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Preparing Climate Adaptive Water Resources Management in the Aral Sea Basin Project

Detailed Climate Risk and Vulnerability Assessment for Water Resources Investment Projects in the Aral Sea Basin

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Asian Development Bank

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Summary

1. The Asian Development Bank (ADB) has formulated and is carrying out the "*Preparing the Climate Adaptive Water Resources Management in the Aral Sea Basin Project".* It aims to modernize outdated irrigation and drainage (I&D) subprojects within Amu Darya and selected reaches of the Zarafshan River Basins in Uzbekistan, using a long term, knowledge based and climate resilient approach. Two subprojects are selected for feasibility studies for modernized and improved Irrigation and Drainage infrastructure: **Jondor (Bukhara oblast) and Babatag (Surkhandarya oblast).**

2. Historic climate trends were assessed for the two subprojects, using a state-of-the-art climate reanalysis product for trend detection in temperature and precipitation. **Results show a trend of increasing temperatures of 1ºC in the period 1979-2019 for both subprojects. Annual precipitation for the same period has decreased slightly.**

3. Both project areas heavily dependent on water delivered by the Amu Darya. **Analysis of historical trends in flows for the last 30 years showed a reduced annual flow volume of around 0.5 km3/year** (which corresponds to around a 10% reduction over a period of 10 year). This historic reduction is likely mainly caused by changing water use patterns in areas of the subprojects, rather than changes in precipitation and snow melt regimes.

4. Due to changes in the glacier and snow dynamics upstream, the seasonality of flows has already changed for upstream countries in the last decade as **peak flows occur earlier in the season**. The impact of this change is yet not notable to Uzbekistan due to the upstream reservoirs. Climate projections analyzed for the upstream Amu Darya basin show however that the flow regime change will be more pronounced over the next decades and could then become notable for water supply to irrigation systems in Uzbekistan. Especially, flows are expected to become more variable: seasonal and inter-annual.

5. To characterize future changes in climate for the two subproject areas, analysis of data produced by a state-of-the-art downscaled multi-model ensemble (NASA-NEX) was conducted. Outputs from the 21 climate models included in the ensemble for two RCP emissions scenarios and 3 time horizons (historical, 2030, 2060) were used to obtain projections for future trends in precipitation and temperature. **All climate models predicted a hotter future for both subproject areas, with most of the models predicting an increase of more than 2ºC for the 2060 horizon (Table S-1).** Figure S-1 shows the increasing trend in temperature for Babatag subproject. **For rainfall, the projections are ambiguous as some models project a drier future and others a slightly wetter one (Table S-2).**

Table S-1. Summary table showing statistics regarding spread in the General Climate Models' (GCM) projections for future changes in daily temperatures for Jondor subproject and Babatag subproject (here only presented for RCP85). ***Median*** **is the projected change in annual average temperature;** ***GCMs >2ºC*** **and** ***>4ºC*** **indicate the number of GCMs (out of 21) that project increases of 2ºC and 4ºC respectively. Changes are calculated from the ERA5 baseline for the reference period (1986-2005).** ***10th and 90th Perc indicate the value below which resp. 10% or 90% of the models are found;***

Sub-project	Horizon_RCP	Median (ºC)	10th Perc. (ºC)	90th Perc. (ºC)	GCMs >2ºC	GCMs >4ºC
Jondor SP	2030_RCP85	1.7	1.3	2.6	7	0
	2060_RCP85	3.3	2.4	4.6	20	6
Babatag SP	2030_RCP85	1.8	1.4	2.6	7	0
	2060_RCP85	3.4	2.8	4.9	21	8

Table S-2. Summary table showing statistics regarding spread in Climate Model (GCM) ensemble predictions for future changes in precipitation for Jondor SP and Babatag SP (here only presented for RCP85)

Sub-project	Horizon_RCP	Median (%)	10th Perc. (%)	90th Perc. (%)	GCMs Dryer	GCMs Wetter
Jondor SP	**2030_RCP85**	5%	-21%	17%	8	13
	2060_RCP85	-2%	-21%	22%	12	9
Babatag SP	**2030_RCP85**	2%	-11%	19%	9	12
	2060_RCP85	-1%	-12%	26%	11	10

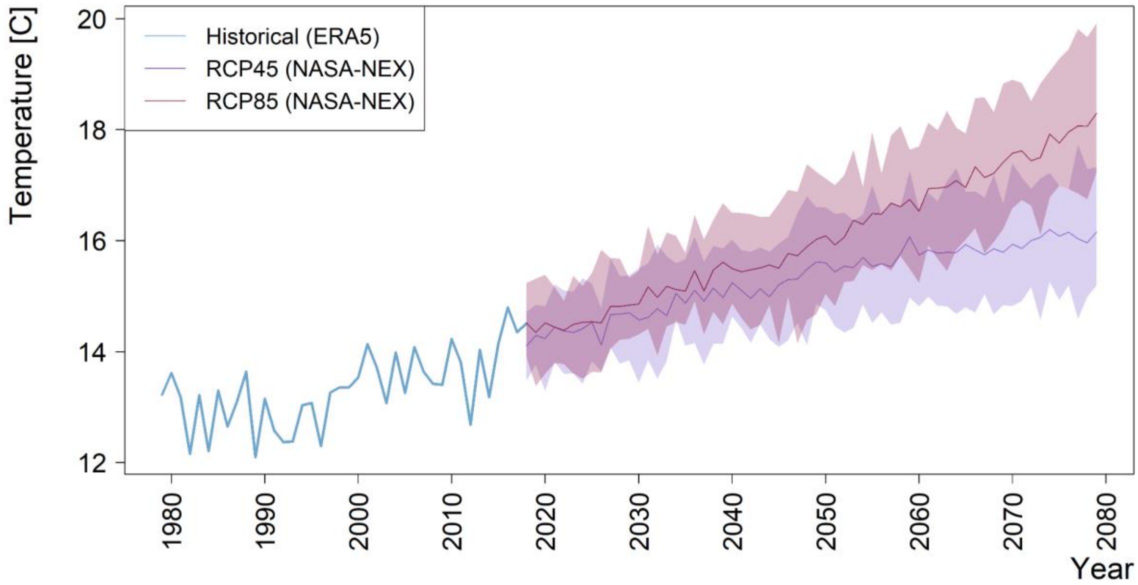

Figure S-1. Time series of mean yearly temperature for the Batabag subproject area (Surkhandarya province) constructed using ERA5 dataset for the historical period (1979-2019), and NASA NEX (per model bias corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model projections.

6. In terms of **seasonality**, climate model ensembles predicted that **temperature increases will be most severe in the already hot summer months** (June – August) for both subprojects. Trends in the seasonality of precipitation were less clear but suggest that current precipitation regimes during the cropping periods will not be significantly change in future.

7. The climate model ensemble also indicated that there will be changes in the severity of extreme climate events over time. Analysis of temperature related extremes indicated a likely **increase in extreme heat events and the number of days per year in which average temperature exceeds 35ºC**. Extreme cold events were predicted as decreasing, with minimum yearly temperatures increasing significantly for both project areas. Analysis of future precipitation extremes shows more uncertain results, with no clear trends predicted for the project areas.

8. Potential impacts were then assessed to categorize the related climate risk and identify priorities for adaptation. Through a combination of field and stakeholder information, quantitative analysis, and expert judgement, the extent to which the key climate risks pose a threat to the project were assessed.

9. The prioritized risks are**: (I) Reduced water availability; (II) Increased water demands; (III) Increased crop heat-stress; (IV) Increased salinization issues** (Jondor)**; (V) Increased erosion and landslides** (Babatag**); (VII) Increased sedimentation of infrastructure.**

10. To analyze the risk for additional water shortages due to climate change, a quantitative modeling framework has been used in which the demand and water supply were simulated. Using several performance metrics and so-called Climate Response Surfaces, the project performance under the plausible range of future climate variables was investigated.

