Asian Development Bank

Agency for Land Reclamation and Irrigation under the Government of the Republic of Tajikistan

ADB Project Number: 53109

Transaction Technical Assistance, TA-9867 TAJ for preparation of a Sector Road Map, Feasibility Studies for Yovon and (priority components of) Qumsangir I&D Schemes, and an Investment Project



CLIMATE AND DISASTER RISK AND VULNERABILITY ASSESSMENT OF THE IRRIGATION AND DRAINAGE MODERNISATION IN THE VAKHSH RIVER BASIN PROJECT

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FutureWater

PREPARATION OF THE IRRIGATION AND DRAINAGE MODERNISATION IN THE VAKHSH RIVER BASIN PROJECT, ADB Project Number: 53109

Transaction Technical Assistance, TA-9867 TAJ for preparation of Sector Road Map, Feasibility Studies for Yovon and (priority components of) Qumsangir I&D Schemes, and an Investment Project

CLIMATE RISK AND VULNERABILITY ASSESSMENT (CRVA)

INCLUDING ADAPTATION OPTIONS

Key Data

Name of Project:	PREPARING THE IRRIGATION AND DRAINAGE MODERNISATION IN THE VAKHSH RIVER BASIN PROJECT
Executing / Implementing Agency:	Agency for Land Reclamation and Irrigation, Government of the Republic of Tajikistan
Financing Agency:	Asian Development Bank
Contractor for Preparation of Project:	Individual Consultants and Firm for Feasibility Design Services Panasia – Tajikgip JV led by: (i) International Team Leader Mr. Alan K Clark, Principal NHC Ltd., and (ii) Deputy Team Leader Mr. Sarboz Niyatbekov, Irrigation Engineer
Start/ End Date:	• Project Preparation under TRTA: 10th February 2020 to 20th August 2020 • Project Implementation: 2021 to 2026 (5 years)
Beneficiaries:	Farmers of Yovon and Qumsangir Schemes
Scheme Command Area and Districts	Yovon scheme: (i) Command Area 40,600 ha (net), (ii) Districts: Yovon, A.Jomi and Khuroson, Khatlon Region Qumsangir scheme: (i) Command Area 26,245 ha (net), (ii) Districts: Vakhsh, Jaloliddini Balkhi (Jaloliddini Rumi) and Jayhun (Qumsangir), Khatlon region
Indicative Project Cost	US$ 25 million ADB Grant and US$ 1.0 million from the GoT

Exchange Rate

US$ 1.00 = TJS 9.70 (21st February 2020)

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List of Abbreviations

ADB	Asian Development Bank
ALRI	Agency for Land Reclamation and Irrigation
CCA	Cultivable Command Area
CIS	Commonwealth of Independent States
CRVA	Climate Risk and Vulnerability Assessment
DMF	Design and Monitoring Framework
DSM	Digital Surface Model (elevation data with surface features)
DTM	Digital Terrain Model (elevations of bare earth)
EA	Executing Agency or Environmental Assessment
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EMP	Environmental Management Plan
EU	European Union
FAO	Food and Agricultural Organization
FEA	Financial and Economic Analysis
FFP	Family Farming Program
GCA	Gross Command Area
GDP	Gross Domestic Product
GIS	Geographic Information System
GOT	Government of the Republic of Tajikistan
GRP	Glass-fibre Reinforced (Resin) Pipe
Ha	hectare
HDPE	High Density Polyethylene
HH	Household
HPP	Hydroelectric Power Plant
I&D	Irrigation and Drainage
IBRD	International Bank for Reconstruction and Development
ICWC	Interstate Coordination Water Commission of Central Asia
IPCC	Intergovernmental Panel on Climate Change
ISF/ ISC	Irrigation Service Fee/ Charge
IWRM	Integrated Water Resource Management
M&E	Monitoring and Evaluation
MOM	Management, Operation and Maintenance
MEWR	Ministry of Energy and Water Resources
MOU	Memorandum of Understanding
O&M	Operation and Maintenance
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NWIS	National Water Information System
NWS	National Water Strategy
PIM	Participatory Irrigation Management
POW	Productivity of Water
PPP	Public Private Partnership
PRA	Participatory Rural Appraisal
RAP	Rapid Appraisal Process
R&U	Rehabilitation and Upgrading
RBMP	River Basin Management Plan
RBO	River Basin Organization
RP	Resettlement Plan
SCADA	Supervisory Control and Data Acquisition
SDC	Swiss Agency for Development and Cooperation TJS
SUE	State Unitary Enterprise
TA	Technical Assistance
TJS	Tajik Somoni (national currency)
ToR	Terms of Reference
TRTA	Transaction Technical Assistance
uPVC	Un-plasticized Poly-Vinyl Chloride

UNFCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
UWUA	Union of Water User Associations
WB	World Bank
WUA	Water Users Association

EXECUTIVE SUMMARY

This Climate and Disaster Risk and Vulnerability Assessment (CRVA) evaluates the potential for adverse consequences of disasters and climate change on the schemes and the proposed project, and identifies disaster risk reduction and climate adaptation activities. The report presents an assessment of historic trends in relevant climate-related variables and analyses future climate projections for the project. Based on these projections, an assessment is presented on the disaster and climate risks, considering current vulnerabilities and projections in the related climate variables. Risks are classified and disaster risk reduction and climate adaptation activities are proposed for the project.

The climate trend analysis was performed based on historic climate data from a state-of-the-art global reanalysis dataset, which is a dataset that blends ground-based observations, satellite-based observations and modelled data (ERA5). Trends were analysed for the irrigation scheme areas specifically. This analysis showed that temperatures have increased in the time period 1979-2019 by around 1.5ºC in 40 years (about 0.4 ºC/decade). Large variations in temperature are evident, with average daily temperatures ranging from around -10 to 34ºC over the course of the year.

For precipitation there is a trend of decreasing mean annual rainfall for this period, but with a fairly low statistical significance. The majority of this rainfall occurs in the months October – May, with a period of extremely dry conditions prevailing in June – September in which almost no rainfall occurs.

To assess how the climate will change for the project area in the future, climate model projections were analyzed from a multi-model ensemble dataset (NASA-NEX), including a combination of 21 GCMs and two RCPs. Two time horizons were used: "Near future" – year 2030 and "Distant future" – year 2060.

The model ensemble predicts a warmer future climate in the project area (TABLE I-1). Climate models are in good agreement with each other on tendency in this variable. For the Near future horizon, temperatures are likely to go up by around 1.5ºC, compared to the historic reference period. For the Distant future, this is around even 3 ºC.

For precipitation, the models do not provide a consistent signal and the sign and magnitude of change is highly uncertain (TABLE I-1). Some models predict a dryer future, some models a wetter future. The number of models predicting a wetter future is slightly higher. Overall, the predicted range of relative change is between -6% and + 11% (considering 25% and 75% percentiles of the model ensemble).

TABLE I-1 SUMMARY TABLE SHOWING STATISTICS REGARDING SPREAD IN CLIMATE MODEL (GCM) ENSEMBLE PREDICTIONS FOR FUTURE CHANGES IN MEAN ANNUAL TEMPERATURE AND PRECIPITATION IN THE PROJECT AREA.

	Temperature			Precipitation		
	Median (ºC	**GCMs >2ºC**	**GCMs >4ºC**	**Median (%)**	**GCMs Dryer**	**GCMs Wetter**
2030_RCP45	+1.7	4	0	4%	7	13
2060_RCP45	+2.8	19	1	2%	8	12
2030_RCP85	+1.9	8	0	3%	9	11
2060_RCP85	+3.9	20	7	3%	8	12

Besides changes in means, also changes in extremes can lead to increased climate risk. Despite inherent limitations that climate models have in predicting extremes, information can be extracted that can be useful in designing a robust project that considers the range of possible negative trends. From this extreme analysis, it is concluded that:

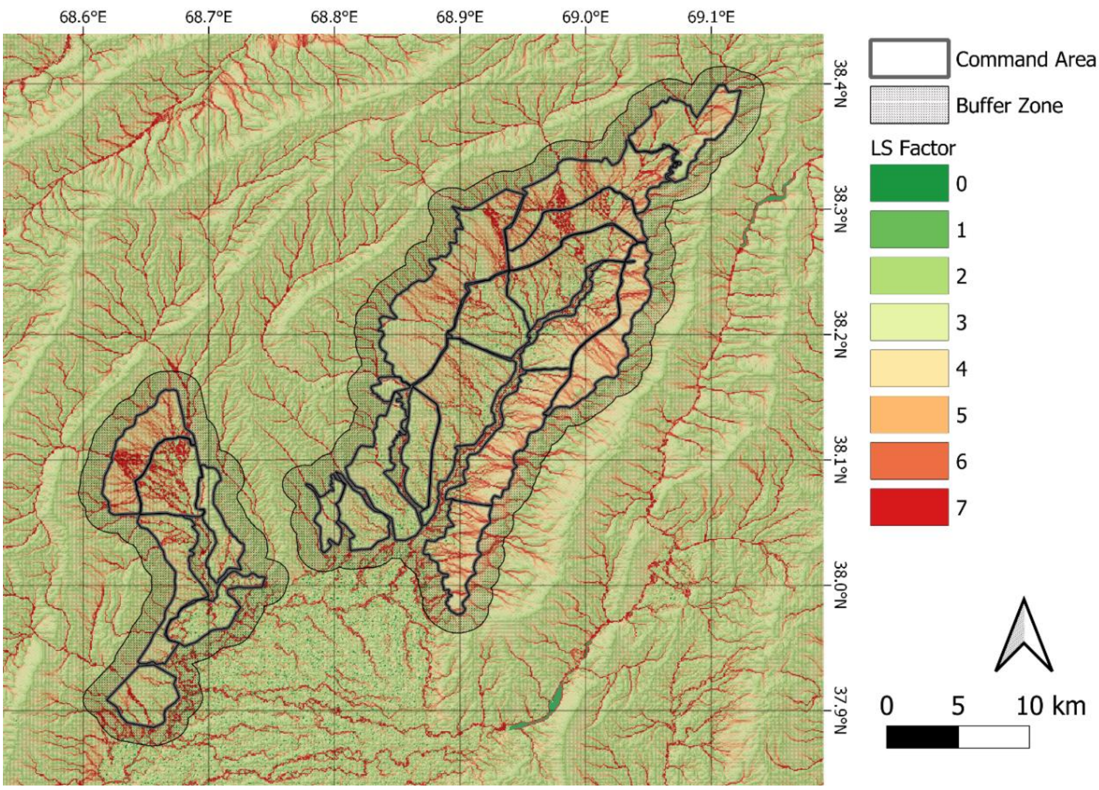
- The climate model ensemble shows a clear trend of increasing extreme temperatures under both RCP scenarios and time horizons, suggesting an increase in the severity of heatwaves in the area.
- Also, model projections suggest that the intensity of the extreme precipitation events will increase. For example, for rainfall events with a 10-year return period, rainfall intensities may increase by 24% (from 66 mm to 82 mm).
- Besides, the model projections are very clear on a significant decrease in number of ice-days, as proxy for the precipitation falling as snow compared to rainfall. This will affect water availability (less buffering capacity), may increase erosion, and is also a good indicator for permafrost.

The climate risk assessment was performed through a combination of field information, quantitative analysis using GIS and remote sensing, and expert judgement. Based on these sources of evidence, a likelihood and severity of consequences was interpreted and based on this, a risk level was assigned for each hazard.

A key climate risk in the area, as was confirmed by local stakeholders and field visits, is erosion. Erosion is already today leading to loss of productive land and to failure of infrastructure. Erosion occurs in the steeply sloping catchment areas due to overgrazing and lack of vegetative cover, as well as in the command area, due to heavy rainfall and the soil-type (loess), and results in extensive gully formation. In the command area, erosion is aggravated due to: (i) poor irrigation practices such as in-appropriate furrow sizes, lengths, non-uniform and over steep slopes and flows, and (ii) design and maintenance deficiencies of infrastructure.

A spatial analysis of erosion risk was performed, based on slope length and slope steepness. Especially for the Jovon scheme, the erosion risk is relatively high within the command area (FIGURE I-1) but also in the direct surrounding. This leads to high vulnerability to earthquake hazard and consequent failure of slopes and infrastructure, as is also demonstrated by historic events that led to considerable impacts on farmers´ livelihoods in the Yovon scheme.

FIGURE I-1. EROSION RISK FACTOR IN THE JOVON COMMAND AREA



Also, other climate risks were assessed:

- **Increased drainage issues.** There is a high risk that due to more extreme rainfall, drainage issues (i.e. waterlogging, salinity and local flooding) will further increase in the flatter parts of the scheme where properly functional drainage infrastructure is currently absent.
- **Drought risk** is high already under the current climate but will further aggravate under climate change due to more variable precipitation, longer dry periods, increased crop water requirements and poorly functional irrigation infrastructure
- **Changes in water availability** will become increasingly an issue over the next decades. Increased inter-annual and seasonal variability is expected due to reduced snow cover and glaciers – although the extent to which this will affect the project depends on the operations of the large reservoirs upstream. From around 2050, water availability will progressively go down and the effect of reduced water storage capacity in the form of snow and in glaciers will most likely affect water availability to the project.
- **Heat stress**. Impacts of temperature-related stresses on crops are limited in case farmers have the capacity to adapt to the changing climate by diversifying crops and by changing to more flexible irrigation scheduling.

The disaster risk from earthquakes was estimated at high for the project. A recent historic event has been analysed from which clearly the negative impacts on productivity could be seen, thus directly affecting the livelihoods of the farmers. Infrastructure is in a poor state and not fit for seismic loading. Seismic proofing is considered critical for preventing these harmful disasters to compromise the project outcomes.

The project proposes a wide range of adaptation activities that should make sure that the development impact of the project is not compromised by climate change impacts. Under **output 1** the project develops climate and disaster resilient I&D infrastructure and will include seismic retrofitting of key vulnerable infrastructure of the main irrigation system. Further, it will support a modern buried pipe system for 9,830 ha (25% of the command area) with volumetric metering, and hydrants for gated pipe connections for farm land, and hydrant-manifolds for pressure hose and micro-irrigation of homestead areas which are managed by women. Hydrants flows would be controlled by the irrigators leading to crop choice and increased yields even under climate induced changes in water availability. An effective drainage system (ditch and buried slotted pipe) will be provided to reduce risks for increased erosion, floods and salinity causing yield and crop land losses. In addition, nature-based solutions and gabion-gully plugging works will address the risk of erosion from more intense storm events, reclaim the bad-lands and prevent further loss of command area.

Under **output 2** the project strengthens climate adapted management and operation of I&D systems on different levels: ALRI - main system, WUA - secondary and tertiary system, Dekhan farms and for homesteads. Governance institutions will be re-structured to strengthen the adaptive capacity of the institutions responsible for operating and maintaining the I&D system - Agency for Land Reclamation and Irrigation (ALRI) and the Water User Associations (WUA) – and supported to use modern and innovative technologies, such as satellite remote sensing-based crop monitoring, remote flow control, smart cashless metering and volumetric charging for: (i) a higher level of irrigation service to farmers, (ii) to support increased ISFs for sustainable operation and maintenance, and (iii) to enable rapid response to extreme weather events, including quick closure in the event of any infrastructure failure to minimise disaster impact.

For Dekhan farms and homesteads the project will support climate smart agriculture technologies including gated pipe irrigations, and precision land grading, for climate adapted farming giving higher crop yields and reducing erosion risk from extreme rainfall events. Women make up 75% of the labor force and are specifically vulnerable to climate thus the project will include support for pressure hose and micro-irrigation for homesteads.

Under **output 3** policy for climate-adapted, sustainable water management will strengthened by studies and actions to incorporate financial resilience into ALRI and WUAs for sustaining operation and maintenance activities under increased climate risks and promoting women's representation and enabling them to take meaningful roles in ALRI and WUAs to increase their adaptive capacity as they can participate in decision made on responses to climate change impacts.

The proposed investment project brings together several complementary innovative solutions for climate adaptation. These include: (i) remote canal water level and flow monitoring, (ii) satellite crop and crop water productivity monitoring, (iii) buried pipe systems with volumetric smart metering and cashless volumetric charging, and hydrants for (a) gated pipe connections for farms, and (b) manifold - hose connections for homesteads giving water and labor savings, (iv) precision land grading, (v) nature-based solutions for gully stabilization and reclamation, (vi) governance innovation through establishment of a single management agency and also a Union of WUAs, (vii) introduction of tablets and other resources for better access to information, forecasts, inputs, by farmers.

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I. RELEVANCE

A. Project Background

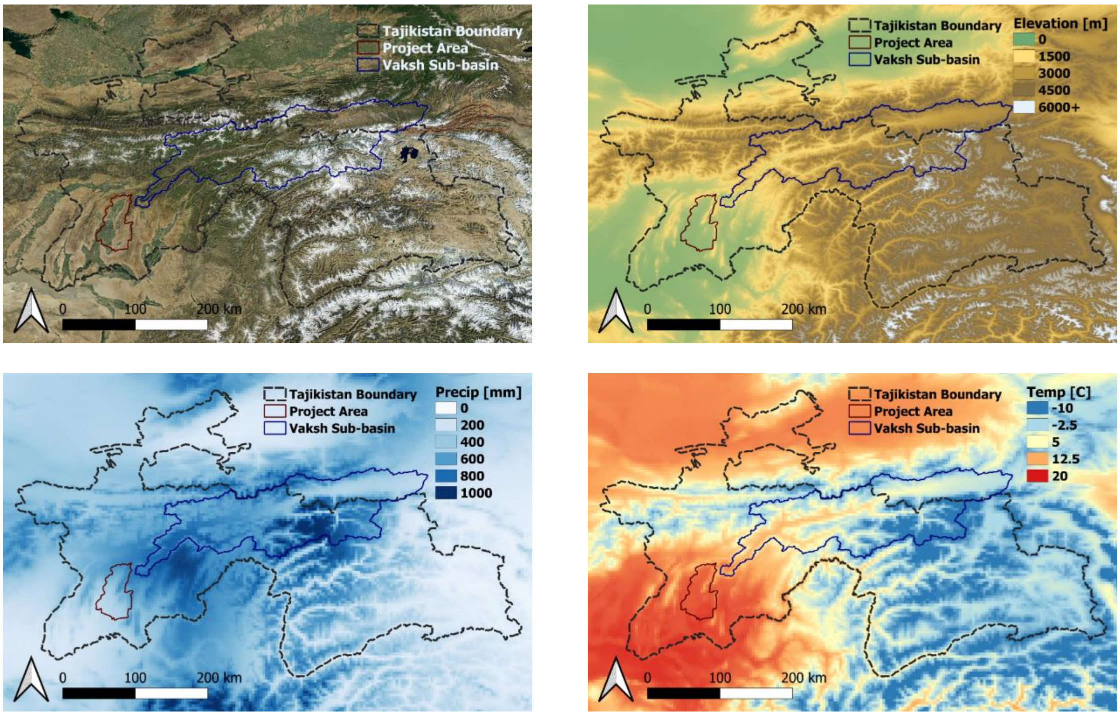
The Asian Development Bank (ADB) is committed to supporting the government of Tajikistan in delivering climate adaptive solutions for water resources management. These solutions aim to modernize irrigated areas, providing increased access to water for use in agriculture. This will allow the country to continue growing its agricultural sector and diversify production with an eventual aim of increasing productivity and exports.

To help Tajikistan achieve these goals, ADB has helped to formulate the Preparing the Irrigation and Drainage Modernization in the Vaksh River Basin Project. The objective is to modernize two irrigation systems: Yovon and Qumsangir schemes. ADB sees modernization as a process covering all aspects of the irrigation system. The project is thus is not limited to the modernization of only the physical infrastructure but also extends to how the schemes are managed, and agricultural processes are undertaken. Overall, the project seeks to improve performance, with resultant benefits to the communities and farmers.

The proposed project will comprise essential works to modernize the Yovon main I&D system and a core area of the command area. Besides, feasibility studies are being undertaken for both the Yovon and Qumsangir schemes, and it is envisaged that a follow on project may complete modernization of the Yovon scheme, and take up the Qumsangir scheme.

FIGURE I-1 shows a four maps indicating where the project area and the upstream Vaksh basin are located within Tajikistan. The upper-right map shows that the project area is located in the lower part of the country. Precipitation is around 500 mm (lower-left map), falling as snowfall from December to March, and with significant rainfall in April and May. Mean temperatures are around 15ºC (lower-right map), with minimum average temperatures well above freezing from March to November, and peak in July (maximum average temperature close to 40 ºC).

FIGURE I-1. LOCATION OF PROJECT AREA IN TAJIKISTAN, THE UPSTREAM VAKSH BASIN BOUNDARY. UPPER-LEFT: SATELLITE IMAGE. UPPER-RIGHT: ELEVATION. BELOW-LEFT: MEAN ANNUAL PRECIPITATION. BELOW-RIGHT: MEAN ANNUAL TEMPERATURE.



The project area receives water from the upstream basin of the Vaksh river, which includes the large Nurek reservoir (around 10 billion cubic meters of storage capacity). This upstream basin provides about 25% of the flow to the Amu Darya river system. The upstream area is highly mountainous (some areas over 6000m), cold and receives a relatively large total annual precipitation. The flow regime is highly dominated by glaciers and snowfall in the high mountain areas.

The project area has two cropping seasons:

- Main crop growing season (cotton, maize, vegetables, etc.) during the Vegetative period, from 1st April to 30th September
- Secondary cropping season (winter wheat, spring vegetables, etc.) during the winter period from 1st October to 31st March

The canal irrigation system provides water for: (i) Dehkan farms with irrigated field crops, mostly wheat and cotton (majority of irrigable area), (ii) Presidential lands, (iii) Homesteads/ kitchen gardens, and (iv) for industrial/ commercial and potable use. More details can be found in the main report.

B. Potential climate sensitivities

The first step in a climate risk assessment is to evaluate potential climate sensitivities of the project. For assessing potential climate sensitivities of irrigation modernization projects, it is important to include potential climate impacts on the water source, which is the upstream basin of the Vakhsh river. The water balance and the hydrological regime are likely to be impacted by climate change and may affect the project performance in the future.

TABLE I-1. shows the principal potential climate sensitivities for possible components of the modernization project. The last row in the table refers to potential sensitivities related to changes in the upstream water balance. The other rows refer to sensitivities to climate change in the project area itself.

TABLE I-1. POTENTIAL CLIMATE SENSITIVITIES FOR THE SUBPROJECTS

Climate & weather conditions	Expected sensitivities	Related project components
Temperature changes		
Warmer temperatures	• Changes in crop water requirements • Increased evaporation of surface water bodies (mainly reservoirs) • Increasing biological and chemical degradation of water quality. • Changes in watershed agricultural practices and in the resulting pollution loads from agriculture.	• Pipe distribution systems, balancing storages and irrigation practices/technologies
Increases in very hot days and during heat waves	• Modification in crop suitability and productivity (heat stress). • Increase in weeds, crop pests and disease outbreaks. • Increase wildfire risk.	• Support for adaptive measures, including seed, agricultural practices, machinery to enable working during very hot weather
Fewer cold days and nights	• Chilling requirements for specific crops	• Crop selection and support for adaptive measures including crop storages and marketing
Precipitation Changes		

Climate & weather conditions	Expected sensitivities	Related project components
Increase in intense precipitation events	• Increased turbidity and sedimentation of canal water. • Changes in nature of rainfall pattern leading to inadequate infiltration / groundwater recharge resulting in reduced flow and/or yield of water. • Potential loss of reservoir storage as a result of increased erosion in watershed. • Increased loading of pathogenic bacteria and parasites in reservoirs. • Increased waterlogging, inability to cultivate lands. • Damage to drainage systems due to flooding. • Increased extent and intensity of erosion in the command and catchment areas and waterlogging. • Increased pest incidence.	• Irrigation infrastructure • Measures to control soil erosion within the command area on highly erodible (. • Measures to control soil loss in catchment areas, • cross drainage structures • drainage system for water level and salinity control • Decision support tools/ systems to facilitate operating decisions and for asset maintenance • Sediment exclusion measures
Increases in drought conditions	• Reduced replenishment rates of groundwater resulting in declining water tables where net recharge rate is exceeded. • Lower yields from crop damage, stress, and/or failure. • Loss of arable land as a result of land degradation and wind erosion. • Increased risk of wildfires.	• Land management and use to address degradation and erosion • Irrigation distribution and practices/ technologies • Crop selection • Balancing storage
Changes to extreme events		
Increase in the frequency of floods, landslides and droughts and also seismic events	• Crop failure and damage to crops due to flooding. • Yield decreases. • Land degradation and soil erosion, loss of arable land, • Sedimentation of infrastructure. • Increased competition for water (drought). • Failure of structures inadequately designed for seismic loading	• All engineering measures, including: (i) flood runoff/ mudflow channels and escapes upgrading & stabilization to prevent gully erosion, (ii) precision grading and improved furrow to improve efficiency and reduce soil erosion, (iii) improved and upgraded distribution infrastructure including canals, flow control and conveyance structures including siphons, and (iv) new pipe distribution systems for water use efficiency gains and to safely convey water downslope without soil erosion.

