of the original *Vulnerability Sourcebook* (GIZ, 2014) and its supplement, the *Vulnerability Sourcebook Risk Supplement* (GIZ, 2017), which has been applied in more than 20 countries and is cited in ISO 14091. Climate impact chains are the conceptual backbone of the *Climate Risk Sourcebook* and its predecessor documents. They represent a framework for understanding and visualising the causal relationships between changes in the climate and their impacts. These visual representations help to understand the cascading nature of impacts and enable stakeholders to better comprehend how changes in the climate propagate through a social-ecological system with direct and indirect effects.

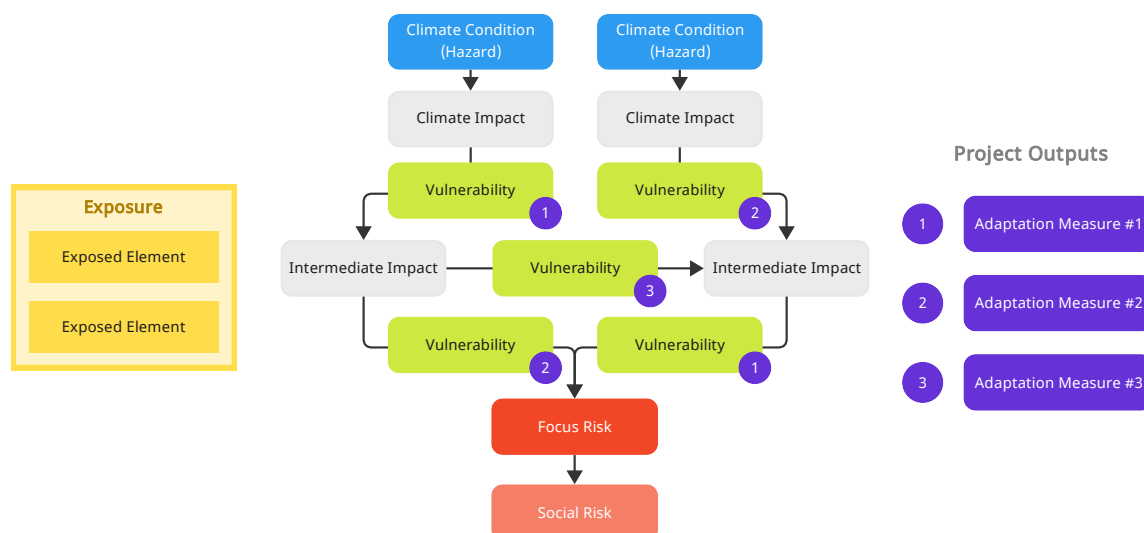
The structure of the Climate Impact Chains applied in this Climate Rationale is aligned with the IPCC AR6 concepts and definitions of climate risk, while adapting the visual logic of the Climate Risk Sourcebook to better represent the more detailed and networked causal relations relevant to interconnected land-use systems (see Figure 6). In contrast to a more linear chain structure, the approach used here shows how multiple climate conditions, cascading impacts, exposure, and vulnerability interact across the systems, and how vulnerabilities also serve as direct entry points for action (GIZ, 2023).

The structure of the Climate Impact Chains includes the following elements:

- **Climate conditions / hazards (blue boxes):** climate-related hazards forming the starting points of the chains.
- **Climate impacts and intermediate impacts (grey boxes):** direct and indirect cascading effects through biophysical and socio-economic systems.
- **Exposure (yellow box):** exposed elements, subsystems, or functions affected by the pathways formed by the cause-effect relations of hazards and impacts as well as between cascading impacts.
- **Vulnerability (green boxes):** sensitivity and adaptive-capacity factors integrated directly into the network wherever they enable or amplify impact pathways.
- **Focus risks (red box):** the resulting climate risk emerging from the interaction of hazards, impacts, exposure, and vulnerability.
- **Social risks (light red box):** consequential risks for people and the overall social system
- **Adaptation measures / programme outputs (purple markers and boxes):** responses linked directly to identified vulnerabilities as entry points for action.

This adapted structure allows the Climate Impact Chains to show not only how climate risks emerge, but also how the proposed measures respond to the vulnerability factors and barriers that drive them. The chains therefore serve both as an analytical tool for understanding climate risk and as a bridge to the programme's adaptation strategy.

Figure 6: Conceptual Climate Impact Chain framework applied across the Climate Rationale



Source: Own illustration

In the concrete case of the present programme, the Climate Impact Chain approach is applied across the two programme areas in Central Asia and across the key land-use systems, namely cropland (rainfed as well as irrigated annual and perennial crops), pasture, and forest land. The chains are used to trace how current and projected climate hazards translate into direct and indirect impacts, how these affect exposed land-use systems and associated functions, and which vulnerability factors shape the

resulting climate risks. While climate hazards are analysed quantitatively, the assessment of climate impacts, vulnerability, and resulting risks is undertaken through qualitative Climate Impact Chains. This qualitative impact modelling is informed by climate and geospatial analysis, existing project documentation, and extensive primary-source evidence from stakeholder consultations, including site-level consultations with land users. These inputs were used to refine and validate the Climate Impact Chains, contextualise the interpretation of modelled hazard signals, and strengthen the identification of practical adaptation entry points.

This assessment is designed to align with current GCF guidance by linking climate hazards, exposure, vulnerability, impacts, and adaptation response within a single line of argument. In particular, it adheres to GCF's four key principles to guide the development of a sound Climate Rationale (GCF, 202a2):

- **Identification:** Demonstrate how current and projected climate hazards lead to specific risks and impacts.
- **Response:** Show how proposed activities reduce climate risks and address implementation barriers.
- **Policy alignment:** Ensure consistency with national climate strategies and development priorities.
- **Monitoring & Evaluation:** Define systems to assess and report climate impacts and effectiveness over time.

The analysis focuses primarily on the identification and response principles, establishing the link between climate risks and adaptation actions. It assesses hazards, exposure, and vulnerabilities across interconnected land-use systems and translates these into impacts and risks. The proposed measures directly address key vulnerabilities and barriers, thereby reducing climate risks. Policy alignments addressed in the Feasibility Study (Annex 2a, Chapter 4); monitoring arrangements are defined in the dedicated Annex 12 "Monitoring and Evaluation Plan".

In addition, the assessment was informed by the technical guidance developed by the GCF's independent Technical Advisory Panel (iTAP), in particular its stepwise approach to strengthening the analytical basis of adaptation Climate Rationales. While the present Climate Rationale is not structured explicitly around the iTAP sequence, the guidance was taken into account in the design of the hazard analysis, the identification of climate impacts and risks, and the articulation of adaptation responses. The approach adopted here is therefore consistent both with the GCF's high-level principles and with the more detailed technical expectations that have emerged from GCF review practice.

3.3 Key Sources of Information

This Climate Rationale is based on a mixed-method evidence base that combines quantitative climate and spatial analysis, programme-specific documentary evidence, and extensive primary-source information generated through stakeholder consultations. In methodological terms, the assessment is semi-quantitative: the Climate Impact Chains represent qualitative causal relations, while key elements of hazards and exposure are informed through quantitative analysis. This combination allows the assessment to connect spatially explicit climate and landscape information with a structured analysis of impacts, vulnerability factors, and adaptation entry points across the land-use systems in scope.

The quantitative component of the assessment is centred on the NEX-GDDP-CMIP6 dataset (Thrasher et al., 2022; NASA, 2025) as the main source of raw climate information for the analysis. It provides the basis for the assessment of historical and projected climate conditions and for the derivation of the hazard indicators used throughout this Climate Rationale. This core climate dataset is complemented by two geospatial datasets used to characterise the physical and land-use context of the programme landscapes. The Copernicus Digital Elevation Model supports the analysis of topographic variation, while the Copernicus Climate Change Service land cover classification dataset is used to represent the spatial distribution of relevant land-use systems. Together, these datasets provide the key quantitative

entry information for the assessment, including the spatial differentiation of hazard patterns and the distribution of cropland, pasture, and forest systems across elevation zones.

These quantitative inputs are complemented by extensive primary-source evidence generated through stakeholder consultations. Workshops conducted in October and November 2025 and February 2026, complemented by smaller site-level consultations with land users in February 2026, were used to validate and refine the Climate Impact Chains, contextualise the interpretation of hazard and exposure patterns, and identify key vulnerability factors, barriers, and adaptation entry points. The assessment also draws on programme documentation and related analytical materials to ensure consistency with the broader proposal logic and supporting annexes. Further details on the consultation process are provided in Annex 7a, Summary of stakeholder consultations. The quantitative datasets and their methodological application are described in greater detail in the next section.

3.4 Climate Modelling Methodology

Quantitative data sources

The quantitative analysis is centred on the NASA NEX-GDDP-CMIP6 Version 2 dataset, which provides daily downscaled climate projections from the CMIP6 archive at 0.25° spatial resolution, equivalent to approximately 25 km at the equator (Thrasher et al., 2022; NASA, 2025). The dataset was selected because it provides daily gridded time series suitable for deriving both mean climate conditions and impact-relevant indices at a scale appropriate for landscape-level analysis. NEX-GDDP-CMIP6 v2 applies statistical downscaling and bias correction to the underlying global climate model output, thereby improving the local usability of projected temperature and precipitation signals while retaining consistency with the broader CMIP6 climate response (Thrasher et al., 2022). The underlying projections are drawn from CMIP6 and its ScenarioMIP framework, which provide the common model and scenario architecture used for current climate-change assessment (Eyring et al., 2016; O'Neill et al., 2016).

To support the spatial interpretation of climate hazards across the programme landscapes, the analysis also uses the Copernicus Digital Elevation Model (DEM), GLO-30 Public, which provides near-global elevation data at approximately 30m spatial resolution (Copernicus Programme, 2021). Here, the dataset is used to characterise topographic variation across the assessment areas and to relate projected climate signals to elevation-dependent landscape conditions. This is particularly relevant in the present context as climatic gradients, water availability, and the distribution of land-use systems vary substantially with elevation and terrain. The DEM therefore supports the spatial differentiation of hazard patterns and their interpretation across lowlands, foothills, and mountain-influenced areas.

In addition, the analysis uses the Copernicus land cover classification gridded maps derived from satellite observations, which include annual land cover information for 2022 (Copernicus Climate Change Service, 2019; updated 2025). This dataset is used to represent the spatial distribution of relevant land-use systems and thereby support the exposure dimension of the assessment. In particular, it helps distinguish the location and extent of cropland, pasture, forest land, and related land-cover classes across the programme landscapes. Combined with the climate and elevation data, the land cover dataset supports the spatial linking of the projected hazard patterns to the land-use systems assessed in the Climate Impact Chains.

To support the analysis of upstream runoff timing, the assessment additionally uses the HydroBASINS dataset, which provides standardized river-basin and sub-basin delineations derived from HydroSHEDS (Lehner & Grill, 2013). The dataset is used to identify the hydrologically connected basin systems relevant to the two programme areas – the Syr Darya upstream basin for the Fergana Valley programme districts and the Amu Darya upstream basin for the Southern Border Region programme districts – including both the programme districts themselves and the upstream areas feeding them. Combined with the climate projections, these basin delineations provide the spatial basis for

aggregating upstream indicators related to warming, snowfall-condition precipitation, and snow share, which are used in 6.8 as proxy indicators for likely changes in seasonal snow storage and runoff timing.

Treatment for local conditions

To strengthen relevance for the programme area, climate indicators are first calculated at grid-cell level and then spatially aggregated to the analysis zones using area-weighted averaging. This allows the results to reflect the distribution of climatic conditions across the target geography rather than relying on single-point extraction. In addition, the model ensemble was restricted to 20 CMIP6 models¹ that provide the full set of variables required for the analysis across the historical period and both future scenarios used here, namely air temperature, minimum and maximum temperature, precipitation, wind speed, and relative humidity. As a further screening step, only models whose historical precipitation patterns are reasonably consistent with observed spatial and seasonal precipitation characteristics in the programme area were retained. This approach improves the robustness of the derived indicators, particularly for precipitation and drought-related analysis, while preserving a sufficiently broad ensemble of plausible futures.

Periods and scenarios

The analysis considers one historical baseline period, 1991–2010, and two future time slices, 2040–2059 and 2080–2099. These periods are used to assess both medium-term and longer-term change relative to recent historical conditions. Future projections are evaluated under two emissions pathways: SSP2-4.5, representing an intermediate emissions trajectory, and SSP5-8.5, representing a high-emissions trajectory (O'Neill et al., 2016). For the calculation and standardization of SPEI-3, the reference period is 1981–2010 in order to provide a stable climatological baseline for estimating the monthly distribution of climatic water balance.

Treatment of uncertainty

Projected changes are assessed using the ensemble of 20 climate models (see above) in order to reflect structural uncertainty across the CMIP6 model set. For each indicator, the central estimate is represented by the ensemble median. Uncertainty within each scenario is summarized using the 16.7th and 83.3rd percentiles as lower and upper estimates, respectively. This defines an interval containing approximately two thirds of model outcomes within a given scenario and corresponds to the “likely range” terminology commonly used by the IPCC. Presenting results in this way allows the analysis to show not only the most representative projected change, but also the spread of plausible outcomes relevant for climate-risk screening and adaptation planning.

Indicators and indices

The analysis applies a small set of indicators to describe the climate conditions and hazards most relevant to land-use systems in the programme area. The selection is intended to capture both gradual climatic shifts and the main extremes likely to affect agricultural production, pasture and rangeland condition, soil stability, and seasonal water availability. It draws on established approaches used in climate-impact assessment, including the ETCCDI framework for precipitation extremes and the SPEI framework for drought analysis (Alexander et al., 2006; Zhang et al., 2011; Vicente-Serrano et al., 2010; Beguería et al., 2014).

The selection is intended to capture not only gradual shifts in mean climate conditions and the main extremes, but also changes in the seasonal timing, concentration, and short-term variability of hazards that are critical for AFOLU systems. For land-use systems in the programme areas, when a hazard occurs within the year can be as important as how strongly it changes in annual terms.

¹ ACCESS-CM2, ACCESS-ESM1-5, CMCC-ESM2, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, EC-Earth3-Veg-LR, FGOALS-g3, GISS-E2-1-G, INM-CM5-0, IPSL-CM6A-LR, MIROC-ES2L, MIROC6, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRI-ESM2-0, NorESM2-LM, NorESM2-MM, TaiESM1, UKESM1-0-LL

Mean temperature. Long-term warming is represented by annual mean near-surface air temperature. This indicator provides a measure of the underlying shift in baseline climatic conditions relevant to crop suitability, evapotranspiration demand, snow and melt dynamics, and the broader agroecological conditions within which land-use systems operate. It is used to assess the extent to which the programme area is expected to move towards a warmer climate regime over time.

Extreme heat. Extreme heat is represented by the annual number of days with daily maximum temperature at or above 35°C. This threshold is used as an indicator of agriculturally significant heat stress affecting crops, pasture systems, livestock, and outdoor work. In the context of land-use systems, an increase in very hot days is an important signal of growing exposure to heat-related productivity losses and higher moisture demand.

Hot, dry and windy conditions. To reflect compound conditions that can intensify land degradation, the analysis also includes an indicator for hot, dry and windy days. A day is counted where three conditions occur at the same time: daily maximum temperature is at least 35°C, daily precipitation is below 1 mm, and daily wind speed exceeds the local 90th percentile of the reference-period wind distribution. While this is not a standard index from the climate-extremes literature, it provides a clear and relevant proxy for conditions associated with rapid soil drying, crop desiccation, and wind erosion. This is particularly pertinent in dryland environments and exposed agricultural landscapes in Central Asia.

Seasonal precipitation patterns. Precipitation conditions are represented through monthly and seasonal total precipitation. Seasonal reporting is emphasized because, for land-use systems, the timing and distribution of rainfall across the year are often more important than annual totals alone. This indicator is therefore used to assess how water availability may shift across the agricultural calendar, including implications for planting conditions, growing-season moisture supply, recharge, and runoff generation. The treatment of precipitation-related indicators is consistent with the ETCCDI family of indices widely used in climate-impact assessment and IPCC-related analysis (Alexander et al., 2006; Zhang et al., 2011).

Drought conditions. Drought is assessed using the Standardized Precipitation Evapotranspiration Index at a 3-month timescale. This timescale is appropriate for capturing short- to medium-term moisture anomalies relevant to cropping systems, pasture condition, and seasonal water availability (Vicente-Serrano et al., 2010; Beguería et al., 2014). SPEI is based on climatic water balance, defined as precipitation minus potential evapotranspiration, and reflects not only rainfall deficits but also the effect of increasing atmospheric evaporative demand. Potential evapotranspiration is here estimated using a Penman-Monteith-type approach consistent with FAO-56 principles (Allen et al., 1998). In methodological terms, SPEI-3 is represented as:

$$D_m = P_m - PET_m$$

$$D_m^{(3)} = \sum_{i=0}^2 D_{m-i}$$

$$SPEI3_m = \Phi^{-1}\left(F_{LL}\left(D_m^{(3)} + s\right)\right)$$

where P_m is monthly precipitation, PET_m is monthly potential evapotranspiration², $D_m^{(3)}$ is the 3-month accumulated climatic water balance, F_{LL} is the cumulative log-logistic distribution fitted separately for each calendar month over the reference period (here 1981-2010), (s) is a non-negative shift applied

² Potential evapotranspiration was estimated using a simplified Penman-Monteith approach based on the climate variables available in the dataset (mean, minimum and maximum air temperature, relative humidity, surface wind speed, incoming short- and longwave radiation and elevation – hence vapor pressure, pressure, and net radiation needed to be derived from the available fields using standard approximations assuming a fixed reference-crop albedo of 0.23.

where required for stable fitting, and Φ^{-1} is the inverse standard normal distribution (Vicente-Serrano et al., 2010; Beguería et al., 2014).

A concise interpretation is that SPEI values below 0 indicate drier-than-normal conditions, values below -1 indicate drought, values below -2 indicate severe to extreme drought, and values below -3 indicate exceptionally extreme drought; conversely, values above 0 indicate wetter-than-normal conditions.

Heavy rain. Heavy rainfall is represented by **R20mm**, defined as the number of days with daily precipitation of at least 20 mm. R20mm is a standard ETCCDI precipitation-extreme index and is used here as a direct measure of the frequency of intense rainfall events. It is relevant for assessing risks of flash flooding, erosive runoff, gullying, sediment mobilisation, localized waterlogging, and damage to agricultural land and rural infrastructure. It is included because it is methodologically robust, widely used, and readily understandable in the context of proposal appraisal (Alexander et al., 2006; Zhang et al., 2011).

Upstream runoff shift. For the assessment of upstream runoff shift, snowfall-condition precipitation is defined as precipitation occurring on days with mean daily temperature below 0°C, and snow share as the share of such precipitation in total precipitation. Together with projected warming, these indicators are used as proxy measures for likely changes in seasonal snow storage and runoff timing in the hydrologically connected upstream basins. Note that this is an interpretive proxy analysis rather than a hydrological discharge model.

Limitations

The analysis provides a robust basis for climate-risk screening, but several limitations should be noted. Despite bias correction and downscaling, the climate data remain relatively coarse for complex terrain and cannot fully capture local topographic effects or microclimates. Projected changes also remain uncertain, particularly for precipitation, wind, and compound extremes, due to differences among models, scenarios, and downscaling methods. In addition, the selected indicators are simplified representations of hazard conditions and do not fully reflect local soil conditions, hydrology, irrigation, land management, or socioeconomic vulnerability. The modelling therefore informs the climate hazard dimension of the Climate Rationale, while the qualitative assessment of impacts and vulnerability in the following chapters remains essential to understanding overall climate risk and adaptation needs.

4. Problem Statement: Climate Risk

This chapter formulates the overarching climate risk that the programme is intended to address across the intervention areas. While each land-use-specific Climate Impact Chain identifies a distinct climate risk, many of the resulting implications are shared across the interconnected Agriculture, Forestry and Other Land Uses (AFOLU) systems of the programme landscapes. The purpose of this chapter is therefore to synthesise these common implications into a single programme-level problem statement. This overarching risk is subsequently unpacked in the following chapters through the separate analysis of exposure (5), climate hazards (6), climate impacts (7), vulnerabilities (8), and the proposed adaptation response (9).

Across the programme areas, rising temperatures, changing precipitation patterns, intensifying drought conditions, and more frequent extreme weather events are expected to increase pressure on transboundary AFOLU systems. Because these systems are interconnected across elevation zones and along upstream-downstream gradients, climatic pressures in one part of the landscape can propagate into others, particularly through effects on water availability, land productivity, pasture condition, and forest ecosystem functions.

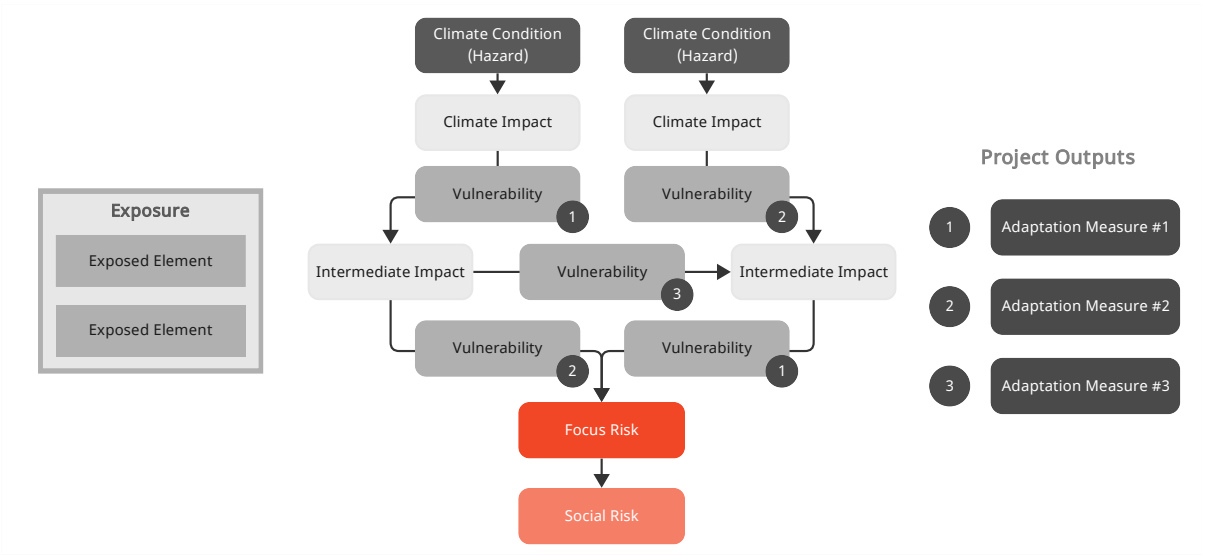
At programme level, this results in an increasing risk of declining agricultural productivity, reduced pasture carrying capacity, and degradation of forest and ecosystem functions, with associated consequences for rural livelihoods, income security, and resilience. These risks are further aggravated by underlying vulnerabilities, including land degradation, constrained water availability, weakened ecosystem integrity, limited access to finance and climate information, weak institutional support, and insufficient adoption of sustainable land management practices.

Table 3: Problem Statement

Problem Statement
Transboundary AFOLU systems and the rural populations that depend on them in the programme areas face increasing climate risk of - declining agricultural productivity, - reduced pasture carrying capacity, and - degradation of forest and ecosystem functions, driven by - rising temperatures, - changing precipitation patterns, and - increasing frequency and intensity of droughts and extreme weather events, and aggravated by - land degradation and weakened ecosystem integrity, - constrained water availability, and - limited adaptive capacity, access to information and finance, and institutional support.

This programme-level risk is unpacked analytically through Chapters 5 to 8 and addressed through the adaptation logic presented in 9. Figure 7 below highlights the focus risk within the conceptual Climate Impact Chain framework. It illustrates how land-use-specific hazard, impact, and vulnerability pathways converge into a broader climate risk that provides the rationale for the programme response.

Figure 7: Conceptual Climate Impact Chain framework applied across the Climate Rationale - resulting risks and problem statement

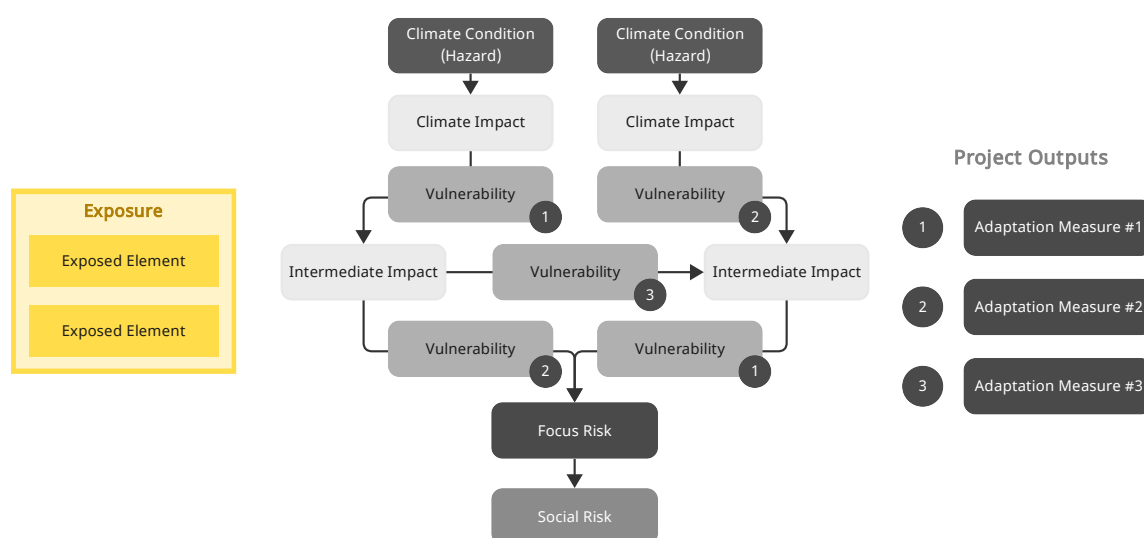


Source: Own illustration

5. Exposure

Within climate risk assessment, exposure is one of the three core components of climate risk, together with hazards and vulnerability. Climate risk results from the interaction of these components and describes the potential for adverse consequences for human and ecological systems (GIZ, 2023). In this context, exposure refers both to the elements at risk (exposed elements) and to their spatial distribution. The land-use-specific Climate Impact Chains therefore distinguish between different exposed elements (Figure 8). This chapter focuses on the identification of exposed elements, their spatial distribution, and their social dimensions.

Figure 8: Conceptual Climate Impact Chain framework applied across the Climate Rationale - exposure



Source: Own illustration

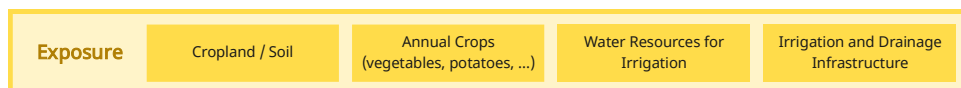
Building on this concept, the exposure of the five key land-use systems in the programme areas reflects the spatial distribution and interconnection of climate-sensitive systems across vertically structured mountain-valley landscapes. Irrigated annual and perennial crops, rain-fed agriculture, pasture systems, and forest landscapes are not only widespread across the region but also functionally interconnected through hydrological and ecological processes. Their exposure is therefore both direct, due to their physical location in hazard-prone environments (e.g. drought-prone lowlands or landslide-prone uplands), and systemic, as interdependencies across elevation zones transmit climate impacts across the landscape. In addition, the degree of exposure is amplified by the high concentration of rural populations and livelihoods that depend on these systems, as well as by transboundary dynamics that complicate coordinated management of shared water and land resources. As a result, exposure in this context is not static but shaped by the distribution, intensity, and interconnectedness of land-use systems and the socio-economic assets they support, forming a critical determinant of overall climate risk.

The Climate Impact Chains identify the key exposed elements across the main land-use systems in the programme area. In irrigated cropland systems, exposure includes soils, crops, water resources, and irrigation infrastructure, while rainfed systems depend primarily on cropland, crops, and rainfall-related infrastructure. Forest and pasture systems are exposed through forest and pastureland, livestock, water points, and supporting infrastructure. Together, these elements represent the critical resources underpinning agricultural production, ecosystem services, and rural livelihoods, and form the basis for understanding how climate hazards translate into impacts across interconnected land-use systems.

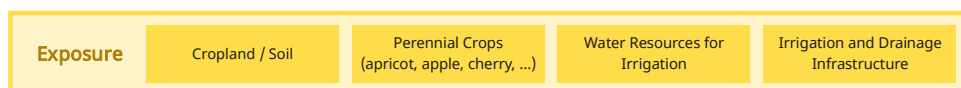
The chapter proceeds in two steps: it first identifies the exposed land-use systems and their spatial distribution across the programme landscapes and then considers the population groups whose livelihoods are most directly tied to those exposed systems.

Figure 9: Exposed Elements from the Climate Impact Chains (cf. Chapters 7 and 8)

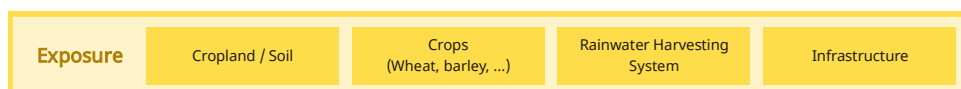
Irrigated Cropland -annual.



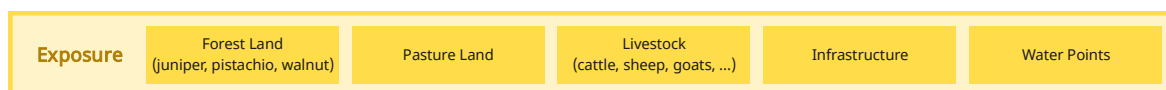
Irrigated Cropland -perennial.



Rainfed Cropland



Forests and Pasture Land



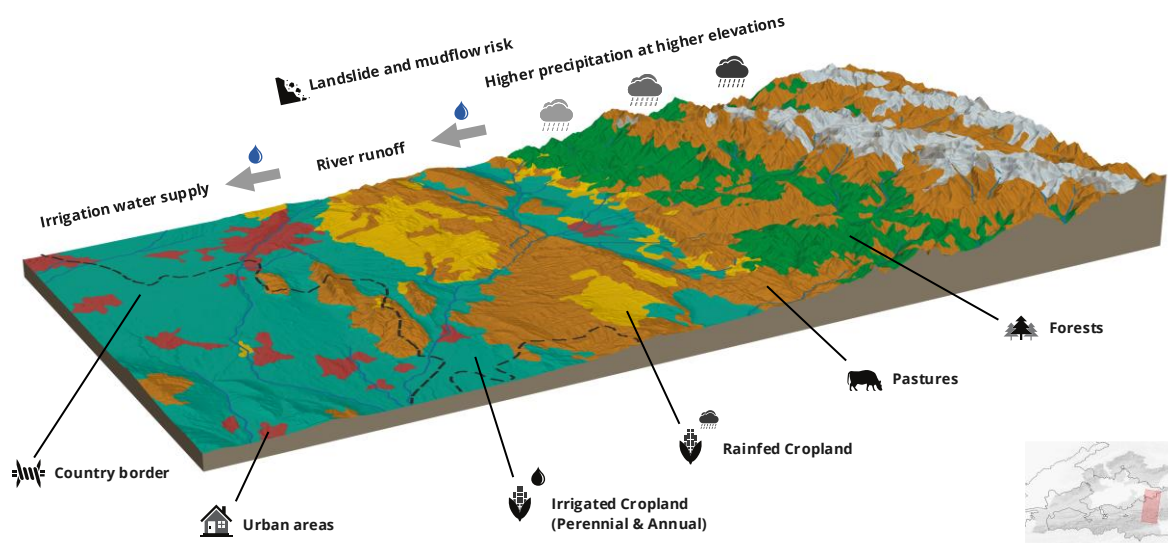
Source: Own illustration

Key land-use systems – irrigated cropland (perennial and annual), rainfed cropland, forests, and pastures – as exposed elements play a central role in shaping climate risk across the programme area. Understanding their spatial distribution is therefore critical for assessing risk. The next step examines where these exposed elements are located in relation to hazard-prone areas.

Figure 9 should be read as the bridge between the abstract concept of exposure and the concrete system analysis in Chapter 7. It shows that exposure in this rationale is not limited to land area alone but includes the productive resources and infrastructure through which climate hazards affect each land-use system differently. The next step therefore examines where these exposed systems and functions are concentrated across the programme landscapes.

The five key land-use systems are distributed along vertically connected landscapes (see Figure 10 for a schematic overview), ranging from lowland areas dominated by irrigated crop production (both annual and perennial crops) to foothill zones where irrigated, rainfed agriculture and pastures coexist, followed by mid-elevation pastures used for livestock grazing, and upper mountain forests that provide essential ecosystem services. These zones are closely linked through hydrological interdependence, as downstream agricultural areas depend on water resources originating in upstream catchments. At the same time, national borders intersect these landscapes, often complicating coordinated national resource management and land-use governance across the transboundary system.

Figure 10: Vertical geography scheme typical for the programme area (exemplarily for the area around Nookat, Kyrgyz Republic; land use data has been smoothed for presentation)

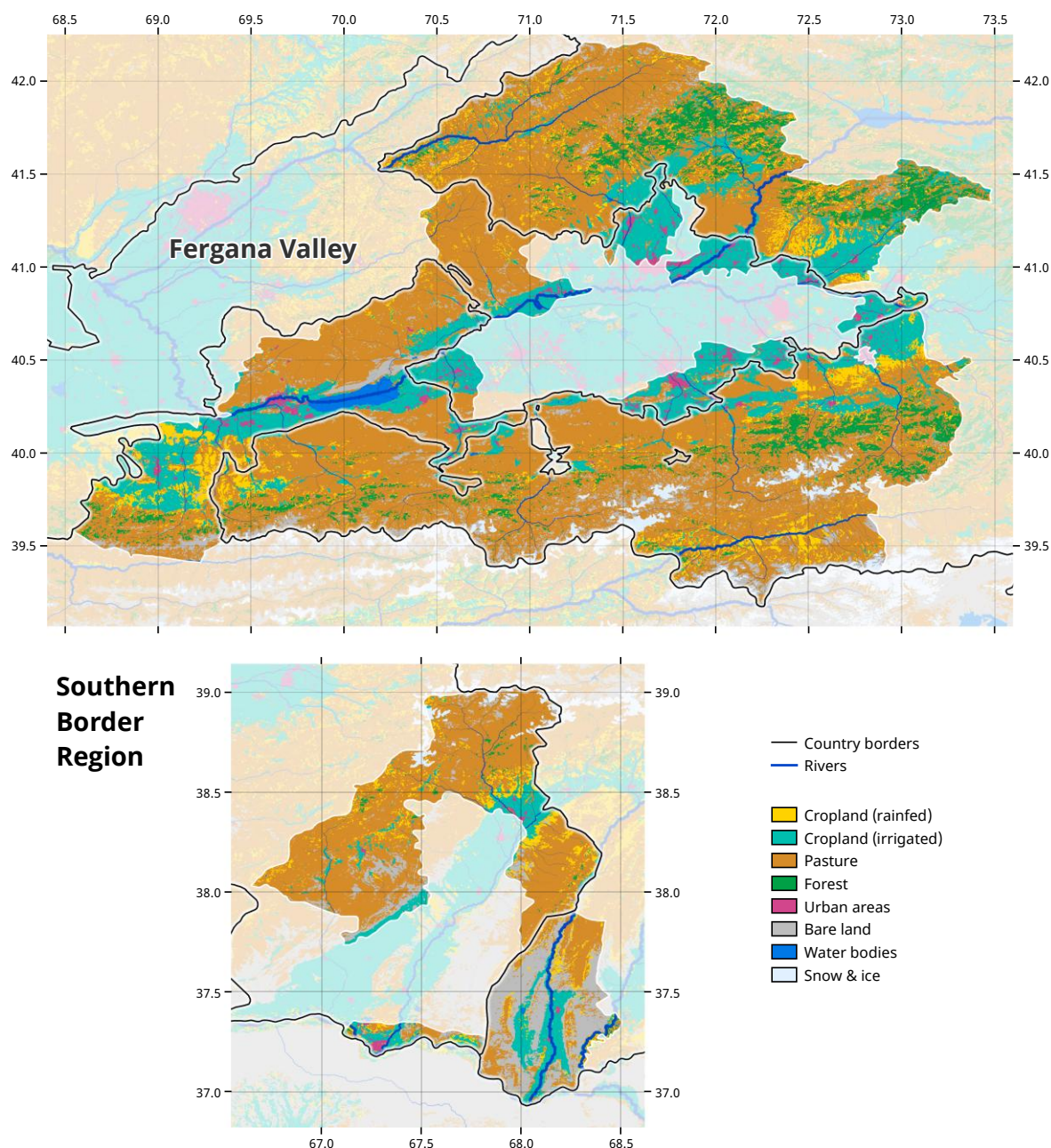


Source: Own illustration based on Copernicus Climate Change Service, 2019

Spatial Distribution of Key Land-use Systems

Figure 11 presents the spatial distribution of major land-use systems across the programme areas, offering a detailed view of how these systems are arranged within and across the Fergana Valley (top) and the Southern Border Area (bottom). The maps illustrate the relative extent and geographic concentration of irrigated and rainfed cropland, pasture/grassland, and forest, as well as other land-cover types such as urban areas and water bodies. This spatial representation helps to identify areas of intensified agricultural use, zones dominated by extensive land management, and regions where natural vegetation remains prominent. By visualizing these patterns, the figure provides an important basis for analysing how climate variability may affect different land-use systems depending on their location and resource conditions, particularly in relation to water availability and land-use intensity. It should be noted that the dataset is derived from satellite observations, and the differentiation between irrigated and rainfed cropland reflects historical estimates rather than current operational distinctions.