11. **For both subprojects, the project water demand is likely to increase by at least 10% in the next 30 years.** Using the climate model-ensemble (21-members), the uncertainty in this estimate was assessed, as presented in Table S-3. As can be seen, for example, an increase of 5% or more is very likely (21 models out of a total of 21). On the other hand, an increase of more than 15% is unlikely (0 models out of 21).

Table S-3. The number of climate models per RCP scenario and horizon that predict an irrigation demand increase above a certain threshold (representative for both SPs).

Scenario/horizon	Change > 5%	Change > 10%	Change > 15%
rcp45			
2030	20	6	0
2060	21	19	7
rcp85			
2030	21	10	0
2060	21	21	18

12. Given the already very low precipitation amounts for both subprojects during the cropping season, changes in precipitation have limited influence on irrigation demands. Amu Darya flow changes however, as expected, have a major impact on future performance of the irrigation systems. Figure S-2 shows the Climate Response Surface for Coverage (percent gap between demand and supply). As can be seen, Coverage is mainly influenced by flow changes in the Amu Darya river, but also increased local temperatures impact the project performance to some extent.

13. Overall, the gap between supply and demand **could increase by around 20%.** This is due to the long-term negative trend for Amu Darya flows, increased variability, and water demand increases by around 10% due to increased temperatures and crop water requirements. The reliability of the supply is impacted similarly. The analysis further confirmed the extremely high water stress at the basin-level which will be further aggravated by climate change, and may lead to conflicts among users and uses.

14. Temperature-related impacts were assessed looking at the heat tolerance-level of several crops and cold temperature thresholds. This showed that especially for the 2060 horizon, there will be **a significant increase in the number of days on which the heat-threshold is breached during the growing season**. The increase is substantial and may make the production of cotton unfavorable over the next decades, but also other crops currently cultivated in July and August.

15. Other climate risks that were found most relevant are **salinization for Jondor**, **erosion and landslides for Babatag**, and **sedimentation of infrastructure for both subprojects**.

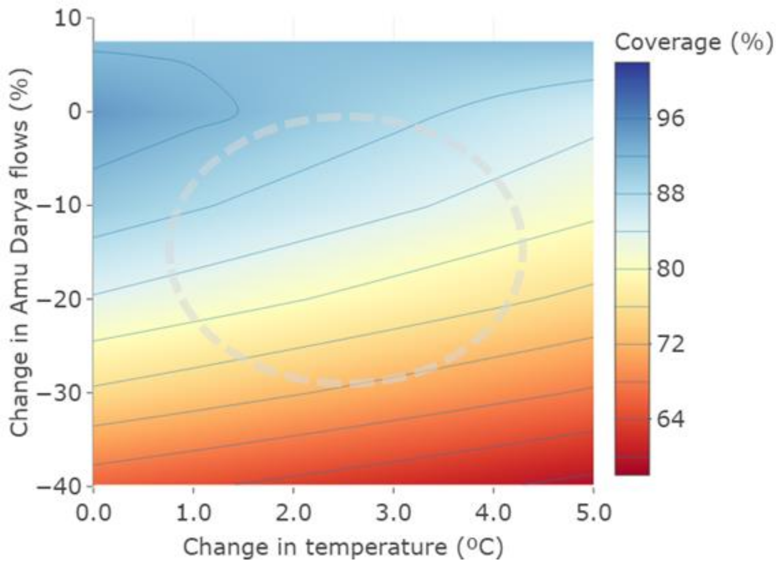

Figure S-2. Climate Response Surface for Coverage (Percent of demand met by a supply) of the Jondor SP, as function of changes in local temperature and Amu Darya flows. The grey circle gives an indication of where most of the projections (temperature) and studies (flows) are pointing to.

16. The overall aim of the project is to respond to and reduce the climate risks that were evaluated as most relevant for the respective SPs. Thus, an integrated package of proposed interventions was prepared which will reduce the prioritized risks and thus make the system as whole more resilient.

17. Key climate risks **(i) reduced water availability, (ii) increased water demands,** which lead to increased water shortages and will be addressed by several project components across the three outputs of the project, including: re-sectioning and modernization of main canals, interfarm canals, establishment of improved control structures and protective works, construction of improved measurement and canal control systems, introduction of modern climate resilient irrigation technologies, and a comprehensive package of capacity building activities targeting WMO and WCA´s on different topics, introducing climate adaptive water resources management and allocation approaches.

18. Additional climate change finance (ADF-13) will be employed to finance specific project components that **target increased resilience of those farmers that are currently suffering most from unreliable and unequitable water distribution. A key highly innovative activity** to be financed through this finance source is the remote sensing-based monitoring of water consumption and water productivity to improve allocation and project performance evaluation. This will enable farmers and irrigation system management to reduce the unequitable service levels and distribution in the system.

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1 Relevance

1.1 Project background

1. The Asian Development Bank (ADB) is committed to supporting the government of Uzbekistan in delivering climate adaptive solutions for water resources management. These solutions aim to modernize irrigated areas, providing more reliable access to water in agriculture. This will allow the country to continue growing its agricultural sector and diversify production with an eventual aim of increasing exports. This is in line with the Strategy of Actions on Further Development of Uzbekistan (2017), which identifies the introduction of water saving technologies, further improvement of irrigated lands and modernisation of agriculture as crucial to the development of the country.

2. To help Uzbekistan achieve these goals, ADB have helped to formulate the *Preparing the Climate Adaptive Water Resources Management in the Aral Sea Basin Project.* Its objectives are as follows: "the proposed project (in Uzbekistan) will undertake a long-term and knowledge-based approach to deliver climate adaptive solutions for water resources management. It will modernize outdated irrigation and drainage (I&D) subprojects within Amu Darya and (selected reaches of the) Zarafshan River Basins in Uzbekistan. The project will increase agricultural water use productivity through a threefold approach: (i) climate resilient and modernized I&D infrastructure to improve measurement, control and conveyance within existing systems; (ii) enhanced and reliable on-farm water management including capacity building of water consumer associations (WCAs), physical improvements for land and water management at the farm level and application of high level technologies for increased water productivity; and (iii) policy and institutional strengthening for sustainable water resources management. This will include strategic support to the Ministry of Water Resources (MWR) and its provincial, basin and district agencies and WCAs." (ADB, 2019).

3. As part of the technical assistance, the team will support the government to prepare feasibility studies of two selected (representative) Irrigation and Drainage (I&D) subprojects to be developed under the ensuing loan project. The feasibility studies will identify proposed interventions and include technical (engineering design) and environmental, social, and economic and financial assessments. The selected project areas are as follows (Figure 1-1):

- **Jondor**: Irrigation network in the Centre of the country, fed via a central canal which takes water from the Amu Darya and (Figure 1-2).
- **Babatag**: Irrigation network in the East of the country, fed via a canal which takes water from the Amu Darya (Figure 1-3).