Climate & weather conditions	Expected sensitivities	Related project components
		• Decision support tools/ systems to facilitate operating decisions and for asset maintenance
More frequent dust storms	• Damage to crops and infrastructure	• Water shed management to improve vegetative cover, e.g. controlled grazing
Changes in the water balance upstream of the project		
Increase in temperature and changes in precipitation patterns influencing glacio-hydrological response of upstream river basin	• Reduced water availability at the intakes, increased interannual variability, peak flow earlier in the season, reduced volumes of runoff. • Increased competition for water resources by users upstream (agriculture, hydropower, etc) and downstream of the intake	• Sediment exclusion measures • Measures for improved water use efficiency, including engineering works and management systems, i.e. • Decision support tools/ systems and SCADA

C. Objective

This Climate and Disaster Risk and Vulnerability Assessment (CDRVA) assesses disaster risk, as for example from earthquakes, and climate risks based on historic trends in relevant climate-related variables and analyses climate projections for the subproject area. For all relevant hazards, a risk level is assigned based on various sources of evidence, including field data and satellite data. Based on this, disaster risk reduction and climate adaptation measures are proposed to be considered for a resilient project design.

D. Approach

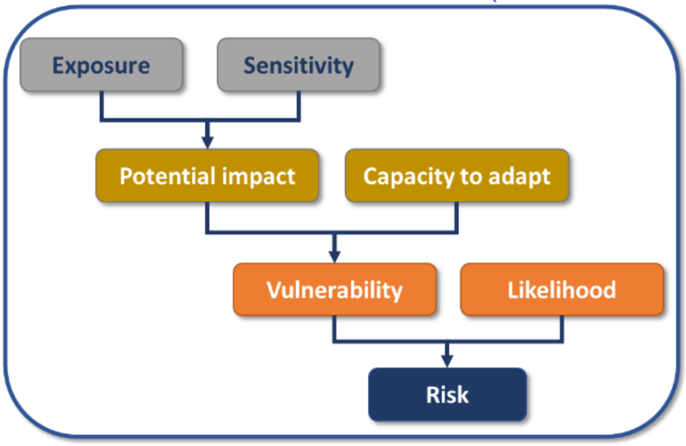
Since 2014, the Asian Development Bank (ADB) has required that all investment projects consider climate and disaster risk and incorporate adaptation measures in projects at-risk from geo-physical and climate change impacts. This is consistent with the ADB's commitment to scale up support for adaptation and climate resilience in project design and implementation, articulated in the Midterm Review of Strategy 2020: Meeting the Challenges of a Transforming Asia and Pacific (ADB, 2014a), in the Climate Change Operational Framework 2017–2030: Enhancing Actions for Low Greenhouse Gas Emissions and Climate-Resilient Development (ADB, 2017), and in the Climate Risk Management in ADB Projects guidelines (2014b).

The principal objective of a climate risk and vulnerability assessment (CRVA) is to identify those components of the project that may be at risk of failure, damage and/or deterioration from natural hazards, extreme climatic events or significant changes to baseline climate design values (ADB, 2011, 2014 and 2017). This serves to improve the resilience of the infrastructure to the impacts of climate change and geo-physical hazards, to protect communities and provide a safeguard so that infrastructure services are available when they are needed most. As part of this process, the nature and relative levels of risk are evaluated and determined to establish appropriate actions for each proposed investment to help minimize climate change associated risk. If applicable, also a Disaster Risk Assessment (DRA), identifying and assessing risks from geophysical hazards, should be performed for the project. This report combines both in one: Climate and Disaster Risk and Vulnerability Assessment (CDRVA).

CRVAs and DRAs use a variety of often confusing definitions relating to risk and climate change. In this study the following definitions are used (adapted from IPCC, 2014), with links between concepts shown in Figure I-2:

- Exposure: The 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 by climate change and variability.
- Sensitivity: The degree to which a system, asset, or species may be affected, either adversely or beneficially, when exposed to climate change and variability.
- Potential impact: The potential effects of hazards on human or natural assets and systems. These potential effects, which are determined by both exposure and sensitivity, may be beneficial or harmful.
- Adaptive capacity: The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences of hazards.
- Vulnerability: The extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It depends not only on a system's exposure and sensitivity but also on its adaptive capacity.
- Likelihood: A general concept relating to the chance of an event occurring. Generally expressed as a probability or frequency.
- Risk: A combination of the chance or probability of an event occurring, and the impact or consequence associated with that event if it occurs.

Figure I-2. Climate Risk components. (based on http://www.ukcip.org.uk).



Besides disaster risk, this study assess climate risks which should contain information pertaining to (ADB, 2016):

- Climate sensitivity of key project components (presented here before in I-B);
- Historic climate trends in project area;
- Projected climate change in project area;
- Identification of drivers of vulnerability (combination of physical and socio-economic ones)
- Categorization of potential climate risks; and
- Recommendations for adaptation

This document presents in chapter II the outcomes historic climate trend analysis, in Chapter III the future climate projections for the project area, Chapter IV presents the analysis on vulnerabilities and risks, Chapter V the disaster risk assessment and Chapter VI the recommendations for disaster risk reduction and adaptation.

II. HISTORIC CLIMATE TRENDS

A. Climate data

An essential step in developing a credible and acceptable Climate Risk and Vulnerability Assessment (CRVA) is to look at historic observations of climate and to perform trend analyses. This can reveal whether trends in climate variables can already be observed based on historic data. Obviously, trends, or the absence of trends, do not imply that future changes will follow the historic patterns. Any statistical trend analysis should be accompanied by understanding the underlying physical processes and future projections using GCMs.

1. Global reanalysis dataset

Historic records of precipitation and temperature need a rigorous process of data checking, cleaning and gap filling. This process, often referred to as reanalysis, has been developed strongly over the last two decades to support climate change research and analysis. Reanalysis of past weather data provides a clear picture of past weather, independent of the many varieties of instruments used to take measurements over the years. Through a variety of methods observations from various instruments are added together onto a regularly spaced grid of data. Placing all instrument observations onto a regularly spaced grid makes comparing the actual observations with other gridded datasets easier. In addition to putting observations onto a grid, reanalysis also holds the gridding model constant keeping the historical record uninfluenced by artificial factors. Reanalysis helps ensure a level playing field for all instruments throughout the historical record.

For the purposes of this CRVA, the ERA5 reanalysis product1 from the ECMWF is used to represent historical trends in temperature and precipitation for the project area. This product is used as it provides global, spatially gridded time series of a number of climate variables at resolutions of 31km and sub-daily (3hr) timescales. The dataset is fully operational (updated every month) and runs from 1979 to present. From this dataset, spatially averaged time series of precipitation and temperature are extracted for the project area at daily, weekly and yearly timescales for the entire period that the dataset covers. This allows for the analysis of annual and seasonal trends in historical climate alongside extremes.

ERA5 and ERA5-Land Reanalysis Data

ERA5 is the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis for the global climate and weather for the past 4 to 7 decades. Currently data is available from 1979. Reanalysis combines observations into globally complete fields using the laws of physics with the method of data assimilation (4D-Var n the case of ERA5). ERA5 provides hourly estimates for a large number of atmospheric, ocean-wave and land-surface quantities.

ERA5-Land is a reanalysis dataset at an enhanced resolution compared to ERA5. ERA5-Land has been produced by replaying the land component of the ECMWF ERA5 climate reanalysis. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics. Reanalysis produces data that goes several decades back in time, providing an accurate description of the climate of the past.

Source: ECMWF

2. Local weather station data

To better characterise past climate in the command area of each scheme, ground data from weather stations is considered in reference to reanalysis data (ERA5) presented in the above sections. As a general observation, reanalysis data is highly useful in terms of trend analysis due to its completeness in both space and time but is often liable to biases when compared with ground based

[1] https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

observational data. Precipitation specifically is chosen for comparison exercises as this is often found to be the most liable to bias in reanalysis products.

Several weather stations from the Global Summary of the Day (GSOD)[1] – a network of openly available weather station data – lie within the vicinity of the irrigation schemes. These are shown in relation to each scheme in FIGURE II-1, with details on their coverage in relation to precipitation in TABLE II-1. This shows that records at these stations have many gaps and are sometimes inconsistent in terms of measurements, however these are still considered useful to give an average representation of precipitation observed at ground level. This data is considered for the last 5 years (2014-2019) as this is a period where weather stations have coverage and the period for which rainfall data was required for applications in crop growth models in other sections of this study.

FIGURE II-1. LOCATION OF WEATHER STATIONS IN RELATION TO PROJECT AREA.

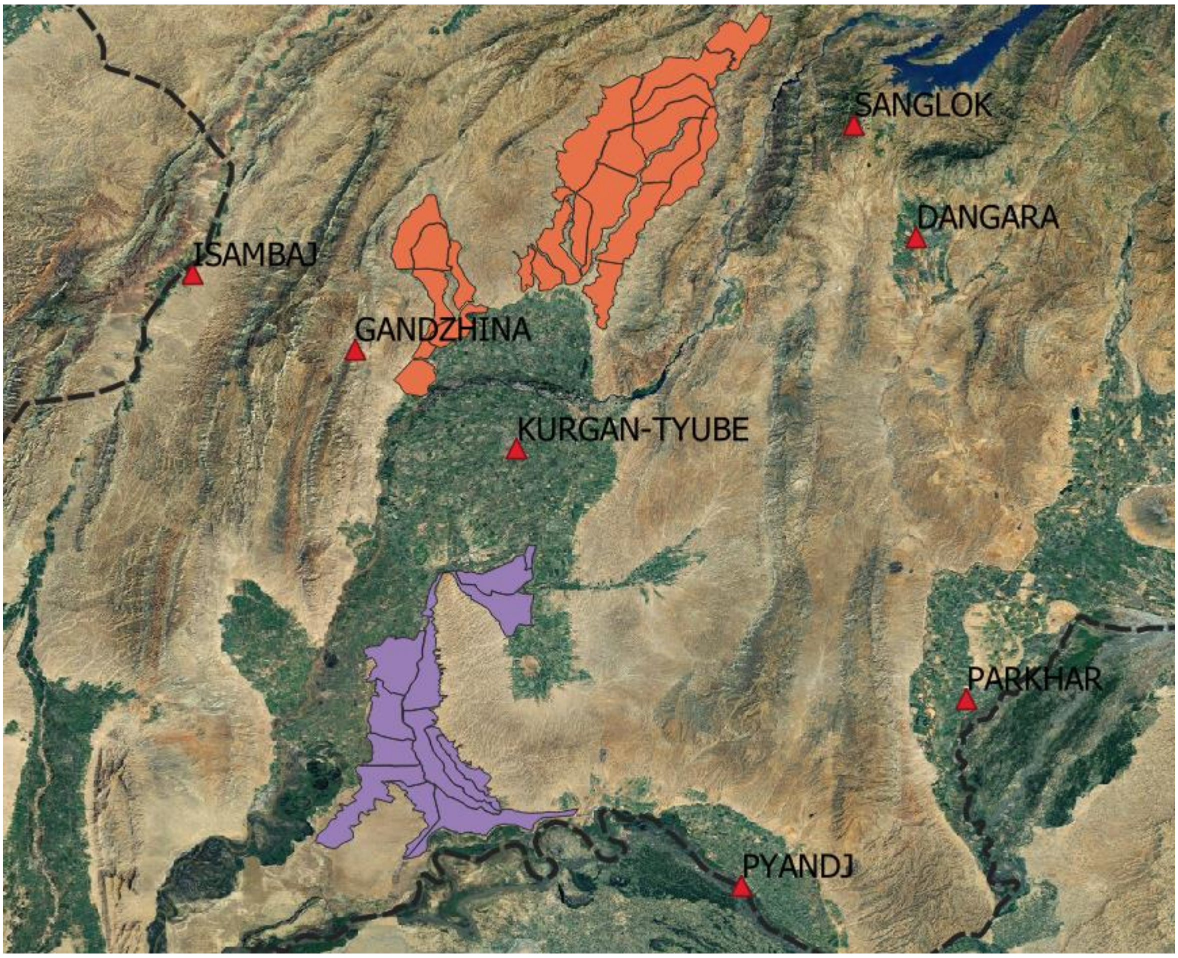


TABLE II-1. CHARACTERISTICS OF WEATHER STATIONS WITHIN THE VICINITY OF PROJECT AREAS.

Station	Lat	Lon	Elev. [m]	Start [YYYYMMDD]	End	No. NAs in Record	Gaps in Record?
Kurgan-Tyube	37.8	68.78	429	19600101	-present	592	Y (2002-2005; 2006-2008)
Gandzhina	37.95	68.57	752	20101001	-present	107	Y (2013-2014)
Isambaj	38.05	68.35	563	19600102	-present	647	Y (1982-2002)
Dangara	38.1	69.32	660	19591102	-present	452	N

[1] https://catalog.data.gov/dataset/global-surface-summary-of-the-day-gsod

Sanglok	38.25	69.23	2239	19730101	-present	569	Y (1982-2005; 2008)
Pyandj	37.23	69.08	363	19480101	-present	215	Y (1956-1973; 1994-2014)
Parkhar	37.48	69.38	448	19591030	-present	501	Y (1962-1979; 1994-2006)

3. Evaluation of datasets

When this data is compared spatially with ERA5 (FIGURE II-2), it is clear that there is a large difference in observations between the two datasets for total annual precipitation. ERA5 consistently shows a much higher level of precipitation (300-1200 mm/year) in the command areas of the two schemes, with GSOD datasets predicting a much lower range (250-600 mm/year). This bias in ERA5 is consistent with previous FutureWater applications in the area, which found that the dataset exhibits a consistent overprediction of precipitation, especially at higher altitudes.

When compared with other climate related studies for Tajikistan (FIGURE II-3), GSOD data compares favourably, increasing confidence in this dataset. Again, this dataset indicates that ERA5 is overpredicting precipitation, but the spatial gradients shown in precipitation over the project area does compare well, suggesting that is it representing spatial variation well.

FIGURE II-2. SPATIAL COMPARISON OF ERA5 (CONTOURS) AND GSOD (POINTS) AVERAGE DATASETS ON OBSERVED ANNUAL PRECIPITATION FOR THE YEARS 2014-2019.

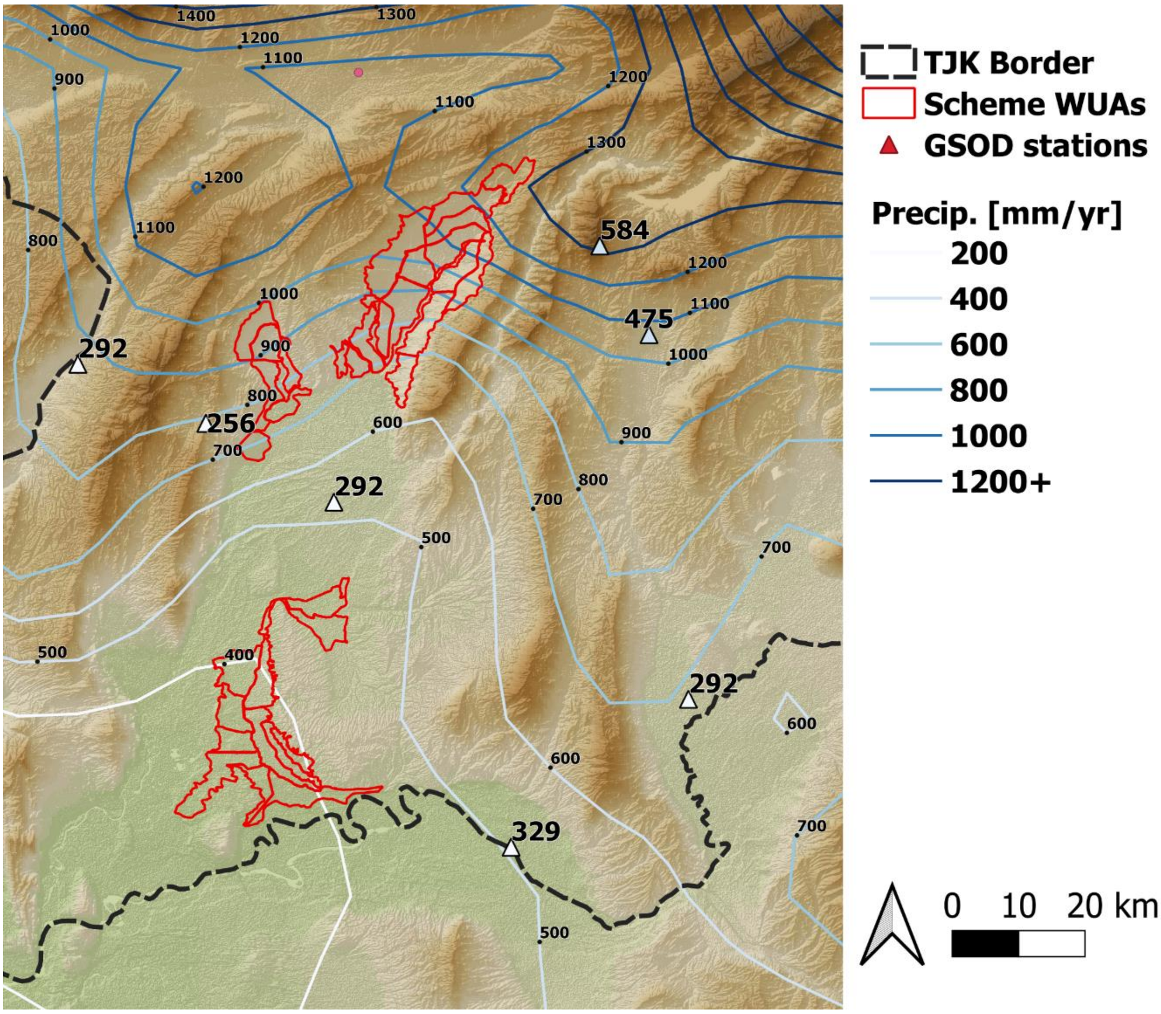
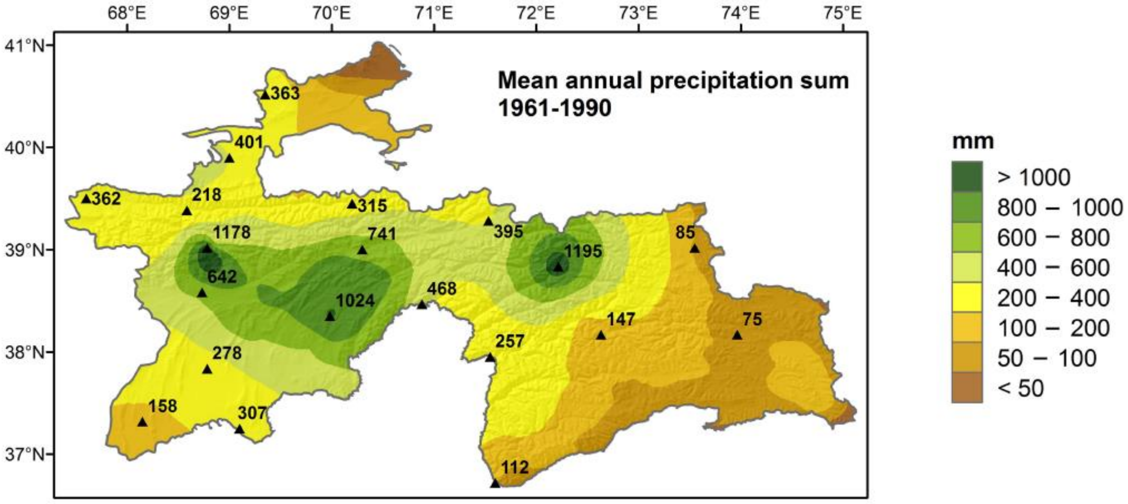


FIGURE II-3. SPATIAL DISTRIBUTION IN MEAN ANNUAL PRECIPITATION 1961-1990 FOR THE WHOLE OF TAJIKISTAN (SOURCE: AALTO ET AL., 2017)



To further assess this discrepancy between datasets, a time series was extracted from the ERA5 dataset in the same location as the Kurgan-Tyube station from the GSOD dataset. When the distribution of these datasets are compared at the daily scale (FIGURE II-4), it appears that ERA5 shows generally higher values for the severe precipitation events. This is corroborated when the seasonality of rainfall observed in each dataset is considered (FIGURE II-5), also highlighting that ERA5 overestimates precipitation most significantly in the earlier, wetter months of each year – this is especially evident for 2017.

FIGURE II-4. QUANTILE-QUANTILE COMPARISON OF DAILY PRECIPITATION FOR THE YEARS 2014-2019 FOR THE KURGAN STATION.

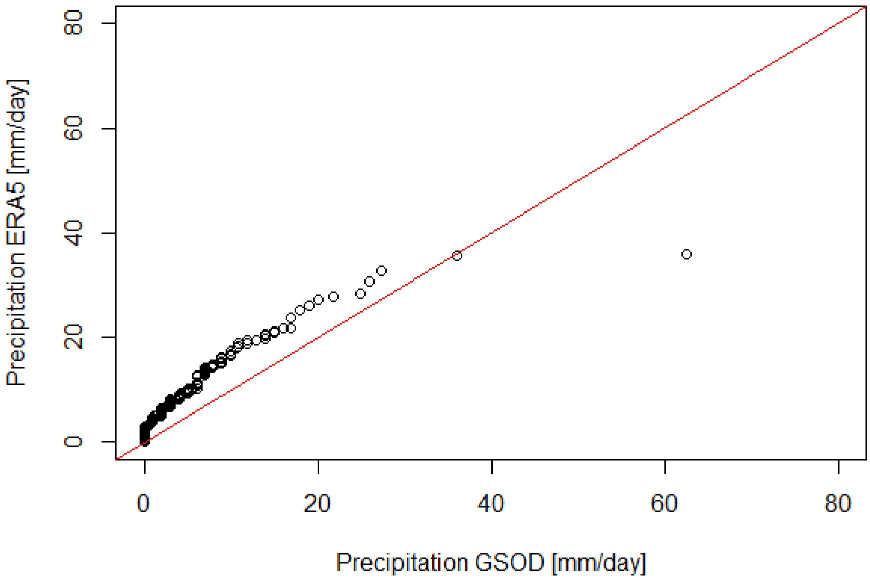
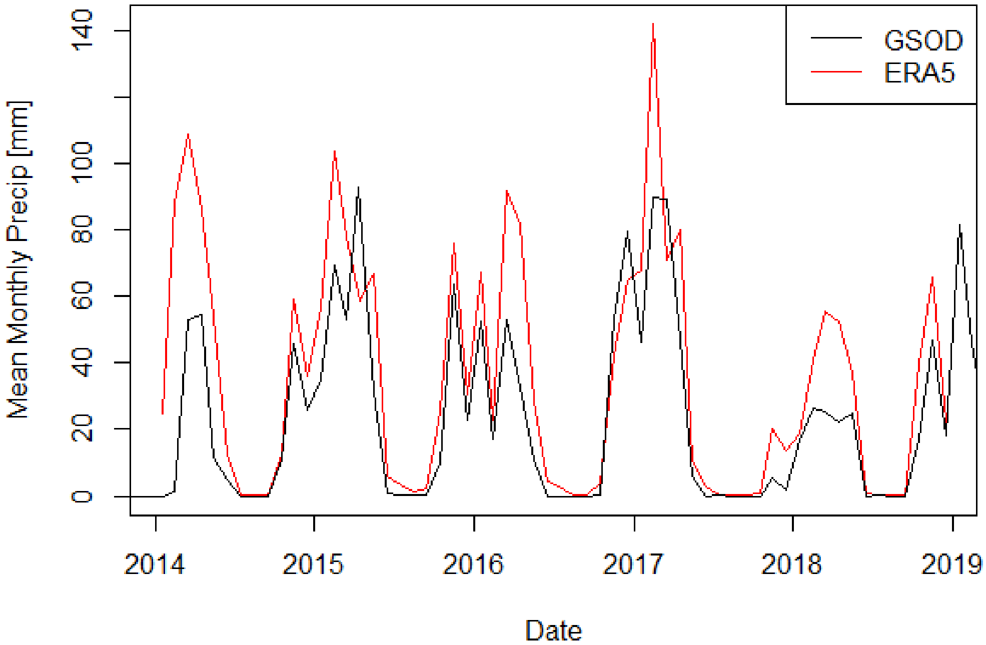


FIGURE II-5. COMPARISON OF AVERAGE PRECIPITATION PER MONTH IN TERMS OF PRECIPITATION FOR THE YEARS 2014-2019 FOR THE KURGAN STATION.



This brief analysis yields the following considerations relating to precipitation datasets for the two schemes considered:

- GSOD station data compares well with previous studies
- ERA5 compares well in terms of spatial distribution, but shows a high positive bias – therefore it requires correction if it is to be used for analysis
- ERA5 holds up best for trend analysis – no gaps, no inconsistencies

B. Temperature trends

Historical data on temperature shows that average annual temperatures are around 16ºC for the project area. Large variations in temperature are evident, with average daily temperatures ranging from around -10 to 34ºC over the course of the year (FIGURE II-6). A clear seasonality is evident in FIGURE II-8, with high average monthly temperatures (around 30ºC) prevailing during the growing season for many common crops (April - September).

Analysis of temperature data shows that temperatures have increased in the time period 1979-2019 (up to 1.5ºC in 40 years, see

FIGURE II-7). This trend is extracted from the yearly average temperature time series and has medium statistical significance.

FIGURE II-6. DAILY AVERAGE TEMPERATURE FROM ERA-5 DATASET.