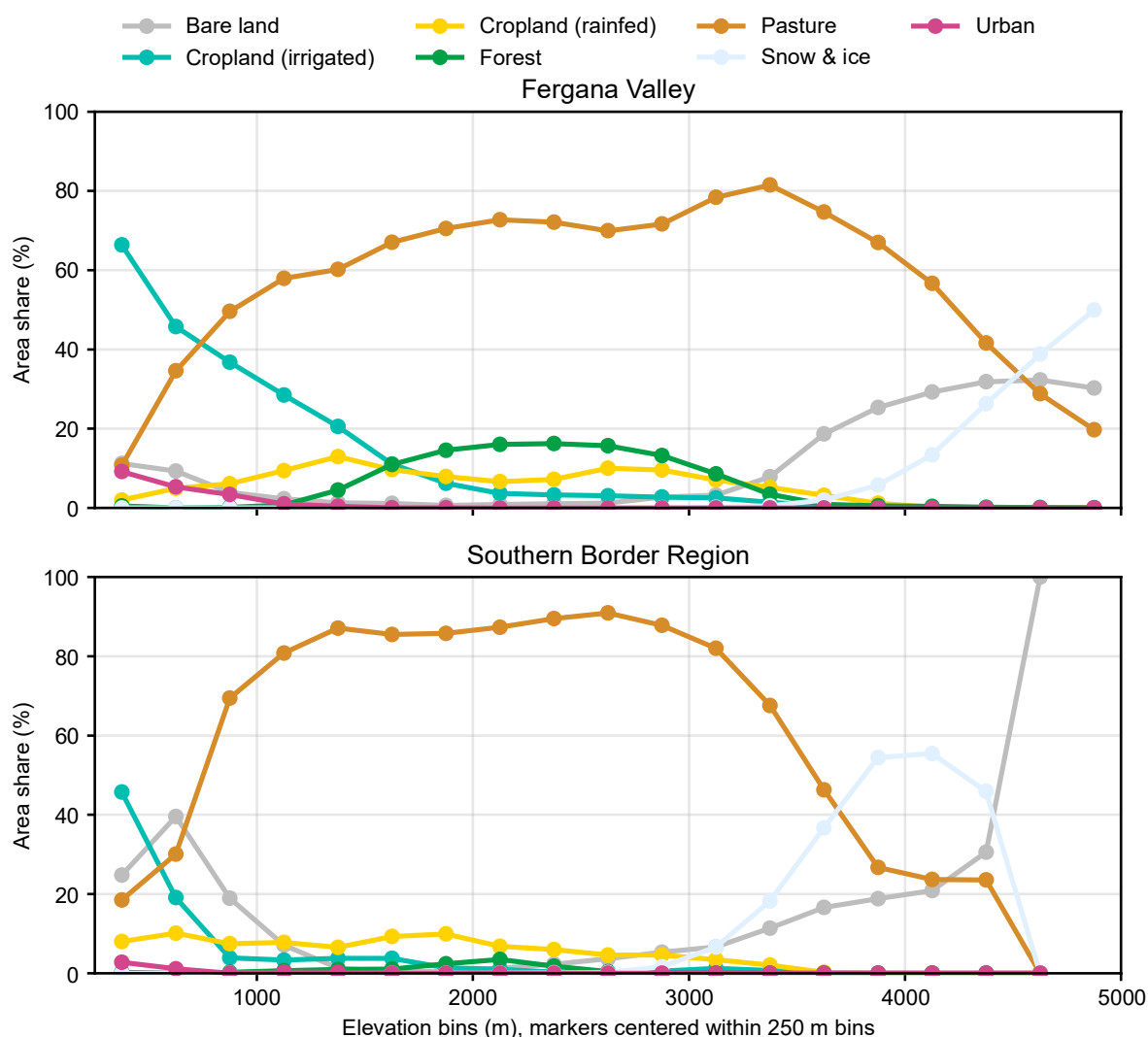
Figure 11: Land use distribution in the programme areas (Top: Fergana Valley; Bottom: Southern Border Area). (Note that the dataset is based on satellite observations and differentiation between irrigated and rainfed schemes for cropland are only historic estimates.)



Source: Own illustration based on GADM, 2022 and Copernicus Climate Change Service, 2019

Figure 12 shows how land-use systems vary across elevation gradients in the Fergana Valley and the Southern Border Region. In both areas, irrigated cropland is concentrated at lower elevations, reflecting favourable conditions for agriculture and access to water. With increasing elevation, the share of pastures becomes dominant, indicating a shift towards livestock-based systems. Forests in the Fergana Valley are primarily found at elevations between 1,500m and 3,500m. These patterns highlight the strong relationship between elevation, land-use distribution, and resource availability, and illustrate how different land-use systems are exposed to climate hazards along the elevation gradient.

Figure 12: Distribution of major land-use systems across elevation gradients in the Fergana Valley and Southern Border Region (share of area for each 250m elevation bin)



Source: Own illustration based on GADM, 2022, and Copernicus Climate Change Service, 2019

Analytically, Figure 12 is central because it shows that the relevant land-use systems do not overlap evenly across the landscape. Instead, the main climate-risk interactions are structured by elevation: lower-elevation hazards fall most directly on irrigated systems, while foothill and upland hazards are more closely associated with rainfed cropland, pasture, and forests.

Land-use patterns in the programme areas are strongly dominated by AFOLU systems, which account for the majority of the landscape. Pastures represent the largest share (approximately 58–61%), making them the dominant land-use system, while cropland systems - both irrigated and rainfed - constitute a further 20-67% and form the main production base. Forests cover a smaller share of the area but play a critical ecological role.

Consistent with these patterns, land-use distribution across the programme areas is strongly structured by elevation, as shown in Table 4: Area and share of land-use systems by elevation (below/above 1,500m) in the programme areas. Pastures are present across nearly all elevation levels and dominate particularly at higher elevations, while irrigated cropland is concentrated in lower zones, especially in the Fergana Valley. Rainfed cropland is more evenly distributed but remains limited in extent. Forests are primarily located at higher elevations, particularly in the Fergana Valley, whereas their presence in the Southern Border Region is comparatively limited. In contrast, the share of bare land increases with

elevation and is more pronounced in the Southern Border Region. These patterns illustrate how elevation shapes the spatial distribution of land-use systems and their exposure to climate hazards across the programme areas.

Table 4: Area and share of land-use systems by elevation (below/above 1,500m) in the programme areas

Land-use System / Programme Area	Area of Land-use System in ha and share of total area in %					
	Area of Land-use system in the Fergana Valley (only programme districts)			Southern Border Region between Uzbekistan and Tajikistan		
	Below 1,500m	Above 1,500m	Across all elevation	Below 1,500m	Above 1,500m	Across all elevation
Irrigated Cropland	1,138,053 (16.5%)	143,879 (2.1%)	1,281,932 (18.6%)	146,844 (11.9%)	5,613 (0.5%)	152,457 (12.3%)
Rainfed Cropland	205,569 (3.0%)	261,401 (3.8%)	466,970 (6.8%)	65,700 (5.3%)	27,080 (2.2%)	92,780 (7.5%)
Forests	31,277 (0.5%)	394,805 (5.7%)	426,082 (6.2%)	2,426 (0.2%)	5,798 (0.5%)	8,224 (0.7%)
Pastures	1,258,433 (18.3%)	2,745,394 (39.9%)	4,003,827 (58.1%)	391,202 (31.6%)	357,043 (28.9%)	748,245 (60.5%)
(Bare land)	162,890 (2.4%)	275,385 (4.0%)	438,275 (6.4%)	178,994 (14.5%)	17,691 (1.4%)	196,685 (15.9%)

Source: Calculation based on Copernicus Climate Change Service, 2019

Given the distribution of land-use systems across climatic zones, the analysis focuses on those areas of the programme where each system is present. Irrigated cropland (annual and perennial) is primarily analysed in lower elevations (below 1,500m), where it represents the dominant and most productive agricultural system. Rainfed cropland and pasture systems are considered across both lower and higher elevations, reflecting their broad spatial distribution under varying climatic conditions, with some areas exhibiting seasonal or spatial overlap between the two land uses. Forest landscapes are mainly analysed in higher elevations (above 1,500m), where they play a key role in ecosystem services. This system-based differentiation ensures that the analysis captures the most relevant land-use systems in relation to their spatial distribution and exposure to climate hazards.

The land-use data presented in Table 4 are derived from remote sensing-based gridded datasets, which allow for a consistent spatial differentiation of land-use systems across elevation zones. For forest systems, these data are complemented by national administrative records in Table 5. A total of 25 State Forest Enterprises (SFEs) were selected across the programme areas based on criteria aligned with the district selection process. In addition, consultations with national forest administrations were conducted to reflect current forest management practices and planned expansion targets, ensuring the programme's additionality. The table below provides an overview of the selected SFEs, including their total area and forest cover.

Table 5: Selected State Forest Enterprises (SFEs) in the programme areas

Country	Region	State Forest Enterprise	Total SFE territory (ha)	Forest area (ha)
	Jalal-Abad	Arstanbap	18,917	9,673

Country	Region	State Forest Enterprise	Total SFE territory (ha)	Forest area (ha)
Kyrgyz Republic		Kyzyl-Unkur	56,150	29,643
		Aksy	62,589	41,303
		Ala-Buka	49,828	30,448
		Chatkal	35,482	16,255
	Batken	Batken	162,410	59,516
		Leilek	110,236	54,578
		Arka	51,147	14,762
		Uch-Korgon	111,583	56,056
	Osh	Kara-Kulja	74,295	18,735
		Nookat	94,237	32,007
Tajikistan	Sughd	Asht	64,470	11,643
		Devashtich	55,970	9,347
		Shahriston	47,175	22,931
	Khatlon	Qobodiyon	28,565	10,628
		Shahritus	407	193
		Nosiri Khusrav	18,548	599
Uzbekistan	Andijan	Andijon	10,540	3,766
	Fergana	Kokand	12,629	5,762
		Fergana	7,061	6,339
	Namangan	Pap	133,712	15,940
		Kasansay	4,143	1,255
	Surkhandarya	Uzun	106,365	28,395
		Boysun	119,452	72,052
		Babatag	65,732	46,878

Source: Forest administrations of the Kyrgyz Republic, Tajikistan and Uzbekistan

Social Dimensions of Exposure and Livelihood Dependence

Climate risks in the programme areas are not experienced uniformly but are shaped by underlying socio-economic conditions that influence which groups are most directly exposed to climate impacts. In the Fergana Valley and the Southern Border Region, livelihoods are closely tied to climate-sensitive land-use systems, making certain population groups particularly exposed to climate impacts. The programme specifically targets smallholder farmers, livestock-dependent households, forest users, and other local actors within focus landscapes due to two main factors: i) the strong dependency of rural livelihoods and local economies on climate-sensitive land-use systems, and ii) the high exposure of

these groups to climate variability and extreme events across vertically interconnected mountain–valley landscapes.

Additional key groups include women-led farming households and youth. These groups face distinct but interrelated constraints that affect their ability to anticipate, respond to, and recover from climate-related stresses. The vulnerability implications of these constraints are examined further in Chapter 8. For a more detailed assessment of gender and social dimensions, please refer to the Gender Assessment and Action Plan (Annex 8 of the Funding Proposal).

Across land-use systems, these social dimensions of exposure are closely linked to dependence on natural resources and the structure of local economies. In irrigated cropping systems, smallholder farmers are highly dependent on reliable water access and functioning infrastructure. Limited financial resources and restricted access to credit constrain their ability to invest in improved irrigation technologies, inputs, and climate-resilient practices. In rainfed systems, this dependence is compounded by limited diversification options and high sensitivity to rainfall variability, increasing the risk of income instability. In pasture and forest systems, these dynamics are linked to limited management capacity, restricted access to resources, and weak institutional support, which reduce the ability of land users to respond to degradation and climate pressures. These factors are taken up more systematically as vulnerability drivers in Chapter 8.

Smallholder farmers represent a primary group of concern, as they form the backbone of agricultural production in the programme areas while relying directly on climate-sensitive land and water resources for their livelihoods. The sector is a major employer, accounting for an estimated 42.6% of total formal employment in Tajikistan, 23.9% in Uzbekistan, and 16.6% in the Kyrgyz Republic in 2021 (FAO, 2024c). The prevalence of smallholder and household farming systems makes agriculture central to rural livelihoods, with around 60% of the region’s population directly dependent on agricultural activities as their primary source of income (UNCCD, 2023).

Smallholder farmers are particularly vulnerable because their livelihoods depend heavily on local environmental conditions, while their capacity to absorb and respond to shocks is limited. Production systems are often characterized by small landholdings, limited diversification, and high dependence on seasonal rainfall or reliable irrigation, making them highly sensitive to climate variability such as droughts, heat stress, and water scarcity. At the same time, limited financial resources and restricted access to credit constrain their ability to invest in improved technologies, inputs, and climate-resilient practices.

Additional constraints include limited access to extension services and climate information, as well as persistent knowledge gaps, which reduce the ability to anticipate and respond to changing conditions. Labour shortages due to outward migration further weaken adaptive capacity, particularly in labour-intensive systems such as irrigated horticulture and pasture management. Together, these factors reduce the capacity of smallholder farmers to manage risks, recover from climate-related losses, and make longer-term investments, thereby increasing their overall vulnerability to climate change.

Women-led farming households constitute a distinct group of concern, particularly in contexts where male outmigration is significant, such as in Tajikistan and parts of the Kyrgyz Republic. Female-headed households account for approximately 20–30% of all households, with higher shares in rural areas (World Bank, 2024b). While women often assume increased responsibility for farm management in the absence of male household members, their decision-making power and access to resources remain constrained. In many cases, women face limited access to land ownership, credit, extension services, and agricultural inputs, as well as legal and institutional barriers that restrict their participation in cooperatives and governance structures. These constraints are particularly pronounced in irrigated systems, where access to water and infrastructure is often mediated through formal or informal institutions, and in pasture systems, where access to grazing resources may be regulated through community-based arrangements. As a result, women-led households often face higher workloads while having fewer means to adapt effectively to climate risks.

Youth constitute another important group of concern. In Central Asia, over 50% of the population is under the age of 30, reflecting a rapidly growing labour force that will shape the region's economic future (UNICEF, 2025). This demographic dynamic creates both opportunities and pressures, as the need for viable livelihood opportunities increases demand on land-based production systems. However, young people face significant barriers to engagement in sustainable land-use systems, including limited access to land, finance, education, and employment opportunities. These constraints are particularly pronounced in rural areas, where economic opportunities remain limited. In irrigated and rainfed cropping systems, restricted access to land and capital limits entry into farming, while in pasture and forest systems, weak institutional inclusion reduces opportunities for participation in resource management. As a result, many young people disengage from agriculture, contributing to rural outmigration and a declining labour base, which in turn undermines the long-term sustainability and adaptive capacity of land-use systems.

At the same time, these groups also possess important forms of adaptive capacity that can be built upon. Smallholder farmers often have strong local knowledge of climatic variability and land management practices, which can support the adoption of climate-resilient techniques when combined with appropriate technical and financial support. Women play a central role in farm and household management and can act as key agents of change when barriers to resource access and decision-making are addressed. Similarly, youth represent a critical source of labour, innovation, and entrepreneurship, particularly in the adoption of new technologies and practices. Strengthening these existing capacities - through improved access to knowledge, finance, and institutional support - provides a key entry point for enhancing resilience across land-use systems.

These constraints across groups are often interconnected and overlapping, resulting in compounded and mutually reinforcing disadvantages. For example, women within smallholder farming households may face simultaneous constraints related to limited access to land, finance, and decision-making power, particularly in contexts of male outmigration. Similarly, young people in smallholder households may encounter barriers to accessing resources and employment, limiting their ability to engage in productive and sustainable land-use systems. These overlapping constraints are expressed differently across land-use systems: in irrigated systems through unequal access to water and infrastructure, in rainfed systems through limited diversification and high climate sensitivity, and in pasture and forest systems through restricted access to communal resources and weak institutional representation. In this way, the social dimensions considered here help identify which groups are most directly exposed through their dependence on climate-sensitive land-use systems and where climate impacts are likely to be experienced most acutely. Chapter 8 builds on this by examining these constraints more systematically as vulnerability factors relevant to adaptation.

6. Climate Hazards

This chapter presents the analysis of observed and projected climatic hazards in the programme areas, with a focus on those hazards most relevant to the key land-use systems, water availability, ecosystem stress, and climate-sensitive livelihoods. In addition to changes in the magnitude of hazards, it also considers shifts in their seasonal timing and within-year concentration, as these are critical for interpreting exposure of irrigated, rainfed, pasture, and forest systems.

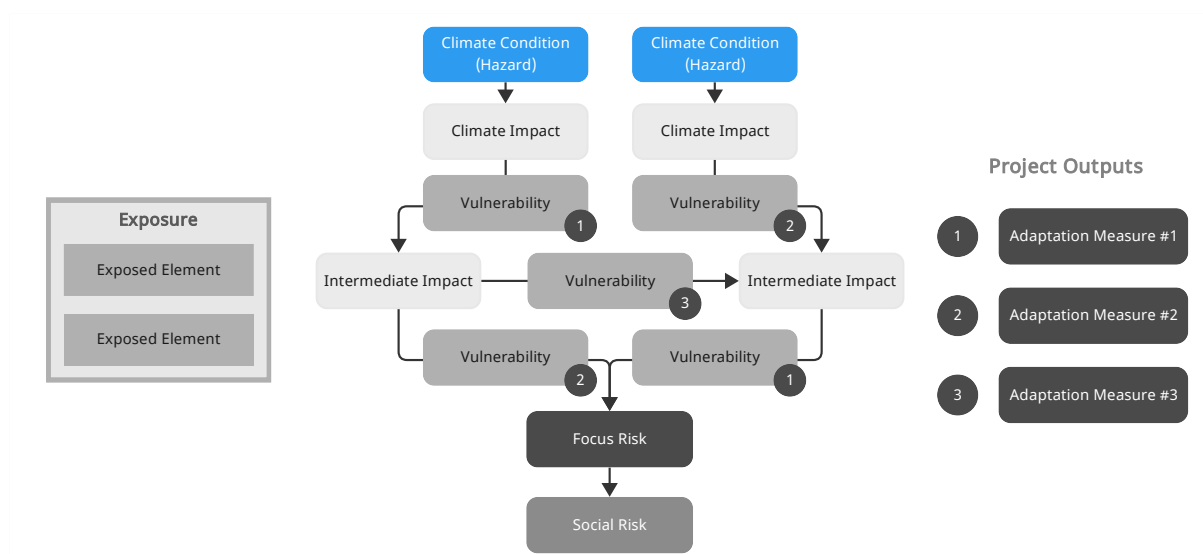
The chapter thereby addresses the hazard component of the Climate Impact Chain framework by examining the climatic conditions that initiate the causal pathways analysed in the subsequent chapters. To maintain a clear analytical structure, the chapter focuses on the climatic signals themselves, while the implications of these hazards for Agriculture, Forestry and Other Land Uses (AFOLU) systems are examined in Chapter 7.

Table 6: Synthesis of key projected climate hazards across the programme areas

Synthesis of key projected climate hazards across the programme areas.
Mean temperature increases across both programme areas and all elevation levels, with the highest absolute temperatures in the lower-elevation zones and particularly strong heat burdens in the Southern Border Region.
Precipitation patterns become more uneven over the year, with wetter wet periods and persistently dry or potentially drier summer conditions, especially relevant for irrigated lowlands where water demand peaks in the dry season.
Drought conditions intensify, especially in summer and autumn, with the signal most pronounced during the warm season in both programme areas.
Climate extremes increase in differentiated ways: extreme heat rises strongly in lower elevations, hot dry wind remains concentrated in the southern part of the Southern Border Region and the western Fergana Valley, and heavy rain increases mainly in foothill and upland areas.

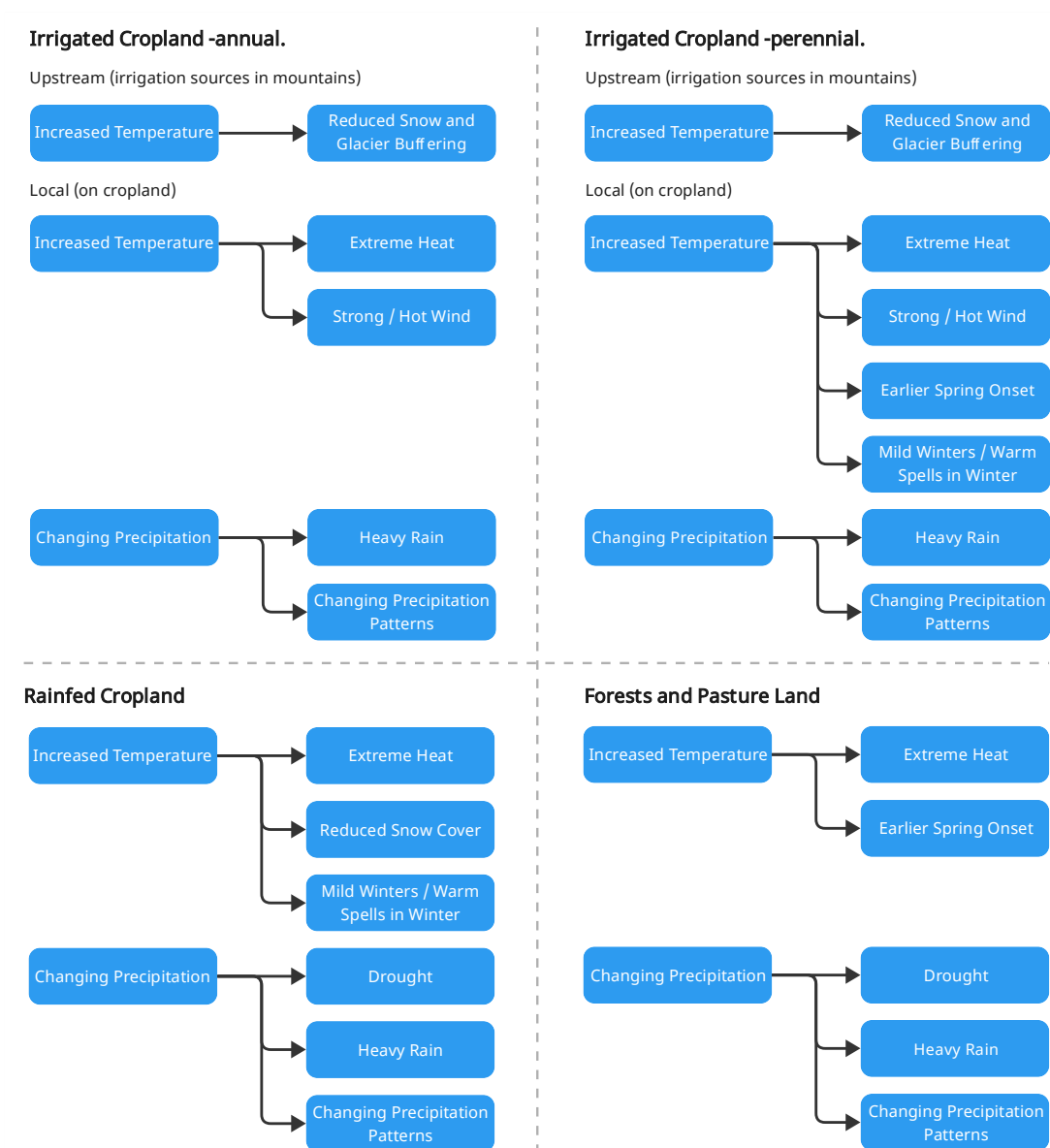
Figure 13 and Figure 14 locate the hazard assessment within the overall Climate Impact Chain logic and show that the entry hazard profile is partly shared and partly system specific. Warming and changing precipitation affect all land-use systems, but irrigation dependence is more central for irrigated systems, while drought, heavy rain, and localized hot dry wind gain prominence in particular rainfed, pasture, forest, and exposed lowland contexts. The remainder of the chapter focuses on the climate signals themselves, presented separately for areas below and above 1,500m and, where relevant, across seasons, as the basis for the impact analysis in Chapter 7.

Figure 13: Conceptual Climate Impact Chain framework applied across the Climate Rationale - climate hazards



Source: Own illustration

Figure 14: Hazard-side components of the land-use-specific Climate Impact Chains



Source: Own illustration

6.1 Selected Indices

The hazard assessment draws on the modelling approach described in Chapter 3 and applies it here to a selected set of climate indicators that are directly relevant to the programme areas and the focus land-use systems. To account for the strong influence of topography on local climatic conditions, results are presented separately for areas below and above 1,500m elevation. Historical conditions are presented for the 1981-2010 baseline, and projected changes are shown for mid-century (2040-2059) and end-century (2080-2099) under SSP2-4.5 and SSP5-8.5. Where relevant, the figures also indicate the likely range across the model ensemble in order to reflect uncertainty in the magnitude of projected change.

Projected change is presented in two complementary ways. In the time series, the ensemble median is shown together with the IPCC likely range across models (16.7th-83.3rd percentiles), which indicates the spread of results for a given scenario. In the mapped projections, lower and upper estimates are used to show a broader plausible range that combines both scenario uncertainty and model spread. The lower estimate represents the more favourable end of this range and the upper estimate the more

adverse end, with the direction interpreted according to whether the respective hazard is projected to increase or decrease (per grid cell).

Where relevant, the assessment therefore considers not only annual change, but also the timing of hazards within the year. For AFOLU systems, shifts in the months or seasons in which heat, dry spells, heavy rain, or compound events occur can be as important as changes in annual totals or annual frequencies.

The following sections examine the main climatic hazards affecting the programme areas: changes in mean temperature, extreme heat and hot dry wind, shifts in mean precipitation patterns, drought conditions, and heavy rainfall. These hazards were selected because of their direct implications for crop, pasture, and forest productivity, irrigation demand and water stress, soil moisture availability, erosion processes, and the stability of climate-sensitive livelihoods. Taken together, they provide the climatic basis for the subsequent assessment of impacts across the focus land-use systems.

6.2 Mean Temperature

The time series in Figures 6-3b/c show a clear increase in annual mean temperature in both programme areas and at both elevation levels. By the end of the century, mean temperature rises by around 3°C (2.5°C lower to 4°C upper estimate) under SSP2-4.5 and by about 5.8°C under SSP5-8.5 (4.8°C lower to 7.3°C upper estimate) in the lower-elevation parts of the Fergana Valley; in the Southern Border Region, the corresponding increase is of a similar order, reaching roughly 3°C (2.6°C lower to 4°C upper estimate) under SSP2-4.5 and around 5.6°C under SSP5-8.5 (4.7°C lower to 7.4°C upper estimate) (Figure 15, Figure 16, and Figure 17). At higher elevations, the warming signal is equally clear, even if absolute temperatures remain lower.

The maps show that this shift is already well established by mid-century. In Figure 6-3a, the projected change maps for 2040–2059 indicate warming across both programme areas even in the lower estimate, with substantially stronger increases by 2080–2099. Figure 6-3a is particularly relevant for interpretation at the regional level: by mid-century, mean temperatures in the lower-elevation parts of the Fergana Valley reach levels comparable to those observed today in the southern lowlands of the Southern Border Region in the historical baseline. In other words, climatic conditions that currently characterise the hotter lowlands of the Southern Border Region are projected to become the norm in the Fergana Valley lowlands as well, including in the lower range of the projections.

Supplementary observed evidence from Kyrgyzstan supports the warming signal presented here. Based on Kyrgyzhydromet station observations for 1976–2019, mean annual air temperature increased by 0.23°C per decade, with the strongest increase in spring (0.45°C per decade), and with particularly strong warming in the valley zones of Osh and Jalal-Abad. While these findings are national and not directly transferable to the full programme area, they provide useful observational corroboration for the strong lowland warming signal identified here in the Kyrgyz part of the programme geography (Kretova, 2020).

This matters because mean warming is not confined to a single hazard pathway but shifts the baseline climatic conditions under which all land-use systems operate. In the lower-elevation valley and lower-foothill zones, where irrigated annual and perennial cropland are concentrated, warmer conditions imply higher evaporative demand, greater irrigation pressure, and broader exposure to heat-related stress. In foothill and higher-elevation zones, warming affects rainfed cropland, pasture, and forest through higher moisture demand and changing seasonal conditions, while also altering upstream snow and melt dynamics that influence downstream water availability. The strongest absolute heat burden remains in the lower-elevation Southern Border Region, but the warming signal also means that climatic conditions currently typical of the hotter southern lowlands increasingly become normal in the Fergana Valley lowlands.

Figure 15: Historical and projected mean annual temperature in the programme areas

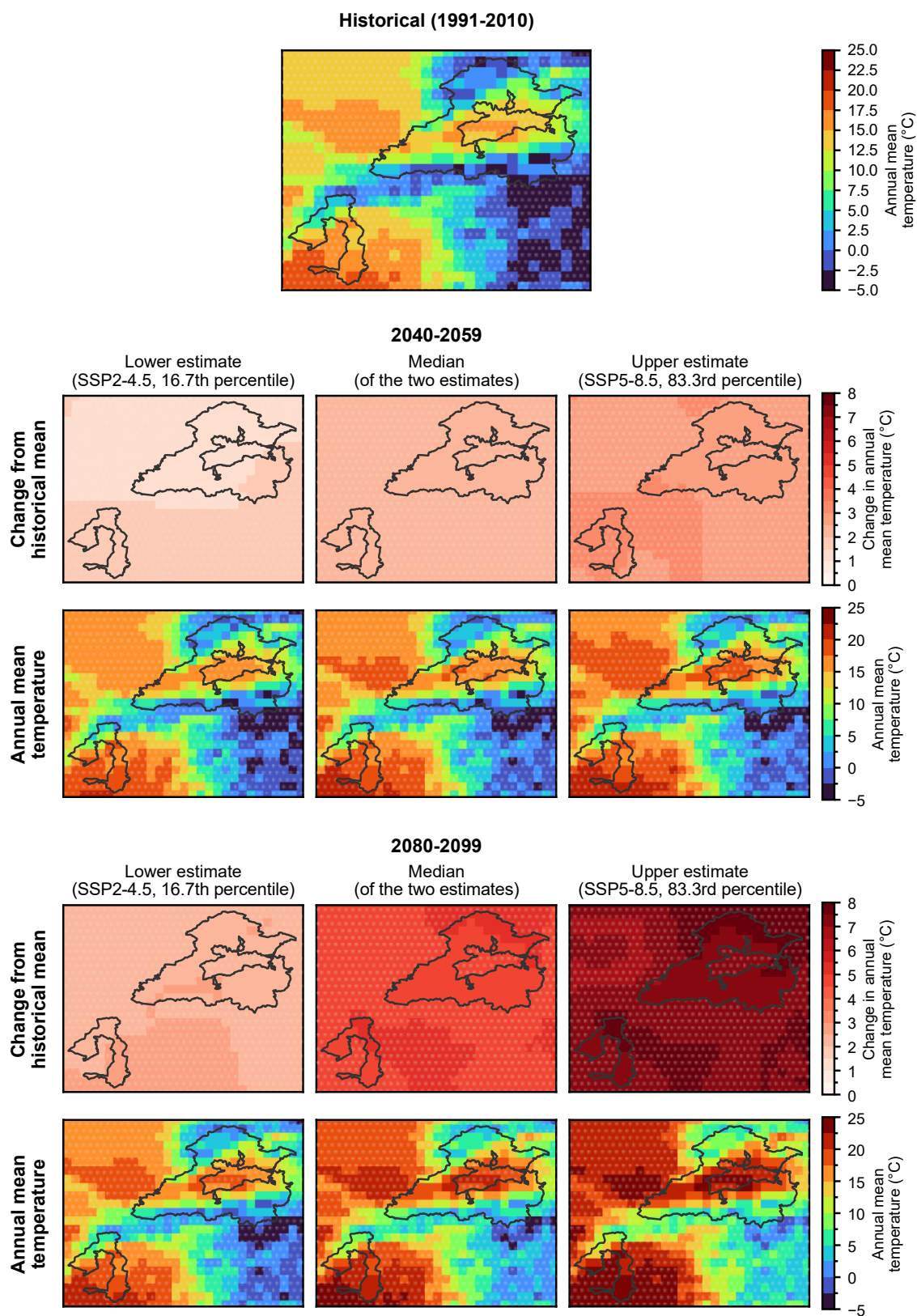


Figure 16: Mean annual temperature over time by elevation zone in the Fergana Valley (only programme districts)

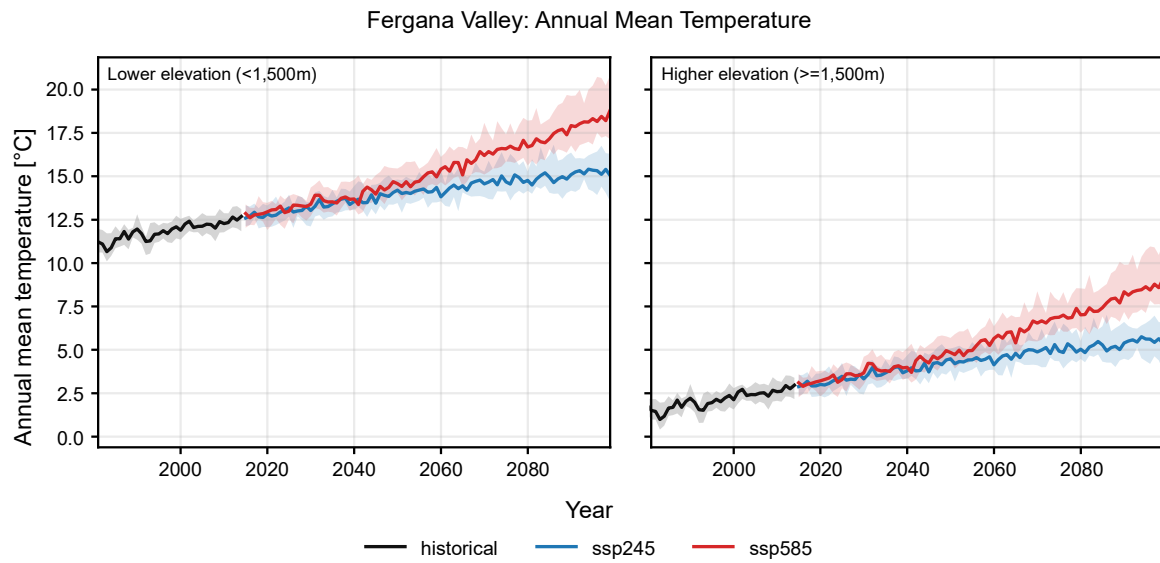
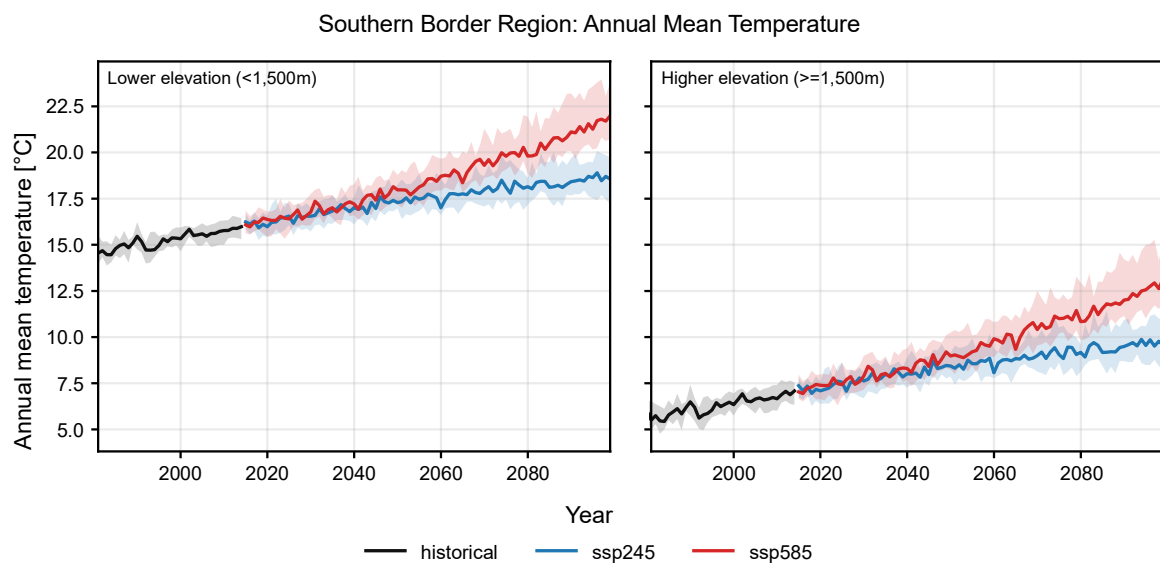


Figure 17: Mean annual temperature over time by elevation zone in the Southern Border Region



6.3 Extreme Heat

Extreme heat is already a significant hazard in the lower-elevation parts of both programme areas and intensifies strongly over time. Figure 6-4a shows that, in the historical baseline, days with maximum temperature above 35°C are already frequent across the lowlands, especially in the Southern Border Region, where many areas record around 50–70 heat days per year. In the lower parts of the Fergana Valley, the baseline is lower but still substantial, generally about 20 days per year with some regions reaching up to 40 days per year. Above 1,500m, such days remain limited in both programme areas (Figure 18).