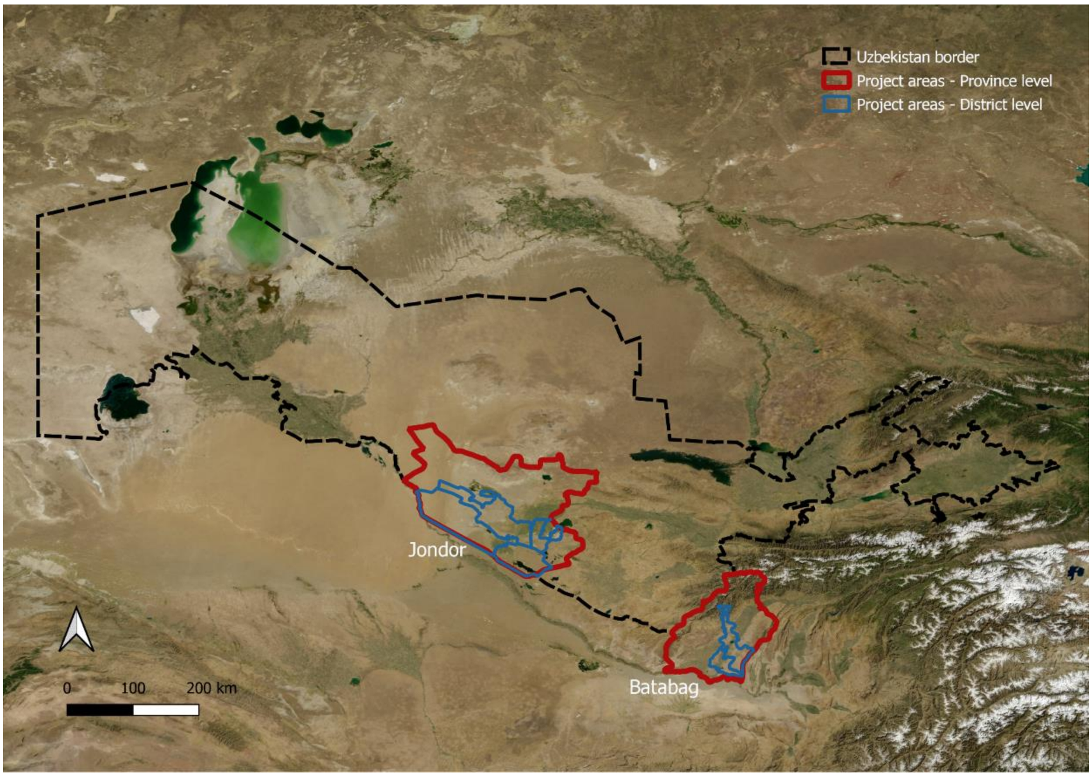

Figure 1-1. Provinces and districts in which proposed water management interventions will take place.

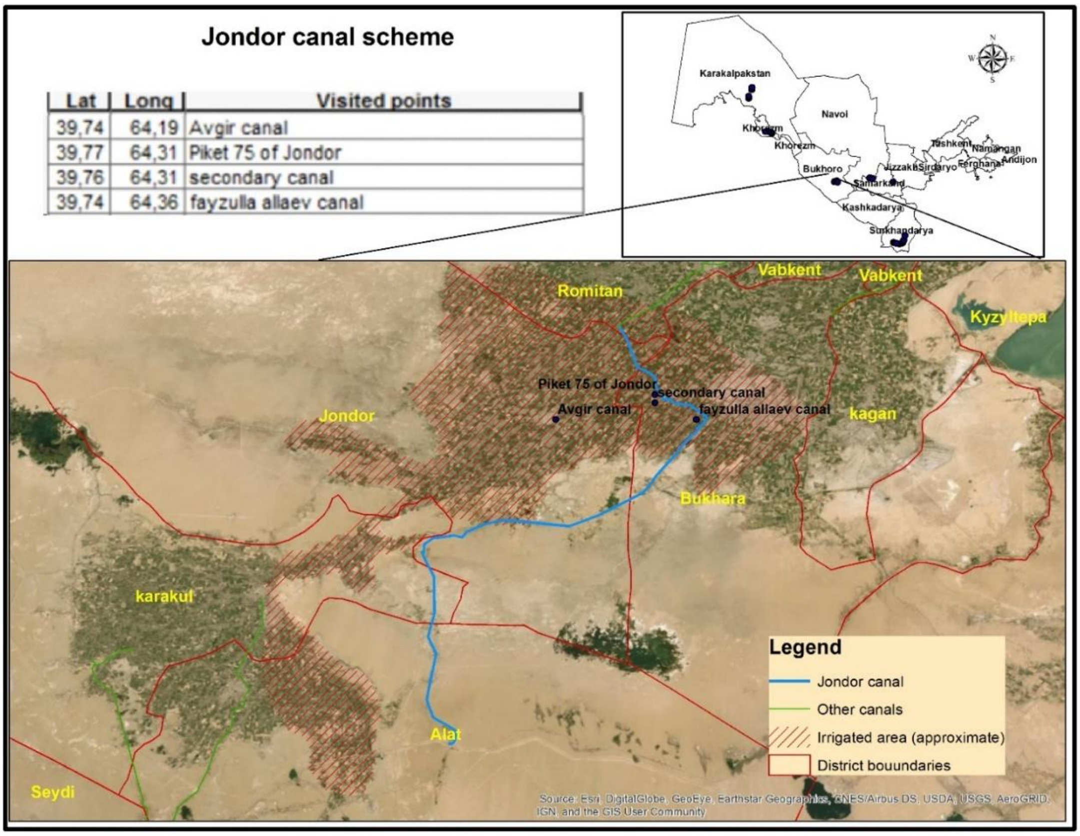

Figure 1-2. Schematic of Jondor canal and associated irrigated area (taken from the Inception report).

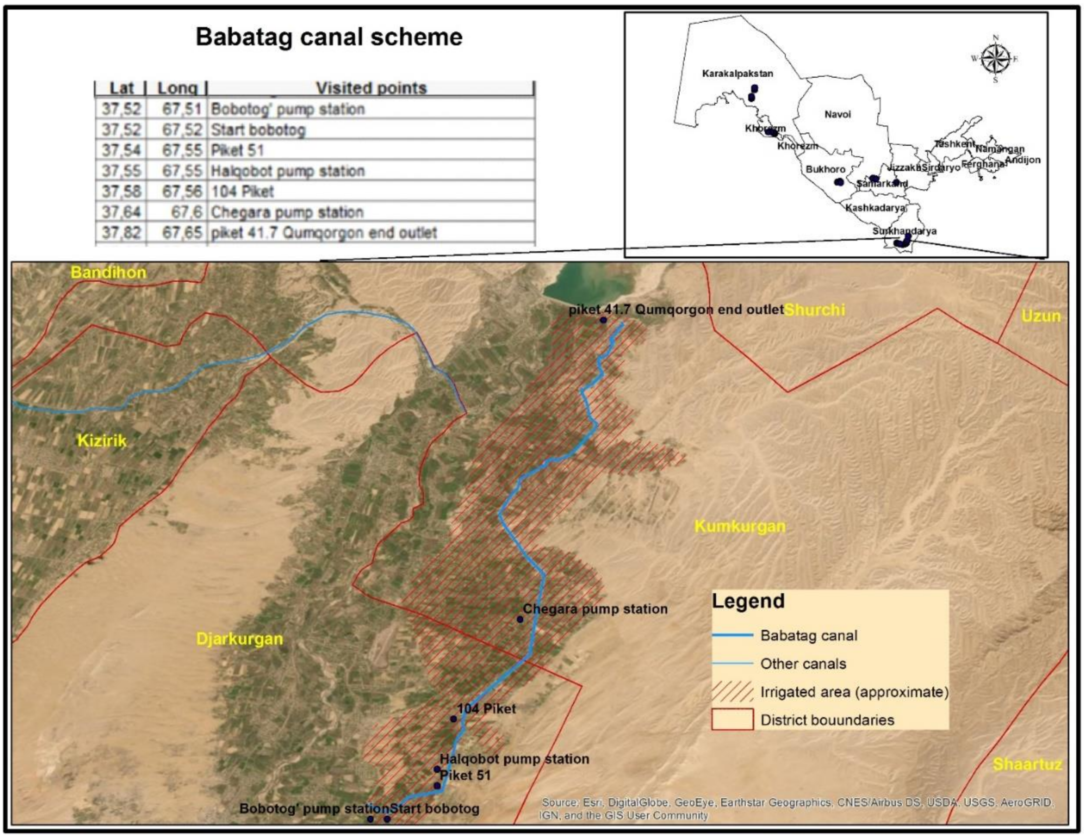

Figure 1-3. Schematic of Babatag canal and associated irrigated area (taken from Inception report).