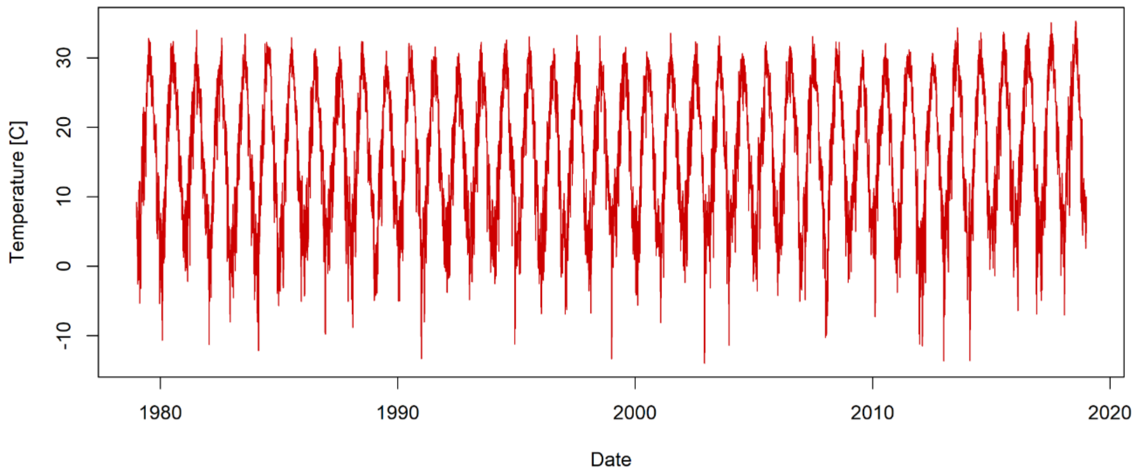


FIGURE II-7. AVERAGE, MAXIMUM AND MINIMUM YEARLY TEMPERATURES FROM ERA-5 DATASET WITH TRENDLINE.

MANN KENDALL TAU VALUE INDICATES THE STRENGTH OF THE MONOTONIC TREND OF INCREASE OR DECREASE IN A TIME SERIES, WITH A VALUE OF 1 INDICATING A STRONG SIGNIFICANT TREND AND -1 INDICATING NO TREND.

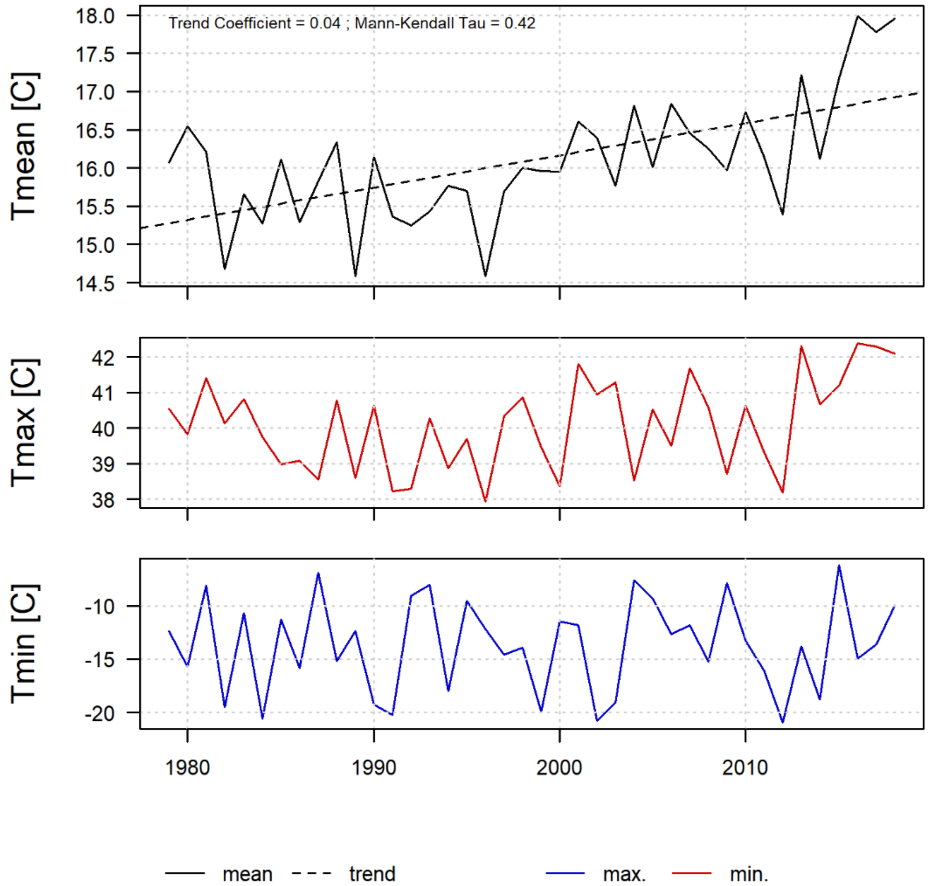
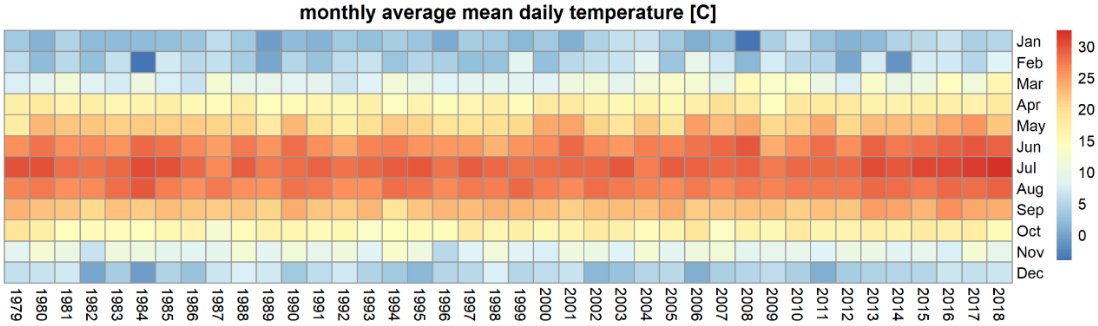


FIGURE II-8. SEASONALITY IN TEMPERATURE FROM ERA-5 DATASET FOR THE PROJECT AREA



C. Precipitation trends

Historical data on precipitation shows that average total annual precipitation is around 500mm on average for the project area (FIGURE II-10). A trend of decreasing total annual rainfall is evident for this period, but with lots of variability around this and fairly low statistical significance attached to the trend. The majority of this rainfall occurs in the months October – May, with a period of extremely dry conditions prevailing in June – September in which almost no rainfall occurs (FIGURE II-11). This illustrates the importance of irrigation networks in this area.

When compared to in-situ ground station measurements, the ERA5 data presented here shows some bias in overpredicting precipitation levels in the area. Indeed, data extracted from weather stations located within the defined project area (Kurgan-Tyube, Gandzhina stations) suggests that annual precipitation is closer to 200mm with much higher variability and the occurrence of numerous consecutive extremely dry years between 2000 and 2010. It must, however, be noted that this data is itself open to a range of biases.

FIGURE II-9. DAILY PRECIPITATION FROM ERA-5 DATASET.

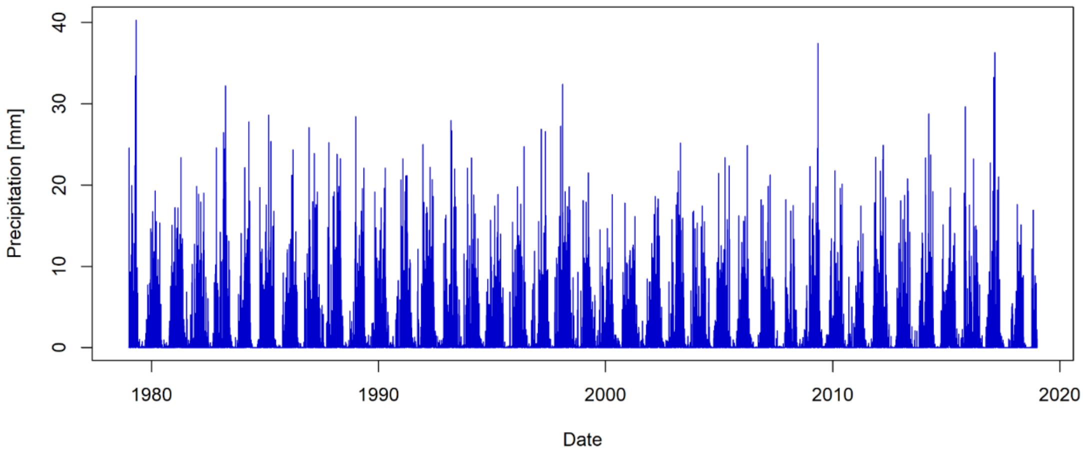


Figure II-10. Total yearly and maximum one day precipitation from ERA-5 dataset with trendline.

Mann Kendall Tau value indicates the strength of the monotonic trend of increase or decrease in a time series, with a value of 1 indicating a strong significant trend and -1 indicating no trend.

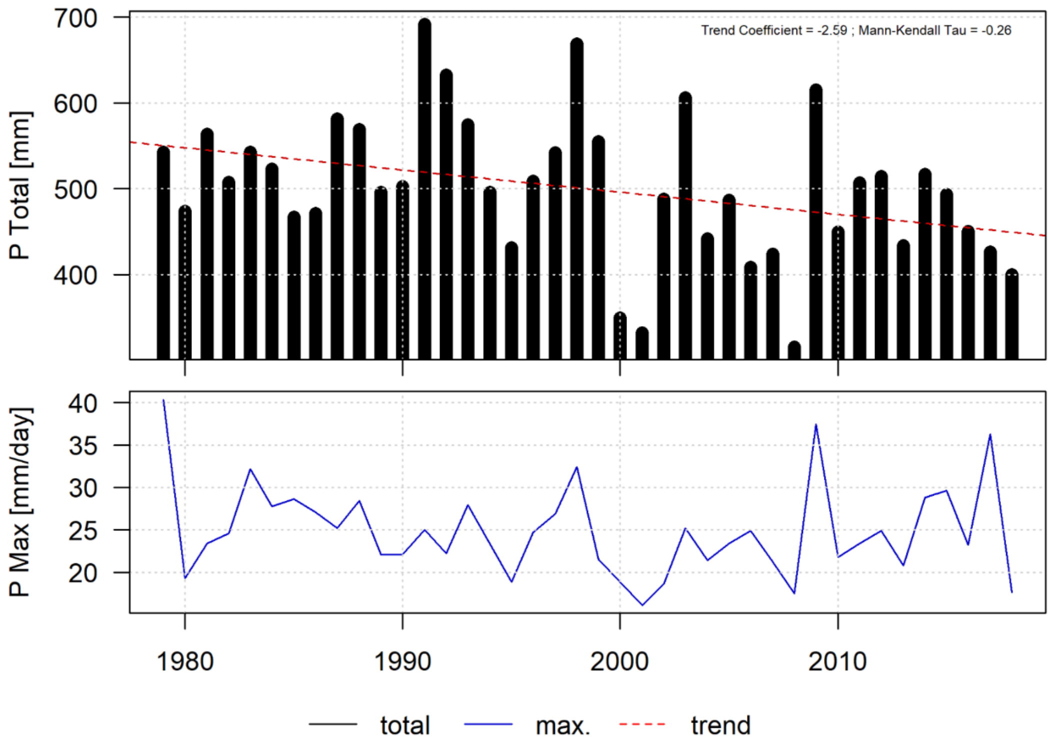
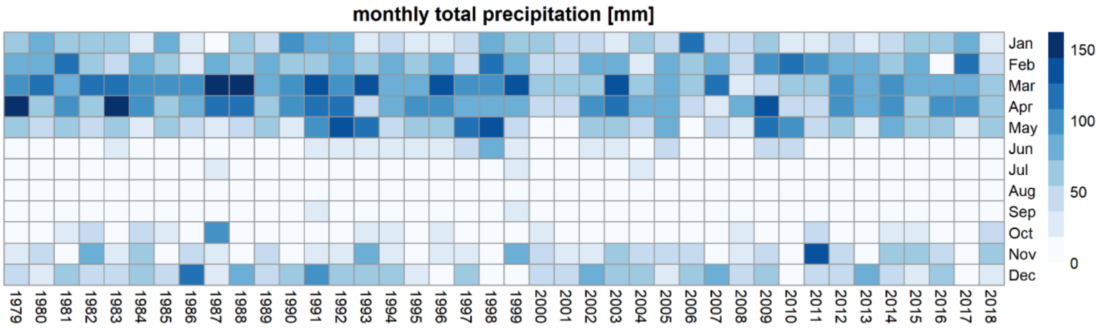


Figure II-11. Seasonality of precipitation from ERA-5 dataset for the project area.



III. FUTURE CLIMATE PROJECTIONS

A. Climate Models Analyses

1. Ensemble projections

For the purpose of this CRVA, NASA-NEX[1] data is used to analyse future climate trends. This dataset is used to provide analysis of trends in terms of temperature and precipitation. This product is used as it provides spatially gridded time series of temperature and precipitation derived from 21 General Circulation Models with global coverage (see TABLE III-1 for descriptions of models). Data is available at downscaled resolutions of ~25 km and daily timeseries, covering "historical" (1950 – 2005) and "future" (2005 – 2100) periods and varying emissions scenarios (RCP 4.5, 8.5).

From this dataset, spatially averaged time series of precipitation and temperature are extracted for the project area at daily, weekly and yearly timescales for the entire period that the dataset covers. This allows for the analysis of annual and seasonal trends in future climate.

TABLE III-1 CLIMATE MODELS INCLUDED IN NASA-NEX DATASET

Model	Research center	Country	Resolution (Original)		Resolution (NASA-NEX)	
			Lat (°)	Lon (°)	Lat (°)	Lon (°)
BCC-CSM1-1	GCESS	China	2.79	2.81	0.25	0.25
BNU-ESM	NSF-DOE-NCAR	China	2.79	2.81	0.25	0.25
CanESM2	LASG-CESS	Canada	2.79	2.81	0.25	0.25
CCSM4	NSF-DOE-NCAR	USA	0.94	1.25	0.25	0.25
CESM1-BGC	NSF-DOE-NCAR	USA	0.94	1.25	0.25	0.25
CNRM-CM5	CSIRO-QCCCE	France	1.40	1.41	0.25	0.25
CSIRO-MK3-6-0	CCCma	Australia	1.87	1.88	0.25	0.25
GFDL-CM3	NOAAGFDL	USA	2.00	2.50	0.25	0.25
GFDL-ESM2G	NOAAGFDL	USA	2.02	2.00	0.25	0.25
GFDL-ESM2M	NOAAGFDL	USA	2.02	2.50	0.25	0.25
INMCM4	IPSL	Russia	1.50	2.00	0.25	0.25
IPSL-CM5A-LR	IPSL	France	1.89	3.75	0.25	0.25
IPSL-CM5A-MR	MIROC	France	1.27	2.50	0.25	0.25
MIROC5	MPI-M	Japan	1.40	1.41	0.25	0.25
MIROC-ESM	MIROC	Japan	2.79	2.81	0.25	0.25
MIROC-ESM-CHEM	MIROC	Japan	2.79	2.81	0.25	0.25
MPI-ESM-LR	MPI-M	Germany	1.87	1.88	0.25	0.25
MPI-ESM-MR	MRI	Germany	1.87	1.88	0.25	0.25
MRI-CGCM3	NICAM	Japan	1.12	1.13	0.25	0.25
NorESM1-M	NorESM1-M	Norway	1.89	2.50	0.25	0.25

2. Scenarios and future horizons

Two RCP scenarios are analysed to give a range of future predictions to be considered in project design. RCP 4.5 represents a "stabilization scenario" in which greenhouse gas emissions peak around 2040 and are then reduced. RCP 8.5, in contrast, represents a worst-case scenario, in which emissions continue unabated throughout the century. These scenarios are selected as they

[1] https://www.nasa.gov/nex/data

represent a good envelope of likely changes in climate and hence cover a wide range of possible future changes in temperature and precipitation relating to project implementation.

Alongside the two RCP scenarios, projections are evaluated at the following time horizons:

- Reference period [1990]: 1976 – 2005
- Near future [2030]: 2016 – 2045
- Distant future [2060]: 2046 – 2075

These periods were selected as appropriate for the project as they are relevant to the project lifetime and therefore cover a realistic range of climate changes which are likely to effect project functioning. A 30-year window was selected as appropriate for deriving average climate changes, effectively considering interannual variations in temperature and precipitation.

TABLE III-2 SUMMARY OF RCP SCENARIOS AND FUTURE TIME HORIZONS USED IN THIS CRVA

RCP Scenarios	Time horizons	Model projections
Historical	1990 (1975-2005)	21
RCP45	2030 (2015-2045) 2060 (2045-2075)	21 21
RCP85	2030 (2015-2045) 2060 (2045-2075)	21 21

3. Climate Extremes Indices

To determine future trends in extreme climate events, CLIMDEX[1] variables are used. These represent a standardized, peer reviewed way of representing extremes in climate data and are widely used in climate analyses. These are produced through processing the NASA-NEX dataset with Climate Data Operator (CDO) software. This takes as input spatially gridded daily time series and returns yearly series of CLIMDEX indices. This process is useful as it effectively reduces the amount of data analysis needed whilst retaining the ability to represent extremes within data in a comparable way.

For the purposes of the proposed Project, the indices described in TABLE III-3 are considered most relevant out of the 27 available. Rx1day and SDII indices are considered appropriate as they are representative of future trends in extreme precipitation and therefore are likely to be a good measure of potential flooding impacts on project components. CDD is important as it provides a useful indication of trends in meteorological drought, which may impact crop production and water supply in irrigated areas. TXX and TNN variables are good predictors of extreme temperature, which may have negative effects on project components and irrigated crops through freezing and extreme heat events.

TABLE III-3 CLIMDEX PRECIPITATION INDICES USED IN THE PROJECT

Index name	Description	Unit
SDII	Simple precipitation intensity index; sum of precipitation in wet days during the year divided by the number of wet days in the year	mm
Rx1day	Annual maximum 1-day precipitation	mm
CDD	Annual maximum consecutive dry days; annual maximum length of dry spells, sequences of days where daily precipitation is less than 1mm per day.	days
TXx	Annual maximum of daily maximum temperature	Celsius
TNn	Annual minimum of daily minimum temperature	Celsius
ID0	Ice days: annual count when daily maximum <0ºC	days

[1] https://www.climdex.org/learn/

B. Climate Projections for the Project Area

1. Average trends in temperature and precipitation

In terms of average climate trends, it is clear that the climate model ensemble predicts an increase in mean temperature for the project area in the upcoming 60 years (FIGURE III-1). It is also clear that under the higher RCP scenario, a larger increase in temperature is expected. For the short-term horizon 2015-2045, changes in temperature in the range of around 1-3°C are predicted by the climate model ensemble, for the longer-term horizon 2045-2075, this increases to around 2-5°C, with a larger spread in model predictions (FIGURE III-3).

The picture in terms of precipitation, however, is much less clear. A large spread in model predictions is evident, with some models predicting future increases in precipitation and others decreases (FIGURE III-2). There is also little to differentiate the two RCP scenarios, with neither indicating any clear trend for the time period considered.

FIGURE III-1 TIME SERIES OF MEAN YEARLY TEMPERATURE CONSTRUCTED USING ERA5 DATASET FOR THE HISTORICAL PERIOD (1979-2019), AND NASA NEX (PER MODEL BIAS CORRECTED) FOR THE FUTURE PERIOD

SHADED AREAS SHOW THE 10TH AND 90TH PERCENTILES IN THE SPREAD OF MODEL PREDICTIONS.

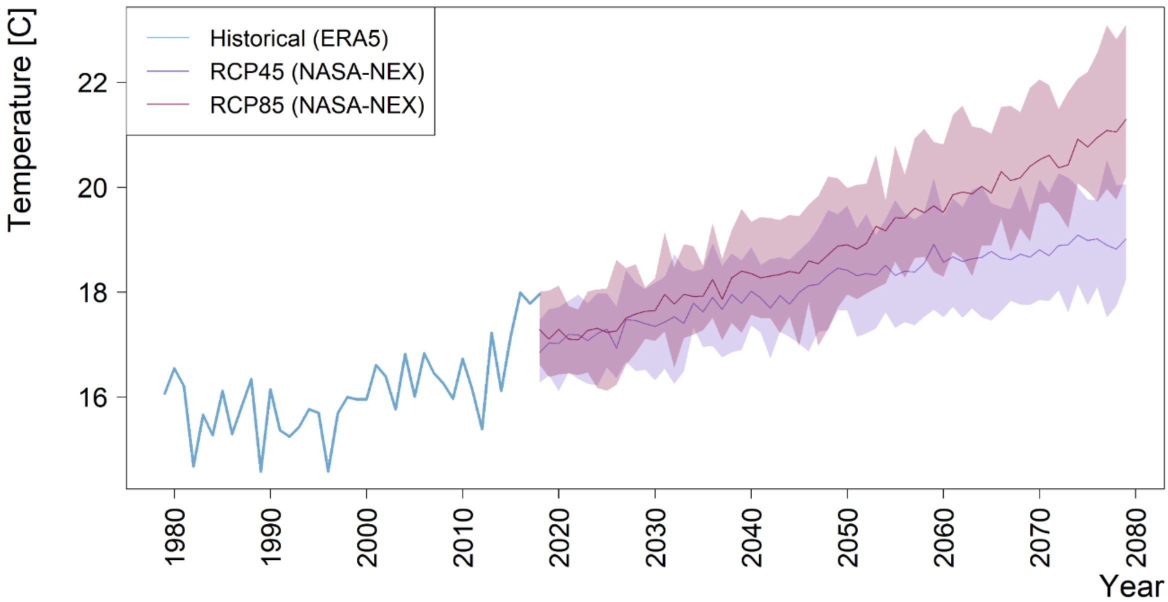


FIGURE III-2 TIME SERIES OF TOTAL YEARLY PRECIPITATION CONSTRUCTED USING ERA5 DATASET FOR THE HISTORICAL PERIOD (1979-2019), AND NASA NEX (PER MODEL BIAS CORRECTED) FOR THE FUTURE PERIOD

SHADED AREAS SHOW THE 10TH AND 90TH PERCENTILES IN THE SPREAD OF MODEL PREDICTIONS.

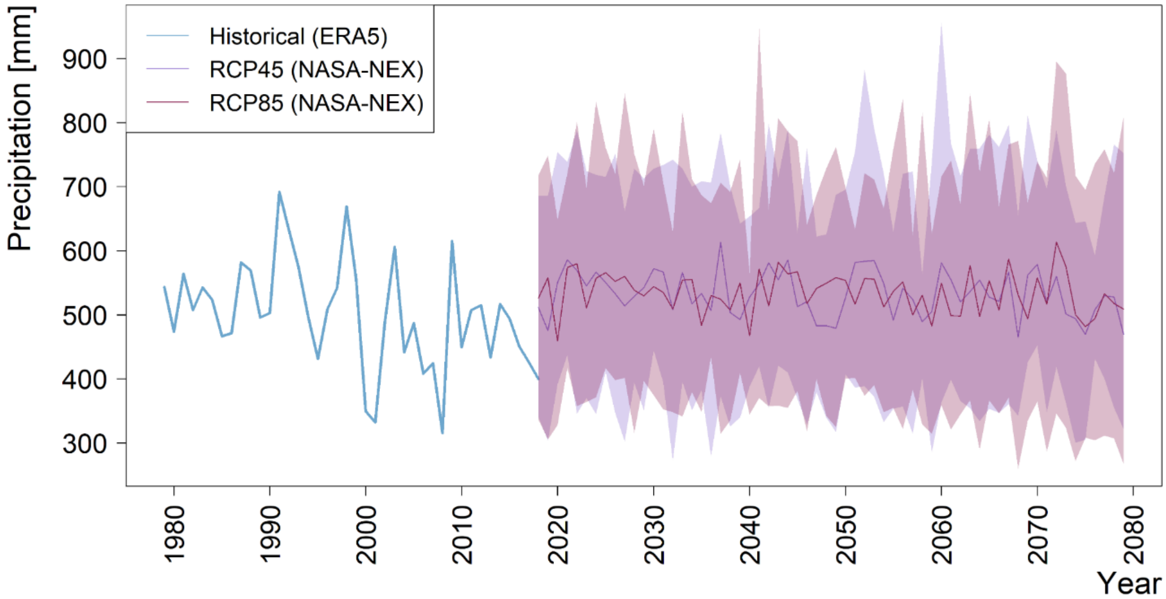
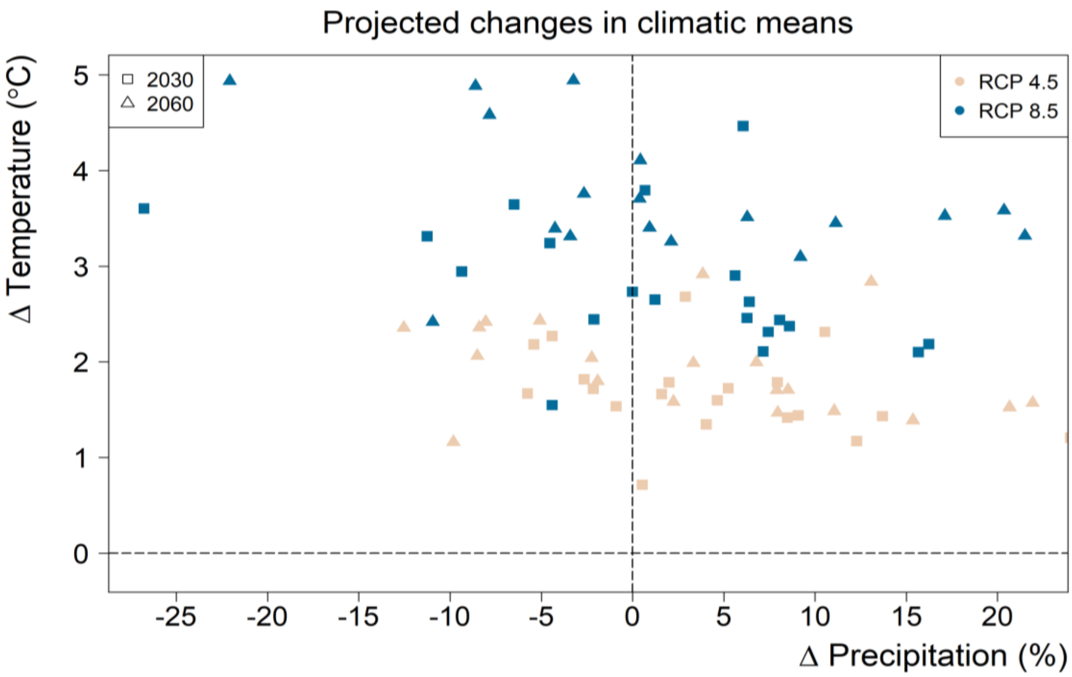


FIGURE III-3 AVERAGE TEMPERATURE AND PRECIPITATION CHANGES IN THE VAKHSH BASIN PROJECT AREA. THESE INDICATE THE DIFFERENCE (Δ) BETWEEN HISTORICAL (1976-2005) AND FUTURE (2015-2045; 2045:2075) TIME HORIZONS FOR THE TWO RCP SCENARIOS



2. Seasonality

In terms of seasonality, climate model ensembles predict a general increase in both minimum and maximum temperatures for all months (FIGURE III-4,5). A greater increase in temperatures is predicted in the longer term (2045-2075) timescale and under the higher RCP 8.5 scenario. Models also suggest that the greatest increases in temperature will occur in the warmer months (May-

September), suggesting a change toward a more extreme seasonality in terms of temperature. Trends are again unclear in the seasonality of precipitation but suggest that in the future climate change may lead to more rain in the wet months of the year (February – May).