The time series confirms that this hazard strengthens in all sub-regions. In the Fergana Valley, the mean number of heat days below 1,500m rises from around 25–30 per year in the recent period to about 60 under SSP2-4.5 and around 100 under SSP5-8.5 by the end of the century (Figure 19). In the Southern Border Region, the corresponding increase is from around 60–70 days already today to about 100 under SSP2-4.5 and around 140 under SSP5-8.5 (Figure 20). At higher elevations, the increase is smaller in absolute terms but still marked, especially under SSP5-8.5, with heat days becoming more common from mid-century onwards (Figure 19 and Figure 20).

The figures show that this increase is already established by 2040–2059. Even the lower estimate indicates a clear rise across both programme areas, while the upper estimate shows a much stronger expansion of extreme heat, particularly in the lowlands. By 2080–2099, the increase becomes pronounced across nearly all lower-elevation areas, adding several additional weeks of extreme heat each year in both programme areas (Figure 19 and Figure 20).

Figure 21 and Figure 22 show that this increase is concentrated very strongly in the hot season. In the lower-elevation Fergana Valley, additional >35°C days accumulate mainly from June to September and peak in July–August. In the lower-elevation Southern Border Region, the increase begins slightly earlier, from May/June onward, and remains strongest through July–August, with some extension into September. At higher elevations, the signal is much smaller and is largely confined to midsummer months. This timing is important because the projected rise in extreme heat coincides directly with the main summer growing season and peak irrigation-demand period in the lower-elevation production zones.

This matters particularly because the strongest increase affects the elevation bands where irrigated cropland is concentrated and where a large share of settlements and productive land-use systems are located. In the Fergana Valley, irrigated cropland is concentrated largely below about 1,500–1,750m, while in the Southern Border Region it is concentrated even more strongly in the lower elevation bands (Figure 12). Pasture also dominates broad lower and mid-elevation zones in both programme areas, especially in the Southern Border Region (same figure). The increase in extreme heat, therefore, falls most directly on the parts of the landscape where agricultural production and rural livelihoods are already concentrated.

Figure 18: Historical and projected annual number of days with maximum temperature above 35°C

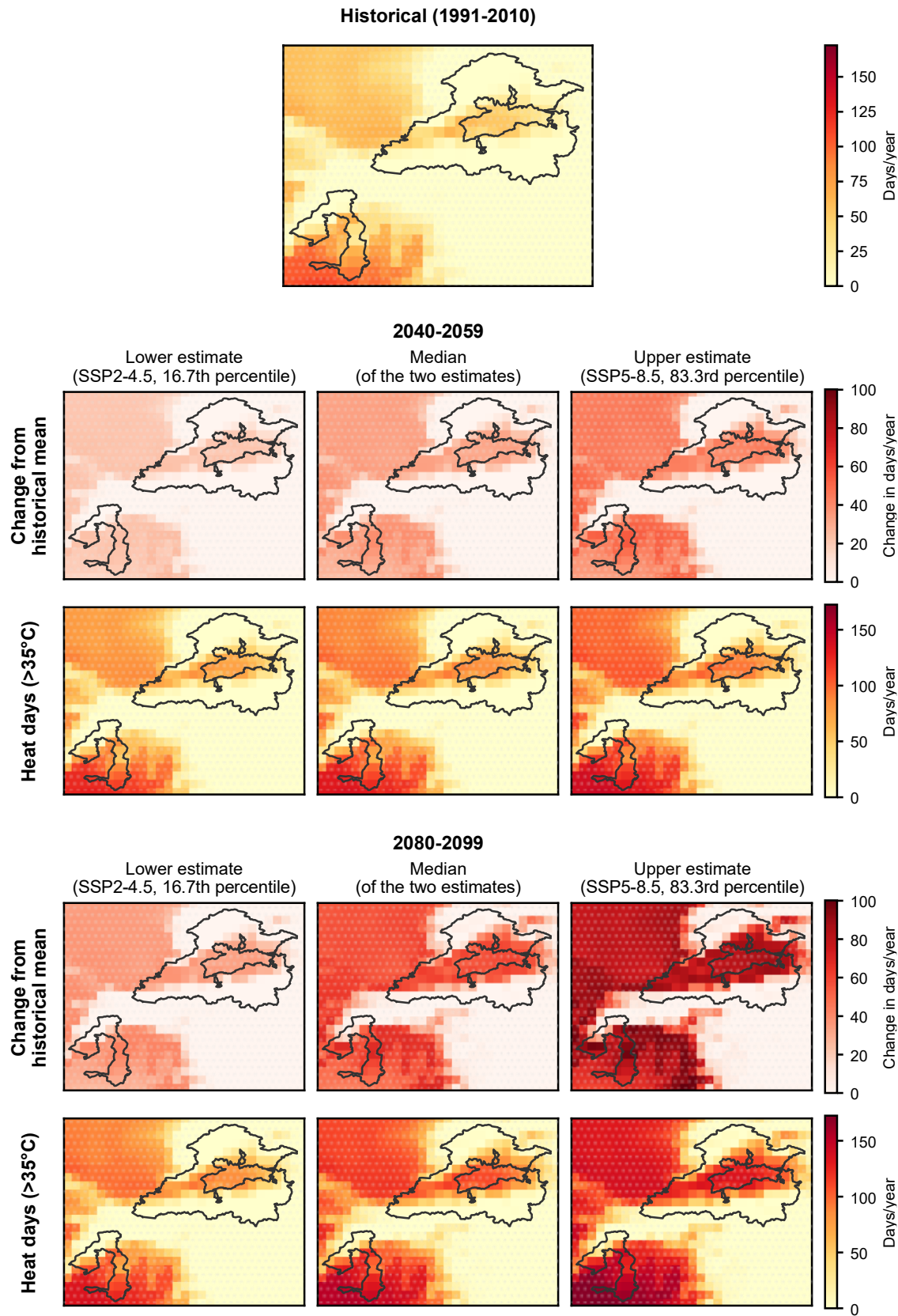


Figure 19: Annual number of days with maximum temperature above 35°C over time by elevation zone in the Fergana Valley (only programme districts)

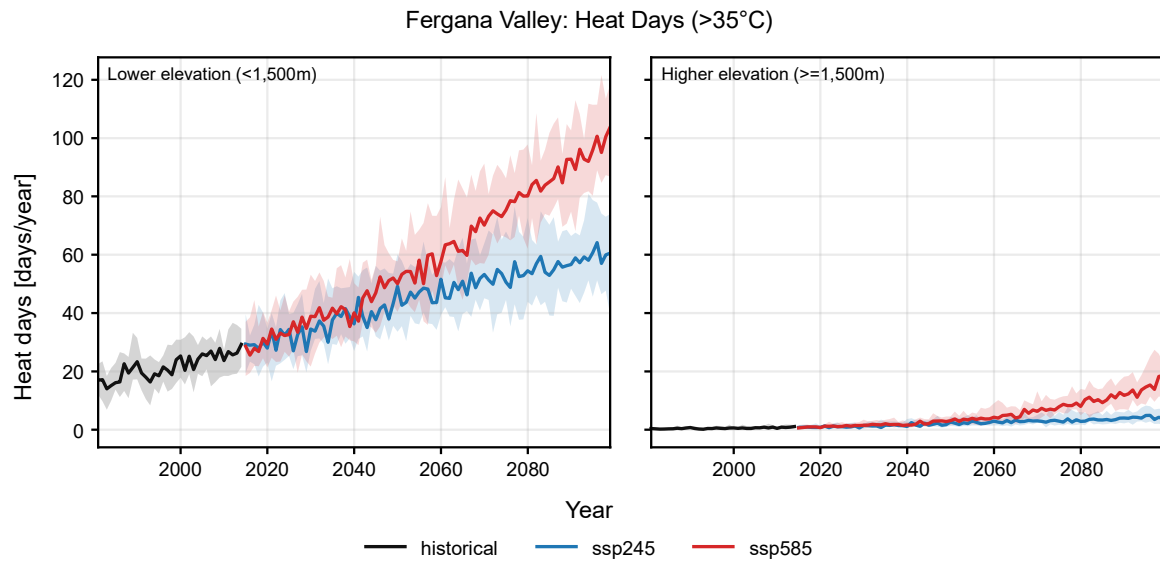


Figure 20: Annual number of days with maximum temperature above 35°C over time by elevation zone in the Southern Border Region

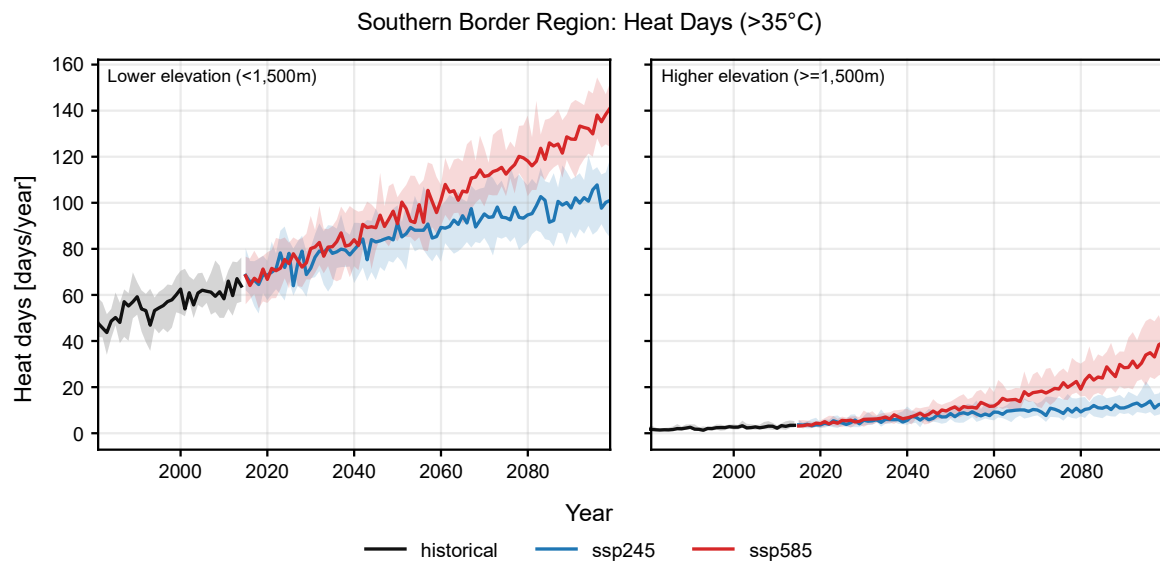


Figure 21: Change in monthly heat days (days in maximum temperature above 35°C) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts)

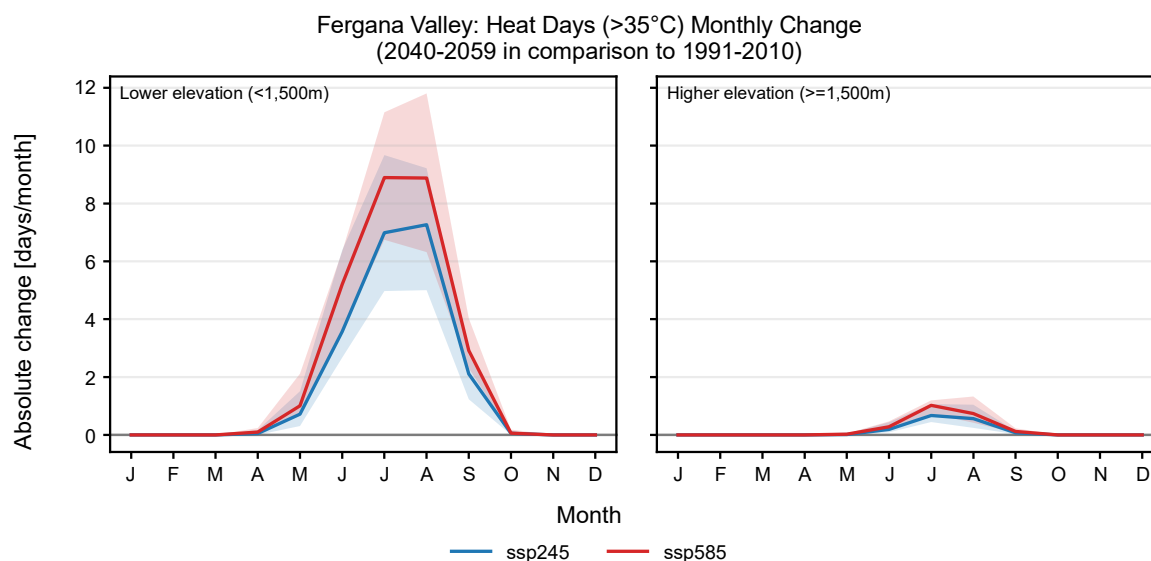
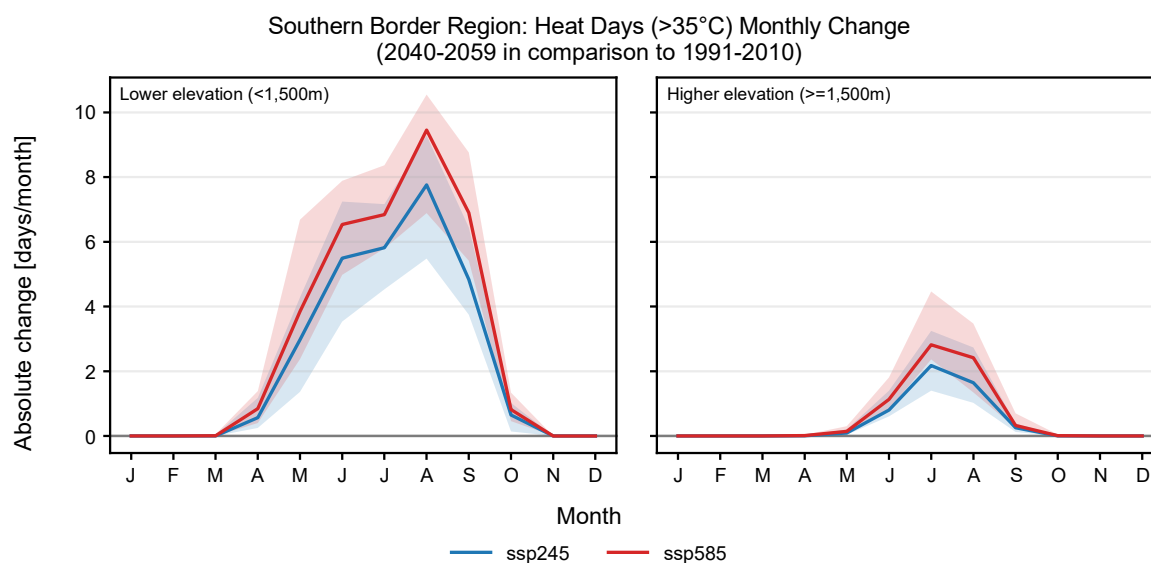


Figure 22: Change in monthly heat days (days in maximum temperature above 35°C) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region



6.4 Hot Dry Wind

Figure 6-5a shows that hot dry windy days are not evenly distributed across the programme areas. In the historical baseline, the clearest concentration is in the southern part of the Southern Border Region, while in the Fergana Valley the signal is more limited and concentrated mainly in its western part. Large parts of the remaining programme area, especially at higher elevations, show little or no occurrence of this hazard (Figure 23).

The projected change maps in Figure 23 show that this spatial pattern broadly persists over time. The hazard does not emerge uniformly across the programme areas; rather, it strengthens primarily in those areas where it is already present. In the Southern Border Region, the increase is most evident in the south and southwest, where the hotspot expands and intensifies. In the Fergana Valley, change is more localised, with the clearest signal in the western lowland belt, while central and eastern parts remain less affected. Higher-elevation areas in both programme areas continue to show only limited occurrence.

The time series in Figure 24 and Figure 25 support this reading. They show only modest changes when averaged across broader elevation zones, especially in the Fergana Valley, because the hazard is concentrated in specific sub-areas rather than spread evenly across the landscape. In the Southern Border Region, the increase is clearer and more sustained in the lower-elevation zone, whereas higher elevations remain much less affected. Overall, hot dry wind remains a localised hazard, but one that becomes more pronounced in the already exposed parts of the Southern Border Region and, to a lesser extent, the western Fergana Valley.

Figures Figure 26 and Figure 27 show that the monthly increase in hot dry wind is concentrated even more narrowly than extreme heat. In both programme areas, changes are centred on midsummer to early autumn, mainly July to September and peaking around August, while the signal outside this window is negligible. Although the monthly increase remains below a full day per month when averaged across broad elevation zones, this still indicates a systematic strengthening of the hazard in its core hotspot months. The signal is clearest in the lower-elevation Southern Border Region and, to a lesser extent, the lowland Fergana Valley, whereas high-elevation zones remain only marginally affected.

This matters particularly for exposed lowland irrigated systems rather than for the programme areas as a whole. The clearest implications are for irrigated annual and perennial cropland in the western Fergana Valley and the southern to southwestern parts of the Southern Border Region, where hot dry wind can intensify crop desiccation, scorching, wind erosion, and quality losses during already water-stressed periods. Because this hazard remains localized and largely absent from higher elevations, it is less relevant for most forest and pasture systems and for many upland rainfed areas. Its significance lies not in broad areal coverage, but in the fact that it affects some of the hottest and most exposed production zones where irrigation-dependent cropping is already under strong pressure.

Figure 23: Historical and projected annual number of hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) in the programme areas

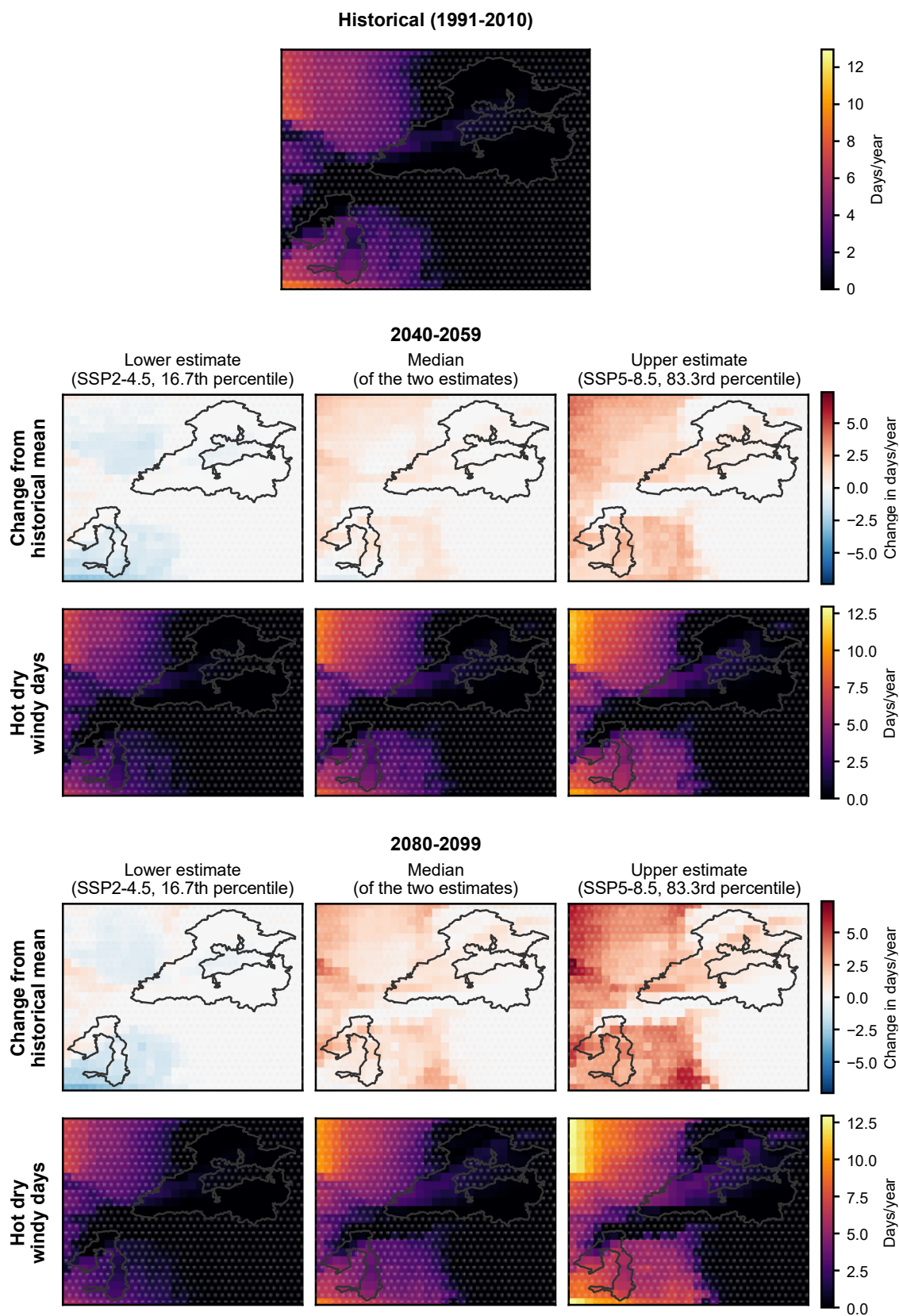


Figure 24: Annual number of hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) over time by elevation zone in the Fergana Valley (only programme districts)

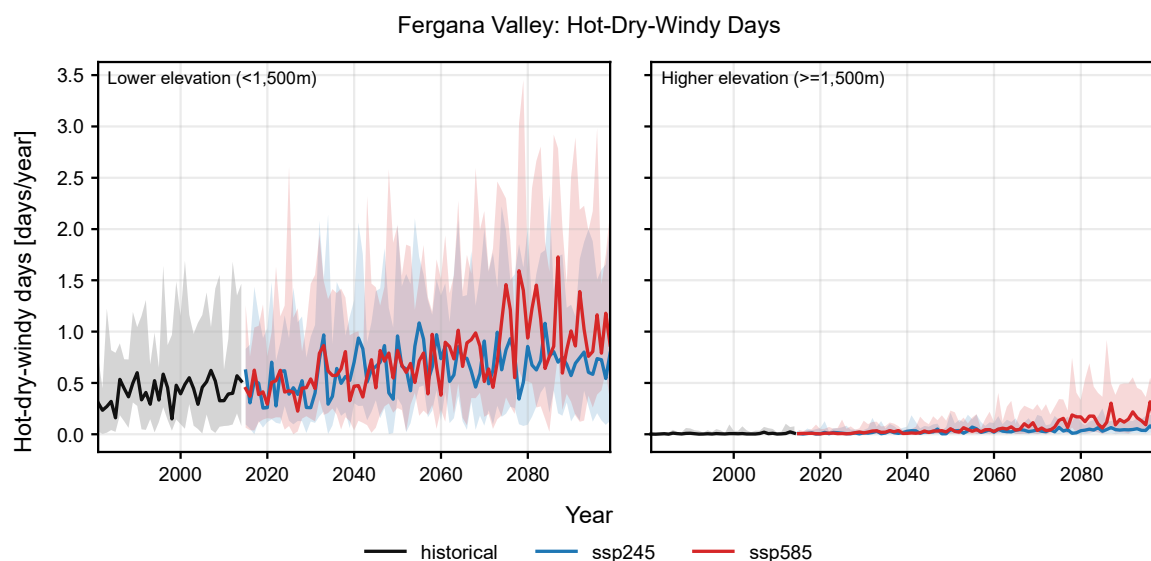


Figure 25: Annual number of hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) over time by elevation zone in the Southern Border Region

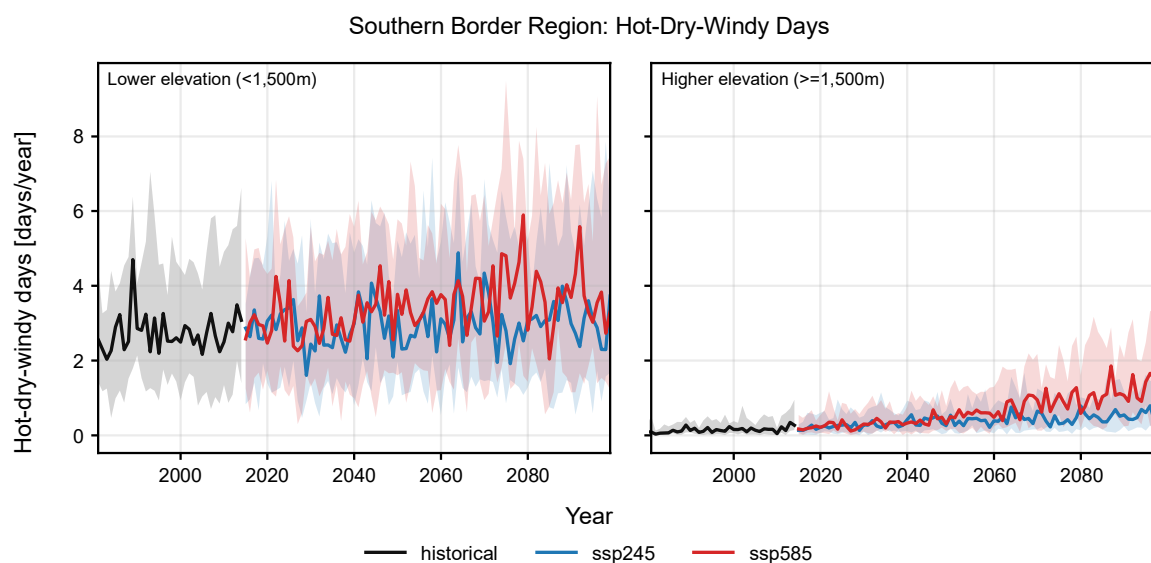
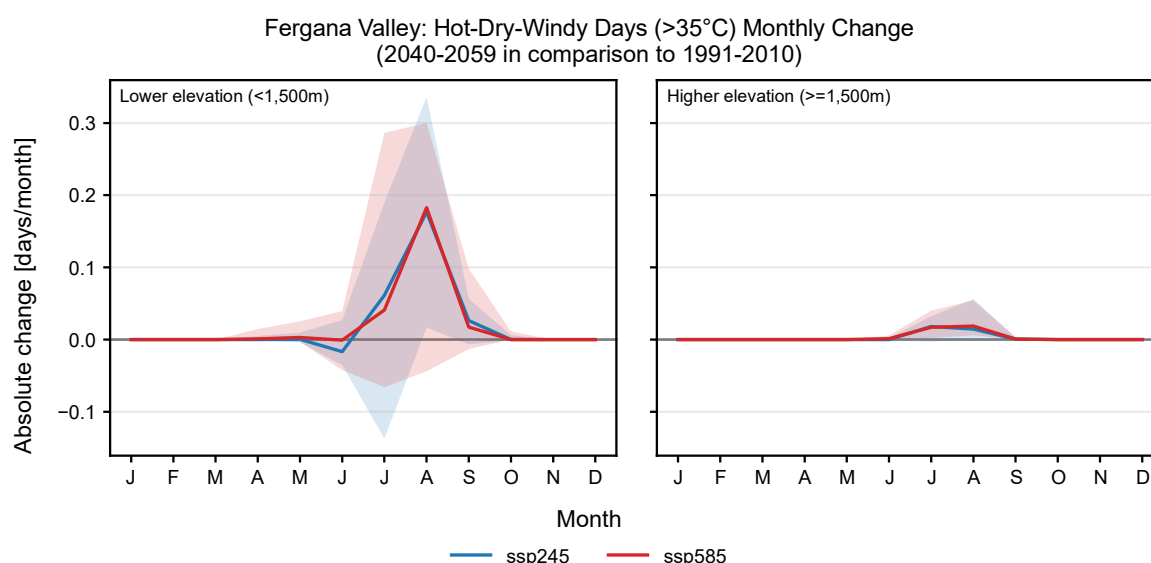
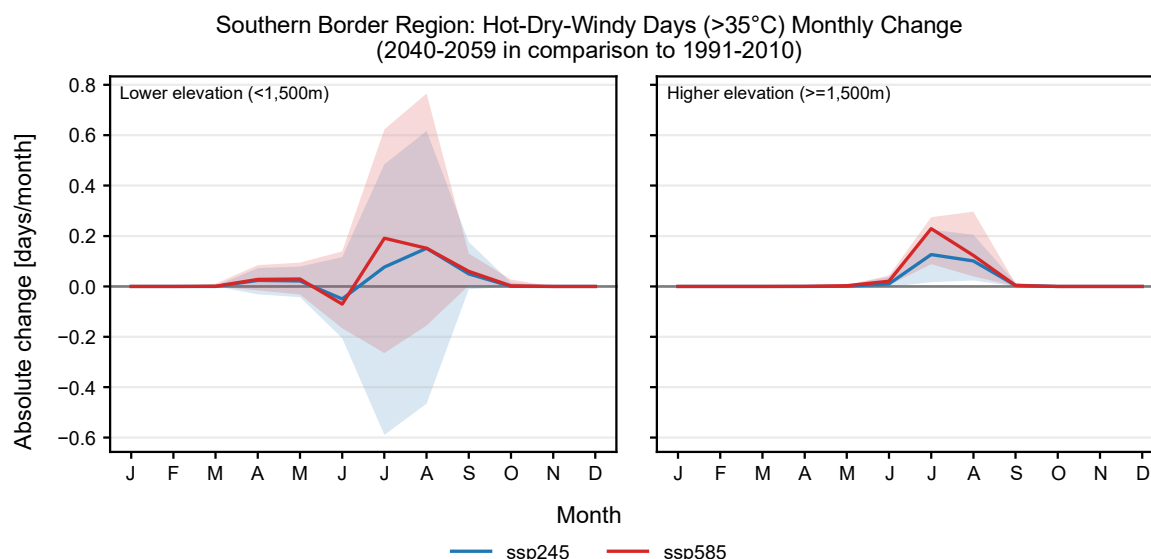


Figure 26: Change in monthly hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts)



(Note that, even though these are less than a single day per month, this is an increase on average for each of these months)

Figure 27: Change in monthly hot dry windy days (maximum temperature above 35°C, less than 1mm/day precipitation, wind above 90th percentile of historic reference period) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region



(Note that, even though these are less than a single day per month, this is an increase on average for each of these months)

6.5 Seasonal Precipitation Patterns

Figures Figure 28 and Figure 29 show a clear seasonal redistribution of precipitation rather than a uniform annual trend. For the wetter part of the year, October to May, precipitation generally increases across both programme areas. The increase is already visible by mid-century and becomes more pronounced in the upper estimate by late century, particularly along the southern belt of the Fergana Valley and across parts of the Southern Border Region (Figure 28). In the lower estimate, changes remain modest, but the direction is still broadly towards wetter conditions in the already wetter season.

For the drier part of the year, June to September, the pattern is different (Figure 29). Here, changes are smaller and less robust, but the lower estimate points to declining precipitation across much of the programme area by late century, while the upper estimate shows only limited increases in some areas. The drying signal is most evident in the Fergana Valley and in parts of the Southern Border Region outside the main local wetting hotspots. In other words, the dry season does not show the same consistent increase as the wetter months.

The seasonal time series in Figures Figure 30 and Figure 31 support this distinction. In both programme areas, winter precipitation increases most clearly, with a smaller but still visible increase in autumn. Spring is more mixed, but generally stable to slightly wetter. Summer, by contrast, remains very dry and shows little change overall, with some indications of further decline in parts of the envelope, especially later in the century (Figure 34 and Figure 35). This pattern appears in both elevation bands, although the absolute totals remain higher at higher elevations.

Figure 32 and Figure 33 help unpack this redistribution within the year: In the Fergana Valley, projected mid-century precipitation increase is concentrated mainly in late autumn and winter, with the clearest positive changes from about November to March, while June to September remain close to unchanged or slightly drier. Spring, however, is less robust: especially in April and May, the model range still allows for either modest increases or decreases, particularly at higher elevations. In the Southern Border Region the pattern is weaker and more mixed overall, but it likewise points to limited wetting in late autumn and winter and no clear evidence of systematic summer wetting. In other words, the additional precipitation does not primarily arrive during the peak irrigation season, and even in spring the transition into the dry season remains uncertain.

Taken together, the figures indicate that precipitation is becoming more concentrated in the months and seasons that are already relatively wet, while the spring transition remains less certain and the dry season remains dry and may become drier in parts of the programme areas. This seasonal shift is important for the interpretation of subsequent hazard indicators: it is consistent with the stronger drought signal in summer and autumn, while at the same time supporting an increase in heavy rainfall and runoff-related hazards during the wetter part of the year.

This interpretation is consistent with broader regional evidence. Across Central Asia, declining precipitation in combination with rising evaporative demand has contributed to drought conditions and reduced surface runoff, while water insecurity is expected to intensify where demand rises and institutions and infrastructure are not able to buffer growing variability (IPCC, 2022; World Bank, 2024a). In the programme context, this means that even where cool-season precipitation increases, this does not automatically translate into improved water availability during the peak irrigation season, when demand is highest and conveyance and allocation constraints are already significant (Dankova et al., 2022).

This seasonal shift is directly relevant to the focus land-use systems. In the lower-elevation zones, where irrigated cropland is concentrated, it points to a growing mismatch between water availability and water demand: a larger share of precipitation falls in the cooler part of the year, while the main irrigation demand remains concentrated in the hot and already dry summer months. This seasonal mismatch is likely to be further amplified by shifts in upstream snow and glacier dynamics that alter the timing of runoff generation (see Section 6.8). At the same time, rainfed cropland, pasture, and forest in foothill and upland areas are increasingly affected by the combination of drier warm-season conditions and

wetter cool-season precipitation, including greater runoff and erosion pressure during the wetter months.