1.2 Geography and climate of Uzbekistan

4. The physical environment of Uzbekistan is diverse, ranging from the flat, desert topography that comprises almost 80% of the country's territory to mountain peaks in the east reaching about 4,500 metres above sea level (Figure 3). Uzbekistan has a generally dry climate with long, warm to hot summers and moderate to cold winters.

5. The country can be broadly divided into two climatic zones: (1) a desert and steppe climate in the western two thirds of the country and (2) a temperate climate characterized by dry summers and humid winters in the eastern areas. The desert plains, which includes the province of Bukhara, receive only around 80-200 millimeters (mm) of precipitation annually, while the foothills (Samarkand province) can get as much as 300-400 mm and mountainous regions up to 600-800 mm per year (Figure 2). Due to these prevailing climate conditions, agricultural output is almost fully dependent on irrigation. Main sources of water are transboundary rivers; Amu Darya and Syr Darya. Uzbekistan receives 52% of the total water available in the region, 92% of which is consumed by the agricultural sector (ADB, 2019).

6. Rainfall occurs mostly in late autumn through early spring, dropping off significantly during the summer months. The country is prone to large fluctuations in temperature, both seasonally and from day to day. Average monthly temperature for the country is highest in July, at 27°C, and lowest in January, at -3°C. However, temperature ranges vary across the country (Figure 4). Uzbekistan's desert regions can reach maximum temperatures of 45 – 49°C, while minimum temperatures in the southern parts of the country can drop as low as -25°C.

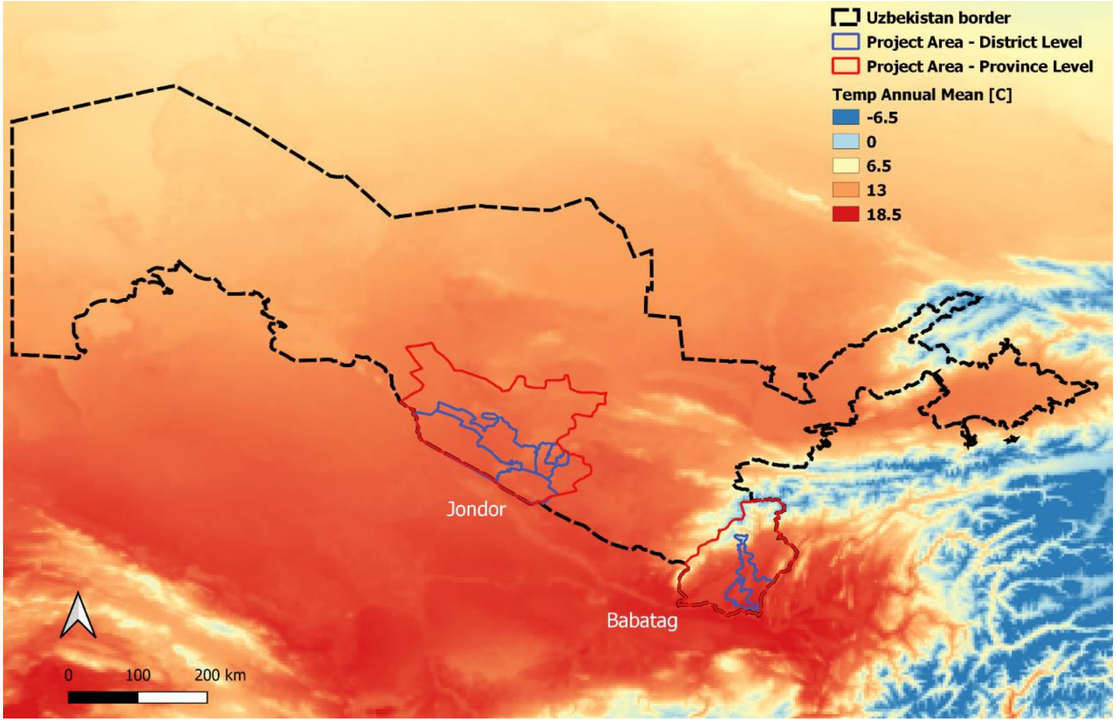

Figure 1. Mean annual temperature of Eastern Uzbekistan including project areas based on WorldClim datasets.

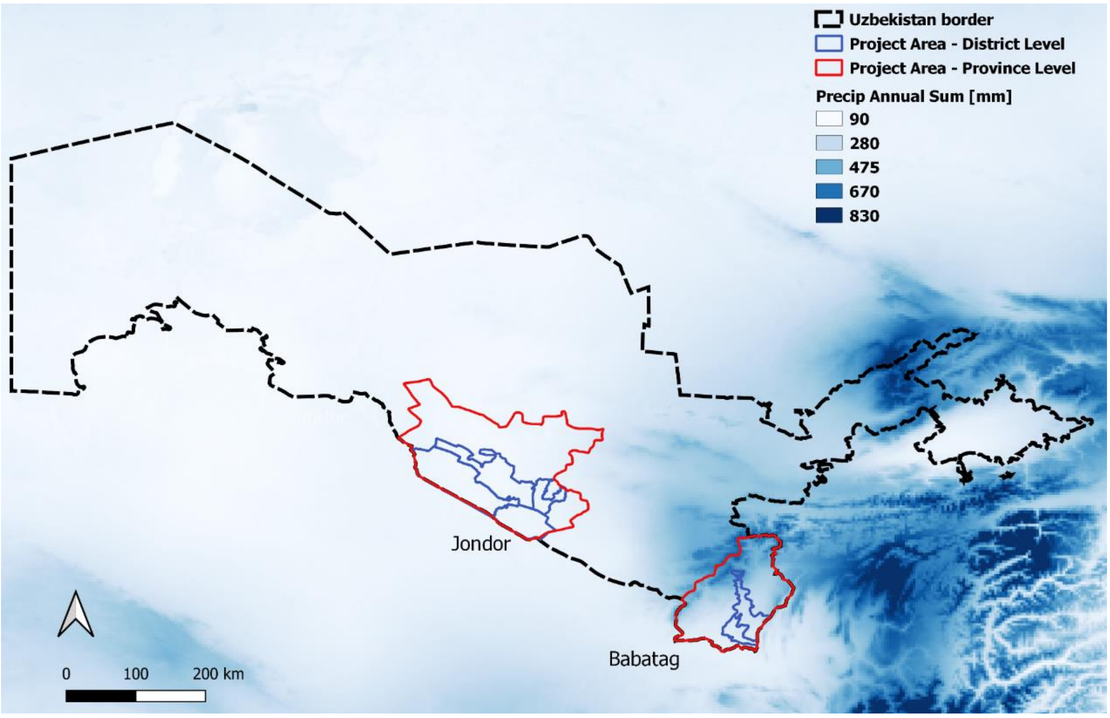

Figure 2. Mean total precipitation of Eastern Uzbekistan including project areas based on WorldClim datasets.