Figure III-4 Average maximum daily temperature per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios

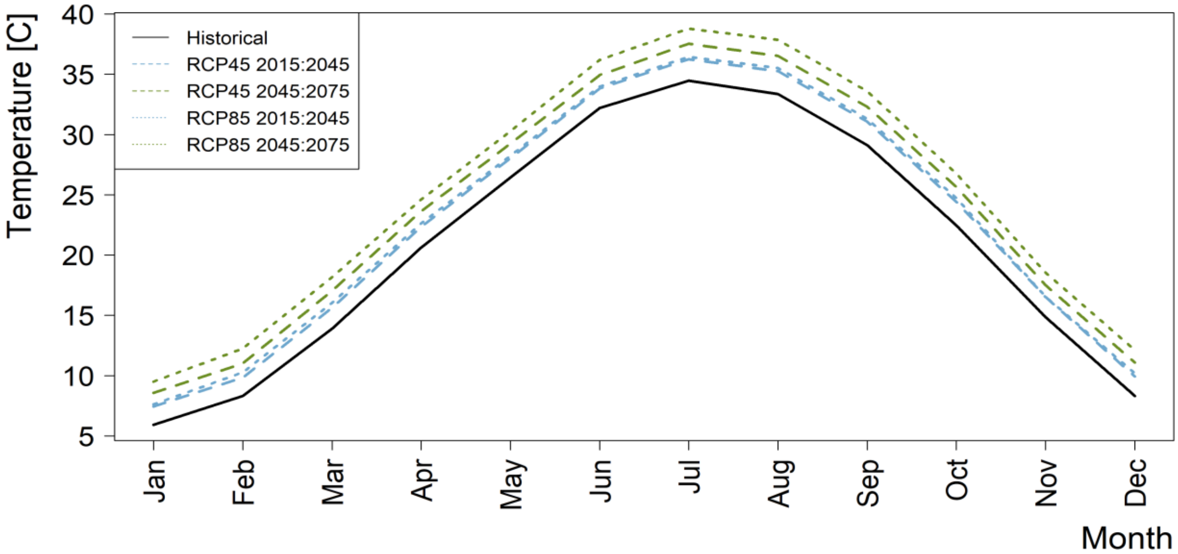


Figure III-5 Average minimum daily temperature per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios.

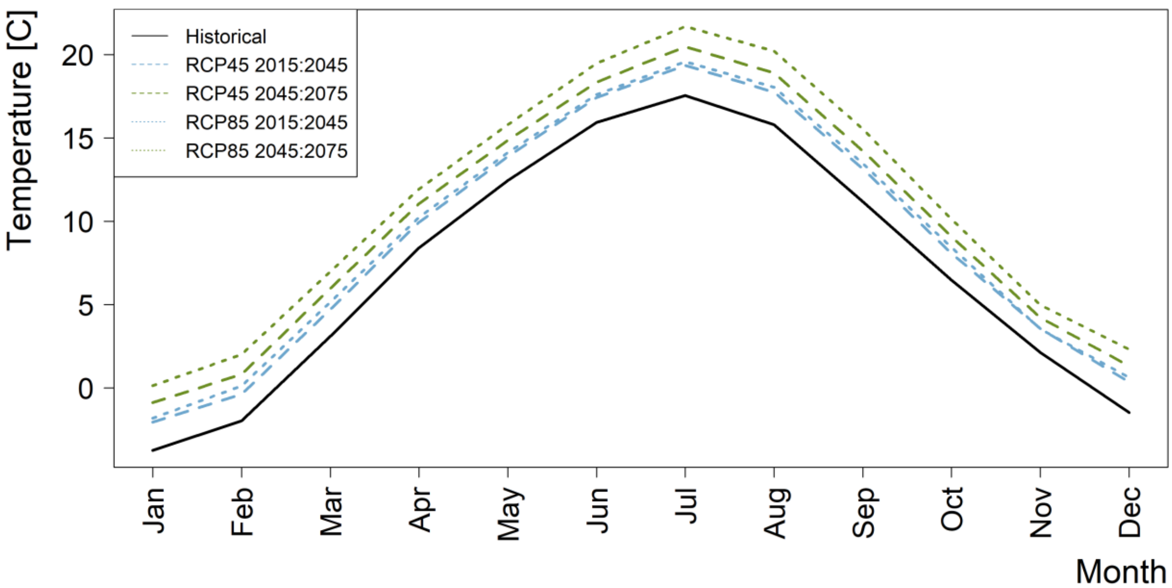
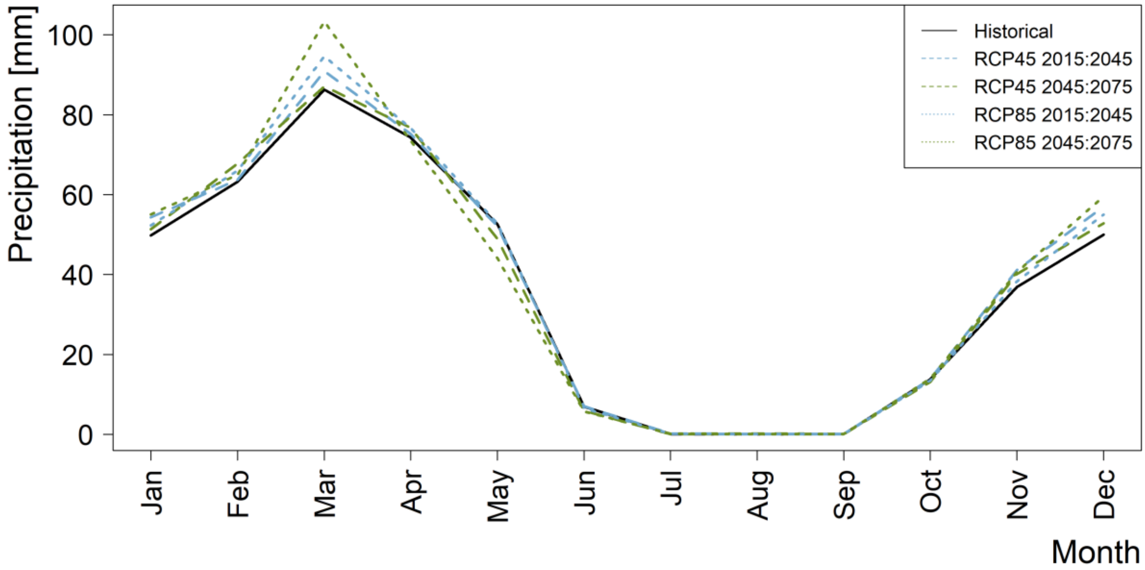


FIGURE III-6 AVERAGE TOTAL MONTHLY PRECIPITATION PER MONTH FOR HISTORICAL (1976-2005) AND FUTURE (2015-2045; 2045:2075) TIME HORIZONS UNDER THE TWO RCP SCENARIOS

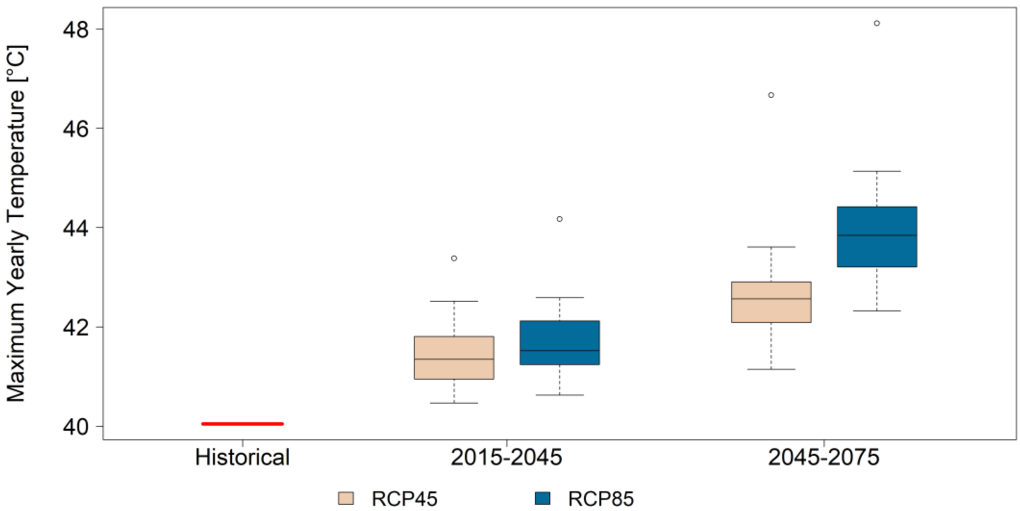


3. Extreme Climate Trends

When extreme trends are considered, a large level of variation is evident in climate model predictions. This is perhaps expected as climate models are inherently limited in terms of predicting trends in extremes due to the stochastic nature of these events. The climate model ensemble does, however, show a clear trend of increasing extreme temperatures under both RCP scenarios and time horizons, suggesting an increase in the severity of heatwaves in the area (

FIGURE III-7).

FIGURE III-7. BOXPLOTS INDICATING THE SPREAD IN CLIMATE MODEL PREDICTIONS OF MAXIMUM DAILY TEMPERATURE PER YEAR (TXX) FOR THE HISTORICAL (1976-2005) AND FUTURE TIME PERIODS UNDER TWO RCP SCENARIOS.



A simplified return period analysis for extreme precipitation events was conducted. For this the third quartile (75th percentile) of climate model ensemble predictions of yearly maximum 1-day precipitation events (Rx1day) were taken. Then the extreme distribution Gumble is fitted assess the design precipitation events at different return periods for each time horizon and RCP scenario. The relative changes (delta values) are then imposed on historical reanalysis (ERA-5) data to allow for the prediction of absolute values for 1-day precipitation events.

This process shows that under climate change, the intensity of the most severe precipitation events predicted by the climate model ensemble will increase, with the largest increases occurring at the more distant time horizon (2050). This likely signifies an increase in intense precipitation associated risks (flooding, landslides) in the future for the project area. These numbers may therefore be useful in designing project components to be resilient to the most severe storms predicted by climate models for the area.

TABLE III-4 THE INTENSITY OF PRECIPITATION EVENTS AT DIFFERENT RETURN PERIODS UNDER A VARIETY OF EMISSIONS SCENARIOS AND TIME HORIZONS

	Return Period [years]					
	2	**5**	**10**	**25**	**50**	**100**
Historical daily maximum precipitation [mm]						
ERA5	30	52	66	84	98	112
Future (90th percentile of GCM distribution) [mm]						
RCP45 2030	34	59	76	97	112	128
RCP45 2050	34	60	78	100	116	132
RCP85 2030	33	57	73	93	108	123
RCP85 2050	37	64	82	105	122	139

4. Summary Tables

The combination of 21 GCMs, two RCPs and two time horizons leads to a total of 84 (21 * 2 * 2) projections for the future. TABLE III-5 shows detailed results for all 84 projections of changes in mean annual temperature and total annual precipitation. This again shows consistency between GCMs in terms of predicting a warmer future climate in the project area (especially for the longer-term horizon) but producing inconsistent predictions in terms of precipitation.

TABLE III-6 and TABLE III-7 show the main statistics (median, 10th percentile and 90th percentile) of the changes in precipitation and temperature, respectively. It also includes the number of GCMs that are showing a positive versus negative change for precipitation, and number of GCMs that are predicting a change above 2ºC and 4ºC. In summary, all GCMs predict a hotter future, with most predictions lying between 2 and 4ºC. There is no clear consensus in precipitation predictions, but a slight majority of GCMs predict a wetter future.

TABLE III-5 AVERAGE CLIMATE CHANGE (DELTA VALUES) IN TOTAL ANNUAL PRECIPITATION AND MEAN ANNUAL TEMPERATURE PREDICTED BY THE FULL CLIMATE MODEL (GCM) ENSEMBLE

This indicates the difference between historical (1976-2005) and future (2015-2045; 2045:2075) time horizons for the two RCP scenarios.

		bcc-csm1-1	BNU-ESM	CanESM2	CCSM4	CESM1-BGC	CNRM-CM5	CSIRO-Mk3-6-0	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	MIROC-ESM-CHEM	MIROC-ESM	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MRI-CGCM3	NorESM1-M
Precip (%)	2030_RCP45	5%	9%	12%	-2%	6%	9%	-3%	2%	6%	13%	-1%	-5%	-4%	5%	2%	11%	-2%	3%	25%	-3%
	2060_RCP45	3%	-1%	3%	7%	8%	17%	6%	6%	8%	10%	-4%	-6%	-26%	-4%	-11%	7%	-2%	11%	13%	-9%
	2030_RCP85	7%	-7%	12%	3%	7%	8%	-2%	4%	0%	-2%	-11%	-7%	-12%	-4%	7%	24%	14%	21%	16%	-9%
	2060_RCP85	-3%	2%	20%	6%	-5%	9%	17%	5%	2%	-4%	-12%	-8%	-22%	-3%	-6%	21%	6%	9%	21%	1%
Tavg (oC)	2030_RCP45	1.58	1.76	2.34	1.71	1.46	1.44	1.65	2.72	1.33	1.14	0.72	2.14	2.24	1.69	1.70	1.43	1.54	1.80	1.20	1.84
	2060_RCP45	2.64	2.71	3.82	2.45	2.32	2.20	2.89	4.51	2.14	2.35	1.54	3.70	3.61	3.22	3.35	2.62	2.43	2.40	2.16	2.94
	2030_RCP85	1.75	2.36	2.87	1.95	1.72	1.42	1.78	2.95	1.61	2.03	1.16	2.40	2.35	2.40	1.98	1.59	1.42	1.56	1.40	2.05
	2060_RCP85	3.83	4.09	5.06	3.47	3.39	3.07	3.53	5.61	3.26	3.29	2.41	4.89	4.96	5.00	4.58	3.59	3.36	3.50	3.33	3.71

TABLE III-6 SUMMARY TABLE SHOWING STATISTICS REGARDING SPREAD IN CLIMATE MODEL (GCM) ENSEMBLE PREDICTIONS FOR FUTURE CHANGES IN TOTAL ANNUAL PRECIPITATION IN THE PROJECT AREA.

	Median (%)	25th Perc. (%)	75th Perc. (%)	GCMs Dryer	GCMs Wetter
2030_RCP45	4%	-2%	9%	7	13
2060_RCP45	2%	-4%	8%	8	12
2030_RCP85	3%	-6%	11%	9	11
2060_RCP85	3%	-5%	9%	8	12

TABLE III-7 SUMMARY TABLE SHOWING STATISTICS REGARDING SPREAD IN CLIMATE MODEL (GCM) ENSEMBLE PREDICTIONS FOR FUTURE CHANGES IN MEAN ANNUAL TEMPERATURE IN THE PROJECT AREA.

	Median (ºC)	25th Perc. (ºC)	75th Perc. (ºC)	GCMs >2ºC	GCMs >4ºC
2030_RCP45	+1.7	+1.4	+1.8	4	0
2060_RCP45	+2.8	+2.3	+3.3	19	1
2030_RCP85	+1.9	+1.6	+2.4	8	0
2060_RCP85	+3.9	+3.3	+4.8	20	7

C. Climate Change and the Vakhsh Upstream Basin

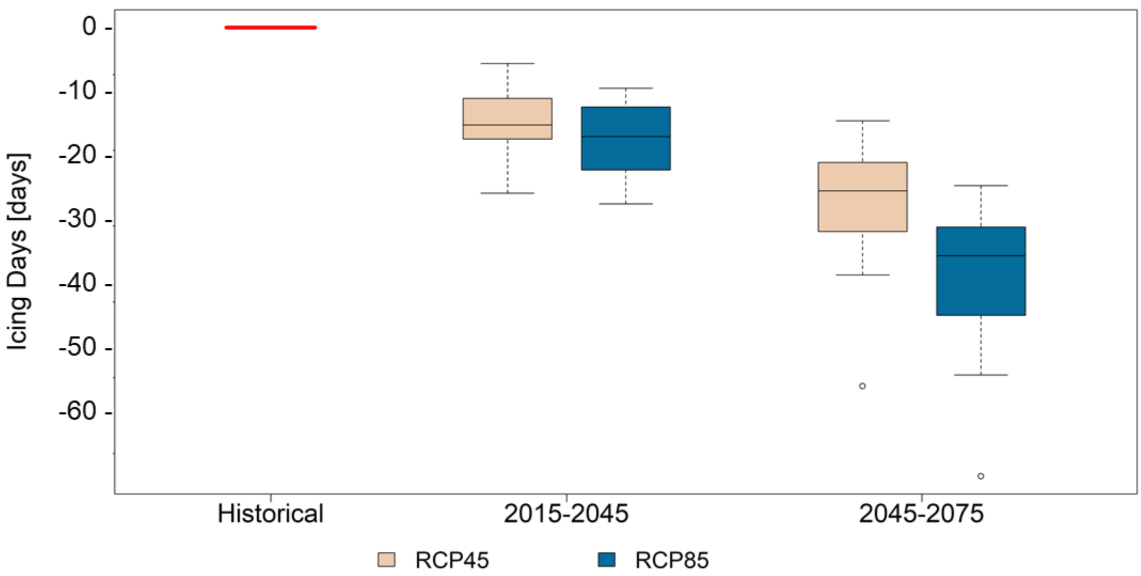
1. Temperature and precipitation changes

To further characterize how future climate change in the region may affect the project, a quick analysis of climate change trends was performed for the part of the Vakhsh basin upstream of the project location. This upstream area was delineated as in a previous FutureWater report (Lutz et al., 2012) which completed a large scale hydrological modelling study of the upstream areas of the Amu Darya basin (see area shown on FIGURE I-1).

Future climate changes in the upstream area were analysed again using the NASA-NEX dataset described in Section III.A. Only the key results are described here and were used to back up the risk assessment afterwards. The analysis shows changes in annual mean temperatures in the range of around 1.5-2.5°C predicted by the climate model ensemble for the short-term horizon 2015-2045, increasing to 2.5-5°C for the longer-term horizon 2045-2075. In terms of precipitation, model predictions are more uncertain, but do show a clear trend of increasing total annual precipitation in the range of 5-30%.

From this analysis, a relevant climate extreme indicator that was extracted from the climate model projections is called Ice Days: the number of days in which maximum daily temperature does not exceed 0ºC. For the upstream Vaksh basin, there is a clear downward trend for this indicator. FIGURE III-8 shows the relative change in number of days compared to the reference period (1990), for the two periods of analysis (2030 and 2060) and two RCPs. As can be seen, over the next decades, the number annual days below zero will go down progressively to up to around 40 days. This will mean considerably less snow cover, and less precipitation falling in the form of snow. It will also reduce glacier extent and permafrost. Overall, this will lead a reduction in storage capacity of the high mountain system, and thus its capacity to store precipitation that falls in winter to release it in spring or summer.

FIGURE III-8. TRENDS IN ICE DAYS PER YEAR FROM CLIMATE MODEL OUTPUTS COMPARED TO HISTORICAL (ERA5) MEAN FOR UPSTREAM NUREK BASIN.

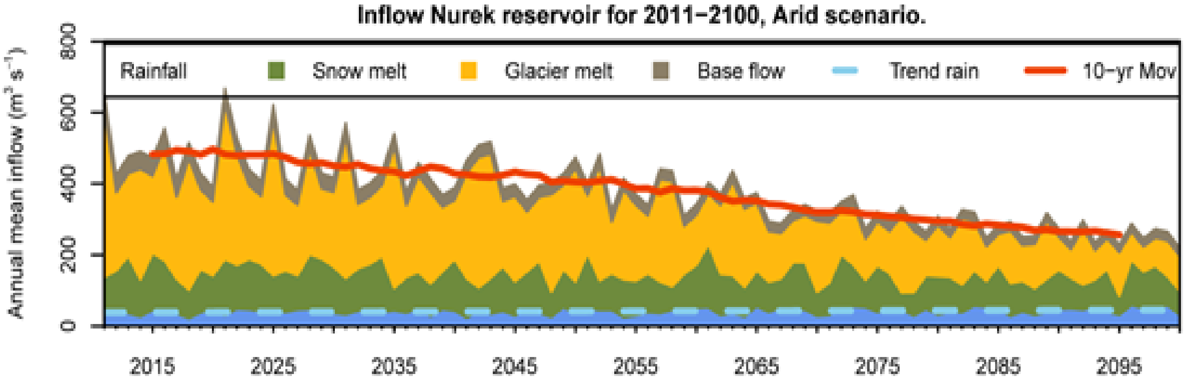


2. Response on river flows in the Vakhsh river

The dynamics of each of the sub-basins of the Pamir mountain range are different and depend on the relative contributions of the different flow types (baseflow, direct runoff, snow and glacier-originated flow). The number of flow components makes predicting total changes in discharge very dependent and uncertain. Kure et al. (2013a, 2013b) analysed climate impacts and hydrologic response, finding an increase in flows for some tributaries and for the near horizon (next few decades) but for others a decrease, depending on the climate scenario. For the far horizon (end-of-century) there is consistent decrease predicted among the scenarios that were analysed.

FIGURE III-9 shows projections for the origin of flows entering the Nurek reservoir: flow originating from direct rainfall, flow from snowmelt, from glacier melt, and base flow. This analysis suggests that in the Vakhsh basin, flows will experience a slight decrease over the first half of the 21st century, followed by a more rapid decrease in the second half. This study also predicts that the majority of decrease in flow will be due to a decrease in the glacier melt component of flow.

FIGURE III-9 SOURCES (RAINFALL, SNOW, GLACIER AND BASEFLOW) OF THE RIVER FLOW ENTERING THE NUREK RESERVOIR, FOR ONE CLIMATE SCENARIO, SHOWING THE INFLUENCE OF REDUCED GLACIER-FLOW



Source: from data in FutureWater report Lutz et al., 2012.

TABLE III-8 summarizes scientific literature on hydrological response to climate change projections in the Amu Darya basin, in terms of relative changes. The table indicates how many studies fall into three categories (slight increase, slight decrease, and moderate to severe decrease).

TABLE III-8 CHANGE IN AMU DARYA FLOWS PREDICTED BY SEVERAL STUDIES

Change	Number of studies	References
Next 30 years (< 2050)		
Slight increase up to +10%	2	(World Bank, 2015) (Kayumov and Novikov, 2014)
Slight decrease up to -10%	2	(Kure et al., 2013a, 2013b) (Taryannikova, 2016)
Decrease between -10% to -40%	3	(Aus der Beek et al., 2011) (Immerzeel et al., 2012; Lutz et al., 2012) (Mannig et al., 2018)
Second half of century (> 2050)		
Slight increase up to +10%	0	
Slight decrease up to -10%	2	(World Bank, 2015) (Kayumov and Novikov, 2014)
Decrease between -10% to -40%	5	(Aus der Beek et al., 2011); (Kure et al., 2013a, 2013b); (White et al., 2014); (Taryannikova, 2016); (Mannig et al., 2018)

As can be seen from TABLE III-8, for the next 30 years, scientific literature shows no consensus on hydrologic response to climate change in the Amu Darya river basin. For the next half of the century, most studies agree that there will be a moderate to severe decrease in flow volumes.

All studies generally agree that there will be a shift in the peak water flow towards earlier in the season, as the buffering effect of snow and glaciers will become less dominant. Even in scenarios that predict an increase in flows, a shift in the peak is predicted (as is already seen in historic data as shown in the analysis done with data of Nurek reservoir inflow, see above). Thus, typically decreases in flows are expected for the second half of the year, especially the summer months (August, September, October), and increases in the first half of the year.