Figure 28: Historical and projected precipitation during the wetter season (October to May)

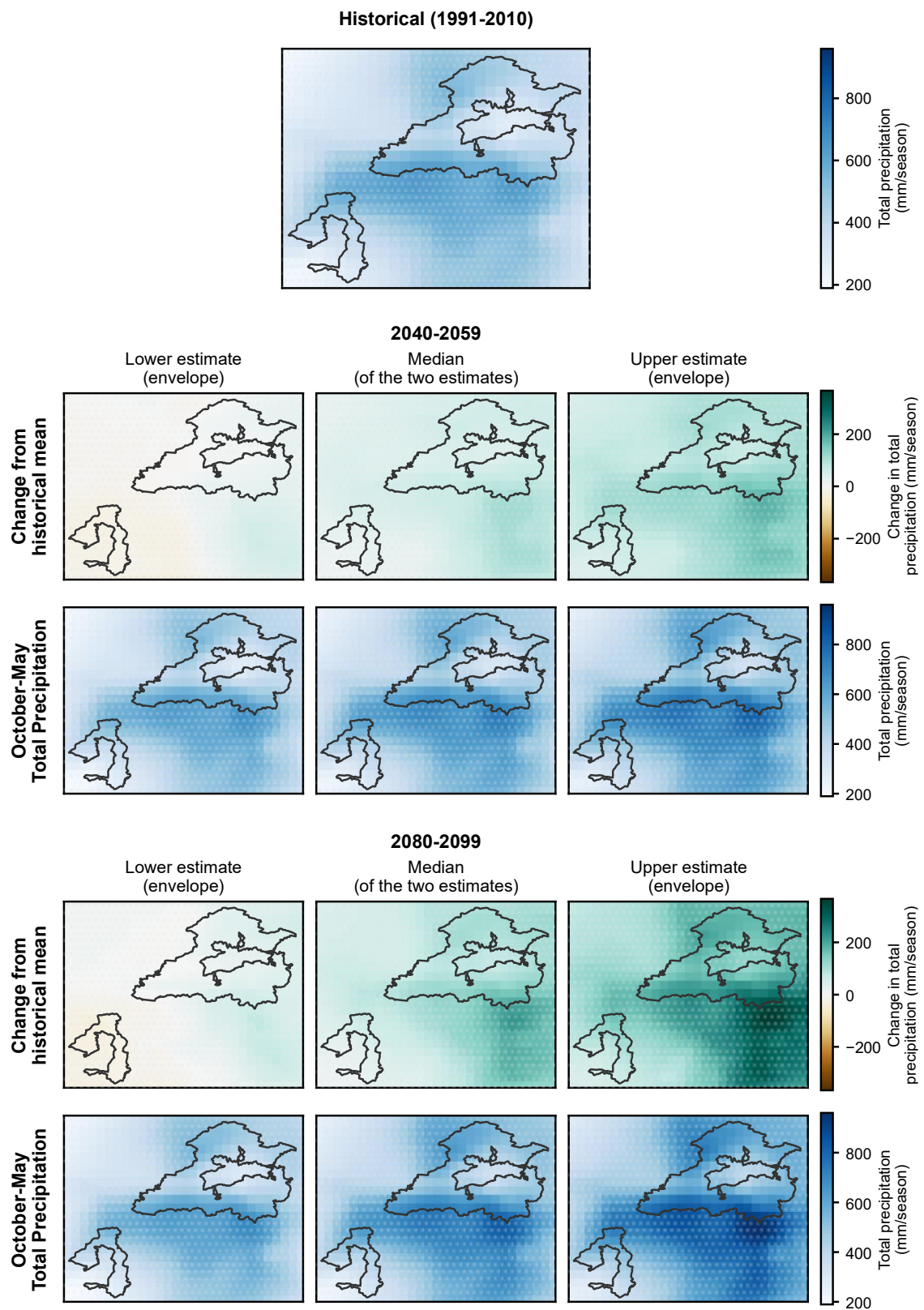


Figure 29: Historical and projected precipitation during the drier season (June to September)

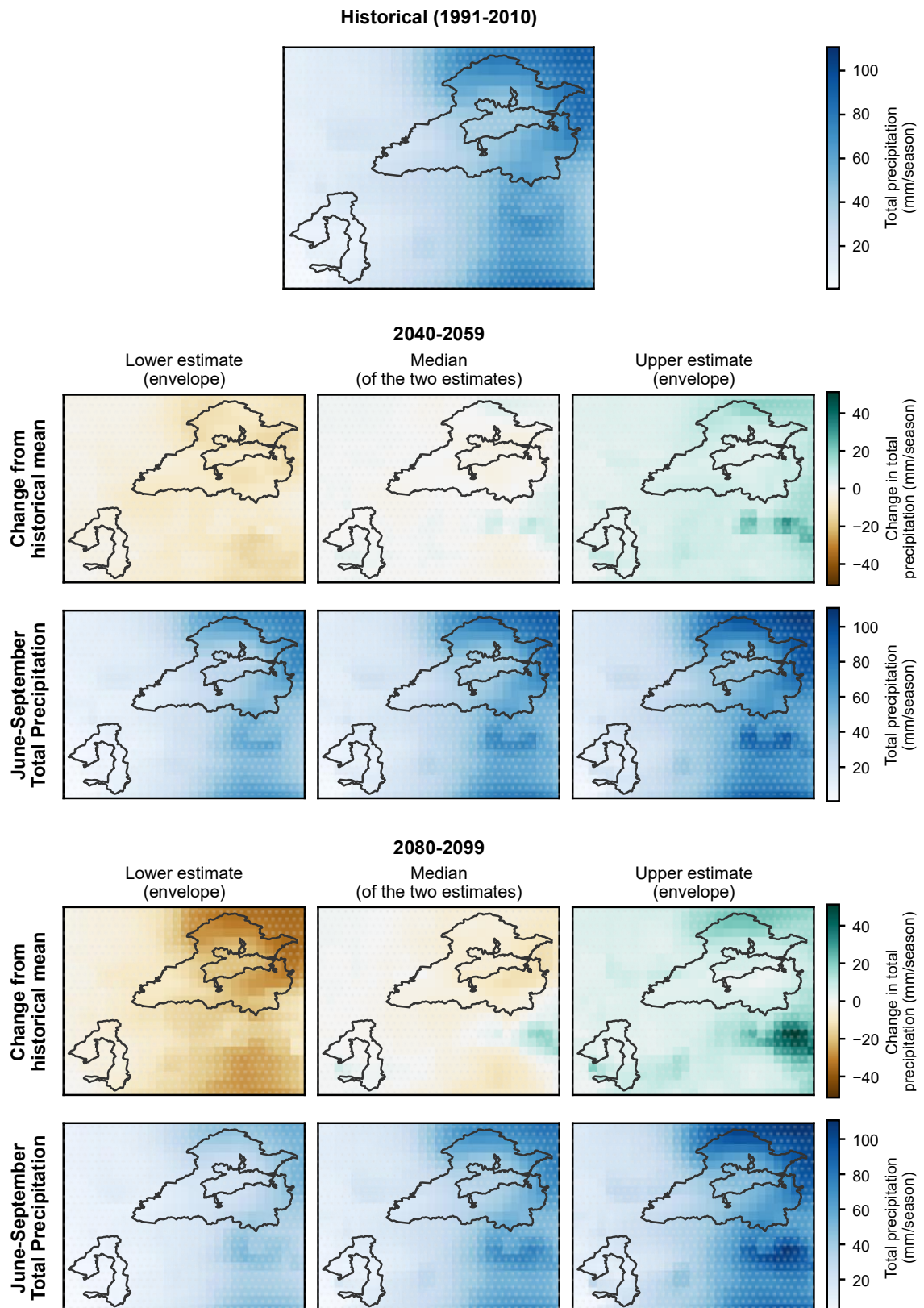


Figure 30: Seasonal precipitation over time by elevation zone in the Fergana Valley (only programme districts)

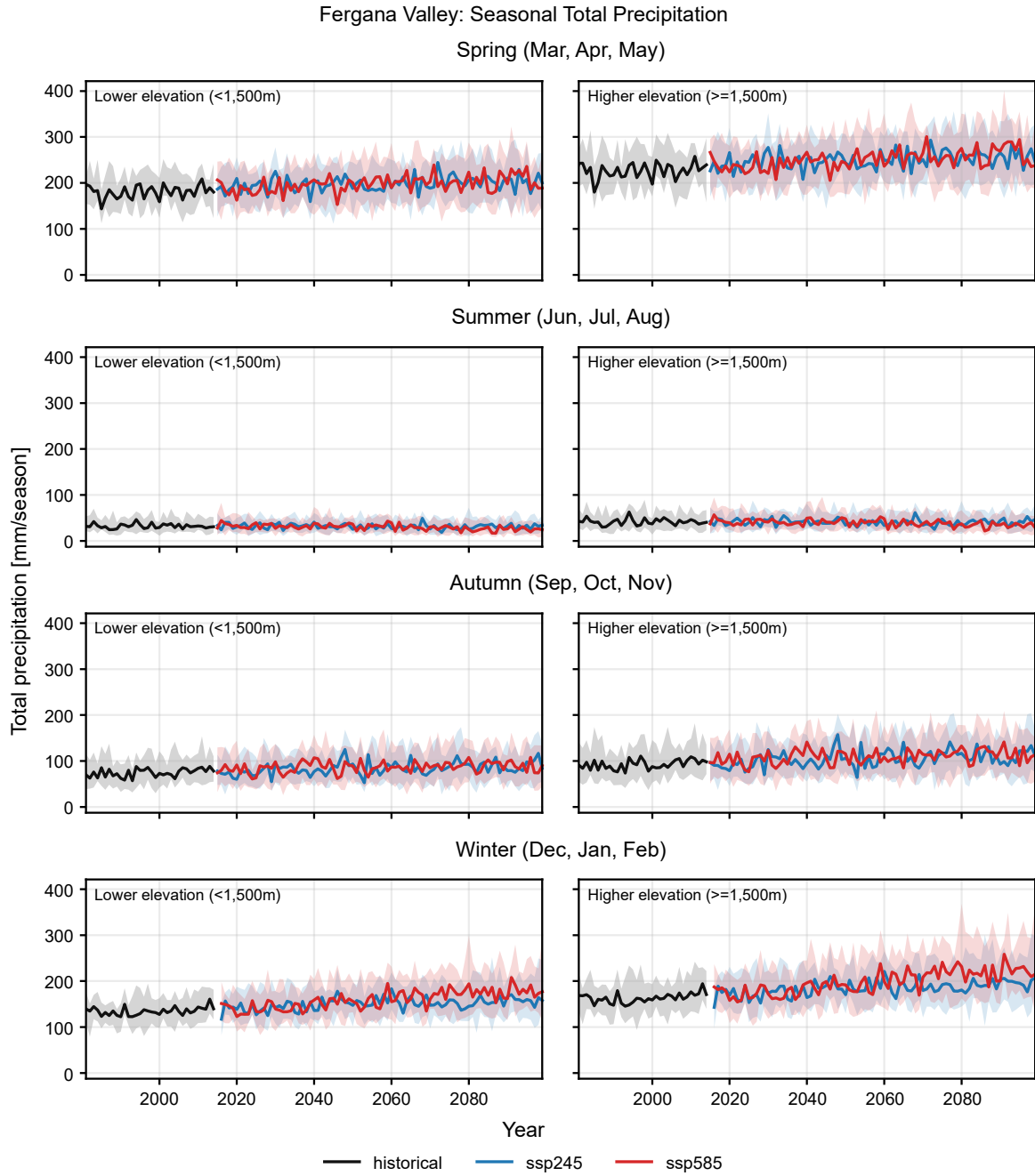


Figure 31: Seasonal precipitation over time by elevation zone in the Southern Border Region

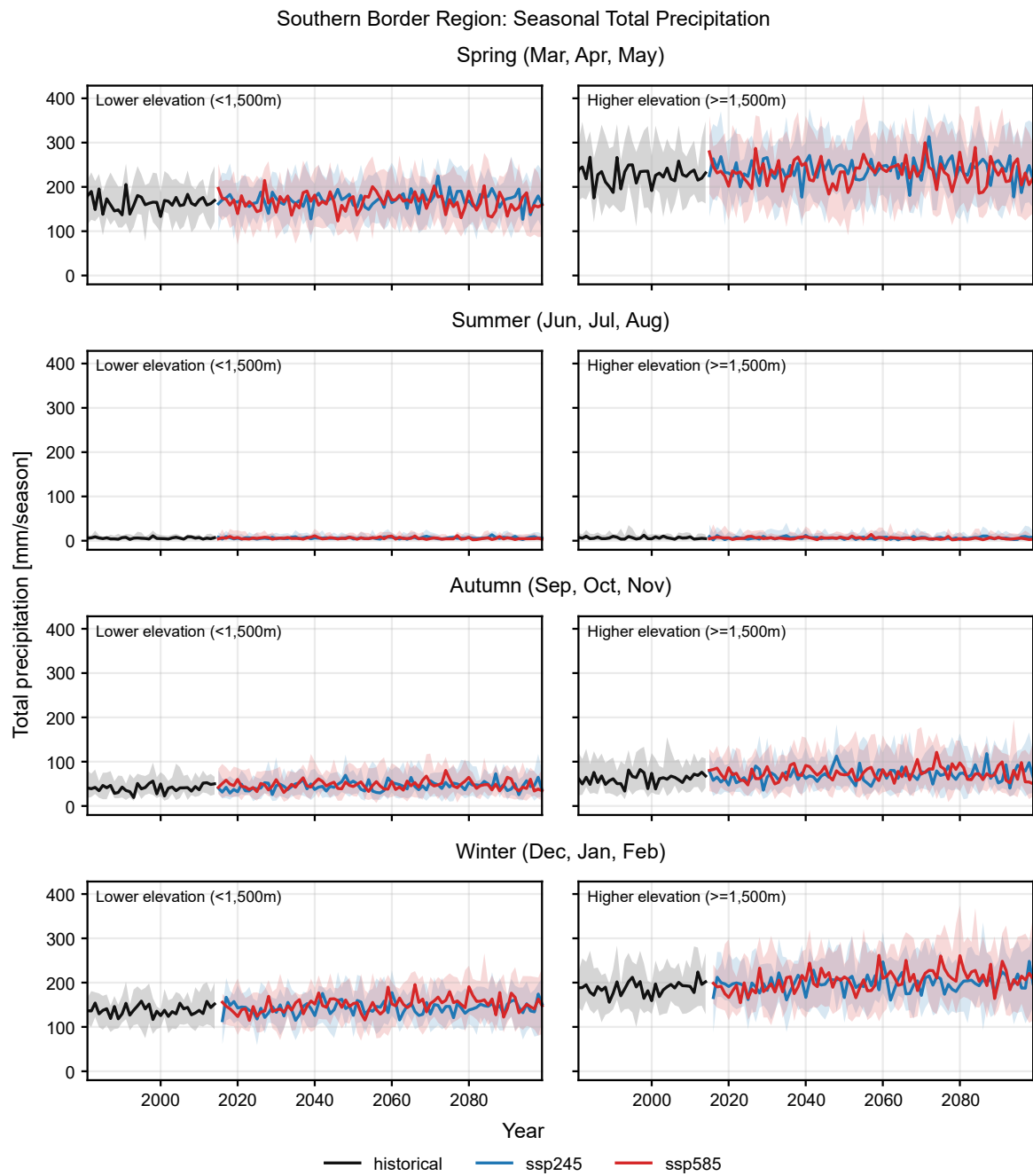


Figure 32: Precipitation for drier months (June to September) over time by elevation zone in the Fergana Valley (only programme districts)

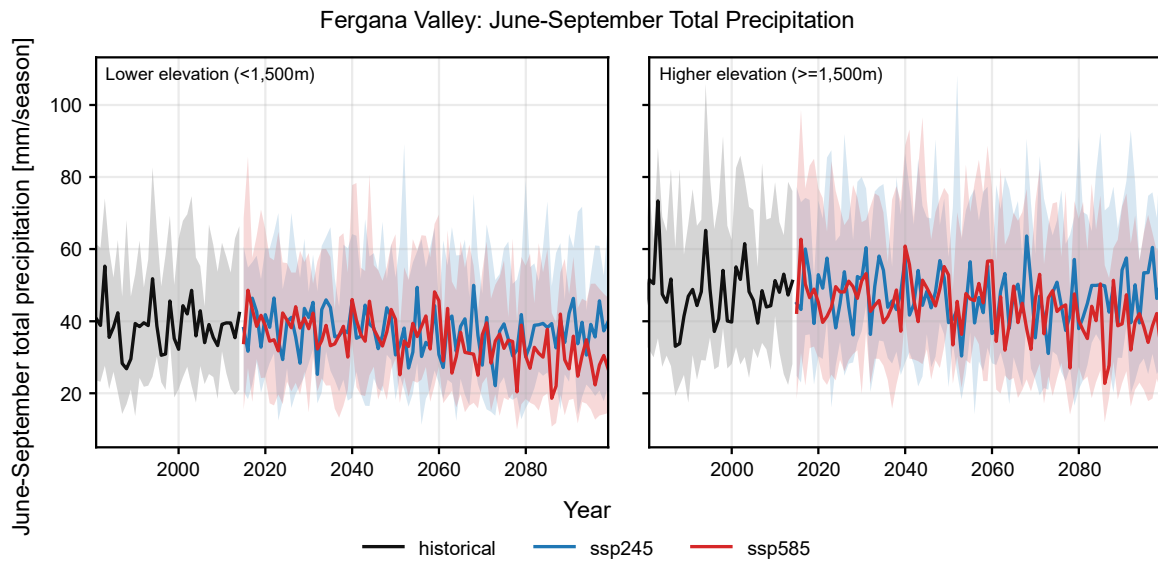


Figure 33: Precipitation for drier months (June to September) over time by elevation zone in the Southern Border Region

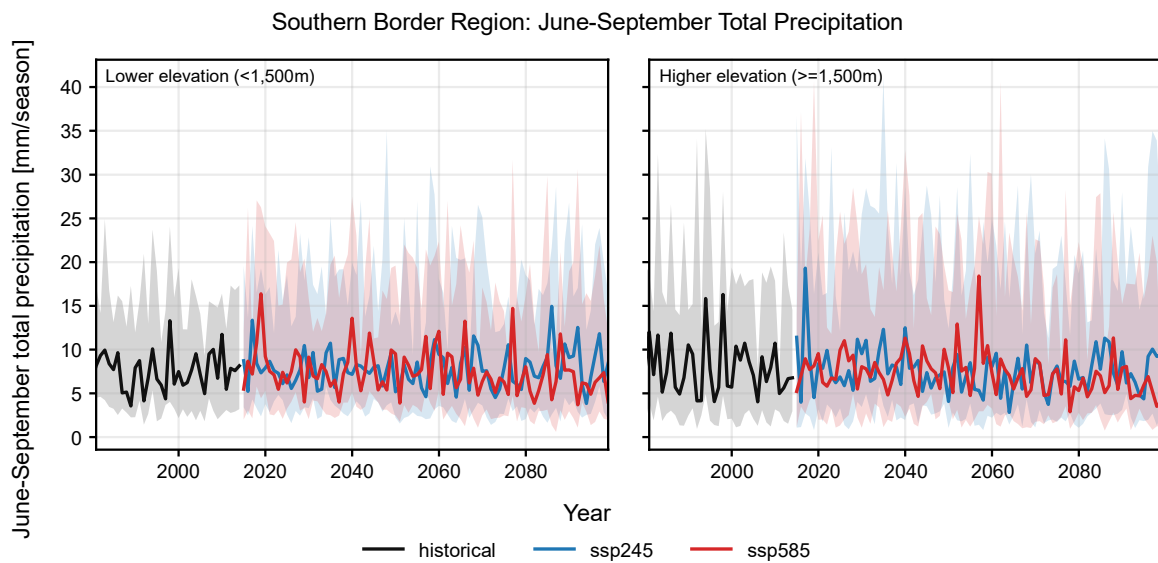


Figure 34: Change in total monthly precipitation for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts)

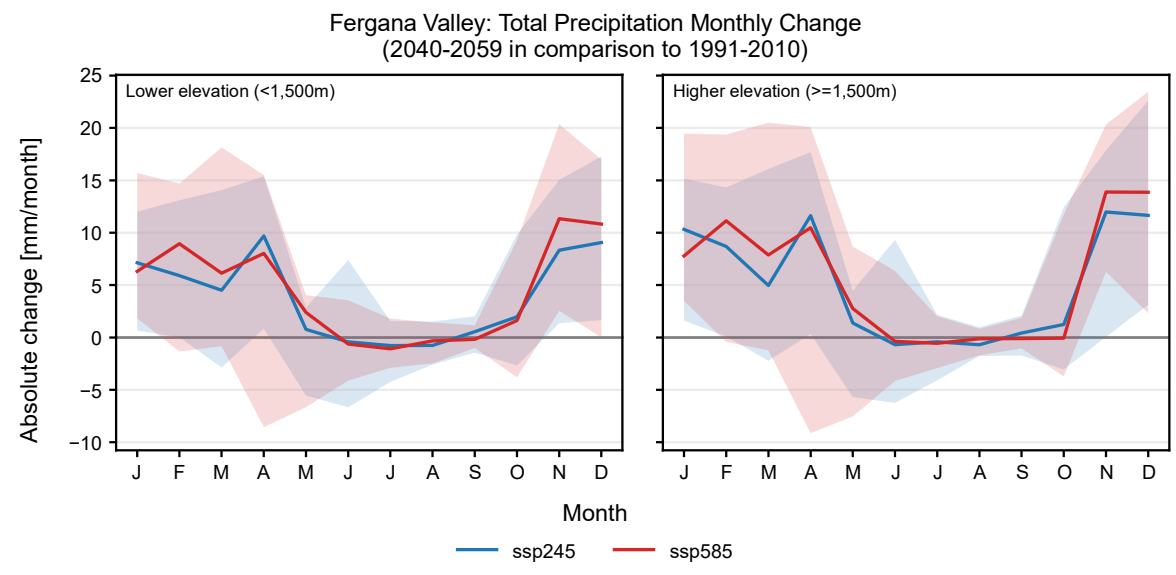
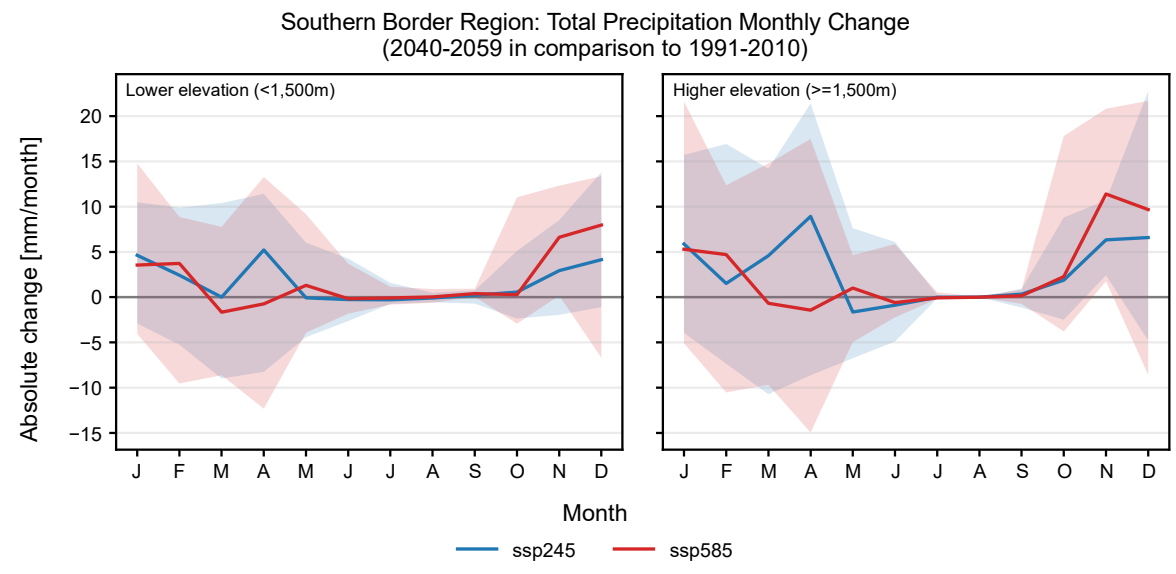


Figure 35: Change in total monthly precipitation for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region



6.6 Drought Conditions

Drought conditions are assessed here using the minimum annual and seasonal SPEI-3 values shown in Figure 36, Figure 37, and Figure 38. This is a short-term drought indicator that captures anomalies in the balance between precipitation and atmospheric evaporative demand. It is therefore most useful for identifying meteorological and near-surface agricultural drought conditions, rather than hydrological drought in rivers, reservoirs, or groundwater systems. The latter is addressed here only indirectly; in the wider climate-risk assessment, hydrological water stress is considered additionally through the analysis of seasonal precipitation shifts and climate-related warming and changes in snowfall share in upstream areas (see Section 6.8), while a full assessment of hydrological drought would require longer-timescale indicators and hydrological analysis.

The results presented here should therefore be interpreted primarily as evidence of intensifying short-term climatic and agricultural drought stress, not as direct evidence of river discharge or reservoir behaviour. That interpretation is consistent with regional literature showing that increasing evapotranspiration and declining precipitation in Central Asia are already contributing to drought conditions and reduced surface runoff, while adaptation challenges in Central Asian mountain regions are strongly shaped by changing water availability and seasonal water stress (IPCC, 2022; Saidaliyeva et al., 2024).

Figure 36 shows that the annual minimum SPEI-3 is already negative across both programme areas in the historical baseline, indicating that short-term drought conditions are already part of the present climate. The projected maps then show a wide envelope. Under the lower estimate, annual minimum SPEI-3 declines markedly across the programme areas by mid-century and even more strongly by late century, pointing to substantially more severe short-term drought conditions. Under the upper estimate, changes are much smaller and in some areas remain limited. The relevant point is not uniform drying in every part of the envelope, but that a clearly drier trajectory is plausible across both programme areas and becomes pronounced in the more adverse part of the range (Figure 36).

As discussed in the preceding section on mean precipitation patterns, this seasonal signal is consistent with a broader tendency for already wet periods to become wetter, while already dry periods are likely to become drier. The seasonal time series in Figure 37 and Figure 38 show where this drying signal is concentrated. In both programme areas, summer and autumn stand out clearly. Summer minimum SPEI-3 declines progressively in both elevation zones, with the deterioration stronger under SSP5-8.5 and more pronounced in the second half of the century. Autumn shows an even sharper shift, with values dropping strongly in both the Fergana Valley and the Southern Border Region, including at higher elevations. By contrast, spring changes are weaker and less consistent, while winter remains comparatively stable and in some cases shows little change relative to the historical range (Figure 37 and Figure 38).

The two programme areas follow the same overall direction, but the Southern Border Region generally shows the broader and more consistent deterioration across seasons, especially in summer and autumn. In the Fergana Valley, the signal is also clear, but somewhat more differentiated by season and elevation. Taken together, this matters especially because the strongest deterioration occurs in summer and autumn, when crop water demand is high and pasture and vegetation conditions are already under pressure. In lower-elevation irrigated systems, this implies more frequent irrigation shortfalls and stronger competition over scarce water during the main production season. In rainfed cropland, pasture, and forest across both elevation bands, it points to declining soil moisture, weaker regeneration, and greater likelihood of establishment failure, biomass loss, and vegetation stress. The broader and more consistent drought signal in the Southern Border Region suggests particularly strong pressure there, but the pathway is relevant across both programme areas.

Supplementary pasture-zone evidence from Kyrgyzstan is consistent with the reading of intensifying warm-season drought stress and marked spatial differentiation. Kretova (2020) identifies the areas around Sary-Tash in Osh Oblast and Baytyk in Chui Oblast as among the most drought-prone pasture

locations during the growing season, while the Jalal-Abad pasture stations are comparatively less affected. The same assessment also shows a stronger drought signal when evapotranspiration is taken into account, which is consistent with the present use of SPEI-based indicators.

Figure 36: Historical and projected annual minimum SPEI-3 in the programme areas

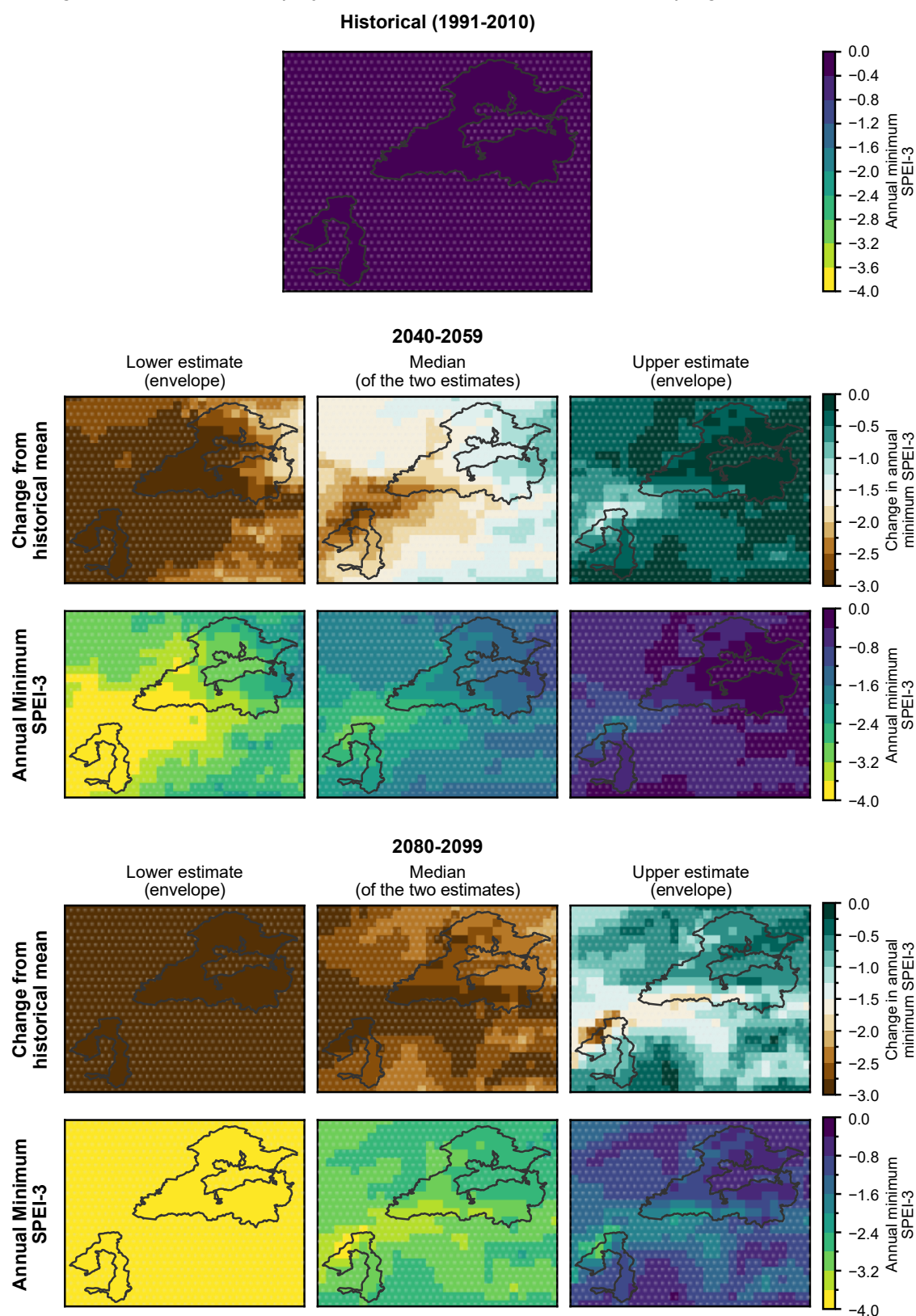


Figure 37: Seasonal minimum SPEI-3 over time by elevation zone in the Fergana Valley (only programme districts)

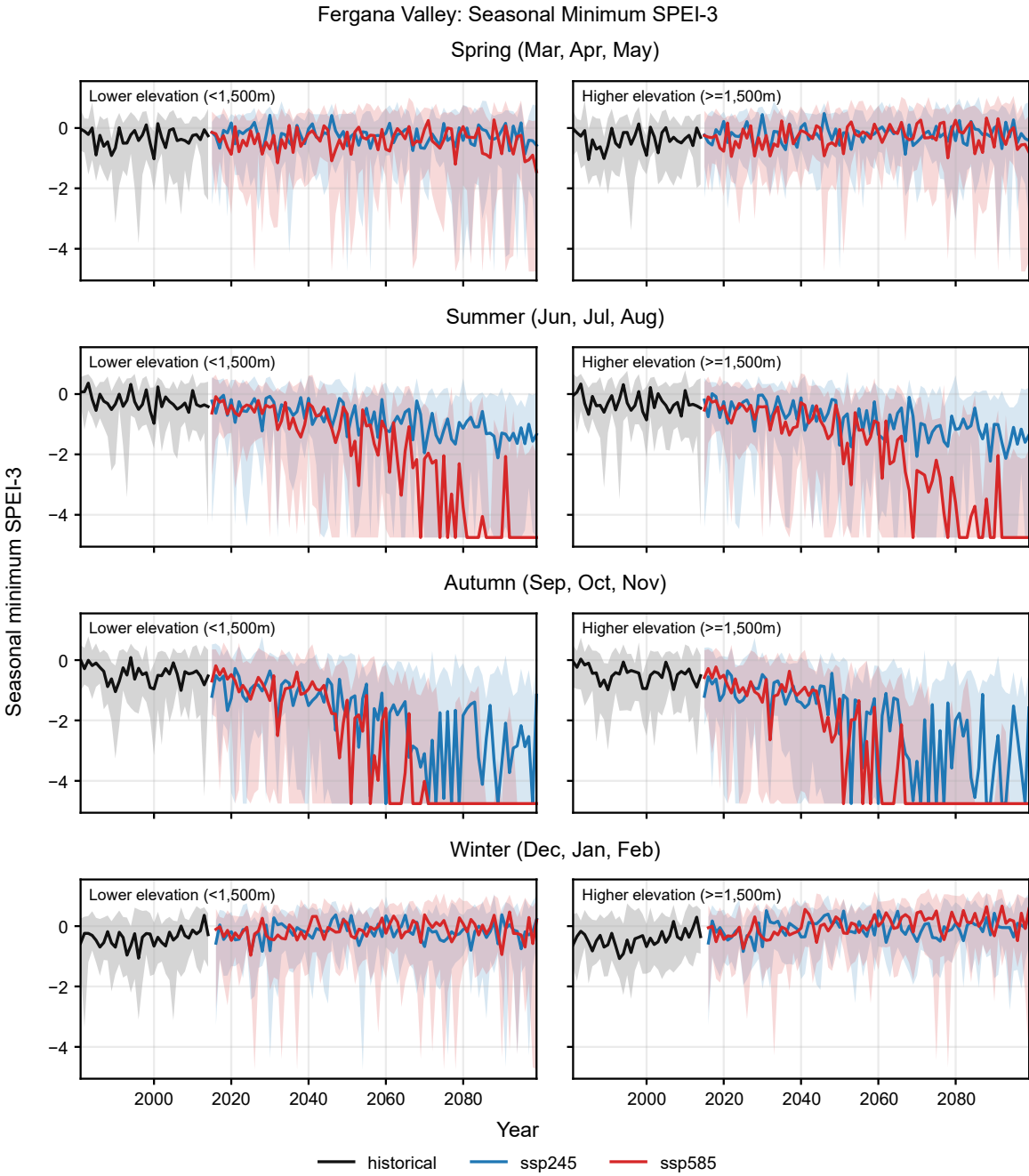
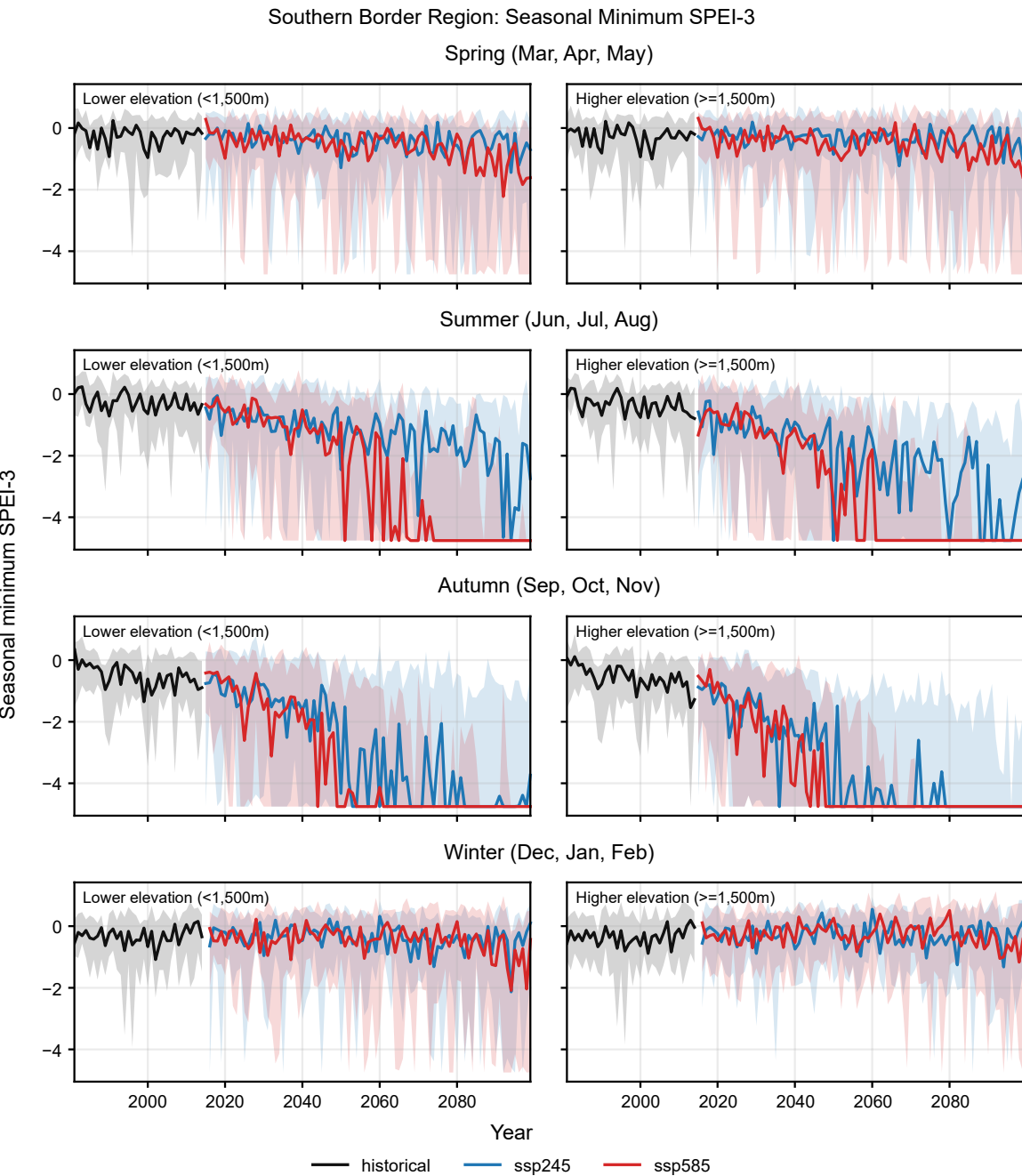


Figure 38: Seasonal minimum SPEI-3 over time by elevation zone in the Southern Border Region



6.7 Heavy Rain

Figure 39 shows that heavy rain days are already part of the present climate in both programme areas, but their spatial distribution differs clearly. In the historical baseline, the highest frequency is concentrated along the southern flank of the Fergana Valley and in the higher parts of the Southern Border Region, whereas the lower-elevation zones in both programme areas record fewer such events. The maps also show that this hazard is not evenly distributed within either region but follows distinct topographic belts (Figure 39 and Figure 2).