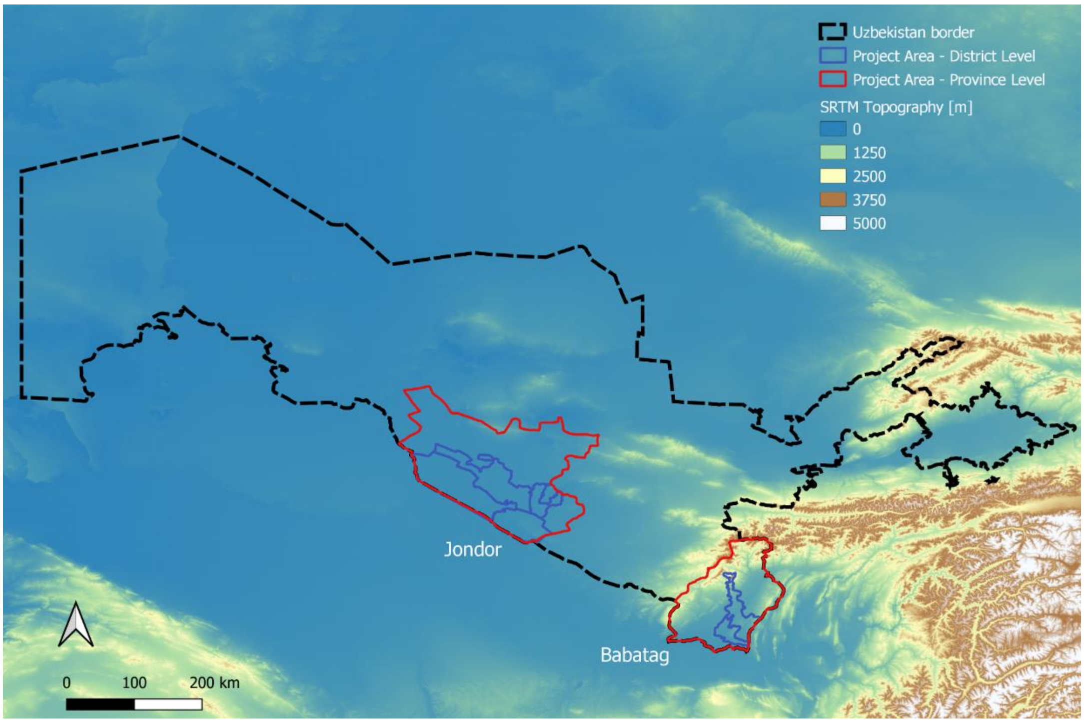

Figure 3. Topography of project areas based on SRTM imagery (30m resolution).

1.3 Expected climate sensitivities

7. Prior to any analysis, a list of expected climate sensitivities was prepared for the two subprojects (Jondor and Babatag), based on the information available so far (project documents, stakeholder consultations, inception meeting, etc). These potential sensitivities are listed in Table 1-1.

Table 1-1. Expected climate sensitivities for the subprojects

Climate and 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 vegetation and increased wildfire and pest risks in watershed areas. • Changes in watershed agricultural practices and in the resulting pollution loads from agriculture.	• Infrastructural interventions • On-farm interventions • Capacity building activities
Increases in very hot days and heat waves	• Modification in crop suitability and productivity (heat stress). • Increase in weeds, crop pests and disease outbreaks. • Increase wildfire risk.	• On-farm interventions • Capacity building activities
Fewer cold days and nights	• Chilling requirements for specific crops	• Capacity building activities
Precipitation Changes		
Increase in intense precipitation events	• Increased turbidity and sedimentation of surface water.	• Infrastructural interventions

	• 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 and waterlogging. • Increased pest incidence.	• On-farm interventions • Capacity building activities
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.	• Infrastructural interventions • On-farm interventions • Capacity building activities
Changes to extreme events		
Increase in the frequency of floods, landslides and droughts	• 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).	• Infrastructural interventions • On-farm interventions • Capacity building activities
More frequent sand storms	• Damage to crops and infrastructure	• Infrastructural interventions • On-farm interventions • Capacity building activities
Changes to upstream water balance		
Increase in temperature and changes in precipitation patterns	• Reduced glacier extent and/or reduced snow cover leading to changes in flow regime: increased interannual variability, peak flow earlier in the season, changed volumes • Increased competition for water resources by users upstream (agriculture, hydropower, etc)	• Infrastructural interventions • On-farm interventions • Capacity building activities

1.4 Approach to the CRVA

8. 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).

9. 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.

10. Generally, Climate Risk and Vulnerability Assessments (CRVA) tools and methodologies are used selectively depending on the sector and purpose. Many recent studies make a distinction between climate scenario-driven impact assessment approaches, often referred to as "top-down" and vulnerability-oriented approaches called "bottom-up." Figure 1-4 shows the main distinction between the top-down and the bottom-up approach; this relates to the way in which the two methodologies utilize GCM projections. The top-down approach is constrained to specific GCM projections, while the bottom-up approach considers a continuous range of potential changes in climate. Further discussions on this top-down and bottom-up approaches are presented by the World Bank (2015). For this climate risk screening analysis, a "bottom up" approach is deemed most relevant as it allows for a wide range of scenarios to be considered by decision makers.

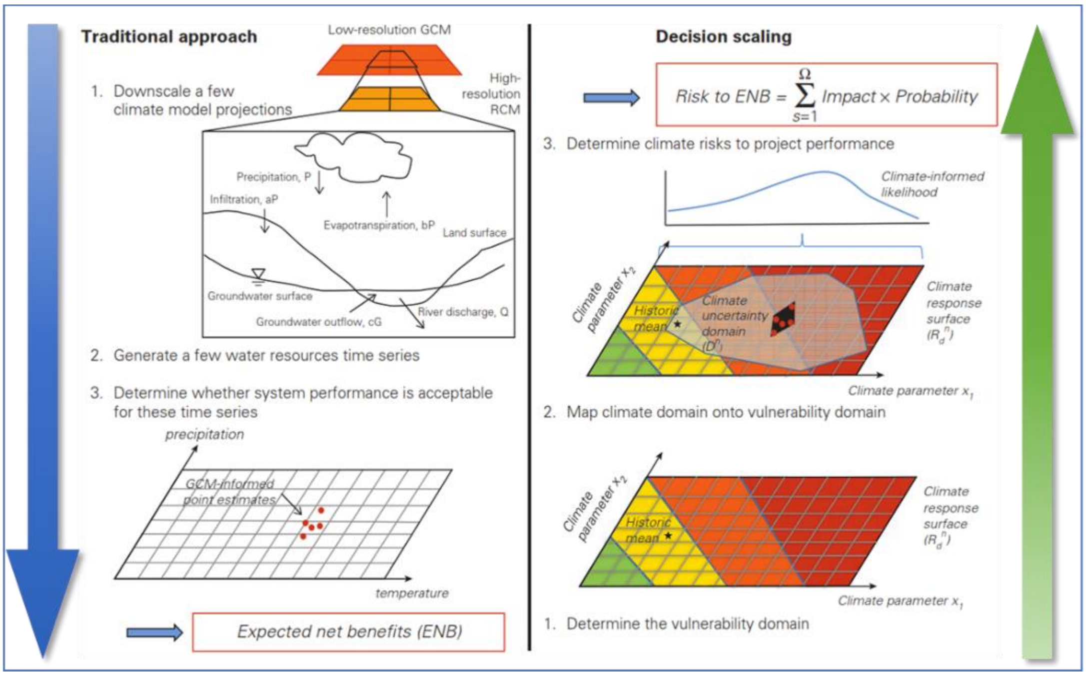

Figure 1-4. Schematic comparison of decision scaling, a bottom-up approach, (right) with traditional approach (left) to CRVAs (based on World Bank, 2015).

11. CRVAs 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 1-5:

- 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.

Please note that as "vulnerability" is part of "risk", recently ADB started using the term Climate Risk Assessment (CRA) instead of CRVA.