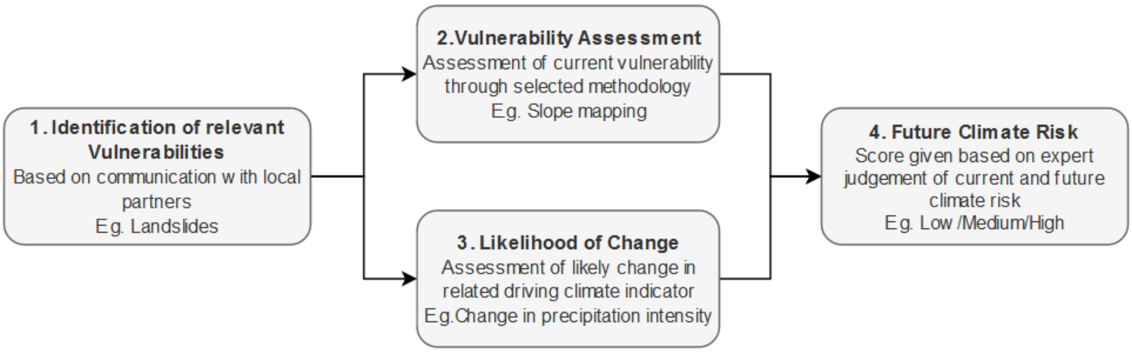
How this seasonal shift propagates to the intake location of the project depends mainly on reservoir operations (for power and irrigation) of the Nurek reservoir, and possibly also from the upstream planned Rogun dam. Besides changes in volumes and changes in the seasonal regime, also interannual variability may increase due to climate change, as the over-year buffering effect of glaciers will diminish. More discussion on this is presented in the the next chapter (

IV. CLIMATE RISK ASSESSMENT

A. Approach

This chapter assesses the climate vulnerabilities for the two irrigation systems. The project has a focus on farmers´ livelihoods and agricultural productivity; as such, this vulnerability analysis attempts to link the climate indicators with potential yield and income loss of farmers. The analysis combines the vulnerabilities with the likelihood of change of a driving climate variable. This results in a score for climate risk, summarized in the last section of this chapter. In summary, the analysis assesses, through a combination of field and stakeholder information, quantitative analysis, and expert judgement, the extent to which the key climate risks pose a threat in these scheme areas, and which are most important to be addressed through climate adaptation activities. FIGURE IV-1 shows the approach in a simplified schematic. Vulnerability in this context refers to the extent to which the irrigation system, including its socio-economic dimension – i.e. farmers´ livelihood, is unable to cope with hazardous climatic events and trends.

FIGURE IV-1. CLIMATE RISK ASSESSMENT METHODOLOGY USED IN THIS REPORT.



To identify the relevant vulnerabilities, information gathered during the preparation of the project from the local partners, field visits and available documentation and data on the area was used. From this process, the following key potential climate change impacts were identified:

- **Erosion** of catchment and command areas, including gullying and mudslides
- **Drainage issues,** leading to water table rise, waterlogging, increased salinity and pluvial flooding
- Increased **drought risk** due to increased crop water requirements and more variable weather patterns
- Water shortage due to **changes in water availability** incurred by changing glacier and snowfall, including possible **shifts in seasonality**
- Temperature-related **crop stress**
- **Fluvial flooding**

Each of these potential climate change impacts will be analysed in the following sections.

B. Increased erosion of catchment and command areas

Stakeholders have indicated and field visits have confirmed that erosion of soils is an important issue for the irrigation schemes and surrounding catchment areas. Erosion affects directly the **productivity of the land and farmer´s livelihoods**, by

- the **loss of the fertile top-layer** of the soil which reduces yields directly, or increases the need for fertilizers
- **loss of arable land** in case of gullying

Spatial estimates of erosion indicators were extracted using GIS which confirm the field observations, as shown hereafter. The driving climate variables for erosion: extreme rainfall, and lower snowfall fraction, were analysed and enable to assess the risk level.

Soils in this area comprise of highly erodible loess soils. From field observations it is evident that erosion occurs especially in the steeply **sloping catchment areas** due to overgrazing and lack of vegetative cover (see for example FIGURE IV-2), as well as in the command area, due to heavy rainfall. This has resulted in extensive gully formation. In the **command area**, erosion also results from: (i) poor irrigation practices such as in-appropriate furrow sizes, lengths, non-uniform and over steep slopes and flows, and (ii) failure and/ or design deficiencies of infrastructure.

FIGURE IV-2. CATTLE AND HORSES WATERING FROM THE RIGHT BRANCH CANAL, YOVON

Erosion is particularly acute in exactly the areas that are developed for irrigation on the more steeply sloping areas. This has led in several locations to clear evidence of impacts on infrastructure and the reliant farmers. Examples of infrastructure failure and/ or design deficiencies leading to erosion and/ or gullying include:

- Erosion of downslope irrigation, cross drainage and escape/ spillage channels. In FIGURE IV-3 it can be seen that insufficient protection of an escape or spill channel has led to the formation of a large gully in Yovon.
- Failure of the buried pipe distribution system, as well as absence of any measures at the end of the irrigation pipelines to safely discharge surplus flow down into the (incised) riverbed, see FIGURE IV-3 for pipeline #15, Chorghul WUA, Yovon
- Inadequate measures to safely discharge water from the sub-surface and surface drainage system into the rivers or their tributaries

FIGURE IV-3. TOP: GULLY FORMATION DUE TO FAILURE/ABSENCE OF PROTECTION FOR AN ESCAPE (SPILL) CHANNEL FROM THE LEFT BRANCH CANAL, YOVON STUDY SCHEME. BOTTOM: DRAINAGE SPILLWAY AT TAIL OF PIPELINE IN CHORGHUL WUA, YOVON.

To obtain an estimate of the spatial differences in erosion sensitivity within the command area and the surrounding catchment area (buffer area), two maps are presented here that were calculated based on a digital elevation model (source: SRTM, 30 meter resolution). The first set of maps (FIGURE IV-4, FIGURE IV-5) show the slopes, categorized in different classes.

FIGURE IV-4. SLOPE IN THE VICINITY OF YOVON COMMAND ZONE AND BUFFER AREA

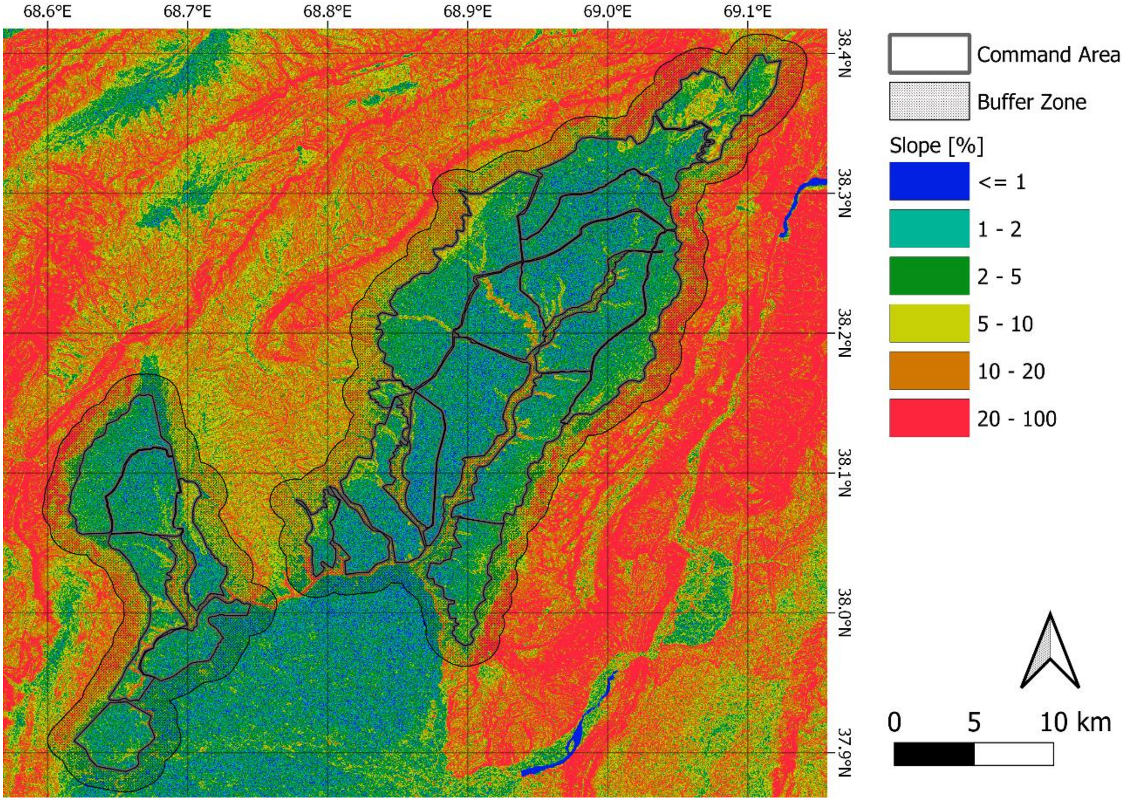


FIGURE IV-5. SLOPE IN THE VICINITY OF THE QUMSANGIR COMMAND AREA AND BUFFER ZONE

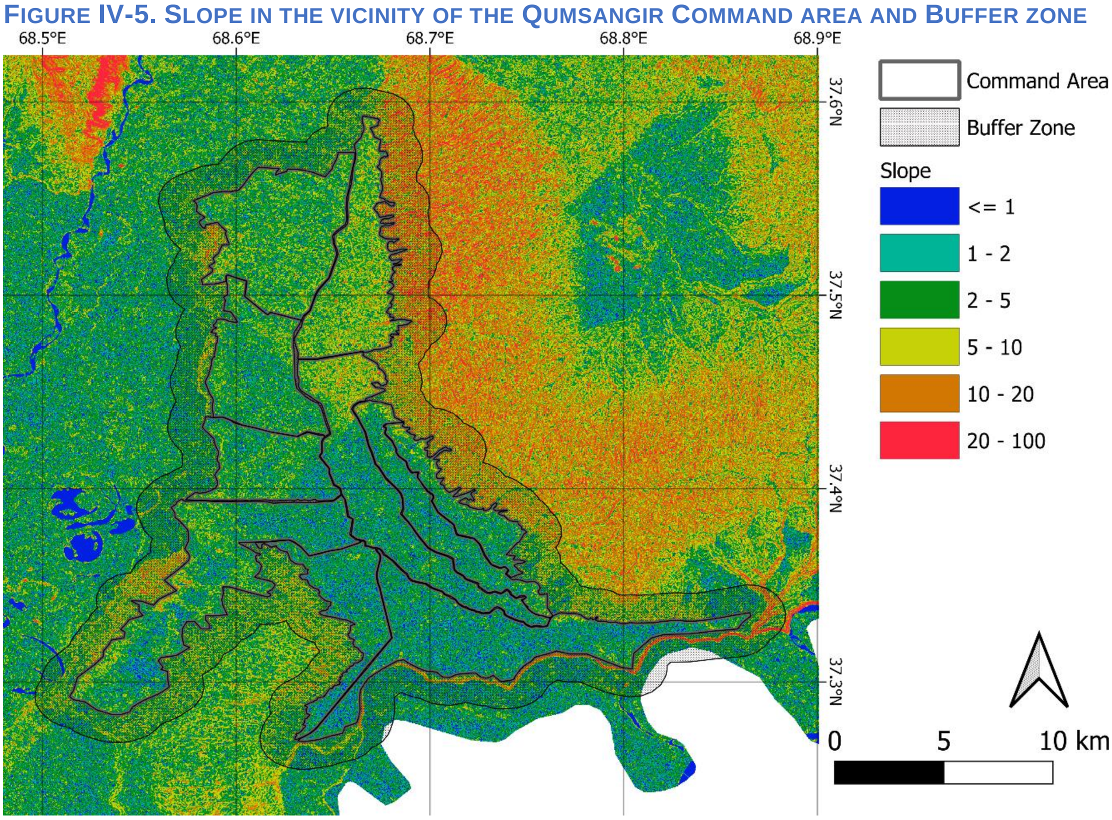
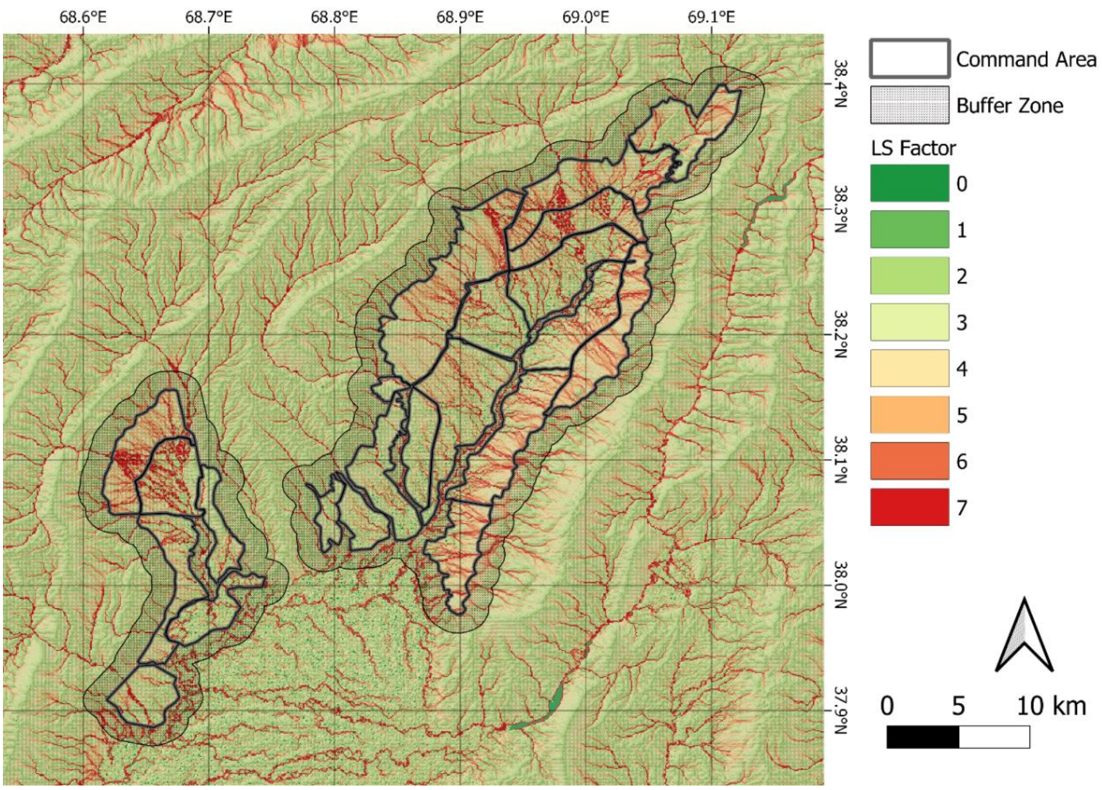


TABLE IV-1. PERCENTAGE OF EACH COMMAND ZONE AND BUFFER AREA MADE UP BY EACH SLOPE CATEGORY.

Slope [%]	Area Yovon [ha]		Area Qumsangir [ha]	
	Command area	Buffer area	Command area	Buffer area
0 – 1	8206	1701	3164	1544
1 – 2	15826	2976	6329	3345
2 – 5	27549	9355	15821	10291
5 – 10	5861	11056	5696	6432
10 – 20	1758	12331	633	3345
20+	0	5103	0	515

The second set of maps (FIGURE IV-6, FIGURE IV-7) show the LS Factor of the Universal Soil Loss Equation (USLE), based on the Digital Elevation Model (DEM). The LS factor is a function of slope and slope length. Soil loss is a function of hillslope length and hillslope gradient. In GIS the combination of both can be calculated using flow accumulation and specific catchment area (SCA) derivation[1]. Low values (<1) indicate low erosion susceptibility, while higher values (>3) indicate high susceptibility. The map can be used to identify hotspots and areas to intervene but should obviously be contrasted with field work.

FIGURE IV-6. LS FACTORS IN THE VICINITY OF THE JOVON COMMAND AREA AND BUFFER ZONE.



[1] Desmet & Govers (1996): A GIS Procedure for Automatically Calculating the USLE LS Factor on Topographically Complex Landscape Units. Journal of Soil and Water Conservation, 51(5):427.433

FIGURE IV-7. LS FACTORS IN THE VICINITY OF THE QUMSANGIR COMMAND AREA AND BUFFER ZONE.

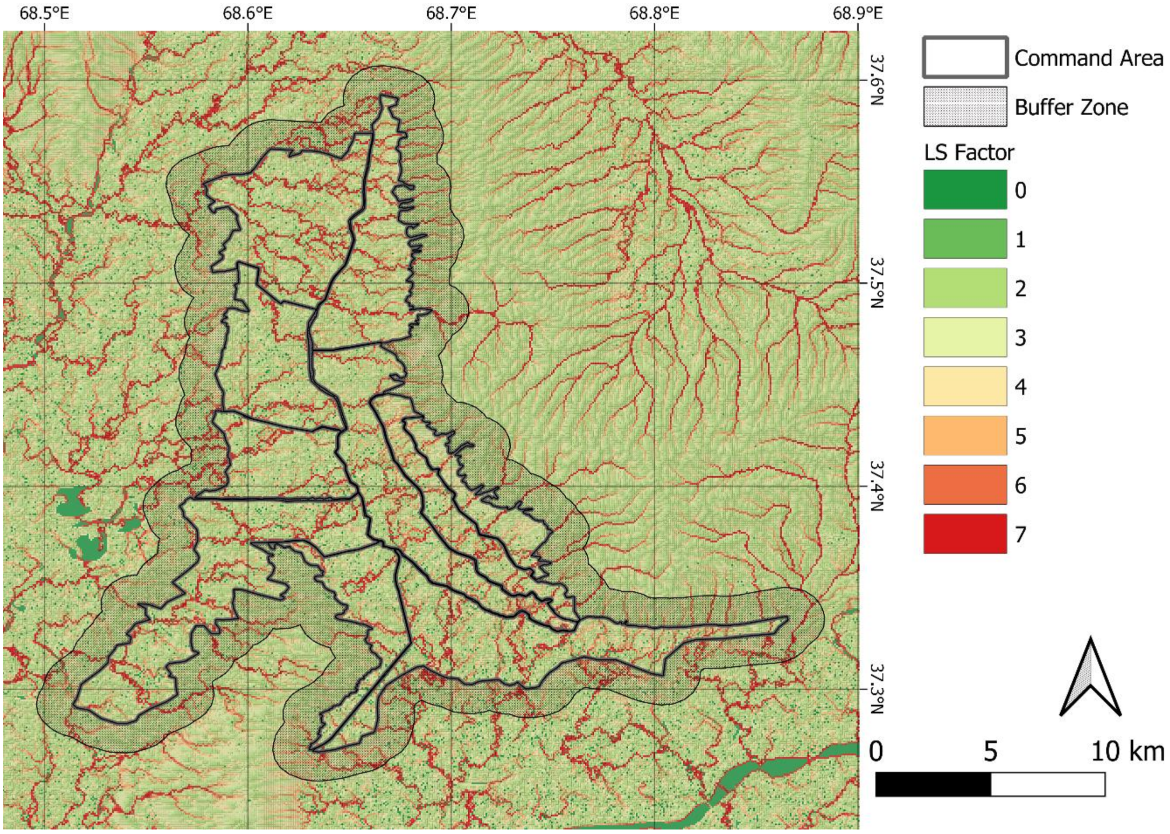


TABLE IV-2. PERCENTAGE OF EACH COMMAND ZONE AND BUFFER AREA MADE UP BY EACH LS FACTOR CATEGORY.

LS Factor	Area Yovon [ha]		Area Qumsangir [ha]	
	Command area	Buffer area	Command area	Buffer area
0 – 2	586	425	949	257
2 – 4	32238	31466	23099	20068
4 – 6	18170	5953	4114	3087
6 – 8	5275	2551	1899	1286
8 +	2345	2126	1582	772

In this area, two climate variables dominantly influence erosion, which are: (i) intense rainfall and (ii) snowfall fraction. Intense rainfall causes soil to be entrained in fast runoff flowing down the slope: the more frequent and intense, the more soil loss and erosion. Snowfall fraction (i.e. the part of precipitation that falls as snow compared to rainfall) is also an important factor for this area. If precipitation falls as snow, erosion is limited or even non-existing even in areas that non-vegetated, poorly vegetated or steep sloping areas. While when precipitation falls as rainfall, these erosion-sensitive areas become prone to erosion. Thus, less snowfall (and less snow cover and less days below zero) increases erosion rates. Also, consequences on permafrost may be an issue in some areas, as has been highlighted for Tajikistan but this requires more study (Kayumov and Novikov, 2014).

Climate model projections (see chapter III) predict an increase in the intensity of rainfall into the future, with increases predicted in the wetter parts of the year. The ensemble predicts that the intensity of extreme precipitation events could increase by as much as 20mm/day for a 1 in 100 year precipitation event (see TABLE III-4). Furthermore, although differing on specific amounts, all models predict an increase in the intensity of precipitation under both climate change scenarios and time horizons.

The second climate variable that drives erosion rates in the region is snowfall and snow cover. Climate model projections analysed for this assessment show that the number of so-called Ice Days (days in which maximum daily temperature does not exceed zero degrees Celsius) will go down considerably in the future (see FIGURE III-8). There is a clear negative trend in this indicator for all climate models in the model ensemble.

Overall, given the scarce vegetation cover in some catchment areas, the erodible soil-type (loess), the steep slopes, as well as the very likely changes in climate variables driving erosion (increased rainfall extremes and reduced snowfall), it is concluded that the risk for **increased erosion** of soils due to climate change is **high**.

C. Increased drainage issues

Some areas in Yovon and Qumsangir are already affected heavily by the negative impacts of poor drainage (salinity, high water tables, waterlogging, local flooding), leading to yield loss or even crop failure. To assess how this risk could increase in the future, GIS analysis was performed.

For drainage, slope and soil hydraulic properties are the most important factors. The global HiHydroSoil dataset was used to assess the soil percolation potential (hydraulic conductivity) in the area. For both schemes, the average hydraulic conductivity (mm/day) is shown in TABLE IV-3. The values correspond to soils that typically drain moderately well. Indeed, soils in the Yovon and Qumsangir command area comprise wind-blown, pale yellow/ light brown loess, with a small proportion of clay and mostly comprising silts and fine sands. They are homogeneous, friable, highly permeable and deep.

TABLE IV-3. HYDRAULIC CONDUCTIVITY (MM/DAY) FROM HIHYDROSOIL DATABASE FOR THE TWO COMMAND AREAS.

Area	Layer	Mean	Min	Max
Yovon	Topsoil	51	28	87
	Subsoil	18	10	30
Qumsangir	Topsoil	60	41	136
	Subsoil	22	14	51

Even if soil hydraulic properties of the soil are not of concern for drainage, land slope in combination with extreme weather, non-optimal irrigation practices and poor infrastructure can lead to drainage issues. FIGURE IV-4 and FIGURE IV-5 show that the Yovon command area is quite steeply sloping on either side, up to about 3.2%, but there are also flatter areas. The morphology of the terrain (changing from steep slopes to flat areas in the valley bottom) can cause locally high water tables in the flatter areas. The Qumsangir command area is largely flat, with very limited slope (0.1% to 0.8%).

For Yovon, prior to scheme development in 1960s, the water table was more than 20 m below ground level, and groundwater was saline. With irrigation, the water table rose quickly, at 0.5-3.0 m/year, with groundwater flow towards the valley bottoms. Seasonally, the water table rises and falls due to seasonal (summer) deep percolation losses. Percolation and effective drainage are needed to ensure that the upper (2 m) soil horizons are free from salinity.

Climate ensemble predictions are fairly uncertain as to whether total yearly precipitation will increase or decrease, with a slight majority of models predicting an increase. However, the ensemble does predict an increase in the intensity of precipitation, with broad consensus. This therefore suggests that it is likely that climate change will increase the risks associated with poor drainage into the future.

Overall, it is concluded that there is a high risk that due to climate change, drainage issues (waterlogging, salinity and local flooding) will further increase in the flatter parts of the Yovon scheme and the Qumsangir schem, where properly functional drainage infrastructure is currently absent. With climate projections predicting increase in future rainfall extremes, drainage and local flooding due to stagnant water is considered a high risk for both schemes. Also Qumsangir which is mainly flat and has historically experienced many drainage issues, is classified as high risk.

D. Increased drought occurrence

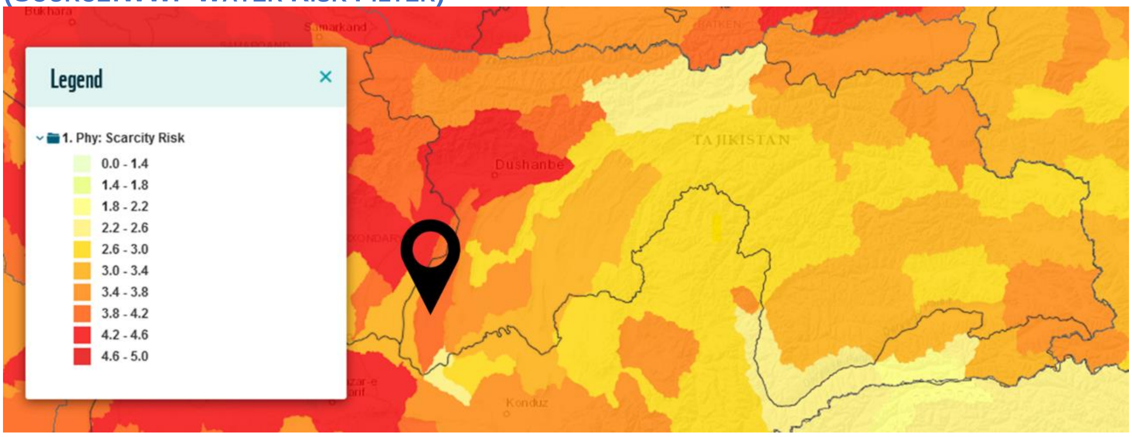
Drought is likely to represent a risk to the proposed irrigation modernization by increasing the pressure on irrigation systems to bridge the deficit between precipitation and crop water requirements. This is pertinent as the project area is in a relatively arid area as shown by the historic climate data presented in Section II.C.