The projected maps indicate a general increase in heavy rain days, but with marked spatial differences. In the lower estimate, changes remain limited across much of the programme areas even by late century (Figure 39). In the upper estimate, by contrast, the increase is clear already by mid-century and becomes pronounced by 2080–2099, especially along the southern belt of the Fergana Valley and across large parts of the Southern Border Region (same figure). The strongest increase is therefore not in the valley lowlands, but in those areas that already show elevated baseline frequencies.

The time series in Figure 40 and Figure 41 are consistent with this pattern. In both programme areas, the increase is stronger above 1,500m than below. In the Fergana Valley, heavy rain days remain relatively infrequent in the lower-elevation zone and increase only gradually, while the higher-elevation zone shows a clearer upward trend, especially under SSP5-8.5 (Figure 40). The same contrast appears in the Southern Border Region, where the lower-elevation zone changes only modestly, but the higher-elevation zone shows a more sustained increase over time (Figure 41). Overall, the signal points to a growing heavy-rain hazard concentrated mainly in the upland and foothill parts of both programme areas. Figure 11 shows that these elevation bands are dominated mainly by pasture and forest, with some rainfed cropland in parts of the mid-elevation zone. The increase in heavy rain, therefore, suggests rising exposure of these land-use systems to runoff, erosion, and local slope instability.

Figure 42 and Figure 43 show that the increase in heavy rain is not distributed evenly across the year. The clearest monthly increases occur in the cooler part of the year, especially from about November to April, with stronger changes in higher-elevation parts of both programme areas and only limited change in the lower-elevation Southern Border Region. By contrast, summer months show little systematic increase. This timing suggests that the main concern is not a uniform rise in summer storms across the lowlands, but more frequent intense rainfall during late autumn, winter, and early spring increasing risks for muddy field conditions, harvest handling and drying in exposed cropland, and for runoff, mudflows, and slope instability in foothill and upland belts.

Figure 39: Historical and projected annual number of days with precipitation above 20mm

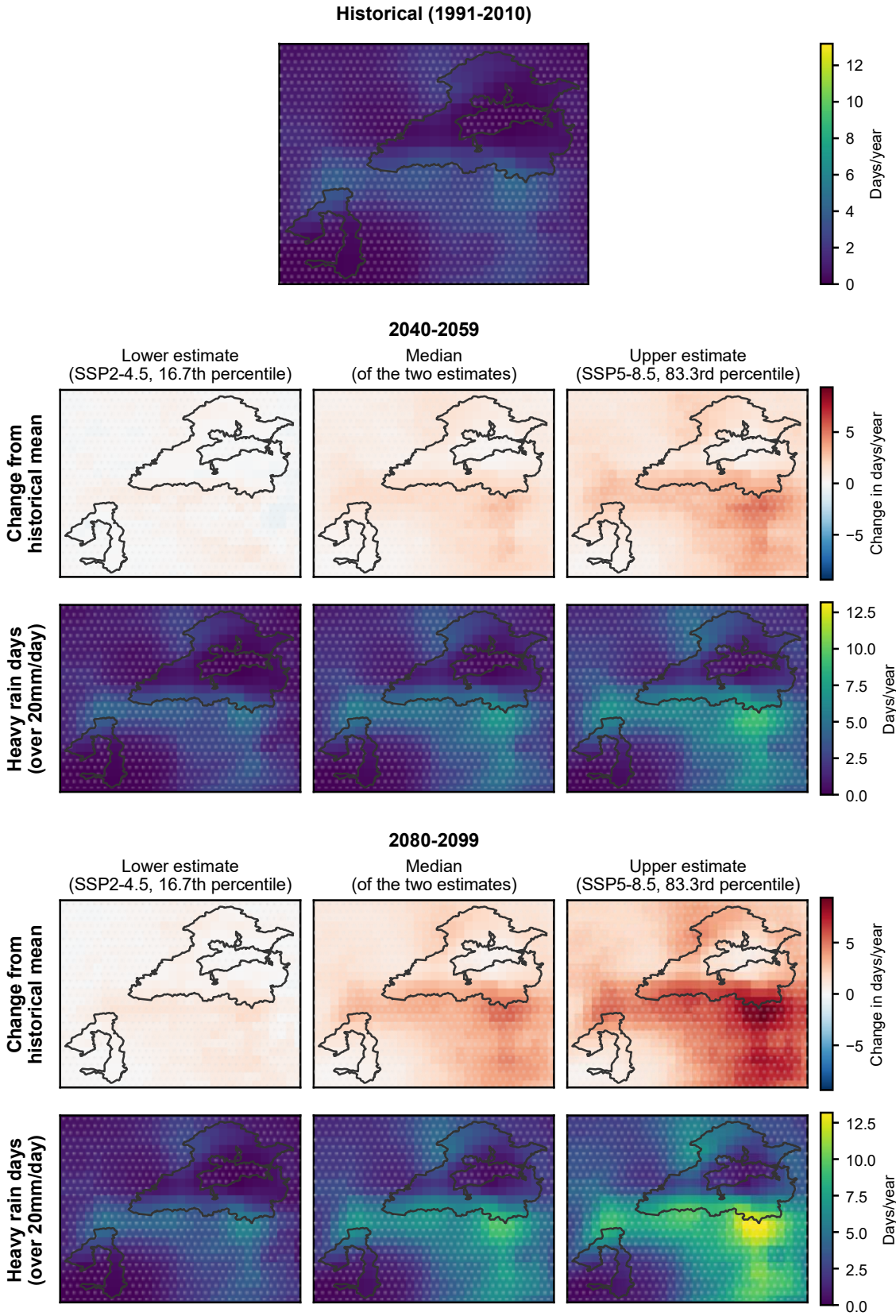


Figure 40: Annual number of days with precipitation above 20mm over time by elevation zone in the Fergana Valley (only programme districts)

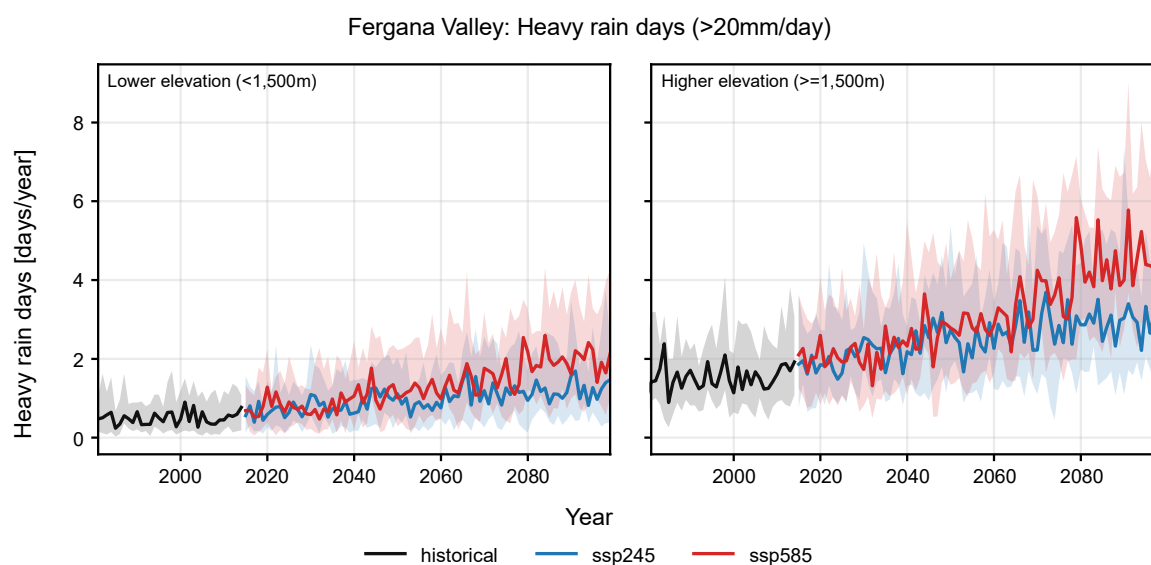


Figure 41: Annual number of days with precipitation above 20mm over time by elevation zone in the Southern Border Region

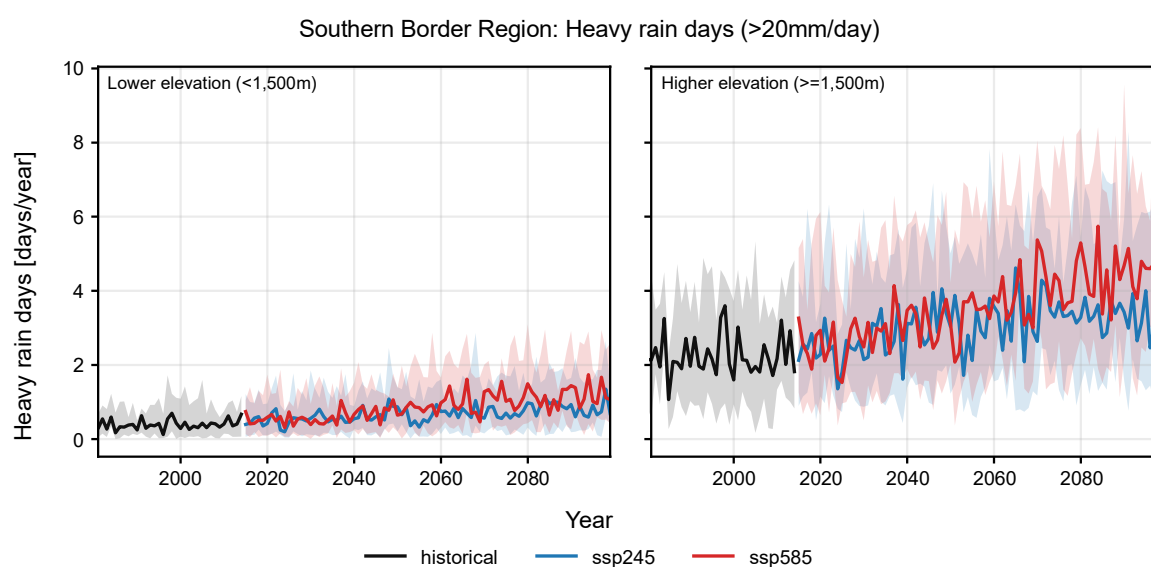


Figure 42: Change in monthly heavy rain days (days with precipitation above 20mm) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Fergana Valley (only programme districts)

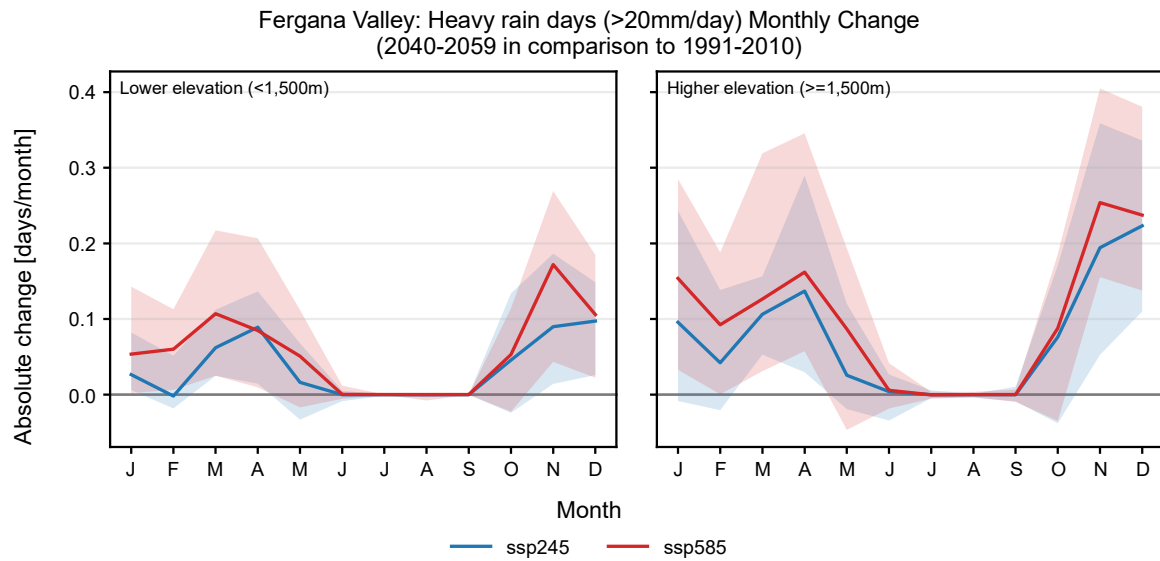
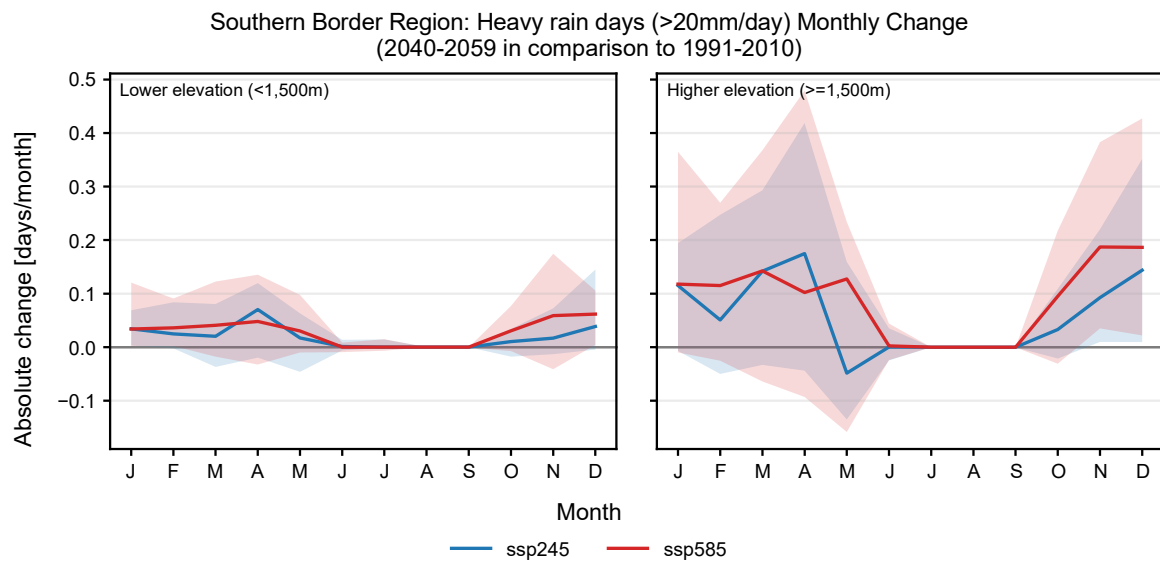


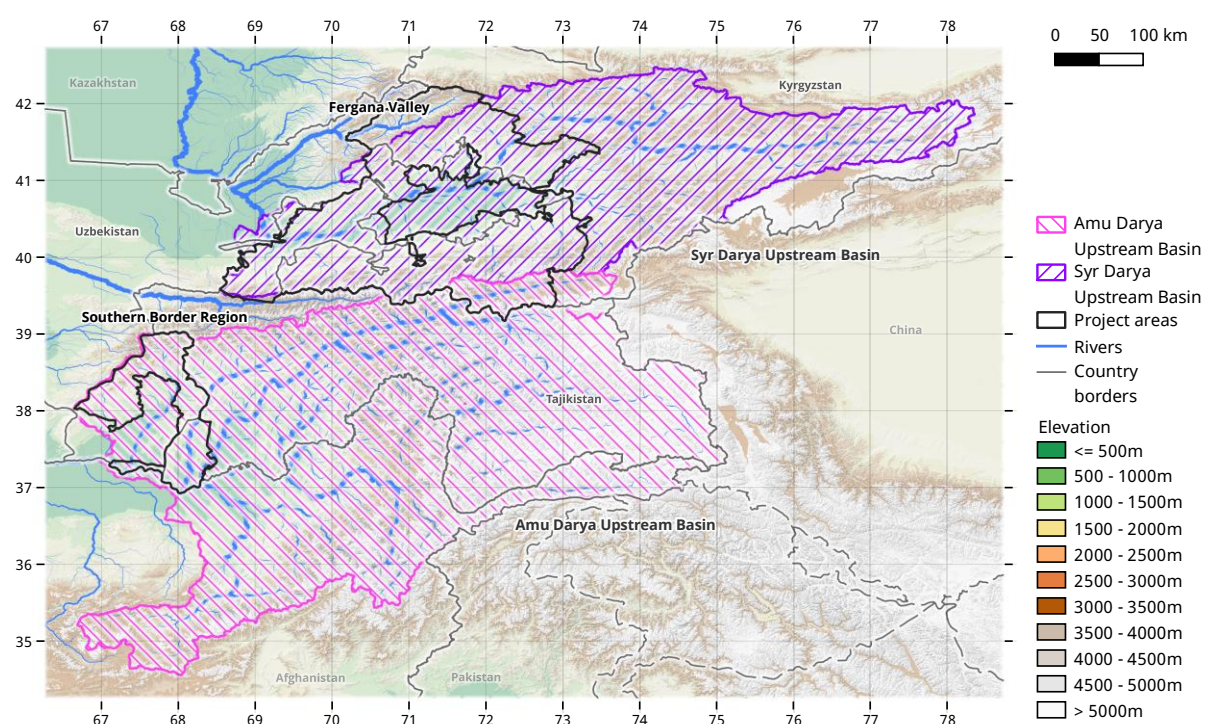
Figure 43: Change in monthly heavy rain days (days with precipitation above 20mm) for the mid-century (2040-2059) in comparison to the baseline period (1991-2010) by elevation zone in the Southern Border Region



6.8 Upstream run-off shift

Because both programme areas depend partly on water generated beyond the programme districts themselves, this section considers, for each programme area, the relevant upstream-basin system as a whole – that is, the basin area that includes the programme districts themselves and the hydrologically connected areas upstream of them that feed downstream water supply. For the Fergana Valley programme districts this is the Syr Darya upstream basin, and for the Southern Border Region it is the Amu Darya upstream basin (Figure 44). Rather than modelling river discharge directly, the following analysis examines basin-wide warming, snowfall-condition precipitation, and snow share as proxy indicators for likely changes in seasonal snow storage and runoff timing. Here, snowfall-condition precipitation refers to precipitation occurring on days with mean daily temperature below 0°C and is used as a proxy for precipitation likely to contribute to snow accumulation. Snow share refers to the share of snowfall-condition precipitation in total precipitation.

Figure 44: Upstream-basin systems relevant to the programme areas (Syr Darya upstream basin in relation to the Fergana Valley programme districts; Amu Darya upstream basin in relation to the Southern Border Region programme districts)



Source: Own illustration based on analysis of the HydroBASINS dataset (Lehner & Grill, 2013)

Figure 45 and Figure 46 show a consistent shift in both upstream basins. Mean temperature rises strongly over time, while snowfall-condition precipitation declines and, even more clearly, the share of precipitation falling under snow conditions decreases under both scenarios, with stronger changes under SSP5-8.5. This indicates that a smaller fraction of cool-season precipitation is likely to be stored temporarily as snow, even where total cold-season precipitation does not necessarily decline in the same way.

The monthly panels show that this shift is concentrated especially in late winter and spring, with notable reductions from about March to May, and with additional declines in autumn. By contrast, midsummer changes are negligible, as precipitation rarely occurs under snowfall conditions then. The hydrological significance of the spring shift is particularly important: where less precipitation continues to accumulate as snow late in the cold season, upstream snow buffers are likely to be depleted earlier in the year, reducing the capacity to sustain runoff into late spring and summer.

The likely implication for both programme areas is therefore not necessarily a simple decline in annual upstream water generation, but a shift in the timing of runoff and a weakening of upstream seasonal buffering. A larger share of cool-season precipitation is expected to be released earlier as rain or earlier meltwater, while snow- and ice-based storage contributes less strongly to buffering later in the year. For downstream systems, this is directly relevant because irrigation demand peaks in the hot and already dry part of the year. The upstream snow-shift signal therefore reinforces the broader seasonal mismatch identified in Section 6.5 and helps explain why dry-season water stress may intensify even where parts of the cool season become wetter.

Figure 45: Annual mean temperature (top left), annual snowfall-condition precipitation (top right), annual snow share (bottom left), and mid-century monthly change in snow share relative to 1991–2010 (bottom right) for the Syr Darya upstream basin relevant to the Fergana Valley programme districts

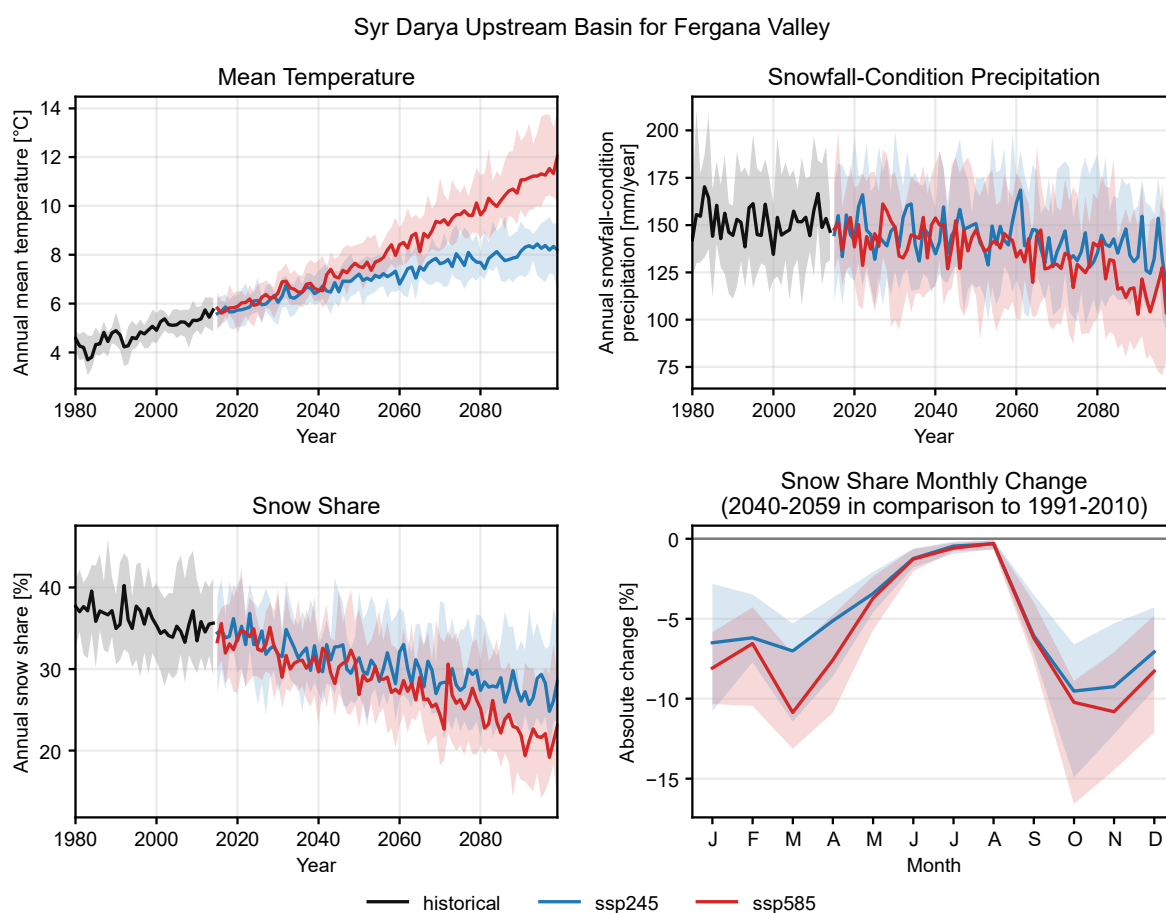
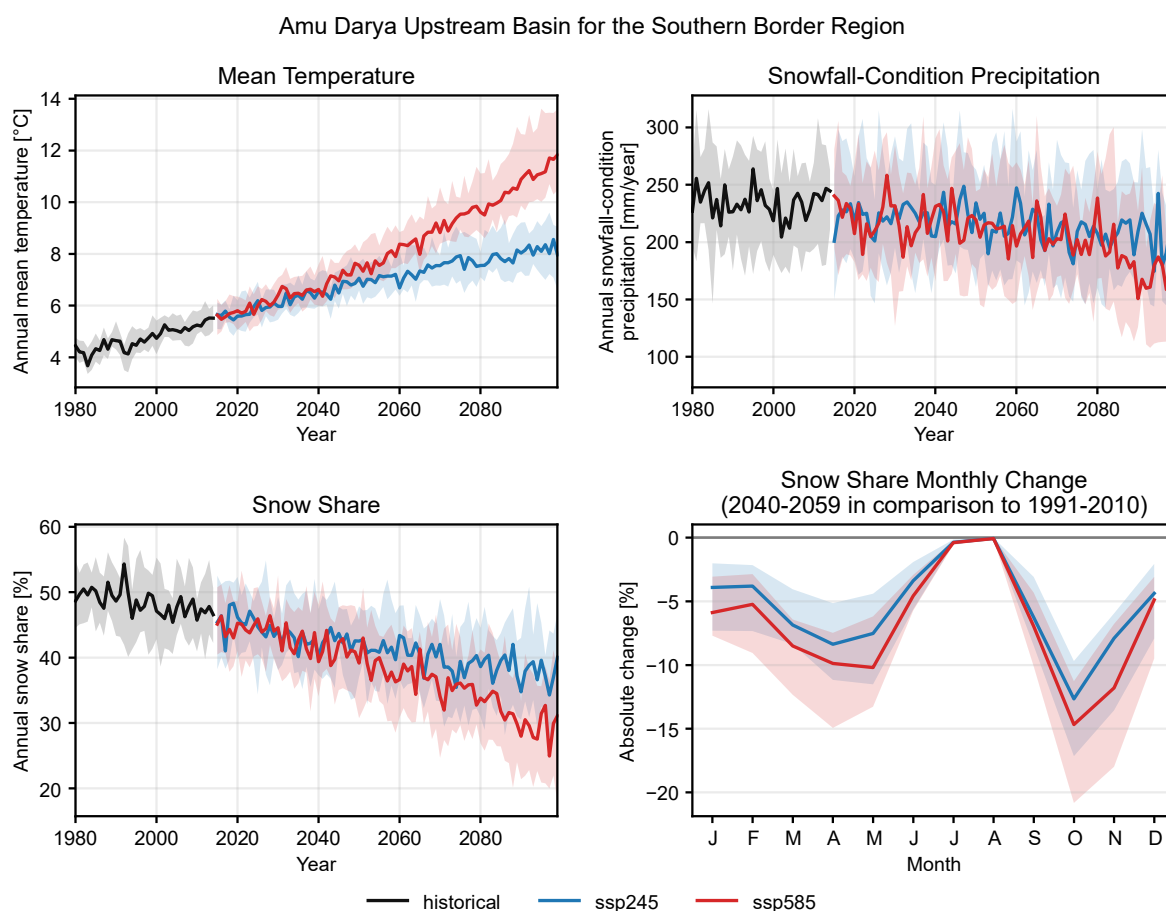


Figure 46: Annual mean temperature (top left), annual snowfall-condition precipitation (top right), annual snow share (bottom left), and mid-century monthly change in snow share relative to 1991–2010 (bottom right) for the Amu Darya upstream basin relevant to the Southern Border Region programme districts

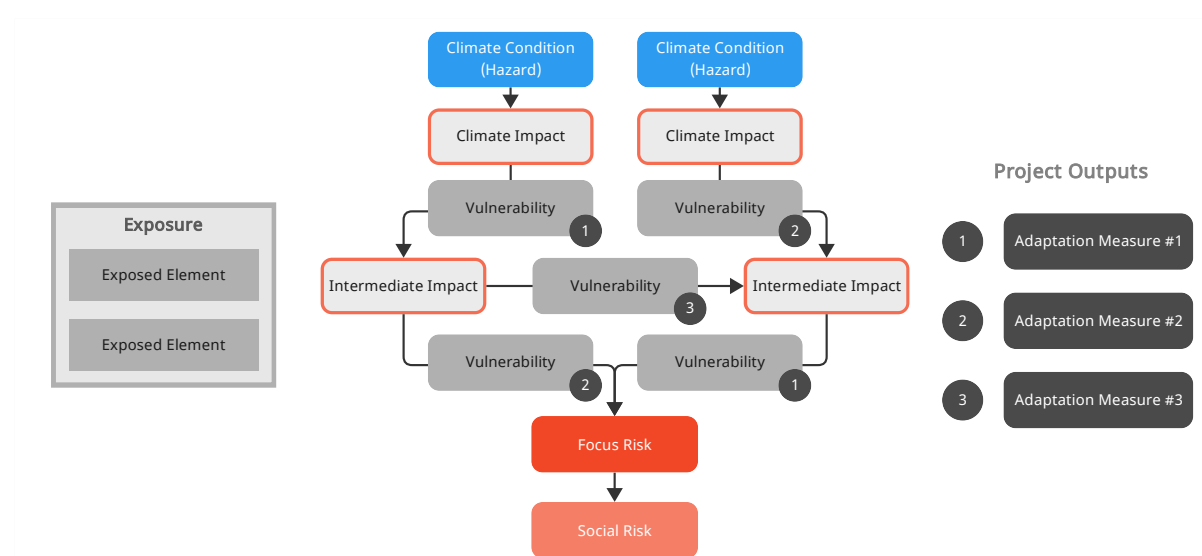


Taken together, the hazard patterns presented in this chapter indicate progressively hotter conditions, a stronger seasonal imbalance in water availability, and increasing pressure from climate extremes across the programme areas. These changes provide the climatic basis for the assessment of resulting impacts across the focus land-use systems in Chapter 7.

7. Climate Impacts

This chapter translates the climate hazards assessed in Chapter 6 into direct and cascading impacts across the focus land-use systems in the programme area. The analysis is structured through Climate Impact Chains, which trace how changes in temperature, water availability, seasonal timing, and climate extremes affect production systems, ecosystem functions, and climate-sensitive livelihoods. It draws on four land-use-specific Climate Impact Chains, complemented by stakeholder consultations and field evidence from the target areas. Although the Climate Rationale distinguishes five core land-use systems overall, pasture and forest are treated jointly here because they form a coupled system with strong ecological and land-use feedbacks in the programme landscapes. Table 7 summarizes the main hazard-to-impact pathways across the key land-use systems; vulnerabilities and adaptation responses are examined in Chapters 8 and 9.

Figure 47: Conceptual Climate Impact Chain framework applied across the Climate Rationale - climate impacts



Source: Own illustration

Table 7: Summary of main hazard-to-impact pathways across focus land-use systems, including geographic differentiation and examples of key crops, pasture, and forest systems

Land-use System	Aspect of Land-use System	Summary of aspect
Irrigated Annual Cropland (Horticulture & Seed Potatoes Value Chains)	Typical crops	Vegetables, melons, berries
	Programme focus	Onions, Tomatoes (on-field & greenhouse), Garlic, Strawberries (greenhouse); Seed potatoes
	Main geographic expression in the programme areas	- Primarily lowland and lower-foothill irrigated areas, especially downstream parts of canal systems (Chapter 5) - Heat and irrigation stress are strongest in lower elevations (Section 6.3) Hot dry wind exposure especially relevant in the western Fergana Valley and parts of the Southern Border Region (Section 6.4)

Land-use System	Aspect of Land-use System	Summary of aspect
		Localized heavy-rain impacts are more relevant in foothill irrigated systems and exposed canal / drainage locations (Section 6.7)
	Main climate hazard pattern	- Mean temperature increase (Section 6.2) - Stronger seasonal water imbalance (Sections 6.5, 6.8) - Intensifying summer–autumn drought (Section 6.6) - Extreme heat (Section 6.3) - Localized hot dry wind (Section 6.4) - Localized heavy rainfall and flooding (foothill and middle elevations) (Sections 6.5, 6.7)
	Main cascading impacts	- Reduced upstream water availability and downstream irrigation shortfalls (Sorg et al. 2012) - Higher evapotranspiration and irrigation demand (Hatfield & Prueger, 2015) - Increasing salinity, soil hardening, and declining soil conditions (Corwin, 2021; Munns & Tester, 2008) - Washout, waterlogging, sedimentation, and canal damage in exposed locations (Assouline & Ben-Hur, 2006) - Crop scorching, early ripening, and rising pest and disease pressure (FAO & Univ. Bonn, 2021; Ma et al., 2025); potatoes especially heat-sensitive (Bustan et al., 2004) and prone to disease (van der Waals et al., 2013)
	Main resulting impacts	- Lower yields and lower market quality of annual crops - Higher irrigation and input costs - Greater production instability - More unequal water access under scarcity
Irrigated Perennial Cropland (Orchard-based Fruit Value Chain)	Typical crops	Orchards and vineyards, especially apricot, apple, plum, pear, cherry, almond, pomegranate, and grapes
	Programme focus	Fruit trees
	Main geographic expression in the programme areas	- Mainly lower-elevation and valley / lower-foothill irrigated systems (Chapter 5) - Especially exposed where orchards depend on canal and pump irrigation from upstream sources (lower elevation) - Some spring-instability effects (e.g. early blooming) also extend into cooler foothill zones - Heat burden especially high in Southern Border Region (lower elevation) (Section 6.3)
	Main climate hazard pattern	- Mean temperature increase (Section 6.2) - Stronger summer–autumn drought (Section 6.6) - Extreme heat (Section 6.3) - Earlier spring onset (Section 6.2) - Continued frost risk after warm spells - Heavy rainfall during flowering and fruit setting (Section 6.7) - Localized hot dry wind (Section 6.4)

Land-use System	Aspect of Land-use System	Summary of aspect
	Main cascading impacts	• Reduced upstream water availability and downstream irrigation shortfalls (Sorg et al. 2012) • Higher evapotranspiration and irrigation demand (Hatfield & Prueger, 2015) • Increasing salinity, soil hardening, and declining soil conditions (Corwin, 2021; Munns & Tester, 2008) • Washout, waterlogging, sedimentation, and canal damage in exposed locations (Assouline & Ben-Hur, 2006) • Reduced fruit size and quality (e.g. for apples: Reid & Kalcsits, 2020) • Altered flowering and earlier phenology (Cleland et al., 2007); pollination mismatch (Trunschke et al., 2024) • Blossom and young-fruit losses from late frost (Pfleiderer et al., 2019) • Fruit rot and disease under wet conditions (e.g. for grapes: Molitor et al., 2016) • Crop scorching, shrivelling, branch damage, and rising pest pressure (FAO & Univ. Bonn, 2021; Ma et al., 2025)
	Main resulting impacts	• Lower and less reliable orchard productivity • Smaller, damaged, or lower-quality fruits • Declining marketability and prices • Higher management costs • Greater long-term risk to orchard assets
Rainfed Cropland (Wheat Value Chain)	Typical crops	Mainly wheat, and in some locations barley and fodder crops
	Programme focus	Wheat
	Main geographic expression in the programme areas	• Mainly foothill and upland rainfed systems (Chapter 5) • Drought impacts are widespread across elevations and programme areas (Section 6.6) • Heavy-rain washout is more localized in sloping and foothill areas (Section 6.7)
	Main climate hazard pattern	• Mean temperature increase (Section 6.2) • Intensifying drought conditions, especially in summer and autumn (Section 6.6) • Extreme heat (Section 6.3) • More erratic rainfall (Section 6.5) • Heavy rainfall in foothill areas (Section 6.7)
	Main cascading impacts	• Declining soil moisture and crop water stress (Filho et al., 2025) (Qaseem et al., 2019) • Weaker germination and crop establishment • Disrupted sowing windows and cropping calendars (Minoli et al., 2022) • Soil hardening, erosion, and nutrient loss (Filho et al., 2025) • Localized washout from intense rainfall and mudflows • Crop scorching, and rising pest and disease pressure (Ma et al., 2025)

Land-use System	Aspect of Land-use System	Summary of aspect
		Reduced animal health (e.g. sheep: van Wettere et al., 2021)
	Main resulting impacts	- Lower and more variable cereal yields (Qaseem et al., 2019) - Greater risk of establishment failure and crop failure (Khah et al., 1986) - Declining soil fertility and moisture retention (Filho et al., 2025) - Reduced reliability of rainfed production (e.g. wheat: Nazari et al., 2021)
Pasture Land	Typical species	- Pasture used for cattle, sheep, goats, and mixed grazing - Grassland
	Main geographic expression in the programme areas	- Across all elevation levels, especially at the interface to other land-use systems (rainfed cropland and forests) (Chapter 5) - Heavy-rain, runoff, and slope-instability impacts are strongest in foothill and upland belts rather than in valley lowlands (Section 6.7)
	Main climate hazard pattern	- Mean temperature increase - Stronger summer–autumn drought - Extreme heat - Declining and less reliable water availability - Heavy rainfall
	Main cascading impacts	- Drying vegetation and weaker regeneration (Jiang et al., 2024) - Rising pest and disease risks (FAO & Univ. Bonn, 2021) - Lower pasture biomass and fodder quality (Liu et al., 2023) - Shorter grazing periods pushing pressure onto forests and cropland (Azarov et al., 2022) - Reduced slope stabilization and water regulation (Straffelini et al., 2024)
	Main resulting impacts	- Declining pasture carrying capacity - Higher erosion, mudflow, and landslide risks - Reduced livestock productivity - Declining protective ecosystem functions (water regulation and soil stabilisation)
Forests (Non-Timber Forest Products Walnuts & Pistachios)	Typical species	Juniper, pistachio, and walnut trees
	Programme focus	Walnut and pistachio forests and their non-timber forest products
	Main geographic expression in the programme areas	Mainly upper elevations; mostly around Fergana Valley (Chapter 5)
	Main climate hazard pattern	- Mean temperature increase - Stronger summer–autumn drought