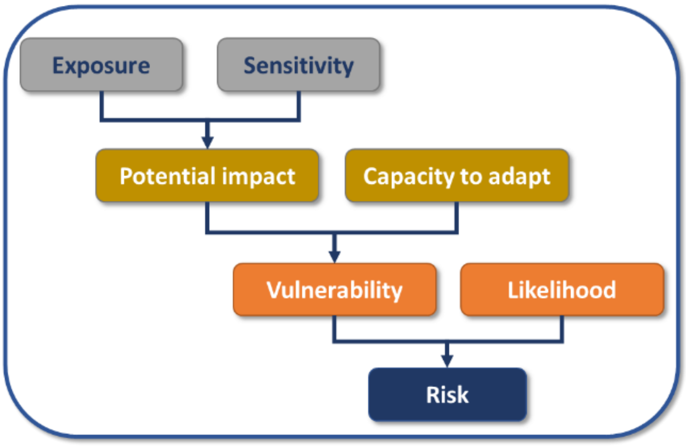

Figure 1-5. Climate Risk components. (based on http://www.ukcip.org.uk).

1.5 Objectives

12. This CRVA assesses historic trends in relevant climate-related variables and analyzes climate projections for the subproject areas. Then, based on these projections, an assessment is presented on the vulnerabilities of the irrigation systems and principal climate risks are prioritized. The climate adaptation measures, part of an integral package of interventions, are then listed that should reduce these climate risks.

13. As such, this detailed climate risk assessment is structured as follows:

- Identification of potential climate sensitivities of key project components (see previous section);
- Analysis of historic trends in key climate-related variables in project area (Chapter 2);
- Broad understanding of projected change in key climate variables in project area (Chapter 3);
- Analysis of potential impacts and likelihoods of change, with a categorization of the climate risks (Chapter 4);
- Climate adaptation measures responding to the prioritized climate risks (Chapter 5).

2 Historic Climate-related Trends

2.1 Climate observational dataset

14. An essential step in developing a credible and acceptable climate risk assessment is to look at historic observations of climate and to perform trend analyses. Note however that 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.

15. 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.

16. For the purposes of this project, the ERA5 reanalysis product[1] from the ECMWF is used to represent historical trends in temperature and precipitation for the given area of interest. 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

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

2.2 Jondor SP

2.2.1 Temperature trends

17. Historical data on temperature shows that average annual temperatures are around 16ºC for the Jondor sub-project area. Extreme variations in temperature are evident, with average daily temperatures ranging from around -18 to 38ºC over the course of the year (Figure 4). A clear seasonality is evident in Figure 6, with high average monthly temperatures (around 30ºC) prevailing during the growing season for many common crops (April - September).

18. Analysis of temperature data shows that temperatures have increased in the time period 1979-2019 (approximately 1ºC in 40 years, see Figure 5). This is supported by communication with local stakeholders who indicated that temperature extremes have increased in recent years, and referenced the year 2019 when extremely high temperatures were measured leading to discomfort for farmers. This source indicated also that the temperature extremes led possibly to more diseases in fruit trees.

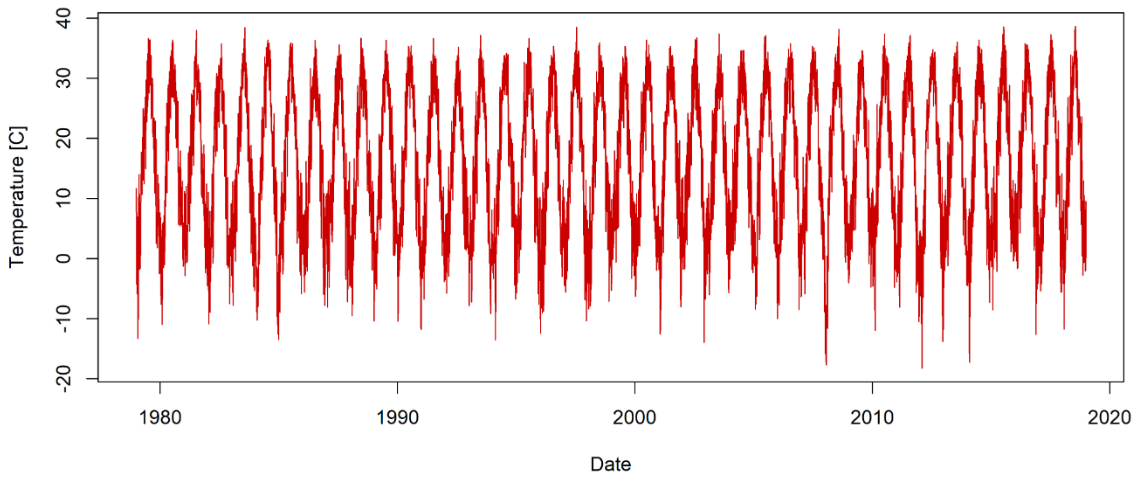

Figure 4. Daily average temperature from ERA-5 dataset for the Jondor area (Bukhoro province).

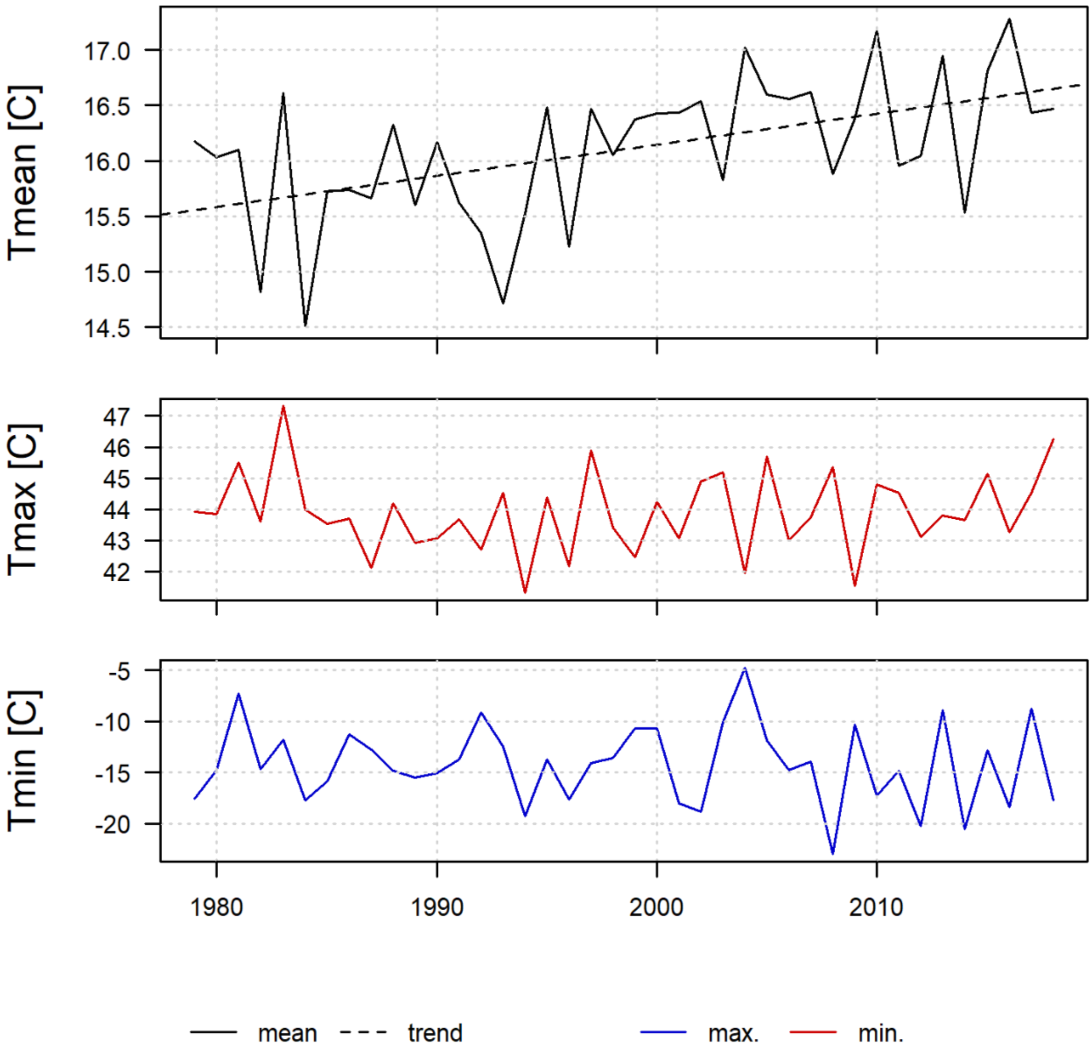

Figure 5. Average, maximum and minimum yearly temperatures from ERA-5 dataset with trendline for the Jondor area (Bukhoro province).