A spatially distributed drought hazard index was derived for the area surrounding the proposed irrigation modernization projects. This was created using Google Earth Engine scripting to calculate the per-pixel average and standard deviation in precipitation, NDVI and land surface temperature. These statistics are then combined to create a single index which is representative of drought hazard for the project area.[1] Figure IV-9 shows the results of this, showing that drought hazard is highest in the South West of the project area and along the valley bottom, with the Qumsangir irrigation scheme showing a relatively higher exposure to drought hazard than the Yovon scheme.

Other datasets were also reviewed to give context to the drought risk in Tajikistan and the project area. Figure IV-8 shows the drought hazard from a dataset developed by WWF at the global level. This shows that in general, Tajikistan has a relatively low drought hazard, but that the area in Uzbekistan which borders the project area has a relatively high risk of drought. It is likely that this also applies to the project area as it has more similar precipitation and temperature characteristics to adjacent areas in Uzbekistan than the surrounding mountainous regions.

Climate change may present an exacerbating influence on drought risk to the proposed interventions to irrigation schemes. Consecutive Dry Days (CDD) per year represents a widely used metric to explore how drought risk may increase according to climate models. The NASA-NEX ensemble described in Section II.A.1 predicts an increase in CDD, but with a low level of agreement between models (Figure IV-10).

Figure IV-8. Drought Risk For Tajikistan, indicating the Project Location (Source:WWF Water Risk Filter)



[1] https://www.futurewater.eu/projects/transboundary-water-management-between-thailand-and-cambodia/

FIGURE IV-9. DROUGHT HAZARD INDEX FOR AREA.

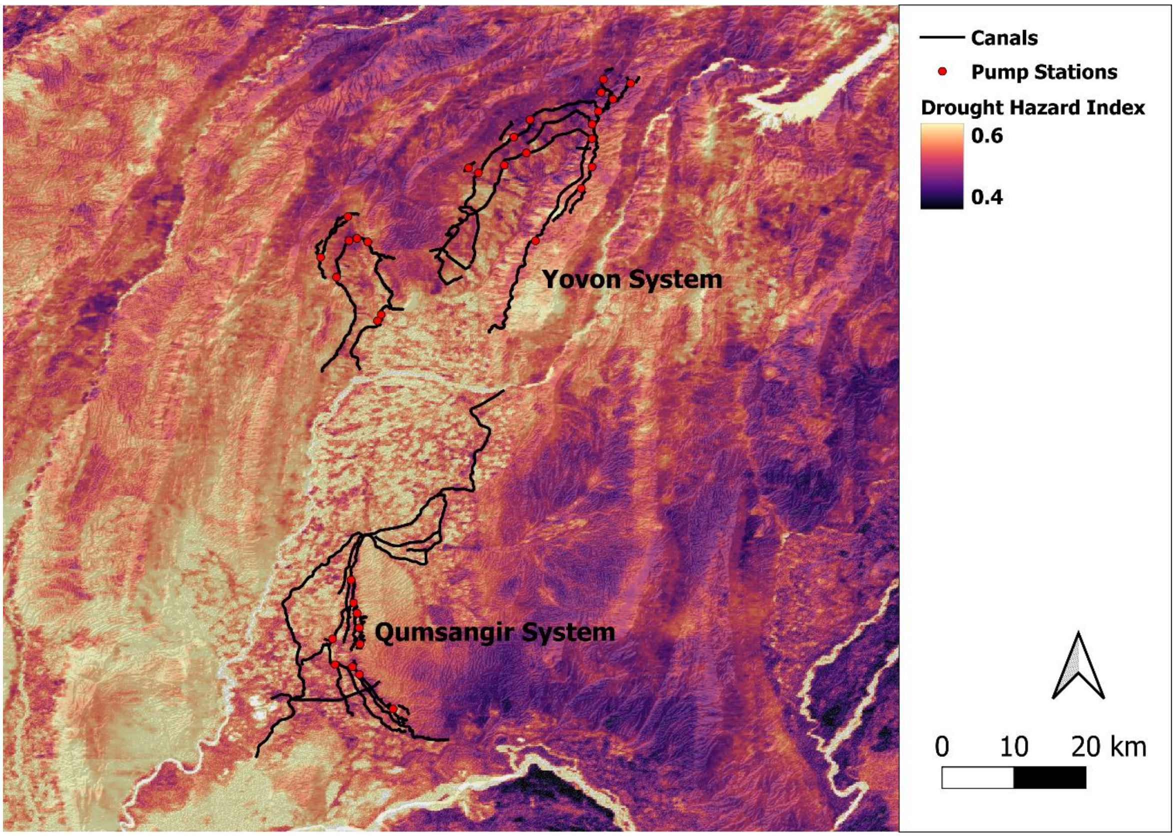
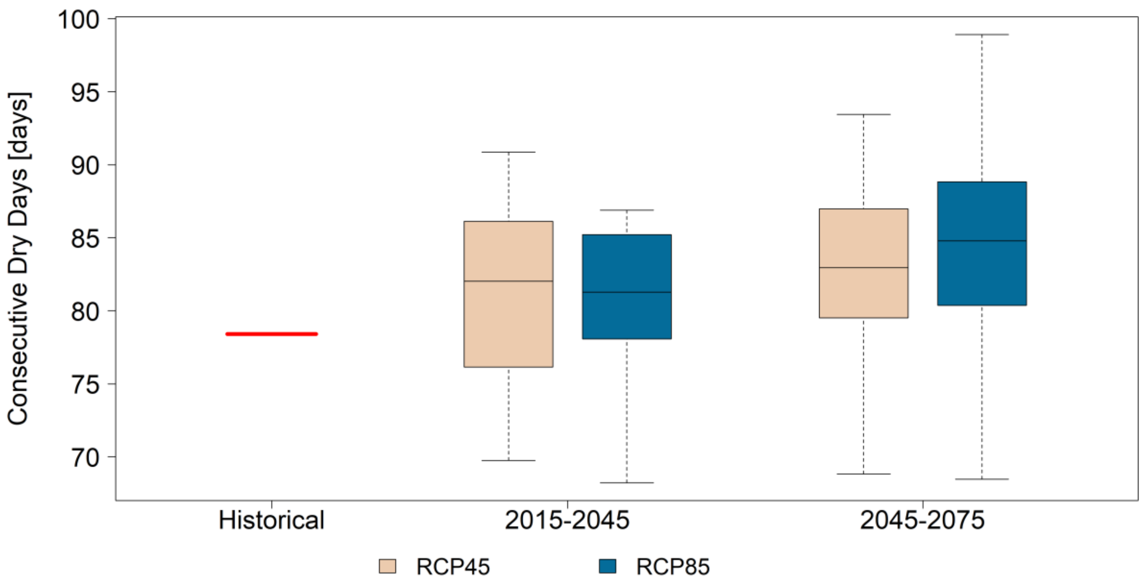


FIGURE IV-10. TRENDS IN CONSECUTIVE DRY DAYS PER YEAR FROM CLIMATE MODEL OUTPUTS COMPARED TO HISTORICAL (ERA5) MEAN



Besides more variable rainfall and increased number of dry days, drought intensity and frequency can also increase if evapotranspiration increases: both of natural vegetation as well as of crops. Temperature increase leads to higher (vegetation and) crop water requirements, besides also being affected by other climate variables as wind and humidity. A simplified approach was applied to estimate increased crop water requirements under increasing temperatures, using the Hargreaves equation. This shows that water requirements will likely increase by up to 4% (around 0.25mm/day) per 2C of warming in the summer growing season (Table IV-4) and up to 8% (0.12 mm/day) per 2ºC in the winter season.

As shown in section III, the likelihood of increased temperatures in the region is very high. Climate model ensembles predict warming of around 2-5C for the project area, hence potentially leading to increased irrigation requirements of around 0.5mm/day. Thus, this suggests that increasing crop water requirements will have to be considered for project design, for example by slightly increasing capacity. Also, this increase normally leads to higher evapotranspiration and thus drought risk.

TABLE IV-4. CHANGES IN WATER REQUIREMENTS FOR SUMMER CROPS UNDER THE RANGE OF TEMPERATURE CHANGE LIKELY ACCORDING TO THE CLIMATE MODEL ENSEMBLE (INCREASE OF 2-6C).

Average Temp. oC	Max. Temp. oC	Min. Temp. oC	Crop Evapotrans. (ET) mm/d	Difference in ET (extra water required) mm/d	%
Present					
30	25	35	5.87	/	/
Future					
32	27	37	6.11	0.25	4.2%
34	29	39	6.36	0.49	8.4%
36	31	41	6.61	0.74	12.6%
38	33	43	6.85	0.98	16.7%

TABLE IV-5. CHANGES IN WATER REQUIREMENTS FOR WINTER CROPS UNDER THE RANGE OF TEMPERATURE CHANGE LIKELY ACCORDING TO THE CLIMATE MODEL ENSEMBLE (INCREASE OF 2-6C).

Average Temp. oC	Max. Temp. oC	Min. Temp. oC	Crop Evapotrans. (ET) mm/d	Difference in ET (extra water required) mm/d	%
Present					
7	2	12	1.48	/	/
Future					
9	4	14	1.60	0.12	8.1%
11	6	16	1.72	0.24	16.1%
13	8	18	1.84	0.36	24.2%
15	10	20	1.96	0.48	32.3%

Overall, it is concluded that increased drought occurrence and intensity is very likely. Drought is already a hazard in this area under the current climate but will further aggravate under climate change due to more variable precipitation, longer dry periods, increased crop water requirements and poorly functional irrigation infrastructure.

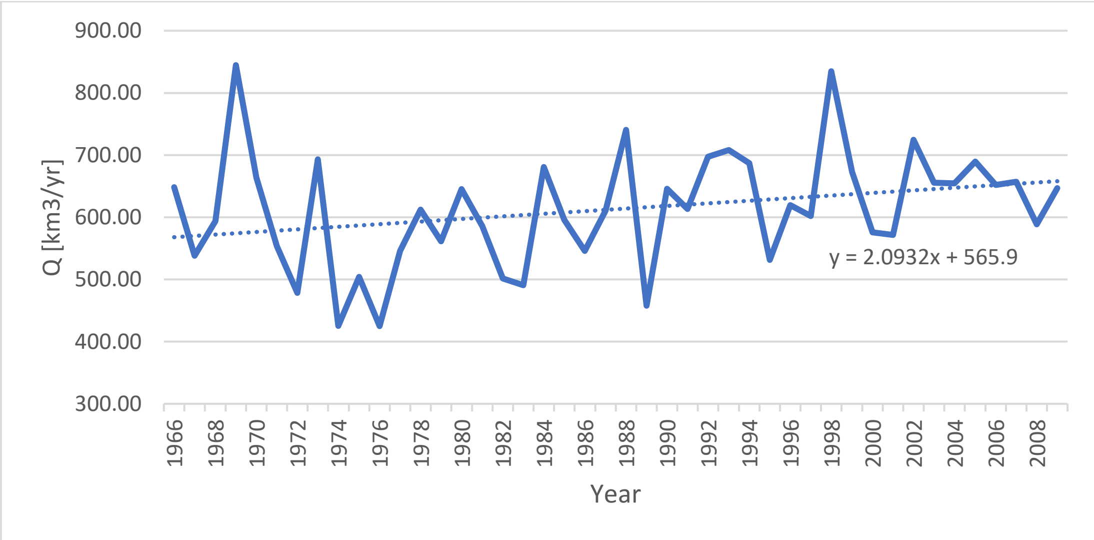
E. More variable water supply

The irrigation system is reliant on water availability in the Vaksh river, discharged from the Nurek reservoir. The Vaksh river is fed with melt water from many glaciers in the high mountain regions (Pamir). These regions have experienced notable changes over the last decades, due to changes in climate, glaciers and snow dynamics. This has caused the snowline to rise (about 150 m for every degree of warming) and water stored in glaciers to reduce: a trend which will further progress in the near and distant future. Additionally, the warming trend in CA is thought to be reinforced through the reduction in the snow albedo feedback (Unger-Shayesteh et al., 2013). Also, scientists recently confirmed a significant observed decline in snowfall fraction, which means that relatively more precipitation falls in the form or rain (Li et al., 2020).

The impact of changes in climate and cryosphere (glaciers and snow) on river runoff is a very complex and dynamic process. Several processes act simultaneously and can have either a positive or negative effect. For example, the loss of glaciers over the next decades can lead to an increase in flows as more meltwater becomes available. It is acknowledged that even in tributaries with a glacierised fraction of less than 5%, glacier melt water can be an important contributor to irrigation in the summer to compensate for scarce precipitation, thus even small changes can have important impacts.

Indeed, over the last decades, small increases in Nurek inflow have been observed as shown by data available data (source: GRDC and BW Amu Darya). Figure IV-11 shows the annual flow volumes derived for Nurek inflow. A very stable water supply is evident with little fluctuation over time. Furthermore, a slight upward trend is evident between 1965-2009 of approximately 2km3/year, however there is lots of variation around this.

FIGURE IV-11. ANNUAL FLOW VOLUMES FOR THE STATION UPSTREAM OF NUREK RESERVOIR.



However, at the same time, a reduction in snowfall and increasing temperatures lead also to increased evapotranspiration. This leads to less runoff, or offsets the increase in runoff due to glacial melt, as has been observed already in the region in several smaller rivers (Li et al., 2020). At the river basin-scale, glacier mass decrease can result overall in more water to be available as shown by Nurek inflow data. However, this will happen only up to a certain point when the glacial mass has shrunk to such a degree that run-off will start to decline. This moment is sometimes called *peak water*. Calculations on the net effect show that overall, changes to river run-off in the region are likely to be very minor up to around 2050 (Reyer et al., 2017). In the second half of the century, flows are likely to go down substantially (Huss and Hock, 2018).

A climate change impact on river flows which is already being observed and will become increasingly important in the next few decades, is the effect on the variability of flows. Glaciers and snow cover store the precipitation that falls in winter in the form of snow and releases it during spring and summer. However, reductions in snowfall fraction (see the trend in days below 0ºC as was extracted from climate model projections in FIGURE III-8), increases in temperature and melt rates, and reductions in glacier mass will reduce this buffering capacity. This reduced capacity to buffer water in the water towers will have three major impacts on the variability of flows:

1. dry years will become drier due to more pronounced inter-annual fluctuations in water resources, and less water security in dry and hot years
2. there will be a seasonal shift in water availability: peak flows happening earlier in the season
3. a less predictable and more variable seasonal regime, as the seasonal glacial melt contribution will be smaller, and flows will thus depend to a larger extent on precipitation

The on-going construction of the Rogun dam upstream of Nurek reservoir will affect the seasonal and inter-annual flow regime in the future and has the potential to mitigate at least part of the climate change effects. Good alignment with hydropower operations is needed though for this to happen. Also, Rogun´s filling of dead storage could have an impact on the downstream flow regime. Possibly, these impacts will be limited though as the project is within the same country and hence the avoidance of adverse downstream impacts will be easier to coordinate.

Overall, it is concluded that decreasing water availability due to climate change impacts is a high risk to the project after around the year 2050. Already over the next decades, increased inter-annual and seasonal variability is expected for the Vaksh basin. The extent to which this will affect the project will depend though on the operations of the large reservoirs (Nurek and Rogun) upstream. The climate risk related to water availability for both schemes is therefore considered to be medium on the short-term and high on the long-term.

F. Increased temperature-related crop stress

Another climate impact that may affect the study scheme profitability is related to increased temperature extremes, affecting the growing cycle, optimal growth conditions, and the overall productivity of crops (for example due to reduced chilling requirements, heat waves, and increased pests and diseases). For this risk analysis, a few crop-specific temperature related characteristics were analysed, based on the FAOs crop characteristics guidance document (FAO, 2012). Several crops were selected which are cultivated in the region and will likely be planted in the command area.

Table IV-6 shows the relative changes in optimum and heat or cold stressed days per growing season for each crop. This shows a relatively positive picture for almost all crops, with significant increases shown in the number of optimum growing days per year for all crops and significant reductions in cold stress days for cotton and wheat. Potato shows an increase in heat stressed days per year, but this is not a major crop cultivated in the area.

A potential concern is that Winter wheat requires a cold period or chilling (vernalization) during early growth for the full growth cycle to eventually occur – this could be compromised by decreases in cold days. Another factor to consider is that under extreme warming, cotton will likely become increasingly temperature stressed – this is especially pertinent towards the end of the century. This stresses the need for crop diversification.

The likelihood of increased temperatures in the region is relatively high, with climate model ensembles predicting warming of around 2-5C for the project area. Ensembles also show an increase in extreme temperatures (maximum yearly temperature) of as much as 7C. This therefore indicates a high likelihood that climate change will exacerbate risks associated with crop stress due to an increase in the severity of one-off extreme temperature events such as heatwaves, which are likely to have a negative impact on crops.

Overall, this analysis shows that the two irrigation schemes have a limited vulnerability to temperature related stresses on crops in case farmers and the irrigation system has the capacity to adapt to the changing climate by diversifying crops and changing and more flexible irrigation scheduling. Only little change in heat stressed days per growing season is expected. A warming climate may produce some favourable growing conditions for particular crops. The climate risk relating to crop stress is considered medium for both schemes, given the fact that adaptive capacity of the scheme and the farmers in terms of cropping practices is low nowadays.

TABLE IV-6. CHANGES IN OPTIMUM AND HEAT / COLD STRESSED DAYS PER GROWING SEASON UNDER CLIMATE CHANGE PREDICTED BY THE CLIMATE MODEL ENSEMBLE FOR A NUMBER OF SELECTED CROPS IN THE PROJECT AREA.

	Change in optimum (days per growing season)			
Crop	**RCP45 2030**	**RCP45 2050**	**RCP85 2030**	**RCP85 2050**
Winter Wheat	10	20	13	27
Cotton	40	57	43	65
Potato	21	33	24	17
Alfafa	40	57	43	65

	Change in heat stressed days (per growing season)			
Crop	**RCP45 2030**	**RCP45 2050**	**RCP85 2030**	**RCP85 2050**
Winter Wheat	0	0	0	0
Cotton	0	0	0	24
Potato	32	48	36	60
Alfafa	0	0	0	0

	Change in cold (stressed) days (per growing season)			
Crop	**RCP45 2030**	**RCP45 2050**	**RCP85 2030**	**RCP85 2050**
Winter Wheat	-21	-35	-25	-55
Cotton	-12	-19	-14	-22
Potato	0	0	0	0
Alfafa	0	0	0	0

G. Fluvial flooding

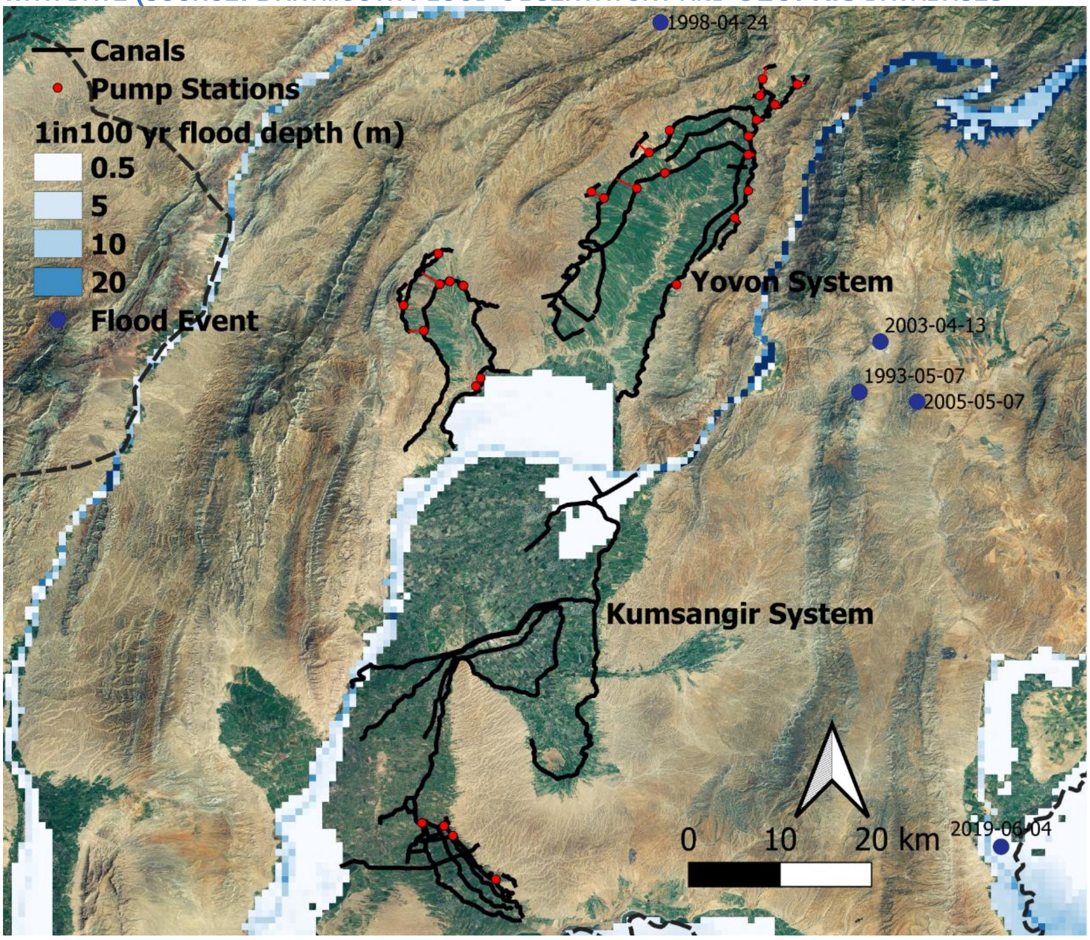
A quick scan of flood risk in the area using the global scale flood hazard dataset GLOFRIS suggests that there is no flood risk in the designated project area stemming from the Vaksh main channel. This dataset suggests that neither scheme would be inundated under a 1 in 100 year flooding event (FIGURE IV-12). The observed incidences of flooding from the Dartmouth Flood Observatory dataset does not show any flooding events recorded in the scheme areas, suggesting that flooding from fluvial sources is not particularly problematic.

Another consideration for the Qumsangir irrigation scheme is the possibly flooding caused by a dam breach scenario occurring in the upstream Nurek Dam. This represents a very large hazard but is unlikely.

Rainfall and flow regimes are likely to change in the future (Chapter III) and may bring higher peak flows in the Vaksh river, due to the reduced buffering effect of glaciers and snow. Climate model ensembles also predict a high likelihood of increasing precipitation intensity which will also likely increase flood risk in the area. On the other hand, a positive side-effect of the Nurek dam and the to-be-built Rogun dam will be that these negative consequences will be offset by the large regulation capacity of these reservoirs.

Overall, it can be concluded that flooding from fluvial (river) sources does not represent a significant risk to the scheme areas and related components as project components are not exposed to flood hazard. This is supported by feedback from local experts and stakeholders

FIGURE IV-12. FLOOD DEPTHS FOR 100-YEAR RETURN-LEVEL FLOODS AND HISTORIC FLOOD EVENTS WITH DATE (SOURCE: DARTMOUTH FLOOD OBSERVATORY AND GLOFRIS DATABASES



H. Climate Risk Categorization

The climate risk analysis has gathered and processed a number of spatial datasets in the public domain, together with climate model projections and local information, in order determine a risk level for each relevant risk type. Table IV-7 summarises the analysis and provides the risk levels to both Yovon and Qumsangir schemes.