Land-use System	Aspect of Land-use System	Summary of aspect
		- Declining and less reliable water availability - Heavy rainfall
	Main cascading impacts	- Reduced slope stabilization and water regulation (Moos et al., 2023) - Increasing pest and disease pressure (e.g. pistachio very sensitive: Kenzhebaev et al., 2023) - Forest fire pressure (Zong et al., 2020) - Decreased forest health and decline in biomass (e.g. for juniper: Seim et al., 2016) - Decreased product quality (e.g. for walnuts: Mahmoudian et al., 2021) - Seedling failure (Pozner et al., 2022)
	Main resulting impacts	- Weaker regeneration and reduced produce yield - Higher erosion, mudflow, and landslide risks (Assouline & Ben-Hur, 2006) - Declining protective ecosystem functions (water regulation and soil stabilisation)
Cross-cutting	Typical system context in the programme area	Connected mountain–foothill–valley landscape linking upper catchments, forests, pasture, rainfed cropland, and irrigated cropland
	Main geographic expression in the programme areas	Upper catchments and steep slopes: reduced snow and glacier buffering and weaker runoff regulation Foothill and middle elevation: stronger erosion, mudflow, and slope-instability risks under heavier rainfall Lower valleys and lowlands: transmitted dry-season water stress and irrigation shortfalls Localized hot dry wind exposure is concentrated mainly in the southern / southwestern Southern Border Region and the western Fergana Valley (Section 6.4)
	Main climate hazard pattern	- Mean temperature increase (Section 6.2) - Stronger seasonal imbalance in water availability (Section 6.5, 6.8) - Intensifying summer–autumn drought (Section 6.6) - Heavy rain in foothill and upland areas (Section 6.7) - Localized hot dry wind (Section 6.4)
	Main cascading impacts	- Reduced upper-catchment water regulation (Sorg et al. 2012) - Less reliable downstream water supply (Sorg et al. 2012) - Reinforcing land degradation (Filho et al., 2025) - Loss of vegetation cover and protective ecosystem functions (Straffellini et al., 2024) - Pressure shifts between pasture, forest, rainfed, and irrigated systems (Azarov et al., 2022)
	Main resulting impacts	- More unstable water availability - Higher erosion, mudflow, and landslide risks (in higher areas) - Stronger pressure on cropland, forests, and pasture

Land-use System	Aspect of Land-use System	Summary of aspect
		Reduced livelihood stability, food security, and resilience

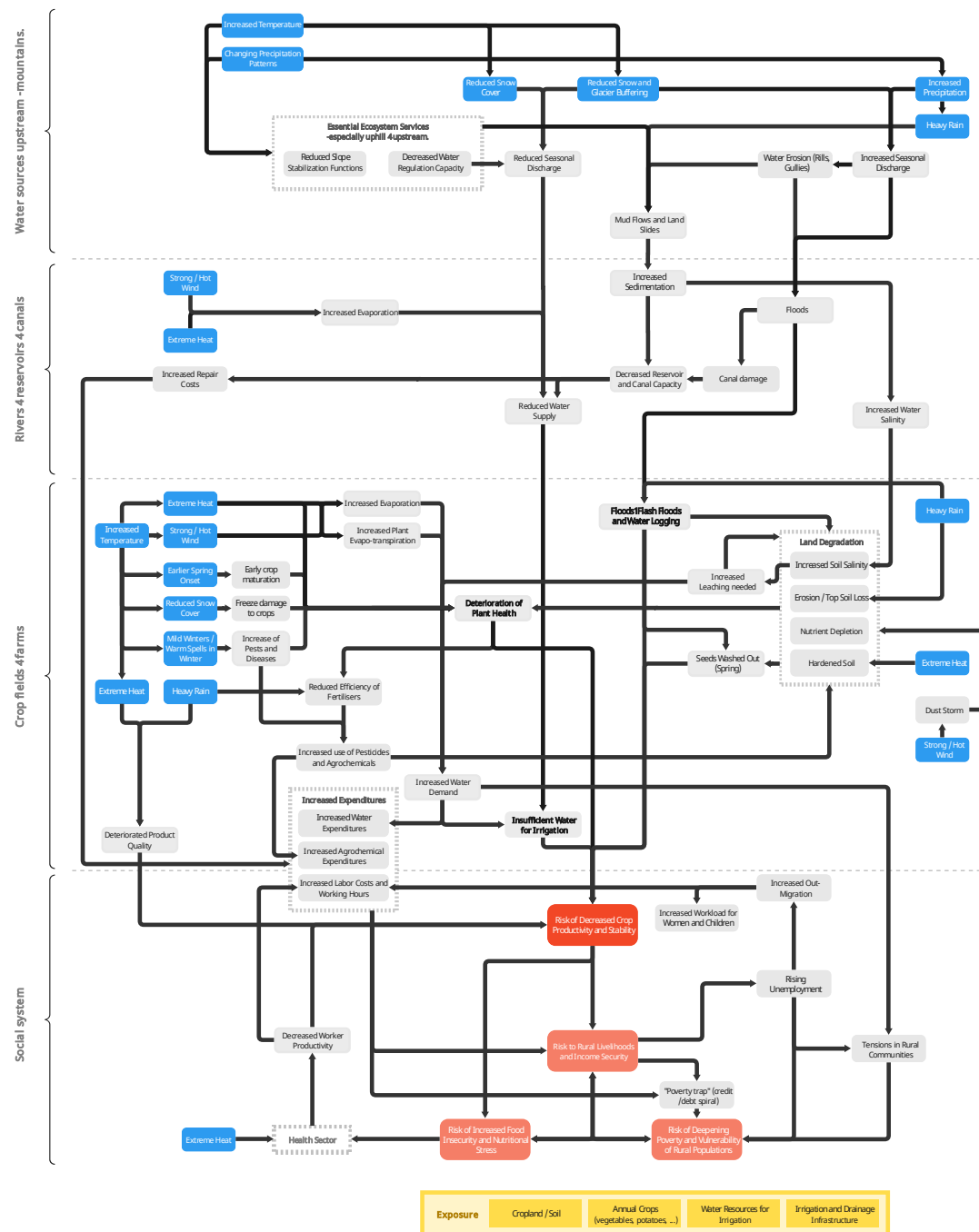
7.1 Impacts on Irrigated Annual Cropland

Irrigated annual cropland is affected primarily through increasing irrigation stress, hotter and drier growing conditions, worsening soil degradation and salinity processes, and episodic damage from intense rainfall, wind, and heat. In the programme area, this concerns above all annual crops such as vegetables, melons, potatoes, and other field crops cultivated mainly in irrigated lowland and lower-foothill systems. The Climate Impact Chain for irrigated annual cropland (Figure 48) shows how rising temperatures, changing precipitation, declining water availability, and heavy rainfall events translate into reduced crop productivity and stability, higher production costs, and greater livelihood stress. Many of these structural pressures are shared with irrigated perennial cropland, but in annual systems they translate more directly into seasonal yield and quality losses within individual production cycles. As the hazard profile shifts further toward hotter conditions, drier summers and autumns, stronger seasonal imbalance in water availability, and continued exposure to hot dry wind and intense rainfall, these pathways are expected to intensify.

Table 7 should be read around three dominant pathway clusters: first, upstream water stress and uneven downstream delivery; second, direct heat, hot-dry-wind, and pest pressure on annual crops; and third, soil and infrastructure deterioration through salinity, erosion, and intense rainfall. The figure thus shows that climate risk in irrigated annual systems arises not from one single hazard, but from the interaction of water stress, heat stress, and land degradation within the same production cycle.

Figure 48: Climate impact chain for irrigated annual cropland in the programme areas

Climate Impact Chain ... Irrigated Cropland -annual.



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Legend

Climate Condition (Hazard) Climate Impact Focus Risk Social Risk Exposed Element

Source: Own illustration

Irrigation shortfalls increasingly reflect upstream hydrological stress, and dependence on upstream water availability. In the upper and left-hand parts of the chain (Figure 48), increased temperature, reduced water storage in mountains, changing precipitation, and drought conditions are linked to increased evapotranspiration, increased irrigation demand, insufficient water for irrigation,

reduced water supply in summer and autumn, and conflict over water. This pathway is well supported by regional evidence. Central Asian agriculture is strongly dependent on irrigated production, and the region's irrigation systems face growing pressure from water scarcity, low efficiency, aging infrastructure, and the need to adapt to more variable climatic conditions (Dankova et al., 2022). More broadly, the literature on regional water-security highlights that downstream economies are particularly vulnerable where climate change interacts with weak institutions, inadequate infrastructure, and dependence on upstream water availability (World Bank, 2024a). Because mountain areas function as critical “water towers” for downstream users, climate-sensitive changes in snowpack, glacier melt, and seasonal water availability have consequences far beyond upper catchments themselves (Saidaliyeva et al., 2024).

In the programme area, this pathway is especially important because most irrigated annual production is located in the lower parts of the landscape, while the water originates further away in mountain and upper-catchment areas, often across national borders. This means that climate impacts on snow, runoff timing, and upstream water availability are transmitted downstream. At the same time, scarcity is not experienced evenly within irrigation schemes. Stakeholder consultations indicate that although neighbouring farmers often organize local water distribution pragmatically among themselves, more formal district-wide allocation arrangements are often weak or inconsistently enforced. Farmers repeatedly complained that those located closer to pumps, gates, or other control points are often able to capture more water than officially allocated, while users further downstream may receive little or none, especially in low-water periods. In Beshariq, stakeholders described water scarcity as the dominant production constraint and referred to unequal water delivery, increasing reuse of low-quality drainage water, and substantial losses in canals and drainage systems. This illustrates well, on a local level, the literature on a regional level: climate pressure does not affect all irrigators evenly, but is filtered through canal condition, pumping access, allocation practices, and downstream position within irrigation systems (Dankova et al., 2022; World Bank, 2024a). As summer and autumn drought conditions intensify further and upstream buffering becomes weaker, these hydrological and allocation-related irrigation shortfalls are expected to become more frequent and more damaging in annual crop systems located in the lower lands.

Heat stress, hot dry wind, and intense radiation reduce crop quality and raise losses. In the central part of the chain (Figure 48), heat stress and rising temperatures are linked to decreased plant health, early crop maturation, increased pests and diseases, reduced labour productivity, and lower crop productivity and stability. In practical terms, this means not only lower yields, but also earlier ripening, crop scorching, quality losses, and greater market risk for irrigated annual crops. Within the programme focus, these pressures are especially relevant for open-field onions, garlic, and tomatoes, as well as for potatoes and seed potatoes, which are comparatively sensitive to high temperatures, while greenhouse tomatoes and strawberries are less exposed to wind directly but remain vulnerable to excessive heat and rising cooling and water requirements (Hatfield & Prueger, 2015; Bustan et al., 2004). Consultations across the programme area described these effects in highly specific terms. In Beshariq, stakeholders emphasized Garmsil (hot wind in summer typical for the area), dust storms, and strong winds as major hazards for open-field vegetable systems, and also described dry hot winds in late spring and early summer as particularly damaging for annual crops, especially tomatoes, through premature drying, yield loss, and lower product quality. In Osh and Jalal-Abad, workshop participants referred to sunburn, early ripening, reduced market quality, and crop damage under prolonged heat. In Khatlon, stakeholders similarly linked excessive heat to crop failure, instability of crop varieties, and rising household debt. Taken together, these patterns suggest not only greater production risk within existing annual systems, but also tightening climatic margins for the most heat-sensitive annual crops in the hottest lower-elevation zones, increasingly requiring changes in crop calendars, crop choice, protective measures, or production location. As extreme heat increases further in lower elevations and hot dry wind remains concentrated in parts of the Southern Border Region and western Fergana Valley, this pathway is expected to intensify.

Soil salinity, erosion, and declining soil condition increase production costs and reduce resilience. In the middle section of the chain (Figure 48), insufficient irrigation, increased leaching needs, increased water and soil salinity, hardened soils, and nutrient depletion are linked to reduced crop productivity and higher production costs. Heavy rainfall and flooding reinforce this through topsoil loss, erosion, sedimentation, and damage to canal and reservoir capacity. Stakeholder consultations in Beshariq, Sughd, and Khatlon repeatedly highlighted salinity, drainage problems, and erosion as key constraints. In Beshariq, stakeholders referred to rising groundwater and drainage water levels, declining soil quality, and the need for more leaching water. In Sughd, consultations highlighted loss of fertile topsoil and untimely precipitation disrupting production. In Khatlon, stakeholders linked soil salinization and erosion directly to yield decline and farmer indebtedness. As wetter wet periods and drier dry periods become more pronounced, this degradation pathway is likely to strengthen, increasing both production risk and the cost of maintaining soil function.

Heavy rainfall causes localized washout, waterlogging, and infrastructure losses. In the upper and central parts of the chain (Figure 48), heavy precipitation and flooding are linked to floods, flash floods, waterlogging, seeds washed out during establishment, erosion, sedimentation, canal damage, and increased maintenance and repair needs. Although drought is the dominant concern in most irrigated annual systems, intense rainfall still produces serious local losses, especially where drainage is weak and canals are damaged or silted. Stakeholder consultations in Batken, Jalal-Abad, Sughd, and Khatlon referred to untimely or severe precipitation, mudflows, flooded fields, washed-out soils, and damage to canals and infrastructure. This pathway is particularly relevant in foothill systems and other exposed locations where heavy rain can destroy planted fields or disrupt irrigation and access. As heavy rainfall intensifies further, such localized losses are expected to become more frequent.

Pest and disease pressure increases under warmer and more unstable growing conditions. In the central section of the chain (Figure 48), higher temperatures and plant stress are linked to increased pests and diseases, higher agrochemical use, and lower crop quality. Within the programme focus, this is especially relevant for irrigated annual horticulture and seed-potato systems, including onions, tomatoes, garlic, strawberries, and seed potatoes, where warmer and more variable conditions can increase infestation pressure, complicate control, and raise the likelihood of yield and quality losses, including in potato systems (Subedi et al., 2023; FAO & Uni. Bonn, 2021; van der Waals et al., 2013). Stakeholder consultations support this strongly. In Batken, Jalal-Abad, Osh, and Khatlon, workshop participants referred to increasing infestation by insects and worms, emergence of new pests and diseases, rising chemical use, and higher treatment costs. Stakeholders also noted that hotter conditions can favour faster pest development and repeated outbreaks within a season, increasing pressure on annual crops. In Osh, stakeholders additionally reported that pests are carried by wind and that more pesticide use is already affecting both costs and environmental conditions. As warming continues and climatic variability increases, pest and disease pressure is likely to become more persistent, increasing the instability and cost intensity of irrigated annual production.

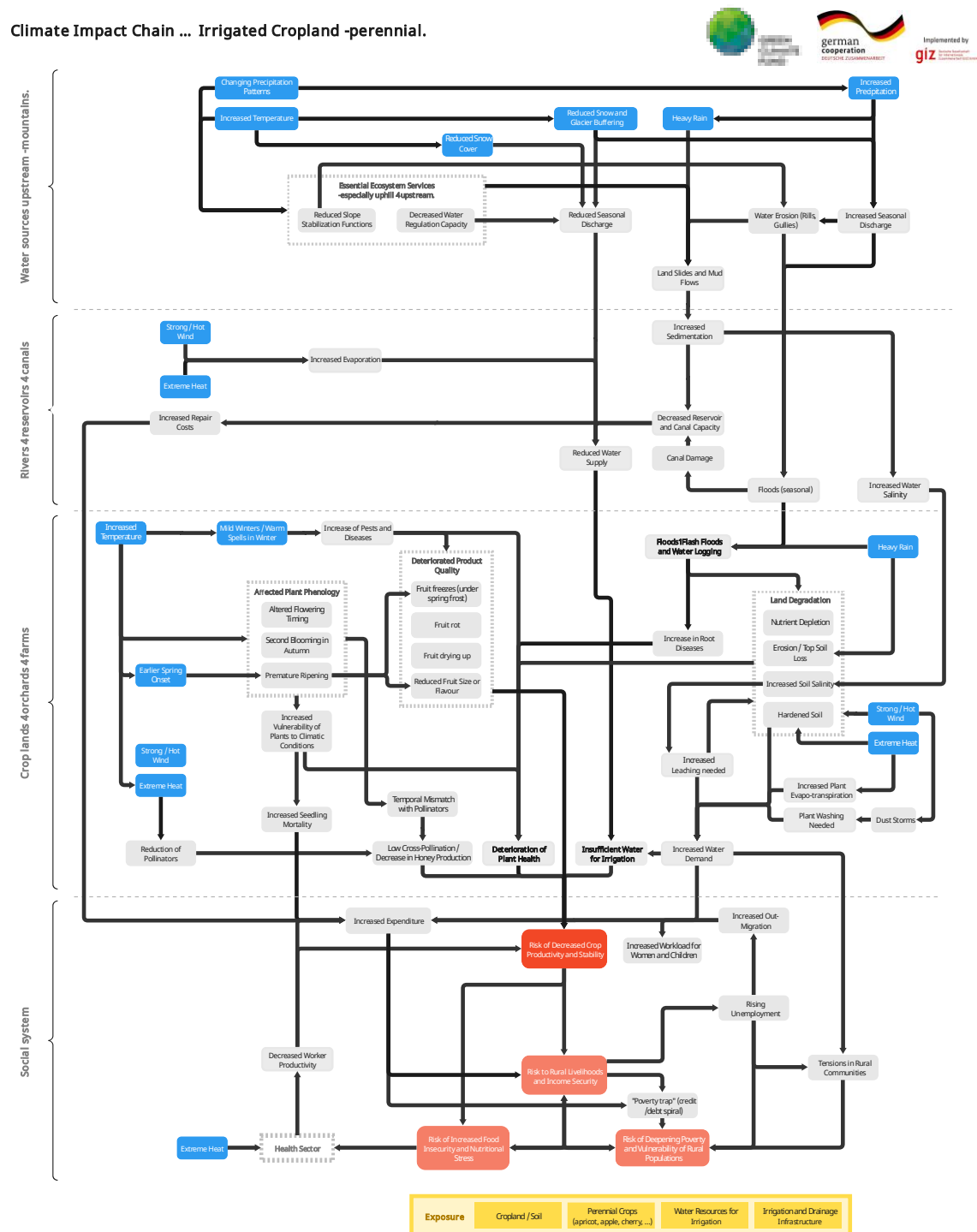
7.2 Impacts on Irrigated Perennial Cropland

Irrigated perennial cropland is affected by a distinct combination of climate impacts because orchard systems are exposed not only to water stress and heat, but also to disruptions of flowering, pollination, fruit set, and fruit development across successive seasons. In the programme area, this concerns above all orchards with apricot, apple, plum, pear, cherry, almond, pomegranate, and grapes. These systems, like irrigated annual cropland, depend on irrigation water originating in more distant mountain and upper-catchment areas and conveyed through canals, pumping systems, and local distribution networks before reaching fields in the valley and lower elevations. The Climate Impact Chain for irrigated perennial cropland (Figure 49) shows how increasing temperature, changing precipitation, and declining irrigation reliability translate into cumulative losses in orchard productivity, fruit quality, and income stability. Many of the underlying structural pressures are shared with irrigated annual cropland, but in perennial systems they accumulate across years because they affect not only seasonal output but also the condition and viability of the orchard asset itself. As the hazard profile shifts further toward

hotter conditions, stronger seasonal water imbalance, more intense summer and autumn drought, and continued spring instability, these impact pathways are expected to intensify.

Figure 49: Climate impact chain for irrigated perennial cropland in the programme areas

Climate Impact Chain ... Irrigated Cropland -perennial.



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Developed by RB Consulting
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Legend

Climate Condition (Hazard) Climate Impact Focus Risk Social Risk Exposed Element

Source: Own illustration

Figure 49 highlights that perennial systems differ from annual systems in two important respects: they are affected not only by seasonal water and heat stress, but also by disruption of spring phenology, flowering, pollination, and fruit set; and the resulting losses accumulate in the orchard asset over time. The figure therefore shows why climate risk in fruit systems is both seasonal and cumulative.

Irrigation stress progressively weakens orchard performance through upstream hydrological stress, transboundary dependence, and unequal downstream allocation. In the left and central parts of the chain (Figure 49), reduced seasonal discharge, higher evapotranspiration, increasing irrigation demand, sedimentation, and salinity lead to insufficient irrigation water, declining plant health, fruit drying, and smaller or lower-quality fruits. In perennial systems, these effects accumulate across years because water stress affects not only the current harvest but also vegetative growth, bud formation, and the condition of the orchard asset itself. Stakeholder consultations in Yangikurgan, Jalal-Abad, Batken, and Sughd consistently linked reduced irrigation water and declining soil moisture to weaker fruit set, lower yields, and worsening orchard condition. As drought conditions intensify further, repeated moisture stress is likely to undermine orchard viability more systematically, especially for smallholders with limited access to water-saving systems.

Earlier flowering and unstable spring conditions increase exposure to pollination failure and frost losses. In the upper and middle parts of the chain (Figure 49), warmer winters and earlier spring onset disrupt phenology, alter flowering timing, and can increase the risk of temporal mismatch with pollinators. This pathway does not affect all perennial crops equally: the degree of risk depends on crop type, cultivar, local site conditions, and the exact timing of warming and late-frost events. In the programme area, it is especially relevant for earlier-flowering orchard crops such as apricot, almond, and sweet cherry, which can become exposed when warm spells advance budbreak and flowering while frost risk has not yet passed; apple is also relevant where warmer winters advance blossom into still frost-prone spring periods. This pathway is well established in the broader perennial-crop literature. Under warming conditions, earlier spring phenology can increase exposure to late frost during sensitive stages such as budbreak and flowering, even where absolute frost frequency declines; climate change can also increase mismatch risks between orchards and their pollinators, with implications for pollination reliability and fruit set where crop and pollinator responses do not shift in parallel (Osorio-Marín et al., 2024; Sánchez-Pérez et al., 2014; Drogoudi et al., 2020; Pflieger et al., 2019; Polce et al., 2014).

This same pathway also raises exposure to late frosts once flowering begins earlier. Workshop participants in Yangikurgan identified shifts in flowering and pollinator mismatch as among the most critical orchard impacts, while stakeholders in Sughd, Batken, and Jalal-Abad referred to early flowering, blossom loss, and freezing of flowers and young fruits during unstable spring conditions, and highlighted apricot, almond, and sweet cherry as particularly exposed orchard crops. This pathway is expected to become more important as warming continues, because earlier development does not remove frost risk but lengthens the period during which orchards are exposed to it.

Heavy rainfall during sensitive stages increases erosion, infection, and fruit loss. The chain (Figure 49) also shows that heavy rain and floods trigger erosion, topsoil loss, root diseases, fruit rot, and sedimentation. In orchard systems, this is especially damaging when rainfall coincides with flowering or fruit setting, because it reduces pollinator activity and increases fungal and bacterial infection pressure. Stakeholder consultations in Yangikurgan, Sughd, Khatlon, and Jalal-Abad specifically linked prolonged rainfall during flowering to poor pollination, flower drop, root diseases, and declining fruit quality. With wetter wet periods projected to become more pronounced, rainfall-related orchard losses are likely to increase alongside drought stress rather than offset it. While the exact magnitude of these effects depends on crop type, timing, and local management, this interpretation is consistent with broader literature showing that temperate fruit and nut systems are highly sensitive to climate-driven disruptions of flowering conditions, pollination processes, and spring extremes (Osorio-Marín et al., 2024; Polce et al., 2014).

Heat, sunburn, wind, and hail increasingly reduce fruit quality and marketability. In the central part of the chain (Figure 49), extreme heat and strong wind are linked to fruit drying, premature ripening,

branch breakage, seedling mortality, and deteriorated product quality. Consultations across the programme area described these effects very concretely: fruit sunburn, shrivelling, staining, darkening, branch damage, premature fruit drop, and hail-related losses were reported in Yangikurgan, Osh, Batken, Jalal-Abad, Sughd, and Khatlon. These impacts are particularly important in orchard value chains because even where some yield is retained, visual damage and reduced fruit size can sharply reduce prices or make produce unsellable. As extreme heat becomes more frequent and heat burdens rise further in lower elevations, this quality-loss pathway is expected to strengthen.

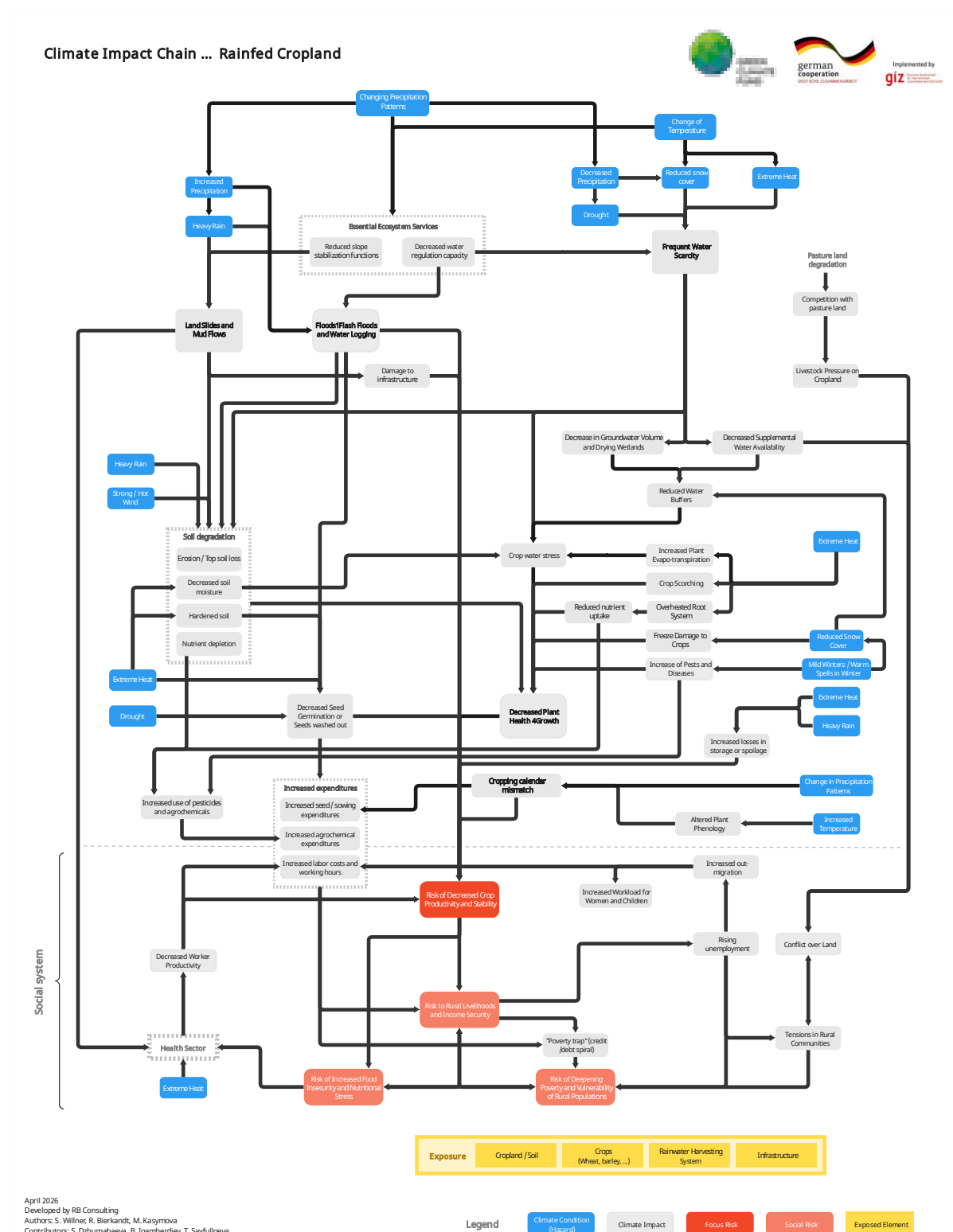
Pest and disease pressure rises under warmer and less stable conditions. The middle section of the chain (Figure 49) links warming, mild winters, plant stress, and altered seasonality to increased pests and diseases. Stakeholder consultations confirm that this is already occurring: farmers in Yangikurgan referred to unfamiliar pests and new diseases, while stakeholders in Batken, Jalal-Abad, Sughd, Khatlon, and Osh reported rising pest pressure, bacterial and root diseases, apple scab, aphids, worm infestation, and more difficult control conditions after mild winters and unstable weather. For orchard systems, this means not only higher biological stress but also rising management costs and greater risk of repeated annual losses. Again, this is consistent with broader findings that warming, altered seasonality, and climate stress can increase pest pressure and complicate pest control across agricultural systems (Subedi et al., 2023). Under continued warming and reduced winter mortality of pests, this pathway is likely to become more pronounced.

7.3 Impacts on Rainfed Cropland

Rainfed cropland is affected through a different impact logic than irrigated systems because production depends directly on seasonal rainfall and soil moisture rather than on managed irrigation supply. In the programme area, this concerns above all rainfed cereal systems, especially wheat, and in some locations also barley, chickpeas, and fodder crops. The Climate Impact Chain for rainfed cropland (Figure 50) shows how rising temperatures, more erratic precipitation, longer dry periods, and occasional intense rainfall translate into declining natural soil moisture, weaker crop establishment, shifting production calendars, increasing soil degradation, and greater production instability. For wheat in particular, the most climate-sensitive stages are establishment after sowing and the reproductive period in spring to early summer, when insufficient soil moisture and hotter conditions can reduce stand establishment, impair flowering, and lower grain development and final yields. As the hazard profile shifts further toward hotter conditions, drier summers and autumns, and stronger variability in rainfall timing and intensity, these pathways are expected to intensify.

Figure 50 brings out two dominant mechanisms in rainfed systems: declining and less reliable soil moisture during key crop stages, and rising instability of sowing and production calendars under more erratic rainfall. It also shows that intense rainfall is relevant mainly as a localized amplifier of soil degradation and washout, rather than as the main system-wide hazard.

Figure 50: Climate impact chain for rainfed cropland in the programme areas



Source: Own illustration

Declining soil moisture and intensifying drought directly constrain crop establishment and yields. In the upper and central parts of the chain (Figure 50), increased temperature, longer dry periods, and changing precipitation patterns are linked to declining soil moisture, increased plant evapotranspiration, crop water stress, reduced nutrient uptake, weaker plant growth, and greater

establishment failure. Because rainfed systems depend almost entirely on natural rainfall, drought is experienced above all through insufficient soil moisture during sowing, early establishment, flowering, and grain filling. For the programme focus on wheat, this means that low rainfall and inadequate soil moisture around sowing can delay or weaken emergence, while drought and heat later in the season can reduce plant growth, impair flowering and grain set, and lower grain weight and final yields (Khah et al., 1986; Qaseem et al., 2019; Sommer et al., 2013). Stakeholder consultations in Kara-Suu, Osh, Jalal-Abad, Batken, and Sughd repeatedly emphasized this point. In Kara-Suu, interviewees reported that severe autumn drought in 2025 delayed sowing until December, with crops remaining unusually short by mid-February, while stakeholders also noted that lack of rainfall in May can sharply reduce grain filling and final yields. As drought conditions intensify further in summer and autumn, rainfed production is expected to become less reliable, with more frequent establishment failure, lower yields, and greater risk of partial or total crop loss.

Soil degradation and erosion reduce the resilience of already moisture-limited systems. In the middle section of the chain (Figure 50), drought, bare soils, strong wind, and heavy rainfall are linked to hardened soils, erosion, topsoil loss, nutrient depletion, and declining soil quality. This pathway is especially important in sloping and foothill rainfed areas, where low vegetation cover and degraded structure increase both runoff during intense rainfall and moisture loss during dry spells. Stakeholder consultations in Kara-Suu, Osh, Sughd, and Batken described soils hardening, erosion on sloping land, washing away of crop fields during mudflows, and progressive degradation of soil structure and organic matter. Here, workshop participants explicitly identified soil degradation, declining fertility, and wind erosion as key impacts that needed stronger emphasis. As wet periods become more intense and dry periods longer, this degradation pathway is likely to strengthen further, reducing the buffering capacity of rainfed soils and increasing vulnerability to both drought and runoff.

Heavy rainfall creates localized losses even where drought is the dominant risk. The chain (Figure 50) shows that heavy rain can trigger floods, flash floods, waterlogging, seeds being washed out, topsoil loss, spoilage losses, and infrastructure damage. In rainfed systems, these impacts are more localized than drought stress, but they can still be severe, especially in foothill and mountainous areas. Stakeholder consultations in Osh and Batken referred to mudflows washing away crop fields and damaging roads and other infrastructure. In Sughd, workshop participants highlighted increased precipitation in foothill areas, soil erosion, and crop stagnation. At the same time, consultations in Kara-Suu stressed that flooding is generally less systemic for rainfed cropland than drought, and that spatial differentiation is needed. This distinction is important: the dominant pathway remains moisture deficit, but intense rainfall still generates substantial losses in exposed locations and is expected to become more relevant as heavy rain intensifies in foothill and upland zones.

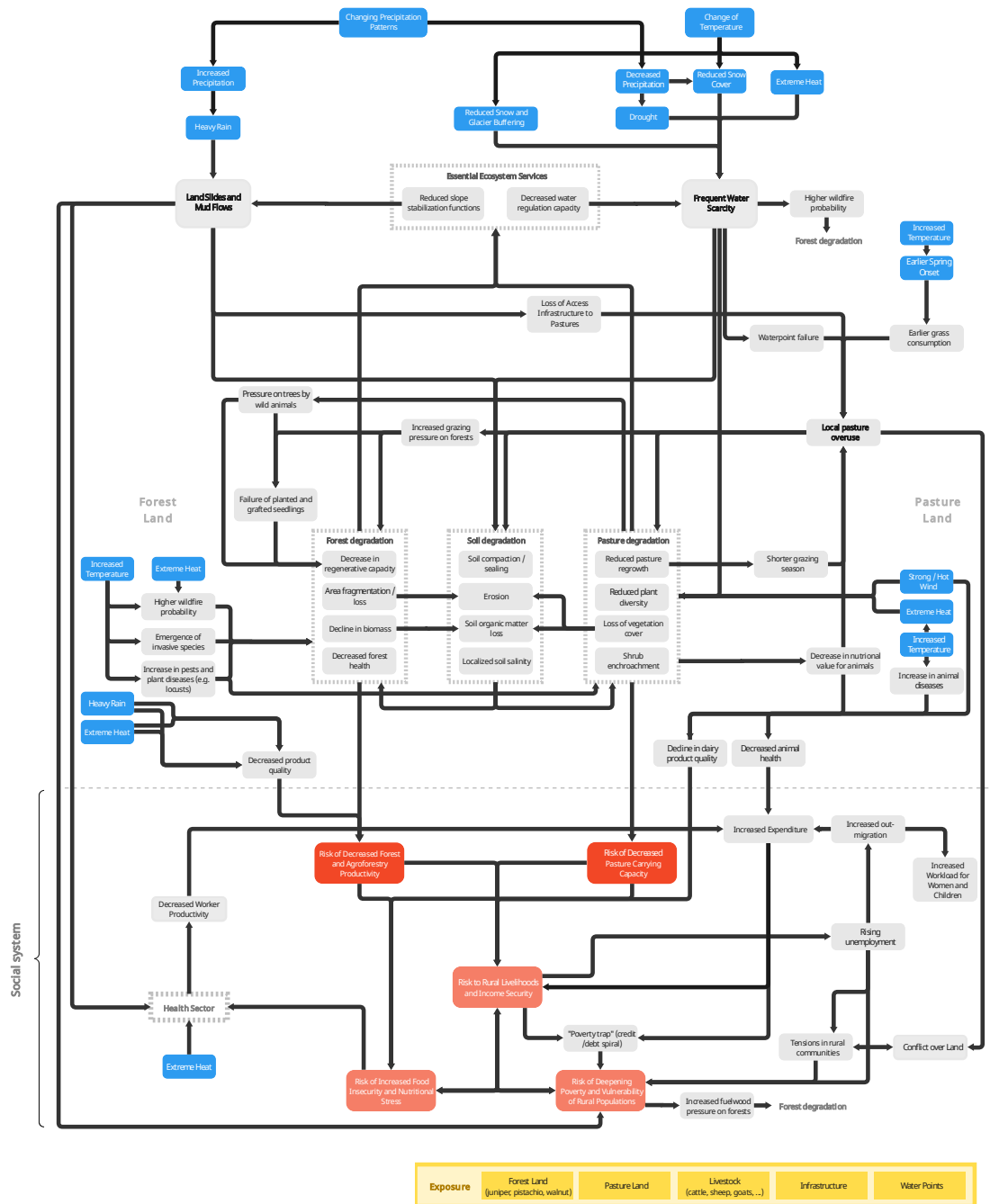
Shifts in seasonal timing disrupt sowing windows and break established production calendars. In the upper and central parts of the chain (Figure 50), changing precipitation patterns, warmer seasonal transitions, and longer dry periods translate into cropping-calendar mismatch, altered plant phenology, delayed or failed establishment, and weaker crop development. In rainfed systems, this pathway is especially important because production depends on a narrow alignment between autumn or spring rainfall, soil moisture availability, and sowing dates. Stakeholder consultations make this very clear. In Kara-Suu, interviewees reported that autumn drought in 2025 delayed sowing until December instead of the usual mid-September to late October window, leaving crops poorly developed by mid-February. Earlier consultations in Batken, Jalal-Abad, and Khatlon likewise referred to seasonal instability and to winters and springs no longer following expected patterns. This is one of the most consequential rainfed impacts because it undermines the practical expectations on which cropping decisions are normally based; as one stakeholder summary put it, “Our expectations are fully broken.” As seasonal variability increases further, these timing mismatches are likely to become more frequent and more damaging.