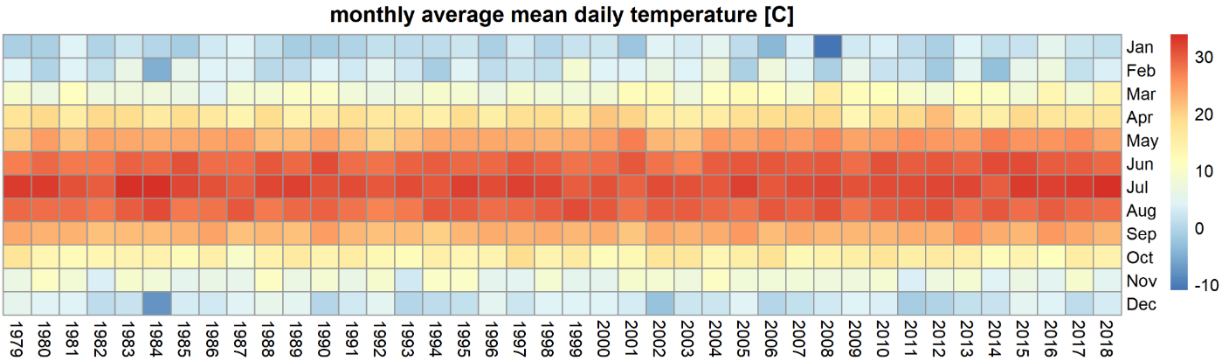

Figure 6. Seasonality in temperature from ERA-5 dataset for the Jondor area (Bukhoro province).

2.2.2 Precipitation trends

19. Historical data on precipitation shows that average total annual precipitation is very low at around 150 mm for the Jondor sub-project area (Figure 8). A trend of decreasing total annual rainfall is evident

for this period, but with high inter-annual variability (Figure 8). 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 9).

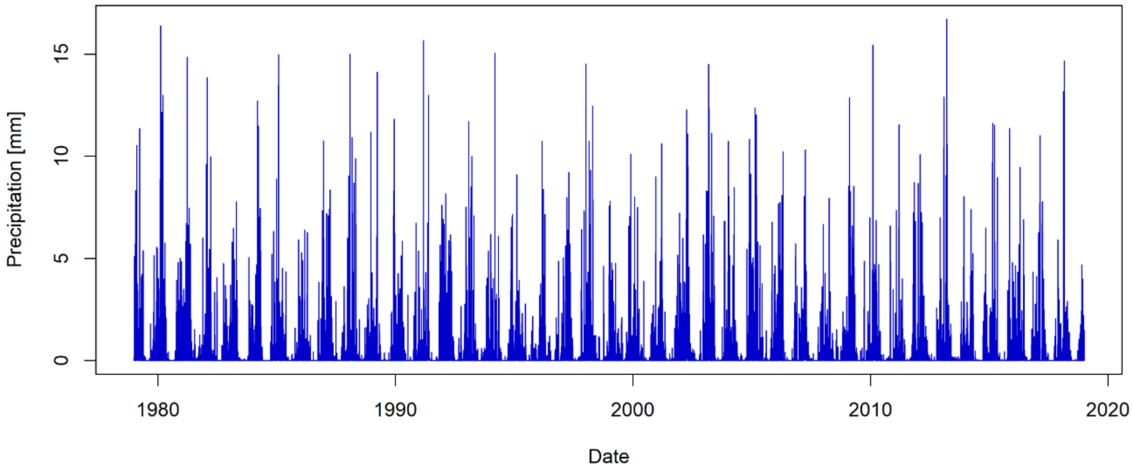

Figure 7. Daily precipitation from ERA-5 dataset for the Jondor area (Bukhoro province).

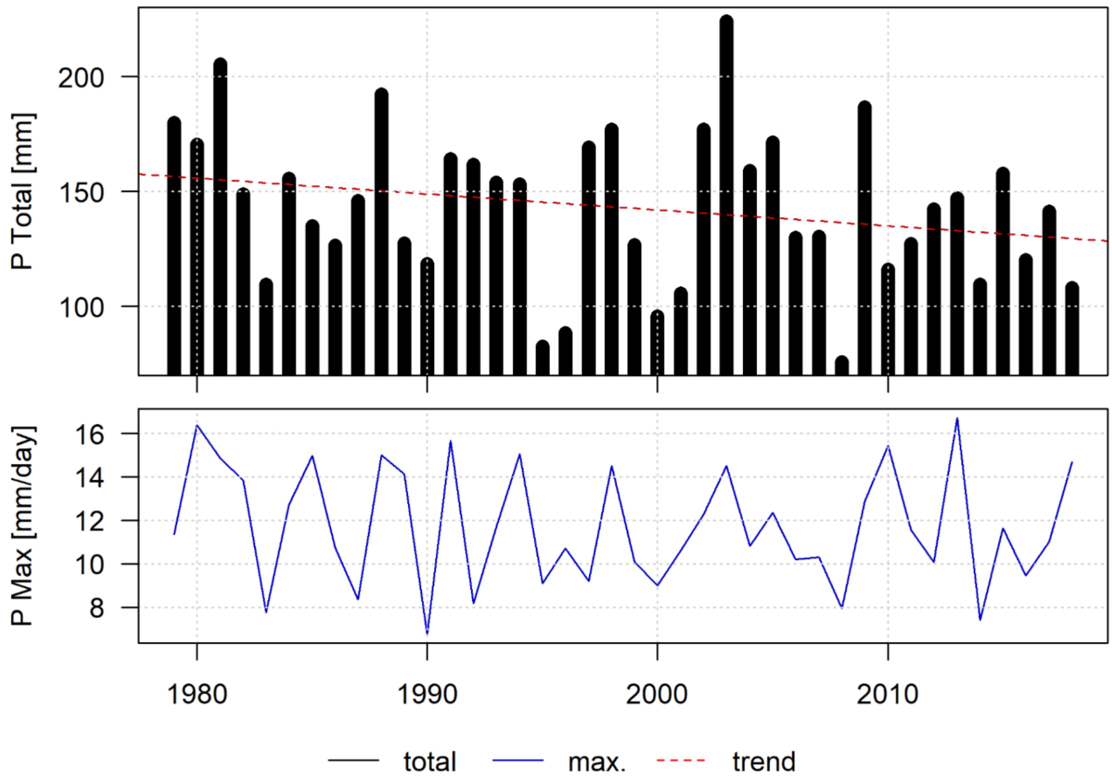

Figure 8. Total yearly and maximum one day precipitation from ERA-5 dataset with trendline for the Jondor area (Bukhoro province).