TABLE IV-7. CLIMATE RISK SUMMARY: HAZARD, SENSITIVE PROJECT COMPONENTS, AND RISK LEVEL

Hazard	Sensitive Project Components	Expected Change in Climate Variables	Relevance and risk level for Yovon	Relevance and risk level for Qumsangir
Erosion of catchment and command areas	**Irrigation system canals and pipe systems, escapes, spill channels**	Increase in maximum 1-day rainfall, precipitation intensity, and lower snowfall fraction	**High** Steep topography combined with highly erodible soil	**Medium** Flat topography reduces risks but soil still highly erodible
Seismic events, landslides and slope failures	**Irrigation canals, command areas**	Increase in maximum 1-day rainfall, precipitation intensity and erosion	**High** Steep topography combined with highly erodible soil, and earthquake risk	**Medium** Medium-high risk of earthquakes but mostly flat topography
Drainage issues (pluvial flooding, waterlogging)	**Drainage system**	Increase in rainfall extremes	**High** Areas with change of slope (steep to flat) can lead to issues	**High** Flat topography combined with poor existing drainage systems
Increased Drought Occurrence	**Irrigation system, Cropping practices**	Increase in Consecutive Dry Days, increase in temperatures, increase in crop water requirements	**High** High drought hazard combined with longer periods of dry days	**High** High drought hazard combined with longer periods of dry days
Water availability / water shortage	**Irrigation system, Cropping practices**	Increased evapotranspiration, expected changes in river flows	**Medium/ High** Short-term: possibly increased variability; long-term: decreased availability	**Medium/ High** Short-term: possibly increased variability; long-term: decreased availability
Temperature stress on crops	**Cropping practices**	Increase in mean, minimum and maximum temperatures predicted by climate model ensemble	**Medium** Warming could lead to reduced stresses on crops and more optimum growing days but only in case of increased adaptive capacity	**Medium** Warming could lead to reduced stresses on crops and more optimum growing days but only in case of increased adaptive capacity
Fluvial flooding	**River offtakes/ headworks**	Increase in maximum 1-day rainfall, precipitation intensity predicted by climate model ensemble	**Negligible (n/a**) as the scheme is supplied by water diverted into a tunnel from the Vakhsh river to the Yovon valley	**Low** There is some risk in areas located closer to the Vaksh river but little risk to the scheme command area which starts at PK189 (18.9 km from the headworks for the Vakhsh main canal)

V. DISASTER RISK ASSESSMENT

A. Historic events

This area is considered highly vulnerable to earthquake damage, either directly due to increased loading, or due to liquefaction of (saturated) soils resulting in landslides, mudflows and infrastructure failures. The potential consequences are severe and lead to an interruption of irrigation supply, possibly for months or years, and significant loss of crops and livelihood impacts.

The vulnerability of irrigation infrastructure to earthquakes is demonstrated by historic events in the area. An earthquake on 7th May 2001 damaged the irrigation infrastructure in the Yovon scheme. It cracked the intake structure of the middle siphon, which quickly eroded soil from below the structure. The absence of a communications system and malfunctioning gates of the escape structures allowed the water to continue flowing for the next 12 hours before the conveyance system was emptied. The siphon intake structure, 100 m of the upstream open canal, and 600 m of the upper reach of the siphon were washed away. That left 11,724 ha of previously irrigated land, 56,000 people, and 65,000 heads of livestock without water. In addition, the water gushing from the intake structure damaged 48 houses, though no casualties were reported, and eroded a large gully through the command area.

Erosion and landslides can also be triggered by heavy rainfall. The fined grain (loess) soils and ground slopes of around 3% mean that the Yovon irrigation scheme is particularly vulnerable, with extensive soil loss, mudslides and gullying over parts of the area due to storm rainfall. Very recently, on 12 May 2021 some areas of the Vakhsh district in Khatlon province, including Yovon, experienced mudslides after a day of heavy rain destroying houses, bridges and partially damaging the Vakhsh Canal

The erosion hazard is covered in the previous section, as this hazard is influenced by climate change. The next section assesses risks from the earthquake hazard.

B. Risk from seismic events

The combination of erosion and aged infrastructure makes the system highly vulnerable to earthquake damage. These can cause landslides and canal blockages or sedimentation, which may lead to water overtopping the banks, leading to breaches and severe erosion to adjacent areas. Channels built across the sloping terraces are particularly vulnerable to failure due to the permeable nature of loess soils. For example, on inspection the existing, unlined bypass canals for two large siphons along the Yovon Right Branch (KM 27.0 and KM 35.6) appear unstable with cracks and signs of slippage and incipient slope failure in the downstream slope, as is shown on the photos below.

The large siphons along the Yovon Right Branch are also vulnerable to failure, either due to failure of the old steel pipes due to rusting, or even fracture of the new GRP pipes under earthquake loading. Further, the Right Branch canal, Yovon, does not have sufficient capacity to meet peak irrigation requirements. Parts of the canal are operated with less than design freeboard, posing a higher level of risk (see **Error! Reference source not found.**).

Non-functional Siphon 1 (2 No. Steel pipes) at 38.1568N, 68.8603E, and (temporary) 4.6 km long earthen bypass canal

The bypass channels are unlined & seepage and small slip failures were observed in the downside slopes, February 2020

Non-functional Siphon 2 (2 No. Steel pipes 590 m long) at 38° 8'01"N, 68°49'54"E, and (temporary) 4.1 km long bypass canal. Lining required.

Short length of lining being constructed by ALRI in part of Siphon 2 bypass channel, February 2020

Siphon 3 (1 No steel pipe and 1 new GRP pipe). Either: (i) Construction of new bypass canal proposed, or (ii) 2nd Siphon required. Capacity to be increased from 9 m3/s to about 15 m3/s.

FIGURE V-1. RIGHT BRANCH YOVON SHOWING EROSION OF CANAL, SUBMERGENCE OF GATE CONTROLLING FLOW TO OFFTAKING PIPELINE AND INSUFFICIENT FREEBOARD

The consequences of these disasters are severe and lead to an interruption of irrigation supply, possibly for months or years, and significant loss of crops and livelihood impacts.

The history of earthquake events in the area was analyzed. **Error! Reference source not found.** Figure V-2 shows a map of earthquakes recorded by the USGS since 1990, showing several events in proximity to both irrigation areas. These are largely smaller events (3-4 magnitude), but also some events of higher magnitude (5+) are recorded that have the potential to be a serious hazard to irrigation infrastructure. This is supported by the GFDRR Earthquake hazard for Central Asia dataset which shows that Tajikistan has one of the highest earthquake hazards in the region.

FIGURE V-2. SEISMIC EVENT EPICENTRES 1990-2021. DATE OF EVENT IS PRESENTED NEXT TO EPICENTRE IN FORMAT YYYY/MM.

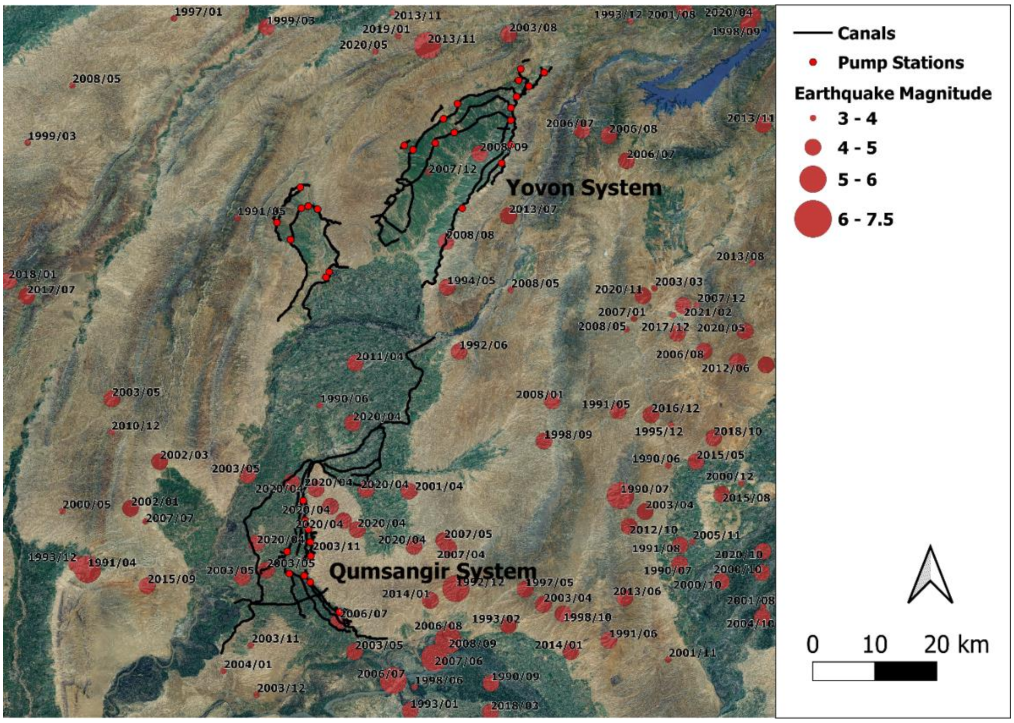
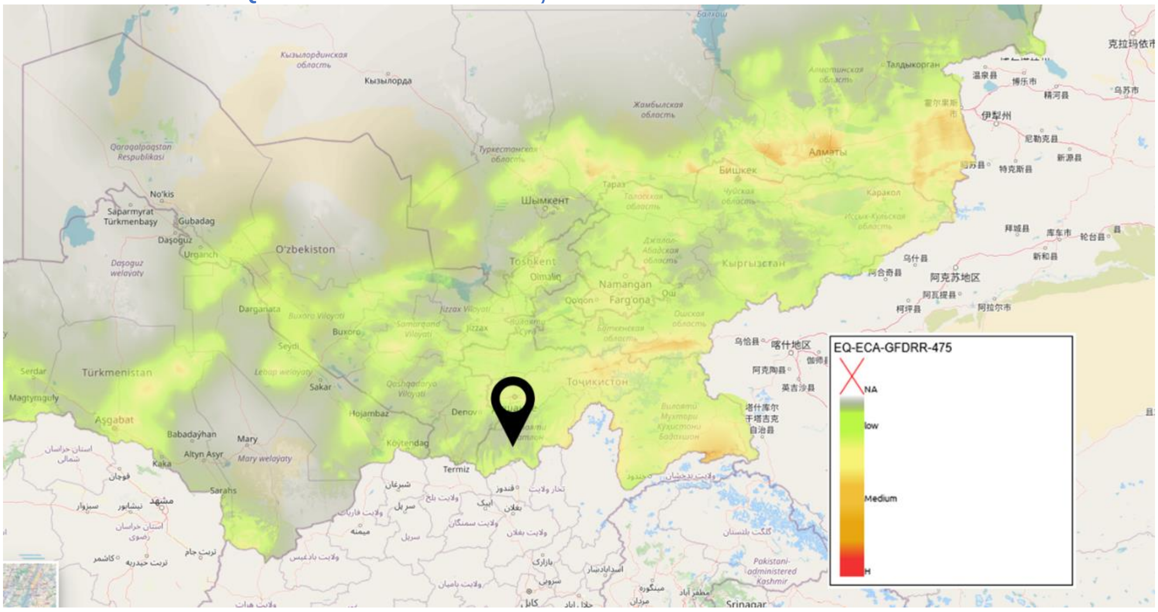


FIGURE V-3. EARTHQUAKE HAZARD AT 475 YEAR RETURN PERIOD FOR CENTRAL ASIA FROM EQ-ECA-GFDRR EARTHQUAKE HAZARD DATASET, TAJIKISTAN.



As described in the previous section, the earthquake on 7th May 2001, caused extensive damage to the Yovon irrigation system, illustrating the risk posed by earthquake events. To examine the effects of the earthquake in 2001 on the irrigation system and resulting impacts on agricultural productivity, a remote sensing-based vegetation productivity analysis was conducted for the Yovon area. The satellite platform used for this analysis has data from 2001 only (MODIS, product used: 8-day MODIS Normalised Difference Vegetation Index (NDVI) data from 2000-2020).

Error! Reference source not found. shows the annual crop health indicators, averaged per month. F or the year 2001, it can be seen that vegetative (crop) productivity dropped considerably after May. Also, it is evident that crop health in 2001 was relatively lower than in other years on the record. **Error! R eference source not found.** further shows that in certain areas within the irrigation scheme, namely in the WUA in the South West of the scheme, crop health in 2001 was considerably lower than the 2001-2020 period average. Also, the year 2002 (orange line) was a relatively poor performing year.

FIGURE V-4. NDVI SEASONALITY PER YEAR AVERAGED OVER THE YOVON AREA SHOWING THE IMPACT OF THE EARTHQUAKE EVENT IN 2001.

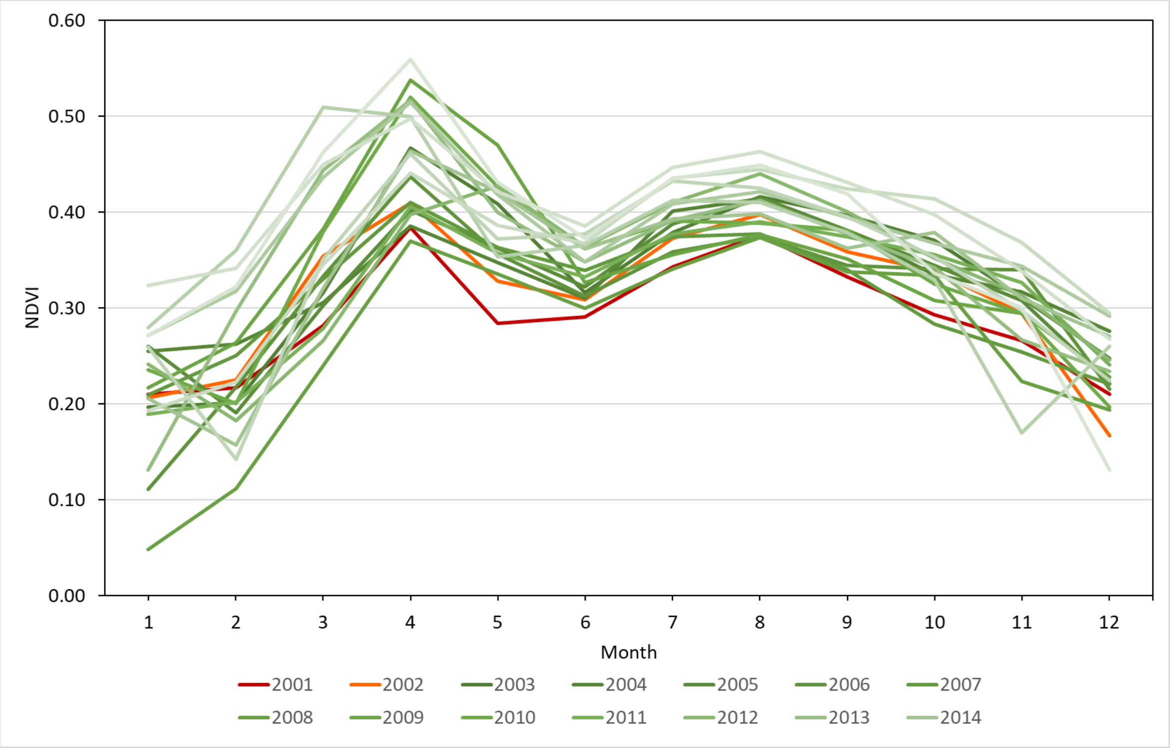
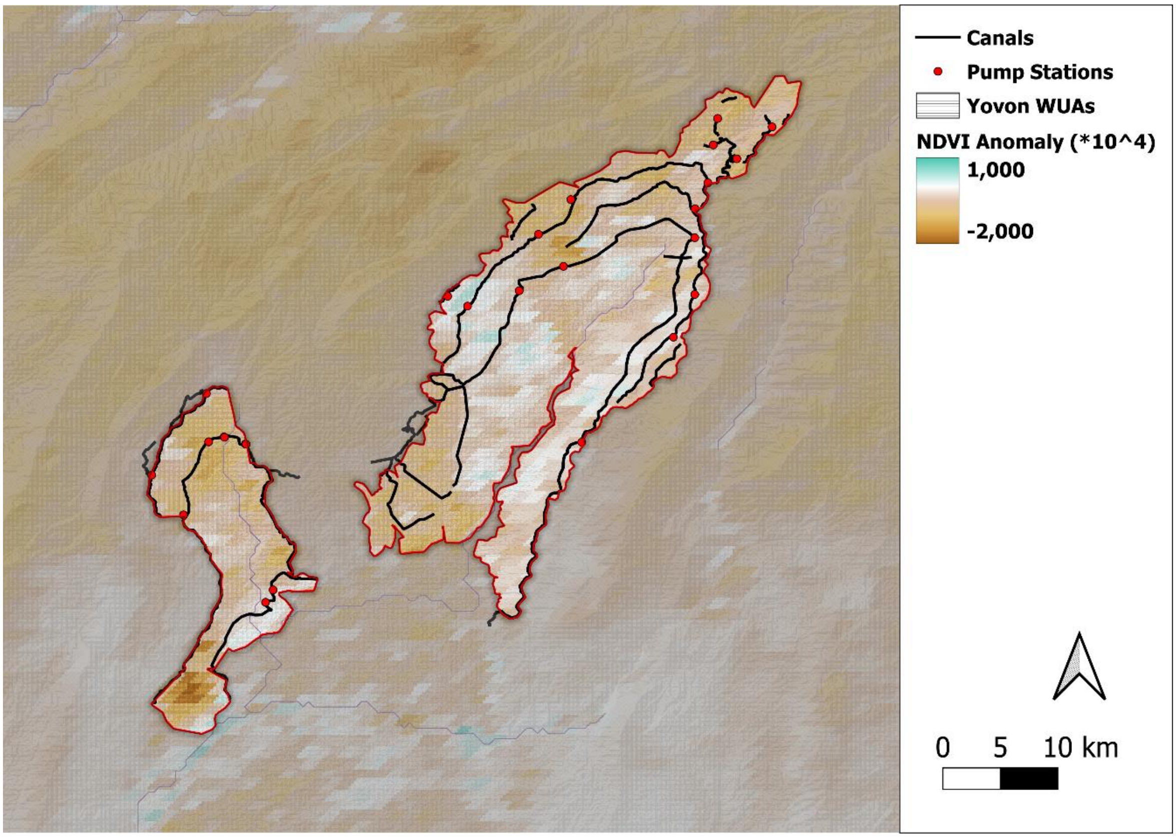


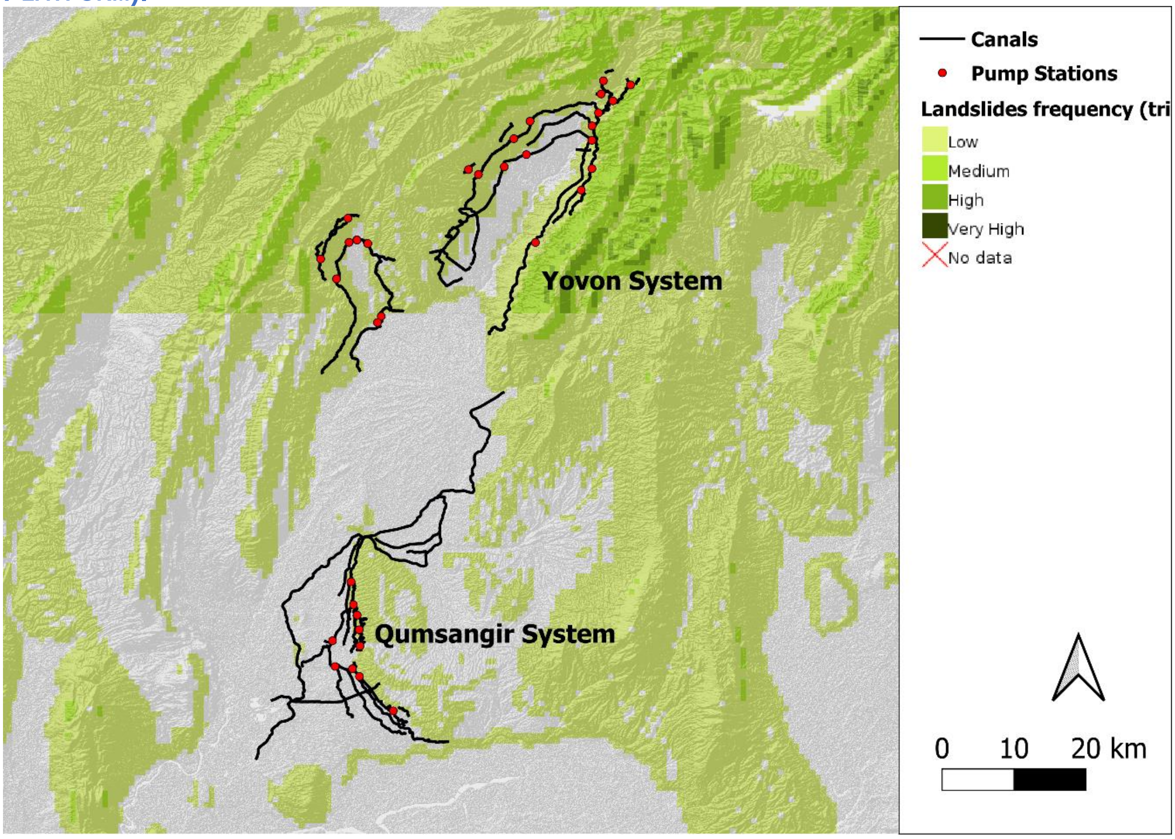
FIGURE V-5. IRRIGATION SEASON AVERAGE (MAY-SEPTEMBER) NDVI ANOMALY 2000-2020 VS. THE YEAR 2001.



The NGI's global landslide hazard dataset provides a tool for rapidly assessing the current hazard related to landslides in the project area. This dataset is presented in **Error! Reference source not found.** showing a medium to high hazard level for landslides on the slopes surrounding the Yovon scheme area and around the Qumsangir area. Earthquakes can trigger these landslides to occur, as happened in the past as described before. Besides, heavy rainfall events can also trigger landslide events.

Climate model projections (see chapter III) predict an increase in the intensity of rainfall into the future, with increases predicted in the wetter parts of the year. The ensemble predicts that the intensity of extreme precipitation events could increase by as much as 20mm/day for a 1 in 100 year precipitation event (see section III.B.3). Furthermore, although differing on specific amounts, all models predict an increase in the intensity of precipitation under both climate change scenarios and time horizons. Thus, there is a high likelihood that landslide risk will increase in the future.

FIGURE V-6. LANDSLIDE HAZARD TO THE TWO PROJECT AREAS TAKEN (SOURCE: GLOBAL RISK DATA PLATFORM).



Overall, it is concluded that the combination of susceptibility for landslides, potentially increased by climate change, and earthquake hazard causes a high risk for earthquake damage in the Yovon scheme, either by direct impacts (infrastructural collapse or alike) or indirect impacts (landslides causing blockages etc). Poorly maintained irrigation structures are currently extremely vulnerable to this geophysical risk. For the Qumsangir scheme, risk is lower, with less overall hazard of landslides, but earthquake risk is still considerable so direct earthquake damage to infrastructure can occur. Seismic proofing measures are highly recommended, and proposed in the next Chapter.

VI. DIASTER RISK REDUCTION AND ADAPTATION MEASURES

A. Introduction

The climate change and disaster risks assessed in the previous chapter for the two study schemes urge for disaster risk reduction and climate adaptation activities that make sure that the schemes and the proposed project development objectives are not compromised by these adverse impacts. These climate adaptation activities complement the “Business as Usual” activities of the project, which are the project activities that did not originate with an explicit intent to address climate change impacts. Without the climate adaptation activities proposed here, the project will most likely not achieve its development objectives due to the adverse impacts of climate change on the medium- (next decades) and long-term (second half of the century). This section describes the climate adaptation activities proposed for the project.

The disaster risk reduction activities aim at reducing exposure and vulnerability to:

- **Seismic events and landslides**. The combination of erosion and earthquake hazard causes a high risk for landslides and slope failures in the Yovon scheme and consequent crop failures. Climate adaptation activities are required that retrofits the scheme to earthquake risk and makes the infrastructure less vulnerable to extreme weather.

The climate adaptation activities target the climate risks to the irrigation systems that were classified as “medium” or “high” in the climate risk assessment (see previous section). In short, these risks are:

- **Increased erosion**. Due to the scarce vegetation cover in the catchment areas, the erodible soil-type (loess), steep slopes, as well as the very likely increase in climate variables that drive erosion (rainfall extremes and snowfall fraction), it is concluded that the climate risk for increased erosion and consequent yield loss is high. Climate adaptation measures are required that specifically reduce erosion risk, to the extent possible through Nature-based Solutions.
- **Increased drainage issues.** There is a high risk that due more extreme rainfall, drainage issues (i.e. waterlogging, salinity and local flooding, leading to yield loss or crop failure) will further increase in the flatter parts of the scheme where properly functional drainage infrastructure is currently absent. Climate adaptation activities should be integrated in the project to improve the drainage infrastructure
- **Increased drought risk** due to more variable precipitation, longer dry periods, increased crop water requirements and poorly functional irrigation infrastructure, affecting crop yields and water productivity in the scheme. Climate smart agricultural practices and modern crop and water use monitoring technologies should be incorporated in the project to increase adaptive capacity of the farmers.
- **Changes in water availability** over the next decades, meaning increased inter-annual and seasonal variability due to reduced snow cover and glaciers. The extent to which this will affect the project depends on the operations of the large reservoirs upstream. From around 2050, water availability will progressively go down and the effect of reduced water storage capacity in the form of snow and in glaciers will most likely affect water availability to the project. The irrigation system should become more responsive as a whole to increased variability: distribution system, billing system, governance, etc.
- **Heat stress**. Impacts of temperature-related stresses on crops are limited in case farmers have the capacity to adapt to the changing climate by diversifying crops and by changing to more flexible irrigation scheduling.

As such, disaster risk reduction and climate adaptation activities have been incorporated into the project, and have been divided over the following components of the project:

- Engineering interventions
- Institutional Development
- Agricultural Development
- Social and Gender Development

Besides, two additional adaptation measures are proposed that do not fall into one of these four categories, detailed hereafter.

B. Engineering interventions

To prevent earthquakes to compromise the project outcomes, seismic proofing is required by upgrading and stabilizing critical infrastructure to reduce risk of failure. The two earthen bypass channels that were constructed after the associated siphons can no longer be safely used and were abandoned due to consequences of seismic events and water erosion. The bypass channels were constructed along the side of a valley over steeply sloping ground. Field inspections found cracks and signs of incipient slippage and failure along the embankments, indicating a very high risk of failure under seismic (earthquake) loadings. Soil liquefaction caused by seismic vibration could cause embankment failure. Table VI-1 presents the disaster risk reduction activity. Costs were estimated based on incremental costs of the seismic retrofitting.