7.4 Impacts on Forests and Pasture Land

Forests and pasture land are best understood as an interconnected socio-ecological system because, in the programme areas, climate impacts on one part of the system quickly propagate into the other. Both systems also provide essential ecosystem functions, including water regulation and slope stabilization. In the programme area, these joint dynamics concern, above all, juniper and pistachio forest systems, as well as walnut-fruit forests and other forest and shrub vegetation in upper and middle elevations, together with pasture systems used for cattle, sheep, goats, and mixed grazing. The Climate Impact Chain for forests and pastureland (Figure 51) shows how rising temperatures, declining and less reliable water availability, more frequent drought, and intense rainfall events translate into drying vegetation, reduced regenerative capacity, declining fodder resources, weaker livestock performance, and loss of protective ecosystem functions. As the hazard profile shifts further toward hotter conditions, stronger summer and autumn drought, continued reduction in water buffering, and greater pressure from heavy rainfall and wildfire risk, these pathways are expected to intensify.

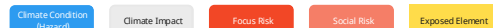
Figure 51 should be read both as a joint climate impact chain for forest and pasture systems and as a feedback diagram. It shows that climate impacts affect the two land-use systems through distinct but interlinked pathways, while also reinforcing one another through shared water stress, reduced regeneration, shifting grazing pressure, and weakening protective ecosystem functions. As a result, degradation in one part of the system can increase risks in the other and in neighbouring land uses and settlements.

Figure 51: Climate impact chain for forests and pastureland in the programme areas



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Developed by RB Consulting
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Legend



Source: Own illustration

Water scarcity and heat reduce vegetation cover, biomass, and regeneration. In the upper and central parts of the chain (Figure 51), increased temperature, reduced snow cover, reduced glacier size, and frequent water scarcity are linked to decreased forest health, decline in biomass, reduced regenerative capacity, reduced pasture regrowth, loss of vegetation cover, and reduced plant diversity.

Stakeholder consultations in Kubodiyon, Bazar-Korgon, Batken, Jalal-Abad, Sughd, and Surkhandarya consistently referred to drying springs, lower biomass productivity, pasture drying, and repeated seedling failure. As drought conditions intensify further and hot periods lengthen, this drying and regeneration pathway is likely to become more pronounced across both forest and pastureland. Kyrgyz pasture-zone evidence similarly points to stronger growing-season drought pressure around Sary-Tash and Baytyk than in Jalal-Abad pasture stations (Kretova, 2020).

This interpretation is consistent with regional landscape evidence showing that Central Asian drylands are among the world's most rapidly degrading and climate-vulnerable areas, with land degradation, erosion, vegetation loss, and biodiversity decline driven by the interaction of arid conditions, land-use pressure, and climate stress (World Bank, 2023). The mountain-adaptation literature likewise highlights that changing water availability is one of the dominant climate-change stressors in Central Asian mountain environments (Saidaliyeva et al., 2024).

Declining pasture quantity and quality reduce livestock productivity while overuse accelerates degradation. In the central and lower parts of the chain (Figure 51), pasture degradation, reduced pasture recovery, loss of vegetation cover, lower nutritional value, and declining animal health converge into reduced livestock productivity, lower dairy and meat quality, and higher expenditure. At the same time, the chain shows that local pasture overuse, limited pasture rotation, under-resourced management, and high livestock density reinforce the same degradation process. This pressure is not spatially uniform. In the more arid pasture zones, overgrazing is one of the main drivers of degradation and desertification, especially where grazing pressure is concentrated on accessible pastures near settlements and around limited water points, while more remote pastures remain underused because access and infrastructure are weak (Mirzabaev et al., 2016; Khazieva et al., 2022). In some areas, climate hazards further aggravate this imbalance by reducing access to already marginal or distant grazing areas. Stakeholder consultations make clear that this pressure is already excessive in many places: there is more grazing livestock than the land can sustainably support, pastures near settlements are under greatest stress, animals are released too early, and enforcement of pasture rules is weak. This is aggravated by the fact that livestock are widely perceived as a financial reserve and, where alternative income opportunities are limited, herd growth can remain an attractive strategy even where carrying capacity is already exceeded. This is important analytically because climate change is not the sole driver of pasture degradation. Rather, the evidence suggests that climatic stress is likely to intensify already existing degradation pathways driven by grazing pressure, weak management, spatially uneven pasture use, and reduced regenerative capacity (World Bank, 2023; Saidaliyeva et al., 2024). As drought and fodder stress intensify further, this pathway is likely to reduce carrying capacity and livestock productivity more sharply, especially where stocking pressure and management constraints are already high.

Pressure shifts from degraded pastures into forest areas and undermines regeneration. One of the clearest feedback pathways in the chain (Figure 51) links reduced pasture productivity and shorter grazing seasons to increased grazing pressure on forests, seedling failure, and further forest degradation. Field evidence confirms this repeatedly. In Bazar-Korgon, livestock movement through forest areas damages undergrowth and regeneration, while in Kubodiyon stakeholders highlighted unauthorized grazing and the need for stronger access control. Earlier consultations in Batken, Jalal-Abad, and Sughd likewise referred to grazing pressure on seedlings and the difficulty of restoring tree cover under current use patterns. In some locations, this spillover also extends into forestry-managed pasture areas and restoration sites, where grazing pressure can damage enrichment planting, newly established no-grazing areas, and freshly planted trees. As productive pasture areas shrink further, this spillover pathway is expected to strengthen - not only increasing pressure on forests, but also on cropland, in particular open rainfed fields. The broader implication is that climate stress may not remain contained within a single land-use system. Instead, declining pasture productivity can shift use pressure into adjacent cropland, forest, and shrub systems, where regeneration is already limited by grazing, moisture stress, and management constraints (World Bank, 2023; Saidaliyeva et al., 2024).

Loss of vegetation cover weakens protective functions and increases risks for neighbouring land uses and settlements. The chain (Figure 51) shows that forest degradation and pasture degradation do not only reduce production; they also reduce water regulation capacity and slope stabilization functions. This is a critical landscape effect. In the drier and more sparsely vegetated pasture zones, localized overuse around settlements and water points can rapidly reduce cover and increase runoff and erosion. In steeper foothill and mountain zones, the same loss of cover can also increase slope instability, erosion, mudflow, and landslide risks. Where grass, shrubs, and trees no longer provide sufficient cover, runoff increases, soils become less stable, and the likelihood of erosion, mudflows, and landslides rises. These effects do not remain confined to forest and pastureland, but increase risks for downstream cropland, irrigation infrastructure, roads, and settlements. Stakeholder consultations support this strongly: in Kubodiyon, mudflows were described as a direct threat to pastureland and village infrastructure; in Bazar-Korgon and Sughd, stakeholders linked reduced vegetation cover and forest decline to erosion, slope instability, and damage to farmland, houses, and roads. As heavy rainfall intensifies and vegetation cover continues to weaken, this protective-function pathway is likely to become more important across the wider landscape. This linkage between vegetation loss, slope instability, and downstream risk is also consistent with wider regional evidence showing that land degradation in Central Asia increases exposure to erosion, floods, mudflows, and other degradation-related hazards, with consequences for agriculture, infrastructure, and livelihoods across connected landscapes (World Bank, 2023).

Pests, disease, and wildfire risks increase under hotter and drier conditions. In the central part of the chain (Figure 51), warming and drying conditions are linked to increases in pests, plant diseases, animal diseases, and higher wildfire probability. In forests, this reduces tree vitality and regeneration; in pasture systems, it lowers fodder quality and animal health. Stakeholder consultations referred to recurring pest outbreaks in walnut systems, locust pressure on vegetation, higher disease incidence, and earlier wildfire seasons in forest areas. In this sense, the consultation evidence is consistent with broader review literature indicating that hotter and drier conditions can alter pest dynamics and increase biological stress in managed and semi-natural systems (Subedi et al., 2023). As heat burdens rise further and dry periods lengthen, this combined pest-disease-wildfire pathway is likely to increase in frequency and severity.

7.5 Cross-cutting and Systemic Impacts across Land-use Systems

In combination, the Climate Impact Chains show that climate impacts in the programme area are not confined to separate land-use systems but unfold across a connected mountain–foothill–valley landscape in which forests, pastureland, rainfed cropland, and irrigated cropland are linked through water flows, slope processes, vegetation cover, and rural livelihood strategies. Read together, Figure 49, Figure 50, and Figure 51 show that the land-use-specific chains are not separate analytical compartments, but overlapping parts of one connected mountain–foothill–valley system. The cross-cutting analysis below therefore synthesizes the vertical and lateral transmission pathways that recur across the figures: upstream–downstream water dependence, land-degradation feedback, pressure shifts between land uses, and cumulative effects on multi-source rural livelihoods.

Upper-catchment change propagates downstream through dependence on upstream water availability. Across the chains, reduced snow cover, glacier retreat, shifting runoff timing, and increasing drought translate into less reliable water availability from upper catchments to lower production zones. This is especially important because much of the irrigated production in the lower lands depends on water originating in more distant mountain areas. Climate stress in the upper parts of the landscape, therefore, propagates downstream through both hydrological change and already stressed local allocation systems. Stakeholder consultations repeatedly emphasized this vertical dependence, as well as growing instability in water availability for lower-lying land-use systems.

This cross-system interpretation is strongly supported by regional evidence. Central Asian mountain regions provide critical environmental functions and downstream water resources, while adaptation

challenges in those mountains are dominated by changing water availability and related hydro-climatic stress (Saidaliyeva et al., 2024). At the same time, regional water-security analysis underscores that downstream systems are particularly vulnerable where changing water availability combines with weak institutions, infrastructure deficits, and dependence on upstream decisions (World Bank, 2024a).

Land degradation is both an impact and a force multiplier across systems. The four chains show recurring pathways of erosion, salinization, soil hardening, nutrient depletion, vegetation loss, and declining regenerative capacity. These processes do not remain confined to one land-use system. Degraded cropland becomes more sensitive to drought and runoff; degraded pastures lose carrying capacity; degraded forests and shrub systems lose their ability to regulate water and stabilize slopes. Consultations across the target area likewise described topsoil loss, drying, and compaction of soils, thinning vegetation, and declining soil fertility as interconnected and mutually reinforcing processes.

This is consistent with regional landscape evidence showing that land degradation, erosion, loss of vegetation cover, and declining ecosystem condition reduce the resilience of both agricultural systems and infrastructure, while also amplifying vulnerability to intense weather events and related disasters (World Bank, 2023).

Loss of vegetation cover increases risks beyond forests and pastures. One of the most important cross-cutting pathways is the weakening of protective ecosystem functions. Where grassland, shrubs, and trees no longer provide sufficient cover, runoff increases, slopes become less stable, and the likelihood of erosion, mudflows, and landslides rises. This affects not only forests and pasture land, but also neighbouring cropland, irrigation infrastructure, roads, and settlements. Stakeholder consultations in Kubodiyon, Bazar-Korgon, Sughd, and other locations directly linked reduced vegetation cover and forest decline to mudflow risks, erosion, and damage to farmland, houses, and infrastructure.

Climate stress shifts pressure from one land-use system into another. The chains show that climate impacts are often displaced rather than contained. Irrigation shortfalls reduce the viability of water-dependent cropping systems; declining rainfed productivity increases pressure on already marginal land; and degraded pastures push grazing pressure into forest areas and other stressed vegetation systems. Stakeholder consultations reported orchards being replaced with wheat in some areas, irrigated land becoming effectively only conditionally irrigated, and livestock pressure increasing where productive pasture is shrinking. These shifts show that climate impacts are restructuring land-use patterns, not just reducing output within fixed systems.

Livelihood impacts accumulate across the social system rather than remaining sector-specific. In the lower parts of the chains, biophysical and production impacts converge into the “social system,” where they translate into reduced income, rising expenditures, lower food availability, weaker livelihood stability, and broader social stress. This is particularly important in the programme area because rural households often depend on several land-use systems at once: irrigated annual and perennial crops, rainfed cereals, livestock, forest products, and seasonal labour frequently form part of the same livelihood portfolio. When climate stress affects several of these income and subsistence sources simultaneously, losses accumulate rather than offset one another.

These broader livelihood and social effects are not directly modelled in this annex and should therefore be read as evidence-based synthesis rather than as quantified impact estimates. They are nevertheless consistent with regional evidence showing that climate change can reinforce mobility pressures in Central Asia, especially where climate-sensitive livelihoods, environmental stress, and limited adaptive capacity coincide (Clement et al., 2021). They are also consistent with broader evidence from Europe and Central Asia that women in rural areas often face barriers in access to land, finance, information, and advisory services, which can constrain adaptive capacity in climate-sensitive agrifood systems (FAO, 2024b).

Across the chains, this convergence is visible in pathways leading from the respective focus risks into stronger livelihood stress and social risk. Stakeholder consultations repeatedly described these effects in concrete terms: rising indebtedness of farmers, increasing labour migration, reduced employment

opportunities, food-security concerns, declining living standards, and higher burdens on women and youth, especially where men migrate and women take on a larger share of agricultural labour. For instance, consultations in Khatlon explicitly identified women as particularly affected because they constitute much of the agricultural labour force, while consultations elsewhere linked repeated production losses to household debt, reduced marketable surplus, and weakening resilience of rural communities. As the hazard profile described in the previous chapter intensifies further, these cumulative effects on the social system are expected to become more severe and more widespread.

7.6 Conclusion

Taken together, the Climate Impact Chains show that the identified hazards are already affecting the programme area through multiple, interacting pathways across irrigated perennial and annual cropland, rainfed cropland, forests, and pastureland. Rising temperatures, increasing seasonal water imbalance, stronger drought conditions, heavy rainfall, and hot, dry wind are translating into reduced productivity and product quality, declining vegetation and regeneration, soil degradation, increasing pest and disease pressure, and growing instability in rural livelihood systems. These impacts are not isolated within individual sectors but propagate across the wider mountain–foothill–valley landscape through shared water dependencies, land degradation processes, grazing pressure, and transboundary allocation dynamics. As the hazard profile described in the previous chapter intensifies further, these cascading impacts are expected to become more severe, reinforcing the need for targeted action to reduce vulnerability and strengthen climate resilience across the interconnected land-use systems of the programme area.

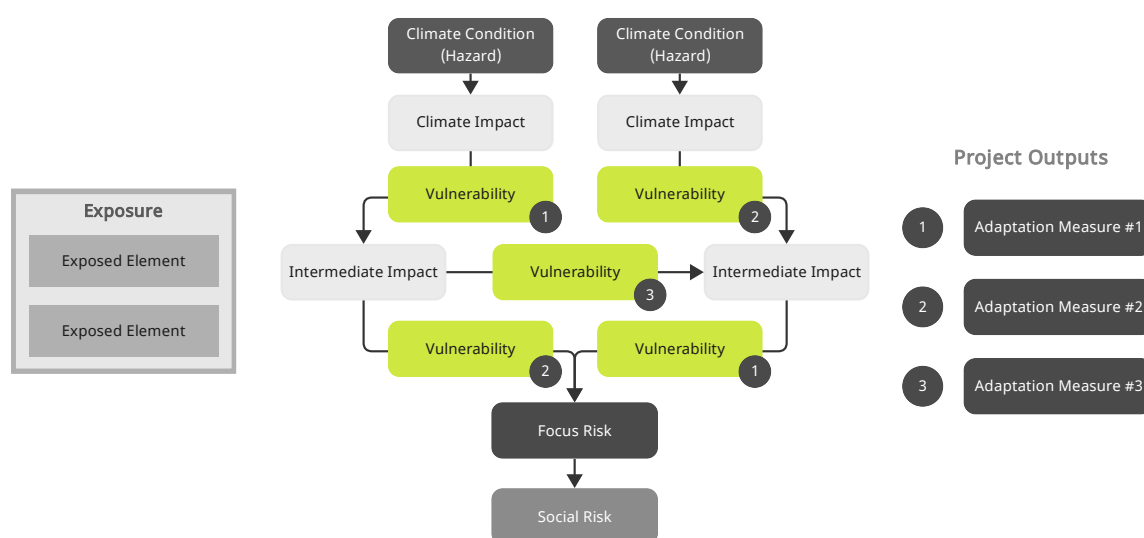
Table 8: Key cross-cutting findings from the impact assessment

Key cross-cutting findings from the impact assessment
Upper catchments and steep slopes: Degradation in upper parts of the landscape is reducing water regulation and slope stability and increasing downstream water stress, erosion, mudflow, and landslide risks.
Lower irrigated valley and lower-foothill systems: In the lower lands, irrigated production is increasingly constrained by dependence on upstream water, declining dry-season availability, and uneven delivery.
Pasture–forest interface in middle and upper elevations: Drought, shrinking fodder availability, and weak management are reinforcing pasture overuse and pushing grazing into forest areas, further weakening regeneration and protective ecosystem functions.
Social system and planning conditions: Increasingly unstable weather patterns are reducing predictability across land-use systems and translating climate impacts into livelihood instability, debt, migration, food-security risks, and greater burdens on vulnerable households.
Reinforcing feedbacks: Several of the identified impacts intensify one another over time: water stress accelerates land degradation, degraded land retains less water and vegetation, reduced vegetation cover increases erosion and mudflow risks, and shrinking pasture productivity increases grazing pressure on forests and other already stressed land.

8. Vulnerabilities

This chapter identifies the vulnerability factors that enable or aggravate the hazard–impact pathways traced in Chapter 7. In the Climate Impact Chain framework, these vulnerabilities are represented along the hazard–impact pathways as the biophysical, management, socio-economic, financial, and institutional conditions that increase sensitivity or constrain adaptive capacity.. The chapter first groups them into cross-cutting barrier clusters, then summarizes the system-specific vulnerability profiles, and finally shows how they are embedded in the vulnerability-extended chains in Figure 53, Figure 54, Figure 55, and Figure 56.

Figure 52: Conceptual Climate Impact Chain framework applied across the Climate Rationale - vulnerabilities



Source: Own illustration

In the programme areas, vulnerability arises from the interaction of biophysical constraints, including land degradation, water scarcity, and fragile ecosystems, with structural socio-economic and institutional limitations such as restricted access to finance, weak support services, and limited technical knowledge. These factors do not operate in isolation. As shown in the vulnerability-extended Climate Impact Chains in Figures 8-2 to 8-5, they shape how specific climate hazards translate into impacts across the different land-use systems and, in turn, constrain the capacity of farmers, pastoralists, and forest-dependent communities to anticipate, absorb, and recover from climate-related shocks. Vulnerability in this context is therefore not only a property of individual systems, but also of the wider landscape, where interdependencies between elevation zones, water flows, and land use can amplify risk.

Reducing vulnerability consequently requires more than isolated technical measures. Improving water-use efficiency, strengthening advisory and extension services, expanding access to climate information, and promoting sustainable land management all represent important entry points, but their effectiveness depends on how well they address the broader structural conditions that keep climate risk high. The systematic identification of vulnerability factors through the Climate Impact Chains therefore provides the basis for prioritizing adaptation measures that are both context-specific and capable of strengthening resilience across the interconnected landscapes of the programme area.

Cross-cutting vulnerability architecture

The vulnerability factors identified across the land-use systems can be grouped into a smaller number of cross-cutting barrier clusters, including:

1. weak climate information and limited use of it in decision-making;
2. outdated or insufficient water, land, and vegetation management systems;
3. weak technical and advisory support for site-specific adaptation;
4. limited access to finance and insufficient incentives for climate-resilient investment;
5. weak land-use planning, cross-sector coordination, and transboundary cooperation.

Vulnerabilities of land-use systems

Table 9 summarizes the main vulnerability factors across the land-use systems in the programme areas, distinguishing between cross-cutting constraints and system-specific challenges. Read together with Figure 53, Figure 54, Figure 55, and Figure 56, it highlights that vulnerability is shaped not only by conditions within individual systems but also by the strong interdependence of elevation zones, resource flows, and land-use systems across the wider landscape. Mid-elevation areas are particularly important in this regard, as multiple pressures converge there: dependence on upstream water resources, seasonal water scarcity, rising irrigation demand, and exposure to land-degradation processes such as landslides and mudflows. Across all systems, structural constraints, including limited access to finance and insurance, weak technical and advisory support, patchy climate information, aging infrastructure, and fragmented governance, narrow the scope for effective response. Against that background, each land-use system exhibits a distinct vulnerability profile.

Across all land-use systems, structural socio-economic constraints interact with increasing climate hazards such as drought, heat stress, and extreme weather events. Access to affordable credit is limited, insurance is often weak or mistrusted, and safety nets are not always sufficient to absorb climate-related losses. At the same time, localized climate services remain underdeveloped, technical guidance is uneven, and persistent knowledge gaps hinder informed and forward-looking decision-making. The result is not only greater exposure to climate hazards, but also a reduced capacity to anticipate change, cope with shocks, and adapt practices over time.

For **irrigated annual cropland**, the main vulnerability lies in increasingly unstable water availability. Figure 53 shows how this is reinforced by inefficient irrigation infrastructure, limited water storage and reuse options, and inequitable or inflexible water distribution. In principle, annual crops offer more scope for adjustment than perennial systems. In practice, however, that flexibility is often narrowed by small plot sizes, limited diversification opportunities, and continued dependence on outdated irrigation arrangements. These factors leave irrigated annual cropland highly sensitive to water shortages and climate variability, with corresponding risks of yield fluctuation and reduced productivity.

Figure 54 points to a related but more rigid vulnerability profile in **irrigated perennial cropland**. Orchards depend heavily on reliable upstream water supply, especially during flowering and fruiting, so interruptions in water availability can have cumulative effects that extend well beyond a single season. This sensitivity is compounded by aging and inefficient irrigation infrastructure, limited water storage and reuse capacity, and rigid or unequal allocation arrangements that restrict adaptive responses. Irrigated perennial cropland is also particularly exposed to temperature and precipitation variability because phenological disruption can directly affect production. Moreover, once orchards are established, producers have limited room to adjust crop choice or location, which locks these systems into longer-term exposure and raises the risk of accumulated losses over time.

Rainfed cropland shows a different vulnerability pattern again. As reflected in Figure 55, it is highly exposed to rainfall variability, including delayed onset of rains, dry spells, and episodes of intense precipitation. Its vulnerability is shaped above all by biophysical constraints: shallow soils with low moisture-retention capacity, declining groundwater levels, and very limited access to supplemental irrigation. Performance depends strongly on the timing and distribution of rainfall, especially during sowing and early growth. Where diversification options are limited and adaptive choices remain constrained, these factors substantially increase the likelihood of crop failure and livelihood instability under changing climatic conditions.

Pasture systems, captured together with forest systems in Figure 56, are highly sensitive to changes in rainfall patterns and water availability because these directly affect forage production and seasonal grazing conditions. Their vulnerability is reinforced by limited pasture rotation, under-resourced and often overburdened management systems, and a strong dependence on access to water points. Many pasture areas are also located on fragile terrain prone to erosion, landslides, and degradation. Once overgrazing, vegetation loss, and declining soil quality begin to reinforce one another, ecosystem integrity weakens further, amplifying climate risks and undermining the long-term productivity and resilience of pastoral systems.

Forest systems share some of these broader landscape pressures, but the vulnerability profile shown in Figure 56 also has its own distinct features. Forest ecosystems are exposed to prolonged drought, rising temperatures, and extreme events that affect species composition, regeneration, and overall ecosystem health. Their vulnerability is closely linked to low natural regeneration capacity, the high sensitivity of seedlings to moisture stress, weak protection measures, and limited enforcement capacity. Underinvestment in sustainable forest management further constrains resilience. Because many forest areas are situated on terrain already prone to erosion and landslides, declining ecosystem integrity can accelerate land degradation and, in turn, increase vulnerability to further climate impacts.

Taken together, these vulnerabilities do not remain neatly contained within separate sectors. They overlap, reinforce one another, and often propagate across connected landscapes. Figure 53, Figure 54, Figure 55, and Figure 56 make clear that effective adaptation therefore needs to be integrated and context-specific, addressing not only immediate biophysical constraints, but also the institutional and socio-economic conditions that keep climate risk high.

Table 9: Major vulnerabilities of systems of each key land-use system, as well as cross-cutting vulnerabilities

Land-use System (Main Value Chain)	Key Targeted Vulnerability Factor(s)
Irrigated Annual Cropland (Seed Potato Value Chain)	• Crop variety selection (crop suitability) • Irrigation schemes outdated for current climate • Insufficient water-saving capacities • Insufficient fertilizer management • Insufficient pesticide management
Irrigated Annual Cropland (Horticulture Value Chain)	• Crop variety selection (crop suitability) • Use of water-intensive crops • Irrigation schemes outdated for current climate • Insufficient water-saving capacities • Insufficient plant protection
Irrigated Perennial Cropland (Orchard-based Fruit Value Chain)	• Use of water-intensive crops • Crop variety selection (crop suitability) • Irrigation schemes outdated for current climate • Insufficient water-saving capacities • Insufficient excess-water management • Limited erosion protection practices • Insufficient drainage practices • Insufficient protection practices (e.g. tree/shrub planting) • Insufficient plant protection
Rainfed Cropland (Wheat Value Chain)	• Insufficient soil protection • Insufficient soil fertility management • Crop selection • Insufficient fertilizer management • Insufficient pesticide management

Land-use System (Main Value Chain)	Key Targeted Vulnerability Factor(s)
Across Cropland	• Limited access to finance • Limited investment for climate-resilient land use • Crop variety selection • Limited erosion protection practices • Knowledge gaps (management/practices) • Insufficient excess-water management • Insufficient water-saving capacities • Irrigation schemes outdated for current climate • Insufficient protective storage capacities (harvest vulnerable to high moisture conditions) • Low value-added value chains
Pastures	• Overgrazing and pasture mismanagement • High livestock density • Limited pasture rotation • Insufficient pasture management • Under-resourced and overloaded pasture management • Insufficient pasture restoration and management • Unsustainable forest use • Type of vegetation species
Forests (Non-timber Forest Products Value Chain, Walnut & Pistachio)	• Land degradation and soil erosion • Insufficient protection of seedlings (low survival rates of tree plantations) • Limited enforcement of land-use regulations • Tree species composition (selection of tree species and forest composition) • Insufficient forest restoration and management • Unsustainable forest use • Insufficient protective storage capacities (harvest vulnerable to high moisture conditions) • Limited access to finance • Low value-added value chains
Cross-cutting Vulnerabilities	• Lack of climate information services • Limited use of climate information in decision-making • Insufficient land-use planning capacities and information base (e.g. limited geophysical soil analysis, use of GIS) • Lack of cross-sectoral coordination • Lack of transboundary landscape planning mechanisms • Low adoption of climate-resilient practices • Limited awareness of adaptation options • Limited technical support services • Limited access to finance (including limited and unattractive loans) • Limited investment for climate-resilient land use • Land degradation and soil erosion • Insufficient protection of soil, infrastructure, and vegetation • Limited enforcement of land-use regulations • Inflexible local water allocation disadvantaging downstream users

The vulnerabilities identified across land-use systems (Table 9) reflect a broader set of underlying systemic constraints that limit the capacity to respond effectively to climate risks. These vulnerability

factors are not isolated but stem from structural barriers related to policies, institutional frameworks, financing mechanisms, knowledge systems, and land management practices. As such, they constrain the transition toward climate-resilient and low-emission land-use systems in the AFOLU sector and hinder the uptake and scaling of adaptation measures.

Building on this analysis, these interconnected vulnerabilities can be consolidated into a set of key barriers, which are summarized below and described in the Feasibility Study (Annex 2a, Section 5.2). These barriers provide the analytical foundation for identifying targeted interventions and define the main entry points for the programme's adaptation approach.

Barrier 1 Insufficient public finance to implement mitigation and adaptation measures: Across the countries in the region there is limited public funding for the implementation of countries' mitigation and adaptation measures and a significant funding gap to finance climate action. The Kyrgyz Republic estimates the funding needed to implement its third NDC at USD 23 billion, of which there is a gap of USD 9.3 billion (Kyrgyz Republic, 2025a). Tajikistan's NDC outlines that at least 7% of GDP is required for financing climate change activities from 2020- 2030, highlighting that this would translate into at least USD 1 billion per year by 2030 in climate finance (with circa 50% related to land use: agriculture, irrigation, and biodiversity-related) (Republic of Tajikistan, 2021). In its recent NDC 3.0, Uzbekistan estimates the investment gap at USD 9.5 billion until 2030 (USD17.4 billion until 2035) for climate change mitigation while the climate adaptation funding deficit reaches USD 7.2 billion until 2030 (Republic of Uzbekistan, 2025).

Barrier 2 Limited coherence of public policies and incentives to enable adaptation and mitigation in the agriculture, livestock, and forestry sectors: the existing national incentive schemes, especially in the agricultural, forest and rangeland sectors, are productivity-focused, promote blueprint solutions and may even be hindering climate action or promoting solutions that will lead to maladaptation. National policy makers lack knowledge of and incentive to change current finance flows towards climate finance.

Barrier 3 Limited integration of climate information into local land use plans, national sector plans and other planning instruments: Weak processes for integration of climate information into land use planning and management, including a lack of remote sensing / GIS-based data and tools for monitoring land use change, and weak data management and sharing systems across sectors and ministries, as well as across countries. Limited capacities of regional and national experts from government, civil society and private sector to integrate climate information into decision-making, especially when it comes to land use planning and management.

Barrier 4 Low technical knowledge amongst land users and limited technical advisory for planning and implementing site-specific adaptation options: Land users lack the expertise, the local advisory services, and access to information (availability and cost) on current and future climate change impacts on specific landscapes and ecosystems, their impacts on their productive practices and context-specific adaptation options for enhancing resilience. Nature-based and climate-resilient business models are not well known or incentivized, especially a true cost-benefit perspective is missing.

Barrier 5 Limited access to finance for the implementation of climate-resilient production models: From the demand side, smallholder farmers and rural enterprises often have limited access to credit due to lack of collateral, limited credit history, and low levels of financial literacy. From the supply side, despite some government-led efforts to green the financial sector in the region through the development of green taxonomies, with the Kyrgyz Republic's taxonomy approved in May 2025, that of Uzbekistan approved in October 2023 but not fully operationalized yet, and that of Tajikistan still under development, including through GCF readiness, and despite a small number of pioneer financial institutions, most local financial institutions (LFIs) and microfinance institutions (MFIs) do not offer green, or climate-informed, products at scale. Many LFIs still lack the capacities required to implement what would be expected under the taxonomies. LFIs in the region also tend to have limited knowledge and capacity to access green and climate finance for the private sector, including limited understanding

of requirements and processes such as documentation, monitoring, and reporting, making it challenging to engage with green and climate funding sources, and to guide clients effectively. This is compounded by limited capacity, as highlighted by LFIs during the consultation missions, to identify and manage climate-related risks, which reduces appetite and ability to invest in climate-resilient and low-emission agriculture, livestock, and forestry models. LFIs also face difficulties in developing strong, bankable, green, and climate project proposals, and they often lack relevant personnel, such as agronomists who can support the tailoring of financial services to land users.

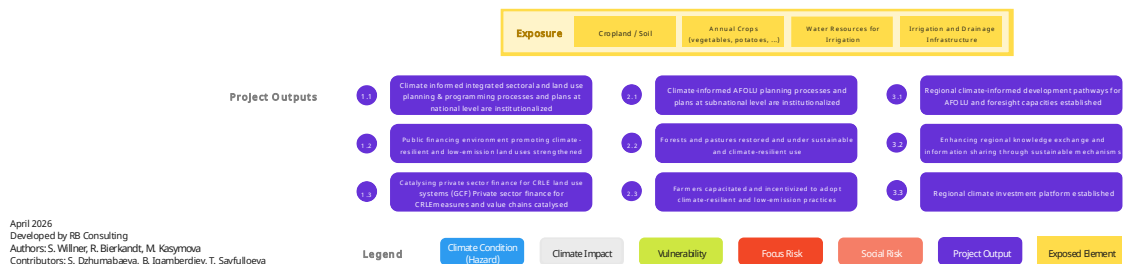
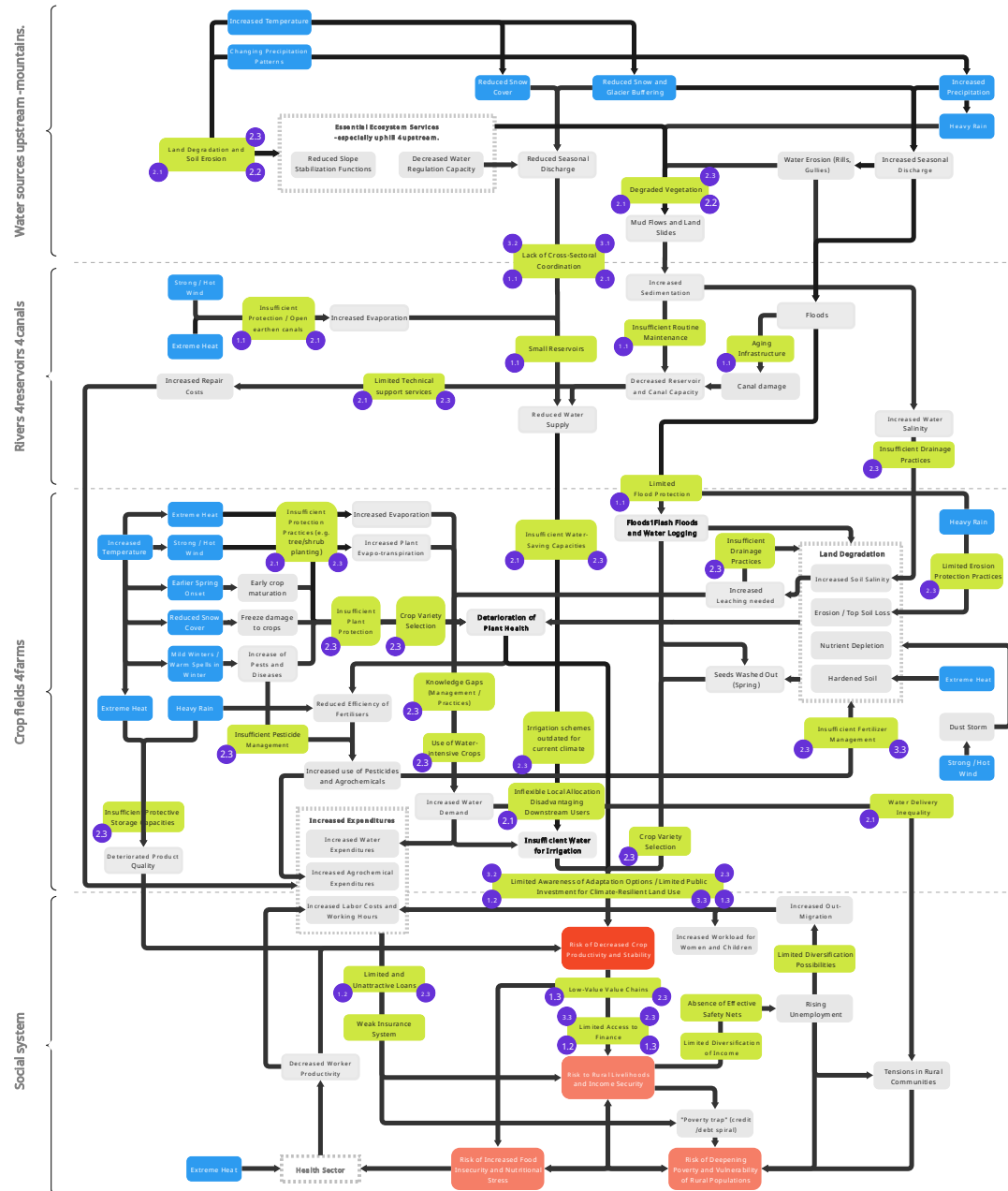
Barrier 6 Insufficient regional cooperation for addressing environmental transboundary issues:

Regional cooperation systems around climate adaptation in land use are weak, especially when it comes to dialogue across different stakeholder groups. Long-term strategic planning and foresight capacities in AFOLU are weak, especially at regional level where there are increased risks of conflicts over natural resources. Weak processes of regional knowledge exchange and learning as well as of cooperation across transboundary landscapes.