TABLE VI-1 PROPOSED ADAPTATION ACTIVITIES AND JUSTIFICATION FOR THE ENGINEERING INTERVENTIONS

Disaster Risk Reduction Activity	Target Disaster Risk	Estimated Disaster Risk Reduction Costs ($ million)	Disaster Risk Reduction Finance Justification
Two bypass channels and siphon	Seismic events and related landslides	3.2	Two bypass channels need to be retrofitted through lining to prevent seepage, flattening of embankment slopes and other seismic stabilization measures. A siphon which failed in May 2001 as a result of an earthquake cannot be replaced with a bypass channel due to terrain conditions; instead, it should be upgraded to withstand seismic loads by the provision of an additional barrel. The estimated finance is based on the incremental costs of seismic retrofitting.

As the climate risk assessment has shown, farmers do currently not have the capacity to cope with climate change impacts: increased droughts, more variable supplies and temperature-related impacts which may require changing crop types and cropping seasons. To large degree this can be attributed to poorly functioning infrastructure, as was demonstrated in the field surveys, interviews, and explained previously. The irrigation system should be transformed to a system that is responsive to increased climate variability and water shortages. Irrigation infrastructure should allow on-demand water supplies to be able to be more flexible in cropping practices.

The project should implement irrigation infrastructure that is fit for the terrain conditions and allows farmers to have better control of deliveries. Given the terrain conditions, it is recommended that these are pipe networks that are buried, including modern hydrants for gated pipe and allow for pressure irrigation. The adaptation activity is summarized in TABLE VI-2, including costs.

TABLE VI-2 PROPOSED ADAPTATION ACTIVITIES AND JUSTIFICATION FOR THE ENGINEERING INTERVENTIONS

Adaptation Activity	Target Climate Risk	Estimated Adaptation Costs ($ million)	Adaptation Finance Justification

Buried pipe system with volumetric metering and modern hydrants for gated pipe and pressure irrigation	Increased drought occurrence and more variable water availability	3.8	Current delivery system has poor control, faces severe erosion issues and high losses and this will be further aggravated due to increased drought risk and more variable water availability. The modernised pipe irrigation systems with volumetric metering, and hydrants for gated pipe connections for farmland will give farmers control of on-demand water deliveries to respond better to increased variability due to climate change, lead to labour saving for farmers (and especially women in kitchen garden areas), reduce erosion and lead to higher yields due to more uniform irrigations. Full costs of new hydrants, meters and rehabiltation or replacement with high density polyethylene for pipes and modernisation of wells are attributed to adaptation costs.

C. Institutional Development

Governance institutions need to be re-structured to strengthen the adaptive capacity of the institutions responsible for operating and maintaining the I&D system. The relevant institutions are the Agency for Land Reclamation and Irrigation (ALRI) and the Water User Associations (WUA). These need to be supported to use modern and innovative technologies, such as satellite remote sensing-based crop monitoring, remote flow control, smart cashless metering and volumetric charging. This should lead to: (i) a higher level of irrigation service to farmers, (ii) support increased irrigation surface fees for sustainable operation and maintenance, and (iii) enable rapid response to extreme weather events, including quick closure in the event of any infrastructure failure to minimise disaster impact. Further, their capacity to maintain the system and complete repairs after extreme weather events will be strengthened to reduce the down-time and impact on cropping and livestock.

An innovative adaptation activity proposed entails the use of satellite remote sensing-based crop and water productivity monitoring for the scheme. Remote sensing technologies can provide spatial information on water consumption and productivity, on a regular basis, for example at the end of each cropping season, and measure the performance of the system based on productivity and water use. This information can be used to update water allocations for the next season or seasons.

Spatial information that can be generated includes indicators related to water productivity, adequacy, equity, uniformity, among others, for example using the latest techniques and algorithms that are in the public domain and used for the FAO WaPOR water productivity portal. The spatial information can be aggregated per crop, with specific attention to emerging crops in the irrigation district (horticultural, etc). Currently such information is not available to farmers. This information enables them to better respond to increased climate variability and other climate risks that affect directly or indirectly the productivity and livelihoods.

Concrete adaptation activities for the institutional development of the project are listed in TABLE VI-3.

TABLE VI-3 PROPOSED ADAPTATION ACTIVITIES AND JUSTIFICATION FOR INSTITUTIONAL DEVELOPMENT

	Adaptation Activity	Target Climate Risk	Estimated Adaptation Costs ($ million)	Adaptation Finance Justification

INST-01	Modern tecnologies (SCADA, GIS, remote sensing-based monitoring of crop performance) and institutional changes to enable real-time monitoring and more flexible operation of infrastructure, including capacity building	Increased drought occurrence and more variable water availability	0.4	Increased variability of climate and irrigation water demands requires real-time monitoring, including satellite-based, and more flexible operation of infrastructure, for timely and on-demand availability of irrigation water and transparent decision-making on allocations.
INST-05	Activity to identify venues for improving policies, financ mangement systems, practices and ways of bringing pumping energy costs down	Increased drought occurrence, increased variability of water availability	0.1	Currently policies and management systems do not respond adequately to increased climate and water resources variability. Also the potential to reduce energy use and emissions needs to be studies to develop recommendations.

D. Agricultural Support

This project is farmer-centred and as such, increasing the adaptive capacity of farmers themselves is critical. Farmers need to be introduced with climate resilient technologies, enabling crop diversification, yield, water productivity and energy efficiency gains. Measures included in support for high value cropping and for increased labour and irrigation efficiency include for planting material, precision land grading and improved furrow design, as well as support for gated pipe and drip systems, and for training. These will increase irrigation efficiencies and crop-water productivity, as well as reduce water runoff/ waste, water logging.

Concrete adaptation activities for agricultural support of the project are listed in TABLE VI-4

TABLE VI-4 PROPOSED ADAPTATION ACTIVITIES AND JUSTIFICATION FOR AGRICULTURAL SUPPORT

	Adaptation Activity	**Target Climate Risk**	**Estimated Adaptation Costs ($ million)**	**Adaptation Finance Justification**
AGR-01	Tables and other resources for better access to information on crop options, water requirements, practices, inputs and weather forecasts	Increased erosion, increased drought occurrence, increased variability of water availability, and increased heat extremes	0.2	Increased variability of climate and irrigation water demands requires better access to information on crop option, requuirements, practices, inputs and weather forecasts

AGR-02	Introduction of climate smart irrigation practices, including precision land grading, gated pipe for furrows, more efficient small scale irrigation technologies	Idem	0.5	Climate smart agricultural practices should prevent farmers´ livelihoods to be compromised by climate change impacts in the near future

E. Social and Gender Support

As was demonstrated, in the two schemes, as also in other regions of Central Asia, female farmers are specifically vulnerable to climate change. The project promotes their representation in WUA and ALRI management. For better coping with climate change impacts, homesteads will be supported with pressure hose and micro-irrigation to enable them to produce food for nutrition security. This activity is summarized in TABLE VI-5.

TABLE VI-5 PROPOSED ADAPTATION ACTIVITIES AND JUSTIFICATION FOR GENDER SUPPORT

	Social and Gender Development			
	Adaptation Activity	**Target Climate Risk**	**Estimated Adaptation Costs ($ million)**	**Adaptation Finance Justification**
GND-01	Support for homestead irrigation	Increased erosion, increased drought occurrence, increased variability of water availability, and increased heat extremes	0.4	Climate change is disproportionally affecting women: for livelihoods to becomes resilient, reduction and rebalance of unpaid care and domestic work is required

F. Additional Climate Adaptation Interventions

Additional climate adaptation measures are proposed to address degradation through soil loss affecting farmers directly (loss of fertile top-layer of soil and loss of arable land due to gullying) and indirectly (increased likelihood for infrastructure failure or underperformance). These measures will focus on the command area, and a buffer strip around the command area where erosion and scarce vegetation cover due to grazing is particularly acute. Most of the proposed measures are so-called Nature-based Solutions (NbS). NbS is a set of practices that maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources, hence representing a climate-resilient set of measures which can be used to help control erosion and reduce vulnerability.

The identification and design of adaptation measures was based on expert judgement, understanding of local conditions and a wide range of literature and databases. Key sources are:

- WOCAT global SLM database[7]
- FAO climate smart agriculture sourcebook[8]
- World bank SLM sourcebook
- UNCCD report - Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation (Sanz et al., 2017)
- Sustainable Sanitation and Water Management (SSWM) database[9]
- Integrated Watershed Management in Rainfed Agriculture (Wani et al., 2011)
- Rainwater Harvesting for Agriculture and Water Supply (Zhu et al., 2015)

The additional climate adaptation interventions divided in two activities:

- CLM-01: Buffer Strip and Riverine Area Development
- CLM-02: Support for Small Scale Gully Stabilisation

In Annex A, a summary sheet is given for both interventions. A description of the interventions and of their implementation in both schemes is given below.

a. Buffer Strip and Riverine Area Development (CLM01)

Extreme rainfall events and scarce vegetation cover has led to deep gully formation and “bad-lands” in the surrounding of the command area. Also poorly maintained escape/ spillway channels from the branch canals have caused deep gully formation. As followed from the climate risk assessment, these large gullies and scarce vegetation cover in the riverine area need to be mitigated, especially given the high likelihood that extreme rainfall events will increase in the future.

The measures included in this intervention comprise the gully stabilisation works and plugging with gabion (drop) structures for the larger gullies, and vegetative measures in the riverine area, requiring machinery and large gabion structures, and thus will need to be implemented by a constructor. Mitigation measures for smaller gullies and field- and hill-erosion are included in CLM02.

For the riverine area, measures to limit grazing in the erosion-prone and gullied areas are also part of this intervention. These measures should restore vegetation cover and hence increasing land stability and soil erodibility. Besides fodder-related measures, this intervention includes fencing in the riverine areas.

To estimate the area where this intervention should be implemented, the spatial erosion risk indicator was used as presented in the Climate Risk Assessment (Section IV-B, **FIGURE IV-6** and **FIGURE IV-7**). The larger erosion features in and around the larger channels and river beds correspond to higher values of the erosion risk factor. An area estimate was made based on those areas where the risk

[7] https://qcat.wocat.net/en/wocat/
[8] http://www.fao.org/climate-smart-agriculture-sourcebook/en/
[9] https://sswm.info/

values (LS-factor) are higher than 10. The below map highlights these areas in cyan colour for both schemes.

FIGURE VI-1. IMPLEMENTATION AREA FOR CLM-01 IN THE YOVON COMMAND ZONE AND BUFFER AREA

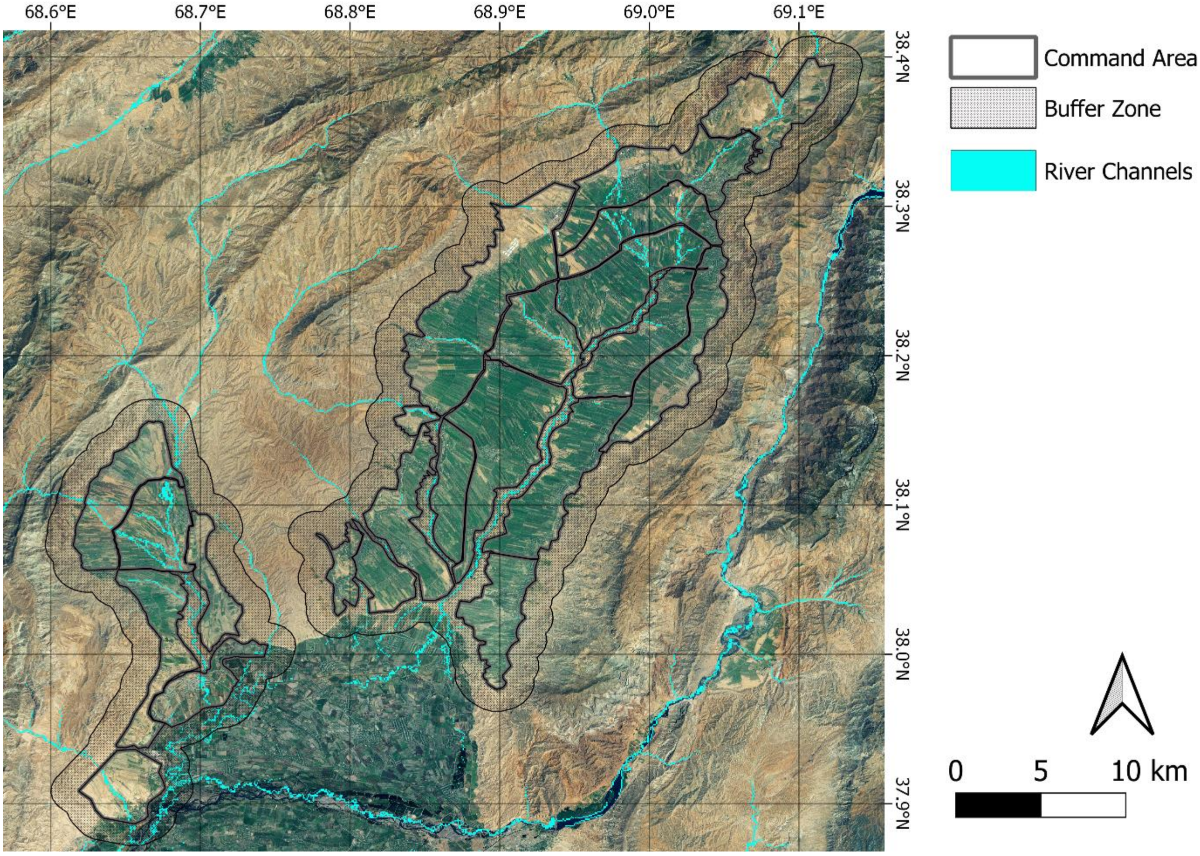
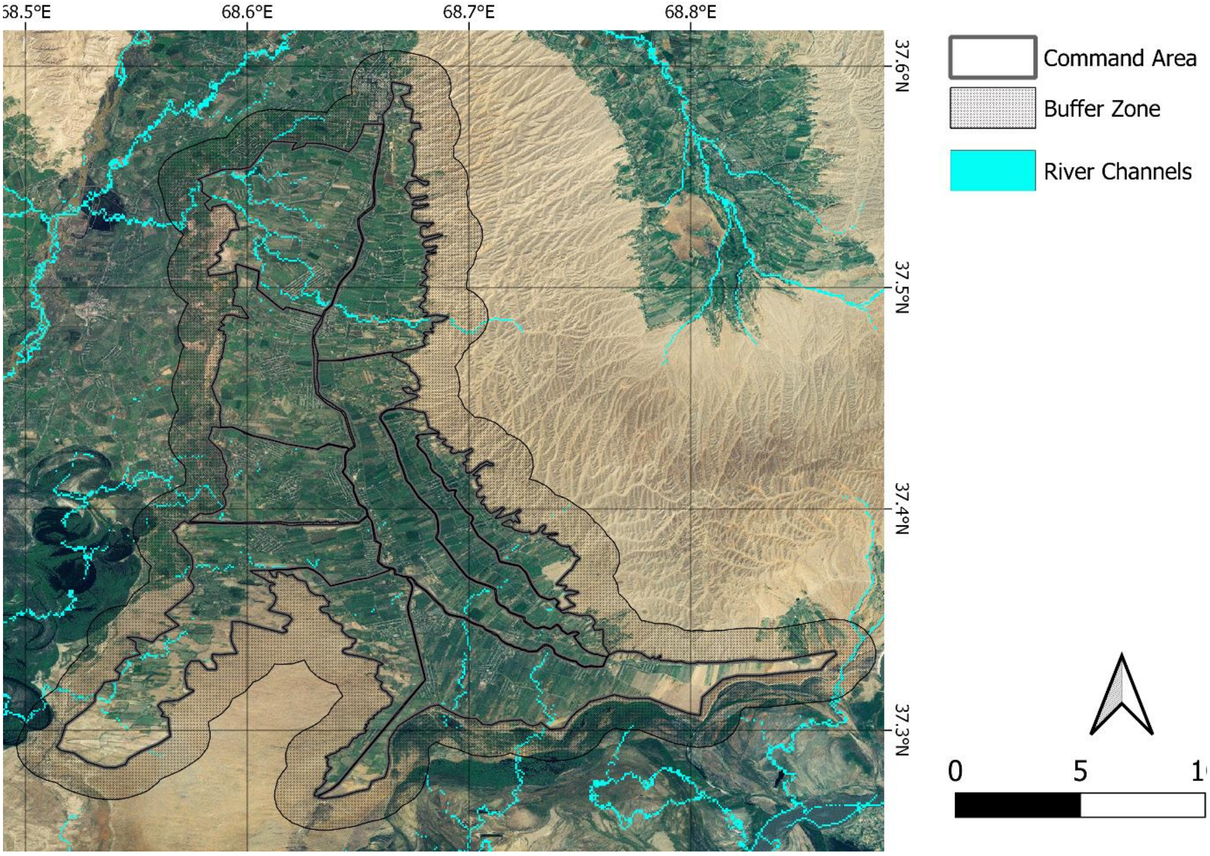


FIGURE VI-2. IMPLEMENTATION AREA FOR CLM-01 IN THE QUMSANGIR COMMAND ZONE AND BUFFER AREA



Based on these area estimates, the following table shows the implementation costs for both schemes, for Project 1 and the Full modernization/scaled-up Project. This intervention will not be included in Project 1 due to budget restrictions. See Annex A for more details on this intervention.

TABLE VI-6. COST TABLE FOR CLM01

Scheme	**Project***	**Area (ha)****	**Unit cost (US$/ha)*****	**Cost (US$)**
Jovon	Project 1	0	200	0
	Scaled-up project	2641	200	528,200
Qumsangir	Project 1	0	200	0
	Scaled-up project	792	200	158,400

** in project 1 only the hotspots*
*** risk areas in command area and 1 km buffer area around command area*
**** areas to be confirmed from 1-m-DEM analysis and cost-estimates are tentative*

b. Support for Small Scale Gully Stabilisation (CLM02)

Besides risk mitigation activities in CLM01 of the larger gullies, a set of measures needs to be implemented to stabilise the smaller gullies, reduce the risk for new gully formation, and reduce erosion from agricultural fields in general. These issues are widespread and related to the lack of crop and vegetative cover, the agricultural practices used nowadays, in combination with the highly erodible loess soil in this area. Thus, stabilizing the smaller gullies which formed through erosion in the catchment, as shown in **Figure VI-3**, is an important aspect to focus on to increase the resilience of land around especially the Yovon scheme.

The WOCAT database shows many Nature-based Solutions which have been implemented in Central Asia to deal with this problem, for example the planting of vegetation and native trees in gully formations to rehabilitate and stabilize land. Planting of deep-rooted grasses can be a very effective measure to stabilize eroded areas, alongside providing an area for sediment to collect rather than washing down the gully. For example, Spanish Drop is a species used elsewhere as useful in rehabilitating eroded gully areas due to its affordability and the fact that it grows relatively and spreads on bare sediments. It is important for the selection of species to rely on experiences in similar agro-ecological zones in the region.

Also controlling runoff from hillslopes to prevent erosion during extreme rainfall events is considered an necessary adaptation strategy for the schemes. The climate model ensemble predicts on average an increase in the intensity of precipitation in the project area – these solutions can therefore fulfil dual roles of decreasing erosion and increasing water retention and infiltration to the subsurface. Implementation of graded bunds are especially recommended in this case. Implementing these measures can be beneficial in terms of both controlling erosion and at the same time improving the livelihoods of the farmers[10].

Figure VI-3. Gully rehabilitation interventions in an area close to the Vaksh valley.

Annex A provides a summary sheet of this intervention. The following table provides a cost-estimate of this intervention per scheme and project.

Table VI-7. Cost table for CLM02.

Scheme	Project*	Area (ha)**	Unit cost (US$/ha)	Cost (US$)
Jovon	Project 1	1,000	50	50,000
	Scaled-up project	2,000	100	200,000
Qumsangir	Project 1	0	50	0
	Scaled-up project	500	100	50,000

** refers to gullied areas only*
*** Areas to be confirmed from 1-m-DEM analysis and cost-estimates are tentative*

[10] https://qcat.wocat.net/en/wocat/technologies/view/technologies_1033/

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ANNEXES

ANNEX A: SUMMARY TABLES OF ADDITIONAL CLIMATE ADAPTATION MEASURES (CLM01 AND CLM02)

ANNEX A

SUMMARY TABLES OF ADDITIONAL CLIMATE ADAPTATION MEASURES (CLM01 AND CLM02)

CLM-01	**Buffer Strip and Riverine Area Development**
1. Background	Infrastructural measures and vegetative measures at peripheries of cultivated areas and along river banks can trap sediment and water running off land. There are several options that are widely used to control sediment delivery to water bodies in these circumstances.
2. Rational	Planting of dense vegetation at peripheries of cutivated areas reduces sediment and water export; planting along irrigation channels reduces sediment delivery and siltation issues; vegetation in the riverine area reduces erosion and sediment export to the river; protection of gully walls with gabion structures are needed to mitigate the larger and deep gullies
3. Objective(s)	Trap water and sediment to stop flow down-slope; reduce entry of sediment to irrigation channels and rivers, and take measures to stabilize the larger and deeper gullies
4. Description of Scope and Activities	- Planting of (native) trees along terrace edges, in buffer zone, along gullies, and along irrigation canals - Maintenance of tail-ends of pipelines where water needs to be safely channelled down into river - Gabion structures to stabilize the deeper gullies in the riverine area and the "bad-lands" area around the command area - Fencing to control grazing
5. Main benefits and beneficiaries	Benefits – reduced loss of productive land, reduced soil erosion, reduced siltation of irrigation channels. Beneficiaries – WUAs
6. Implementing Arrangements	To be implemented by a contractor, given the construction of large gabion structures and vegetative interventions in the riverine area.
7. Costs	Approx 200$/ha for the riverine area and areas with large gullies – both in command area as well as the surrounding "bad-lands".
8. Monitoring arrangements for performance	Monitoring of the effectivness of the stabilized gullies; monitoring of siltation of irrigation channels; inspection of plant / tree health
9. Risks and Uncertainties	Vegetative measures may lead to minor loss of productive agricultural land but this is likely fully offset by the effect that reducing erosion and stabilizing gullies have on the long-term: reducing the loss of productive land. A growth and establishment period is required for the vegetative measures.
References and more info	WOCAT: https://qcat.wocat.net/en/wocat/technologies/view/technologies_1509/

CLM-02	**Support for Small Scale Gully Stabilisation**
1. Background	The project will support small scale gully stabilisation by building capacity among WUAs and providing the required materials and equipment. Gully plugging and vegetative measures are techniques to provide a physical barrier to water erosion through gully formations, already used in Tajikistan elsewhere. Also, breaching of irrigation channels due to poor maintenance led to large erosion events and gully formation in past. A set of measures relieves pressure on systems during high flow and intense precipitation events.
2. Rational	Gullies have formed in the command area of the proposed irrigation scheme, several measures like gully plugging and vegetative measures can help to rehabilitate these areas and prevent further erosion. This

	entails the smaller gullies: the larger and deeper gullies are mitigated in CLM01.
3. Objective(s)	Reduce further field erosion, rehabilitate existing gully formations, reduce risk of channel breach scenarios, more effectively remove water during high flows,
4. Description of Scope and Activities	Support (capacity, equipment and material) to farmers on: - Implementation of graded bunds for collection and safe disposal of excess water (from irrigation and precipitation events). - Stabilise gullies with protection using gabion baskets filled with stones and vegetative measures, etc. - Building of checks and structures in gully formations, by using locally available materials (rock), - Use of temporary structures that can be constructed of eg. brushwood to encourage vegetative growth, constructed laterally to gully downsloipe direction - Planting of fast-growing native species in gully formations (willow, spanish drok). Planting lateral to gully downslope direction. May need temporary structures to shelter seedlings during early growth. - Maintenance of irrigation channels - Fences for grazing control of the gully areas
5. Main benefits and beneficiaries	Benefits - reduced risk of gully formation and deepening, less loss of productive land to erosion, increased infiltration of water
6. Implementing Arrangements	A local NGO with experience in sustainable land management and land restoration
7. Costs	Costs are mainly related to training activities and gabion wires. Within the proposed project (project 1), only the most urgent areas will be mitigated, focusing on gully stabilisation measures with gully plugs. Estimated unit cost: 50 $/ha If scaled-up to the full command area, integrating more sustainable land management activities (as listed above in 4), the estimated unit cost is 100$/ha
8. Monitoring arrangements for performance	Inspection of channels, observation of structures during high precipitation / flood events. Monitoring of trapped silt/ sediment by each check dam; Monitoring of trapped sediment by vegitation, regular inspection of plant / tree health
9. Risks and Uncertainties	Maintenance required, liable to damage, Lateral erosion of gullies; Growth / establishment period required.
References and more info	WOCAT: https://qcat.wocat.net/en/wocat/technologies/view/technologies_1362/ https://qcat.wocat.net/en/wocat/technologies/view/technologies_1541/; https://qcat.wocat.net/en/wocat/technologies/view/technologies_1493/. SSWM: https://sswm.info/sswm-solutions-bop-markets/improving-water-and-sanitation-services-provided-public-institutions-0/check-dams-%26-gully-plugs