The following Climate Impact Chains (Figure 53, Figure 54, Figure 55, and Figure 56) build on the land-use-specific chains presented in Chapter 7 (Figure 48, Figure 49, Figure 50, and Figure 51) by integrating the key vulnerability factors summarized in Table 9. Along the most important hazard–impact, impact–impact, and impact–risk pathways, these vulnerabilities are shown as enabling or aggravating factors in the cause–effect relations. This makes clearer how systemic constraints interact with climate hazards and exposure to shape climate risks across land-use systems, while also helping to identify key entry points for targeted adaptation measures.

Figure 53: Climate impact chain for irrigated annual cropland in the programme areas including vulnerabilities

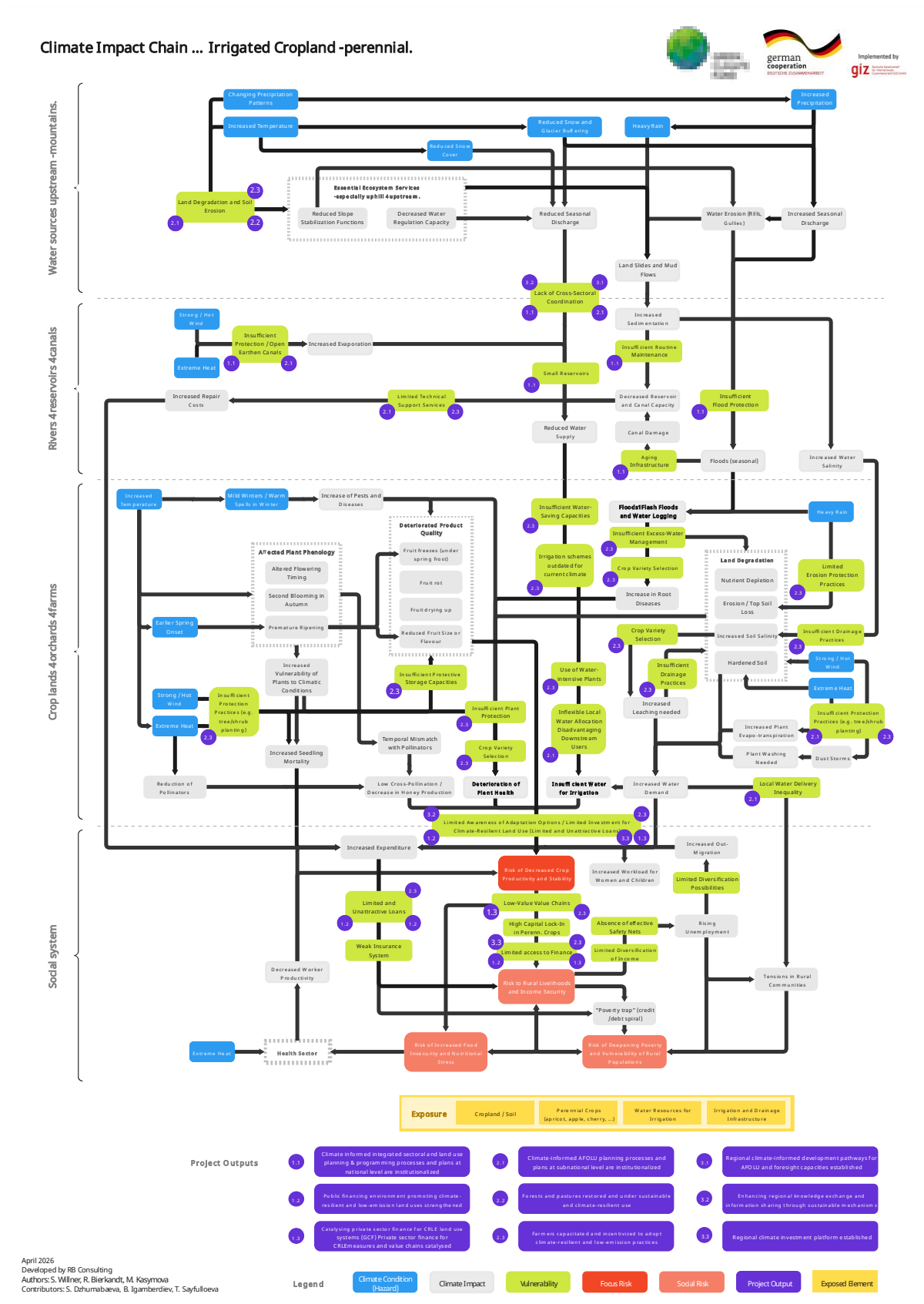
Climate Impact Chain ... Irrigated Cropland-annual.



April 2026
 Developed by RB Consulting
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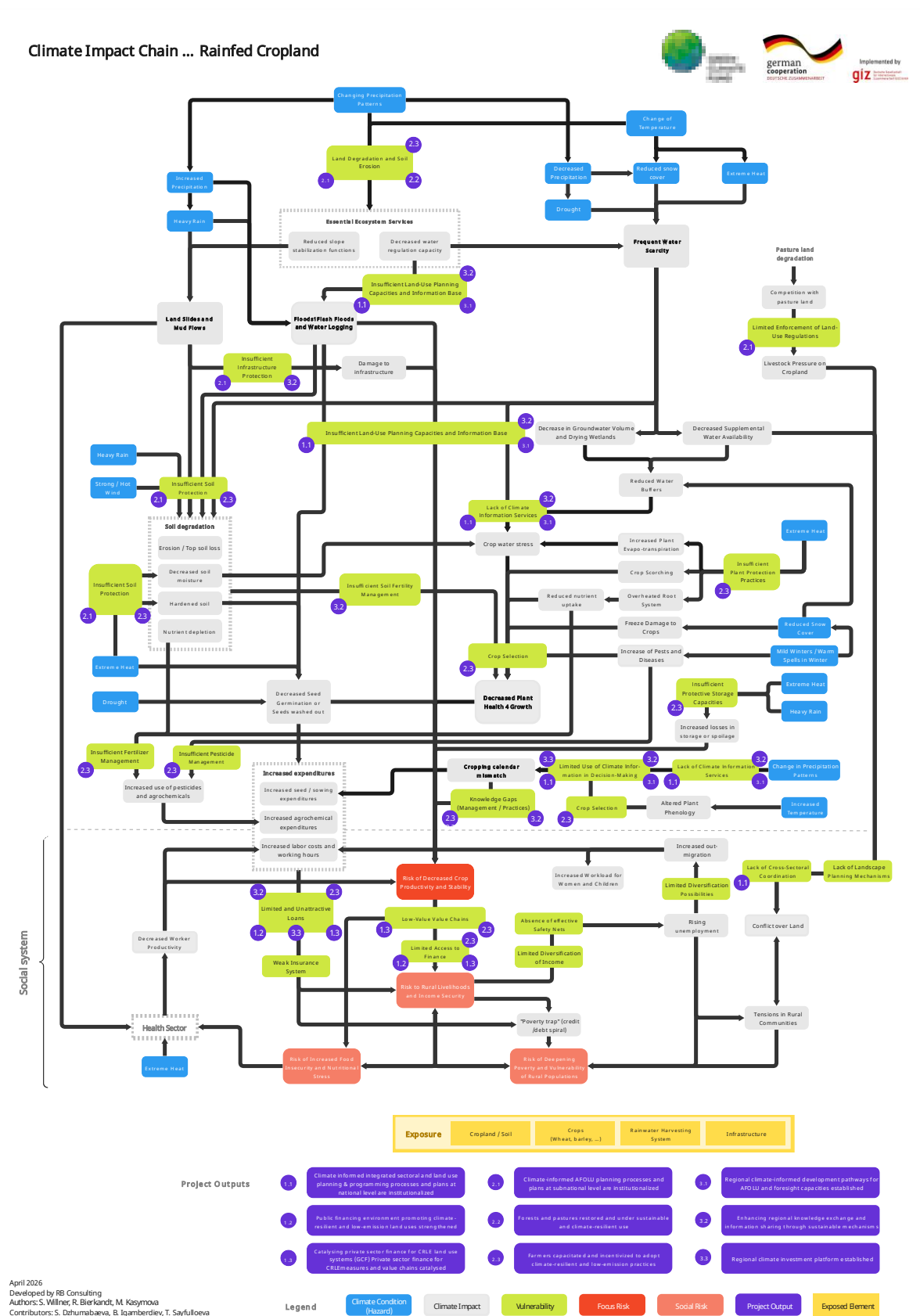
Source: Own illustration

Figure 54: Climate impact chain for irrigated perennial cropland in the programme areas, including vulnerabilities



Source: Own illustration

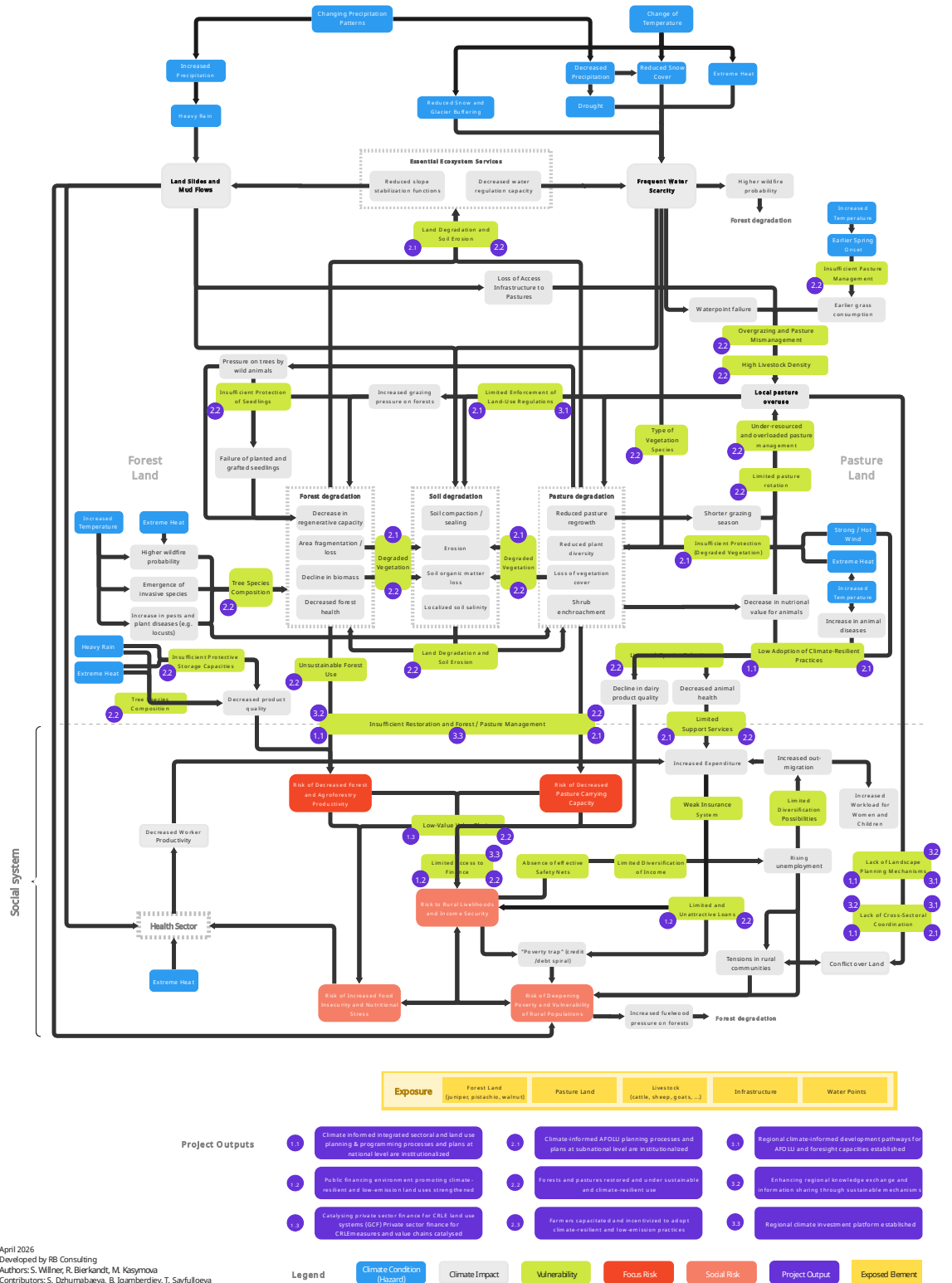
Figure 55: Climate impact chain for rainfed cropland in the programme areas, including vulnerabilities



Source: Own illustration

Figure 56: Climate impact chain for forests and pastureland in the programme areas, including vulnerabilities

Climate Impact Chain ... Forests and Pasture Land

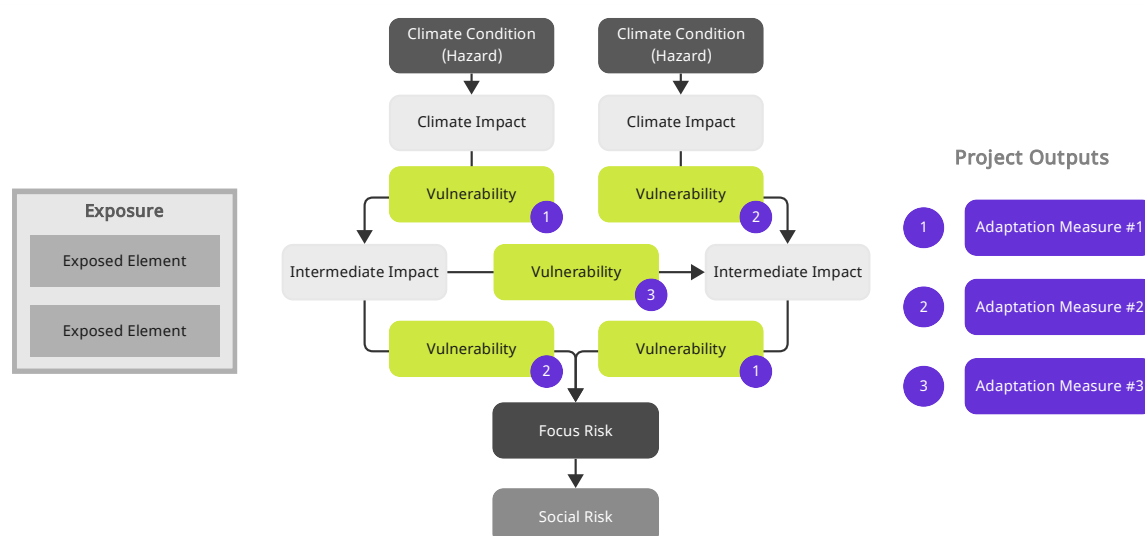


Source: Own illustration

9. Adaptation Measures

This chapter sets out how the programme responds to the climate risks identified in the preceding chapters. The proposed measures are framed as adaptation because they target the vulnerability factors and systemic barriers that convert rising heat, seasonal water imbalance, drought, heavy rain, and localized hot dry wind into recurrent loss, degradation, and livelihood instability across the programme landscapes. Figure 57 locates these response points within the overall Climate Impact Chain logic. Section 9.1 outlines the overarching adaptation approach, while Section 9.2 presents the measure portfolio by land-use system and barrier.

Figure 57: Conceptual Climate Impact Chain framework applied across the Climate Rationale - adaptation measures and programme outputs to address the identified vulnerabilities



Source: Own illustration

9.1 Overall Adaptation Approach of the Programme

Addressing the identified vulnerabilities and barriers requires coordinated action across multiple levels. The proposed programme therefore focuses on creating the enabling conditions for effective adaptation at scale, including strengthened legal, regulatory, institutional, and capacity development frameworks. It supports climate-informed planning, improves transboundary coordination on water and land management, and enhances access to climate-resilient technologies and financial instruments. At the same time, the programme promotes practical measures on the ground, including improved climate-informed advisory and extension services, more efficient irrigation, sustainable land-use practices, and ecosystem-based approaches to reduce land degradation and strengthen the resilience of agricultural, pasture, and forest systems.

The programme aims to enhance the climate resilience of vulnerable populations and the transboundary ecosystems on which they depend in Central Asia by promoting climate-resilient and low-emission land-use systems across interconnected landscapes. Given the strong interdependencies between agricultural land, pastures, and forests across elevation zones, it adopts an integrated landscape approach that addresses climate risks through coordinated interventions at local, national, and regional levels. This approach recognizes that climate risks result from the interaction of hazards, exposure, and underlying vulnerabilities, and that effective adaptation requires addressing both on-the-ground practices and systemic constraints.

On this basis, the programme response is structured in a way that is consistent with the GCF Integrated Results Management Framework, linking the identified climate risks and vulnerability drivers to outputs and outcomes that can be monitored as part of the proposal's adaptation logic (GCF, 2021).

Overall, the programme adopts a three-pronged adaptation approach to address identified climate risks, underlying vulnerabilities, and systemic barriers, as reflected in its three complementary components:

- **Component 1:** Enabling environment for a climate-resilient and low-carbon AFOLU sector at national level
- **Component 2:** Promotion and adoption of climate-resilient and low-emission practices and technologies at local level
- **Component 3:** Strengthening regional cooperation for climate resilience across transboundary landscapes

Component 1 focuses on strengthening the enabling environment at the national level through improved planning processes and public financing frameworks. It supports the integration of climate risks into sectoral and land-use planning and strengthens the alignment of public investments with climate-resilient and low-emission objectives. Currently, adaptation is constrained by limited integration of climate considerations into planning processes and insufficiently targeted public financing. These constraints are addressed through:

- **Output 1.1:** Climate-informed integrated sectoral and land use planning and programming processes and plans at national level are institutionalized
- **Output 1.2:** Public financing environment promoting climate-resilient and low-emission land uses strengthened
- **Output 1.3:** Catalysing private sector finance for CRLE land use systems

Component 2 promotes the adoption of climate-resilient and low-emission practices and technologies at the local level, targeting farmers, pastoralists, and forest users. It focuses on improving land-use planning at subnational level, restoring and sustainably managing forests and pastures, and supporting land users to adopt climate-resilient practices. Current vulnerabilities are driven by unsustainable land management, limited local planning capacity, and insufficient incentives for change. These are addressed through:

- **Output 2.1:** Climate-informed AFOLU planning processes and plans at subnational level are institutionalized
- **Output 2.2:** Forests and pastures restored and under sustainable and climate-resilient use
- **Output 2.3:** Farmers capacitated and incentivized to adopt climate-resilient and low-emission practices

Component 3 strengthens regional cooperation to address transboundary climate risks and support coordinated management of shared ecosystems. It focuses on improving regional planning, knowledge exchange, and access to climate finance. Adaptation efforts are currently limited by fragmented governance, weak coordination, and insufficient mechanisms for knowledge sharing and investment. These are addressed through:

- **Output 3.1:** Regional climate-informed development pathways for AFOLU and foresight capacities established
- **Output 3.2:** Mechanisms for regional knowledge management, exchange, and information sharing strengthened
- **Output 3.3:** Regional climate investment platform established

Together, these components address both the direct drivers of vulnerability at the production level and the broader institutional and governance constraints that limit adaptation. By linking local action with enabling environments and regional coordination, the programme supports the scaling of adaptation measures and contributes to more resilient and sustainable land-use systems across the region.

The Climate Impact Chains in Chapter 8 (Figure 53, Figure 54, Figure 55, and Figure 56) also incorporate the respective programme outputs designed to address the key vulnerabilities

identified across the different land-use systems. Crucially, they thus demonstrate a clear link between the underlying drivers of climate risk and the proposed interventions, showing how action on these vulnerabilities can reduce climate impacts and, ultimately, overall climate risk.

The proposed measures are justified as adaptation not simply because they support agriculture, pasture, or forest management, but because they respond directly to climate risks identified in this annex. They do so by targeting the vulnerability factors and implementation barriers that convert climatic hazards into recurrent loss, instability, and degradation across the programme landscapes. In this sense, the adaptation logic of the programme is not hazard control, but vulnerability reduction: the programme strengthens the capacity of land-use systems and the people who depend on them to withstand hotter conditions, more seasonal water imbalance, stronger drought pressure, heavier rainfall in exposed zones, and the cross-system effects that follow from these hazards.

Given the uncertainty inherent in future climate conditions, the programme prioritises measures that are robust across a range of plausible hazard trajectories and that address existing structural vulnerabilities already contributing to climate risk today. Many of the proposed interventions therefore have no-regret characteristics: they improve resilience under stronger warming and hydrological stress, but also remain beneficial where future changes are less pronounced than the upper range of projections. At the same time, the programme seeks to avoid maladaptation by favouring context-specific, participatory, and climate-informed choices, and by considering trade-offs across land-use systems, stakeholder groups, and landscape functions.

9.2 Individual Adaptation Measures

This section presents a portfolio of **adaptation measures** for the different land-use systems of the programme areas, including irrigated (annual and perennial) and rainfed cropland, pastures, and forests. These measures focus on interventions that reduce vulnerability and strengthen resilience.

Rather than representing a fixed or prescriptive set of interventions, these measures should be understood as a flexible basket of context-specific options. Their prioritization and selection will take place during implementation through participatory processes, ensuring that choices are grounded in local knowledge, conditions, and needs, and thereby enhancing suitability and uptake.

A key consideration in this process is the level and nature of vulnerability in specific locations, so that interventions are targeted where climate risks and sensitivities are most pronounced. The suitability and effectiveness of individual measures depend on factors such as agro-ecological conditions, water availability, soil characteristics, access to inputs and services, and the capacities of land users to adopt and sustain them. This also includes differences in financial accessibility, distinguishing between measures that require significant upfront investment and those that are low-cost and more readily accessible – particularly for vulnerable groups with limited access to credit or financial resources.

Given the inherent uncertainty of future climate conditions, particular attention is placed on identifying robust options – measures that perform well across a range of possible scenarios. At the same time, all interventions involve trade-offs that must be carefully assessed. These may arise between different land-use systems, stakeholder priorities, or desired outcomes, including implications for productivity, livelihoods, and mitigation objectives such as greenhouse gas emissions or carbon sequestration. Where possible, synergies and “win–win” solutions should be prioritized. Equally important is the need to avoid maladaptation by ensuring that interventions do not inadvertently increase vulnerability, shift risks to other systems or groups, or undermine long-term resilience.

While land-based adaptation measures implemented at site level directly contribute to more climate-resilient land use systems (Component 2), a complementary set of auxiliary measures focuses on strengthening the enabling environment for adaptation at national and regional levels (Components 1 and 3). These measures play a critical role in supporting and scaling site-level interventions by (i) strengthening climate-informed planning and programming processes and improving the public financing environment for climate-resilient and low-emission land use (Component 1); (ii) providing

essential support tools to manage climate risks, including enhanced climate information, knowledge exchange, and advisory services, alongside facilitation of access to financial resources for farmers—such as support in developing investment plans and bankable business cases (Components 2 and 3); (iii) addressing underlying socio-economic vulnerabilities through capacity development, institutional strengthening, and improved access to services for land users (Component 2); and (iv) strengthening governance frameworks and coordination mechanisms, including regional cooperation and cross-country knowledge sharing, with a focus on developing shared climate-resilient and low-emission development pathways for the region and strengthening foresight capacities (Component 3). Together, these measures create the conditions necessary for effective, sustained, and large-scale adaptation across interconnected land-use systems and transboundary landscapes.

Table 10 provides an overview of individual adaptation measures for key land-use systems promoted by the programme, covering irrigated and rainfed cropping systems, forestry, and pastoral systems. Further details on the individual measures, including their application across specific value chains, are provided in the Value Chain Analysis (Annex 2c) and the Activity sheets in the Feasibility Study (Annex 2a).

Table 10: List of individual adaptation measures for the key land-use systems promoted by the programme (full barrier titles are provided in Table 11 below)

Output/ Activity	Adaptation Measure	Adaptation Function	Targeted Vulnerability Factor(s)	Targeted Barrier
Irrigated Annual Cropland (Seed Potato Value Chain)				
2.3.1.6	Upgrading local seed multiplication	Improves access to climate-suitable planting material	• Crop variety selection (crop suitability)	B4
	Use of sprinkler irrigation	Reduces drought sensitivity and irrigation demand	• Irrigation schemes outdated for current climate • Insufficient water-saving capacities	
	Improving plant nutrition and pest management	Reduces climate-related crop stress and yield losses	• Insufficient fertilizer management • Insufficient pesticide management	
Irrigated Annual Cropland (Horticulture Value Chain)				
2.3.1.6	Use of climate-resilient seeds and seedlings	Improves crop suitability and resilience to climate stress	• Crop variety selection (crop suitability) • Use of water-intensive crops	B4
	Use of drip irrigation	Reduces drought sensitivity and irrigation demand	• Irrigation schemes outdated for current climate • Insufficient water-saving capacities	
	Improving plant nutrition and pest management	Reduces climate-related crop stress and yield losses	• Insufficient fertilizer management • Insufficient pesticide management	
	Use of insect-proof nets/shade nets	Reduces heat stress, pest damage, and weather exposure	• Insufficient plant protection	
Irrigated Perennial Cropland (Fruit Production Value Chain)				
2.3.1.6	Use of drought/heat/flood/frost resilient root stocks and fruit cultivars	Improves orchard suitability and tolerance to climate stress	• Use of water-intensive crops • Crop variety selection (crop suitability)	B4

	Improving orchard management technologies	Improves orchard resilience to water, soil, and weather stress	• Irrigation schemes outdated for current climate • Insufficient water-saving capacities • Insufficient excess-water management • Crop variety selection (crop suitability) • Limited erosion protection practices • Insufficient drainage practices • Insufficient protection practices (e.g. tree/shrub planting)	
	Use of drip irrigation	Reduces drought sensitivity and irrigation demand	• Irrigation schemes outdated for current climate • Insufficient water-saving capacities	
	Use of insect-proof nets/shade nets	Reduces heat stress, pest damage, and weather exposure	• Insufficient plant protection	
Rainfed Cropland (Wheat Value Chain)				
2.3.1.6	No-till seeding	Improves soil moisture retention and crop establishment	• Insufficient soil protection	B4
	Cover Crops	Protects soil and improves moisture retention		
	Crop rotation using drought-resistant oilseed crops and legumes	Diversifies production and improves drought resilience and soil fertility	• Insufficient soil fertility management • Crop selection	
	Improving plant nutrition and pest management	Reduces climate-related crop stress and yield losses	• Insufficient soil fertility management • Insufficient fertilizer management • Insufficient pesticide management	
Across all Cropland Systems				
1.3.2	Establishing climate-smart agriculture financing facilities and	Mobilizes finance for climate-resilient on-farm investment	• Limited access to finance • Limited investment for climate-resilient land use	B5

	supporting issuance of green bonds			
2.3.1.3 2.3.1.5	Capacity building for CRLE practices and technologies	Improves uptake of climate-resilient land-use practices	- Limited erosion protection practices - Knowledge gaps (management / practices) - Insufficient excess-water management - Insufficient water-saving capacities - Irrigation schemes outdated for current climate	B4
2.3.2.2	Establishing matching grant mechanisms for CRLE technology adoption and value chain development	Lowers investment barriers to climate-resilient technology adoption	Limited access to finance	B5
2.3.3.3	Improving post-harvest handling and storage technologies	Reduces climate-related post-harvest losses	- Insufficient protective storage capacities (e.g. harvest vulnerable to high moisture conditions) - Limited access to finance - Low value-added value chains	
Pastures				
2.2.1.6	Water point construction	Secures livestock water access under increasing drought stress	- Overgrazing and pasture mismanagement - Limited access to water points	B4
2.2.2.1 2.2.2.2 2.2.2.3	Rotational grazing	Reduces overgrazing and supports pasture recovery	- Limited pasture rotation - Overgrazing and pasture mismanagement - High livestock density	
2.2.2.1 2.2.2.2	Capacity building on pasture management	Improves adaptive grazing and stocking decisions	- Under-resourced and overloaded pasture management - Overgrazing and pasture mismanagement - Insufficient pasture management	
2.2.2.3	Pasture management plans	Supports climate-informed grazing and restoration planning	- Limited pasture rotation - High livestock density	

2.2.2.4	Capacity building in pasture restoration	Strengthens restoration of degraded and drought-stressed pastures	- Limited pasture rotation - Overgrazing and pasture mismanagement - High livestock density - Insufficient pasture restoration and management	
2.2.2.5	Pasture rehabilitation (seed-broadcasting, temporary fencing)	Restores vegetation cover and pasture carrying capacity		
	Fencing (permanent and temporary)	Protects recovering pasture and enables controlled grazing		
	Improving access roads	Improves access to underused pastures and reduces localized overgrazing		
	Improving access to water points	Redistributes grazing pressure and improves herd access to water		
	Pasture monitoring	Enables climate-responsive pasture management and early action		
	Climate-resilient forage seeds	Improves forage establishment and drought resilience		
Forests (Non-timber Forest Products Value Chain, Walnut & Pistachio)				
2.2.1.1 2.2.1.2	Capacity building in forest management	Improves climate-resilient forest protection and management	- Land degradation and soil erosion - Insufficient protection of seedlings - Limited enforcement of land-use regulations - Tree species composition (selection of tree species and forest composition) - Insufficient forest restoration and management	B4
2.2.1.3	Forest resources management plans	Guides climate-informed forest use and regeneration		
2.2.1.5	Capacity building in forest restoration	Strengthens restoration of degraded and climate-stressed forests		
2.2.1.6	Reforestation	Restores forest cover and protective ecosystem functions		

	Fencing	Protects seedlings and regenerating forest areas from disturbance	• Insufficient protection of seedlings • Limited enforcement of land-use regulations • Unsustainable forest use	
	Local climate-resilient seedlings	Improves regeneration success under changing climate conditions	• Tree species composition (selection of tree species and forest composition)	
	Increasing tree nursery capacities	Expands supply of climate-suitable planting material for regeneration and afforestation	• Insufficient protection of seedlings (low survival rate of tree plantations) • Land degradation and soil erosion • Insufficient forest restoration and management • Tree species composition (selection of tree species and forest composition)	
	Improving water retention and distribution infrastructure	Improves seedling survival and moisture retention	• Insufficient protection of seedlings (low survival rate of tree plantations) • Insufficient forest restoration and management • Land degradation and soil erosion	
	Monitoring and reporting of forest conditions	Supports early detection and adaptive forest management	• Insufficient protection of seedlings (low survival rate of tree plantations) • Limited enforcement of land-use regulations • Insufficient forest restoration and management	
2.2.2.1 2.2.2.2 2.2.2.3	Sustainable produce collection practices	Reduces resource pressure and supports sustainable regeneration	• Unsustainable forest use • Insufficient forest restoration and management	

2.3.1.6	Improving drying, processing, and storage technologies for produce	Reduces climate-related product losses and preserves value	• Insufficient protective storage capacities (e.g. harvest vulnerable to high moisture conditions) • Limited access to finance • Low value-added value chains	B5
Cross-cutting Adaptation and Auxiliary Measures				
1.1.1.2	Targeted climate information products	Supports climate-informed land-use and farm decisions	• Lack of climate information services • Limited use of climate information in decision-making • Insufficient land-use planning capacities and information base (e.g. limited geophysical soil analysis, use of GIS)	B3
1.1.1.5	Capacity building on climate-informed institutional planning	Strengthens integration of climate risk into planning		
1.1.2.1	Multisectoral and multiscale coordination	Improves coordinated adaptation across sectors and scales		
1.2.1.2	Enhancing access to innovative climate finance	Expands finance for climate-resilient land-use investment	• Limited investment for climate-resilient land use • Limited and unattractive loans • Limited access to finance	B1 B2
2.1.2	Local adaptation plans	Translates climate risk into local adaptation action	• Land degradation and soil erosion • Low adoption of climate-resilient practices • Limited technical support services • Insufficient protection of soil, infrastructure, and vegetation • Limited enforcement of land-use regulations • Inflexible local water allocation disadvantaging downstream users	B3
3.1.1	Capacity building on regional foresight and planning	Strengthens anticipatory planning for transboundary climate risks	• Lack of transboundary landscape planning mechanisms • Lack of climate information services • Limited use of climate information in decision-making • Insufficient land-use planning capacities and information base (e.g. limited geophysical soil analysis, use of GIS)	B6
3.1.2	Regional climate-informed development pathways	Guides long-term climate-resilient regional development		

3.2.1	Regional knowledge exchange and information sharing	Accelerates uptake of adaptation knowledge and practice	• Limited awareness of adaptation options • Limited use of climate information in decision-making • Low adoption of climate-resilient practices • Lack of climate information services	B3 B6
3.2.2	Improving the Central Asia Climate Information Portal (CACIP)	Expands access to usable climate information		
3.3.1	Regional climate investment platform	Mobilizes regional finance for landscape-scale adaptation	• Low adoption of climate-resilient practices • Limited awareness of adaptation options • Limited investment for climate-resilient land use • Limited and unattractive loans • Limited access to finance	B1 B6
3.3.2.2 3.3.2.3 3.3.2.4	Climate adaptation action plans in transboundary landscapes (including protected area management plans)	Operationalizes coordinated adaptation in shared landscapes	• Lack of transboundary landscape planning mechanisms • Low adoption of climate-resilient practices • Limited use of climate information in decision-making • Insufficient land-use planning capacities and information base	

Table 11: Barriers addressed by the programme and referenced in Table 10

Code	Title
B1	Insufficient public finance to implement mitigation and adaptation measures
B2	Limited coherence of public policies and incentives to enable adaptation and mitigation in the agriculture, livestock, and forestry sectors
B3	Limited integration of climate information into local land-use plans, national sector plans and other planning instruments
B4	Low technical knowledge amongst land users and limited technical advisory for planning and implementing site-specific adaptation options
B5	Limited access to finance for the implementation of climate-resilient production models
B6	Insufficient regional cooperation for addressing environmental transboundary issues

The measures presented in Table 10 should be read as an adaptation portfolio operating at three connected levels. At (1) production level, they reduce direct sensitivity to drought, heat, erratic rainfall, erosion, and pest pressure within specific cropping, pasture, and forest systems. At (2) uptake and implementation-support level, they aim to restore water-retention, vegetation-cover, and soil-protection functions across the connected mountain–foothill–valley system. At (3) enabling-environment level, they strengthen the planning, information, financing, and coordination conditions required for sustained adaptation and scaling.

At production level. In irrigated systems, the central adaptation priority is to reduce dependence on increasingly unreliable dry-season water availability while also lowering exposure to heat, salinity, and crop-quality losses. In annual systems, this is pursued especially through climate-suitable planting material, improved irrigation efficiency, stronger plant nutrition and pest management, and protective measures for sensitive crops. In perennial systems, the same water-stress logic is combined with orchard-specific measures, including climate-resilient rootstocks and cultivars, improved orchard management, drainage and erosion protection, and measures to limit heat, pest, and weather damage. The objective is not simply to raise productivity, but to keep irrigated production viable under hotter conditions, stronger seasonal water imbalance, and more disrupted water delivery.

In rainfed cropland, pasture, and forest systems, the emphasis shifts towards strengthening soil moisture, vegetation recovery, and regenerative capacity under more variable rainfall and stronger summer–autumn drought. In rainfed systems, this requires measures that protect soil cover, improve moisture retention, stabilise establishment, and maintain fertility under greater climatic variability. In pasture systems, the priority is to reduce localized overuse, improve grazing management, and restore vegetation cover and carrying capacity. In forests, the priority is to improve regeneration, seedling survival, and protective ecosystem functions under drought, erosion, grazing pressure, and rising biological stress. Across these systems, the adaptation function is therefore not only protective but restorative: it seeks to rebuild the buffering capacity of land-use systems whose degradation would otherwise amplify climate impacts across the wider landscape.

At uptake and implementation-support level. A second cluster of measures supports the uptake and durability of adaptation. Finance facilities, matching grants, post-harvest technologies, climate information products, advisory services, and capacity building are necessary because many of the identified risks are aggravated by weak access to knowledge, capital, and locally appropriate technical

support. These measures are therefore integral to the adaptation logic rather than auxiliary to it. They help determine whether land users can actually implement and sustain the site-level changes required under increasing climate stress. Across these land-use systems, the programme also builds on existing incentives for adaptation. Although land-tenure arrangements vary across the three countries and remain outside the direct scope of the programme, continued access to land often depends in practice on maintaining productive and economically viable use. This creates a concrete incentive for land users to adjust their practices where climate and resource constraints are already undermining viability – for example, by replacing orchards where irrigation has become unreliable, investing in small on-farm water storage, shifting towards more climate-suitable planting material, or adopting more resilient production methods. In this sense, the programme does not seek to create adaptation incentives from scratch. Rather, it aligns technical support, finance, climate information, and planning processes with incentives that already exist, while addressing the barriers that currently prevent land users from responding effectively.

At enabling-environment level. Finally, the programme’s planning- and cooperation-related measures reflect the fact that the main climate risks in the programme area are not confined to individual plots or districts. Water stress, runoff shifts, erosion processes, and pressure transfers between land-use systems propagate across elevation zones and national borders. Climate-informed planning, regional knowledge exchange, foresight, and climate investment mechanisms are therefore required to complement site-level adaptation.

Together, all these measures form a connected adaptation portfolio that responds to the differentiated geography of climate risk across the programme landscapes and strengthens the longer-term resilience of the AFOLU systems and rural livelihoods on which the programme areas depend.

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