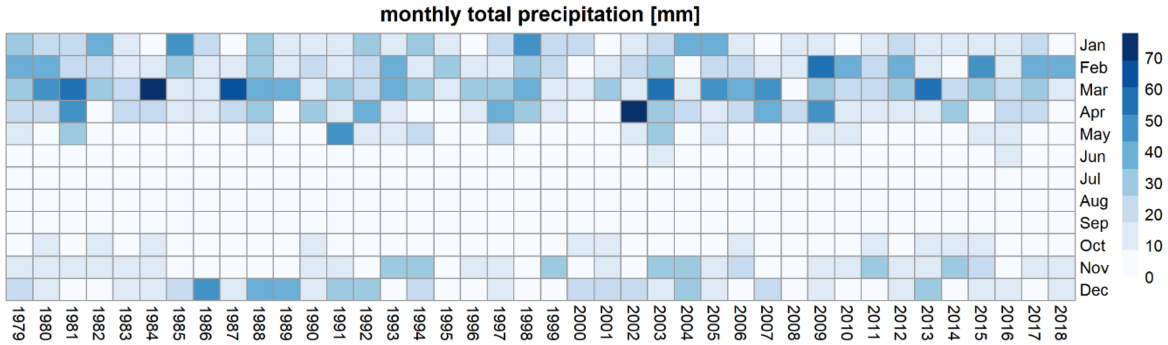

Figure 9. Seasonality of precipitation from ERA-5 dataset for the Jondor area (Bukhoro province).

2.3 Babatag SP

2.3.1 Temperature trends

20. Historical data on temperature shows that average annual temperatures are around 13.5ºC for the Babatag sub-project area. Extreme variations in temperature are evident, with average daily temperatures ranging from around -5 to 30ºC over the course of the year (Figure 10). A clear seasonality is evident in Figure 12, with high average monthly temperatures (around 25ºC) prevailing during the growing season for many common crops (April - September). Please note however, that there are large altitude differences in this region, which means that the absolute values for temperature at the project area are probably different, and higher. For trend analysis (purpose of this assessment), this limitation that generates a systematic bias is fortunately not relevant.

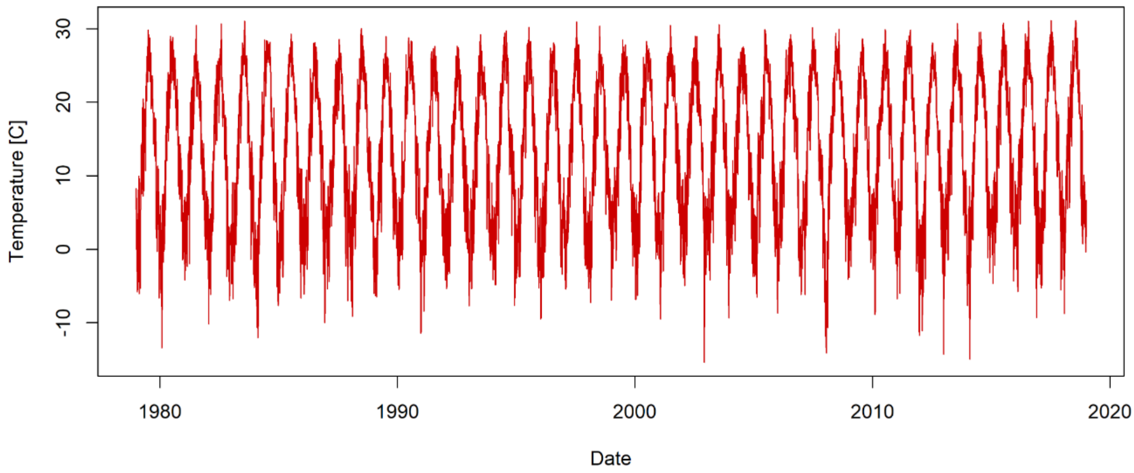

Figure 10. Daily average temperature from ERA-5 dataset for the Batabag area (Surkhandarya province).

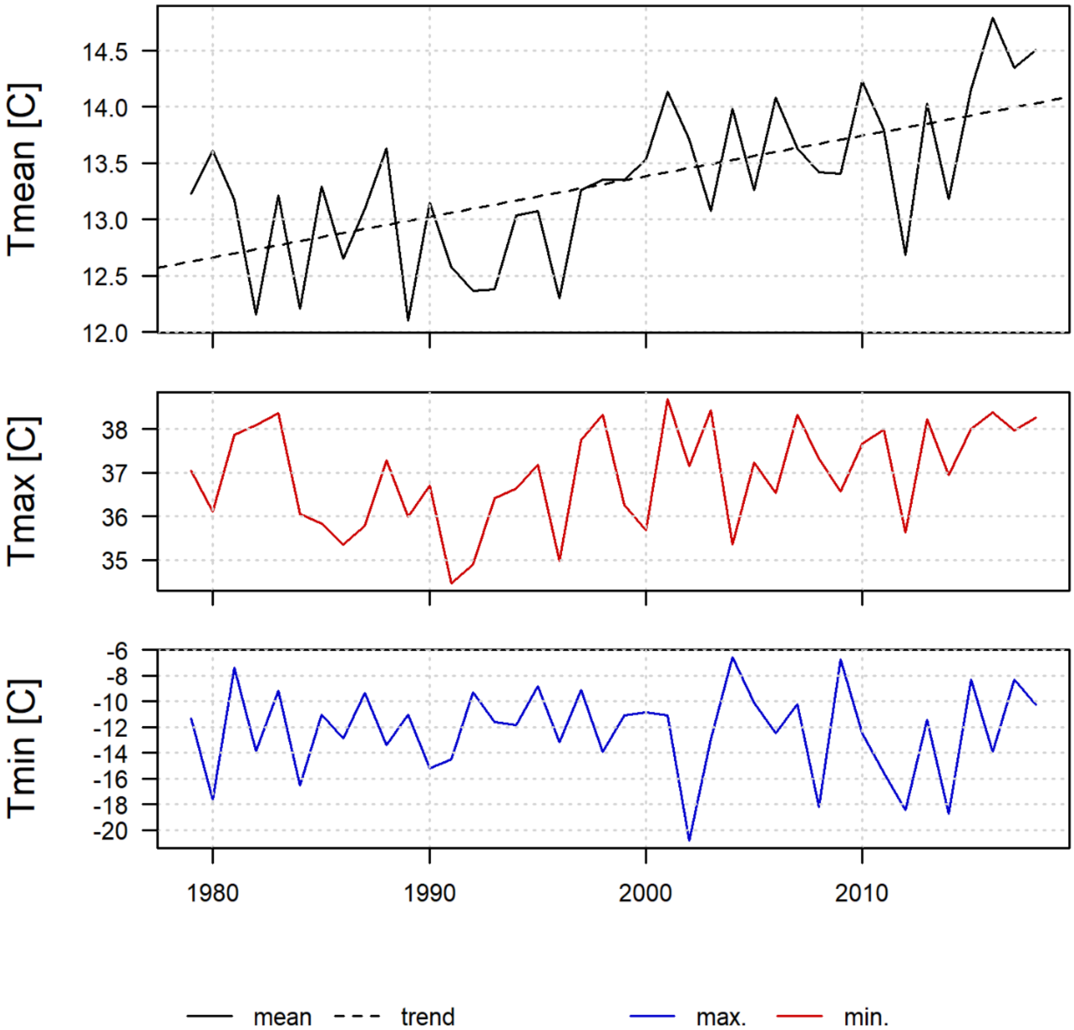

Figure 11. Average, maximum and minimum yearly temperatures from ERA-5 dataset with trendline for the Batabag area (Surkhandarya province).

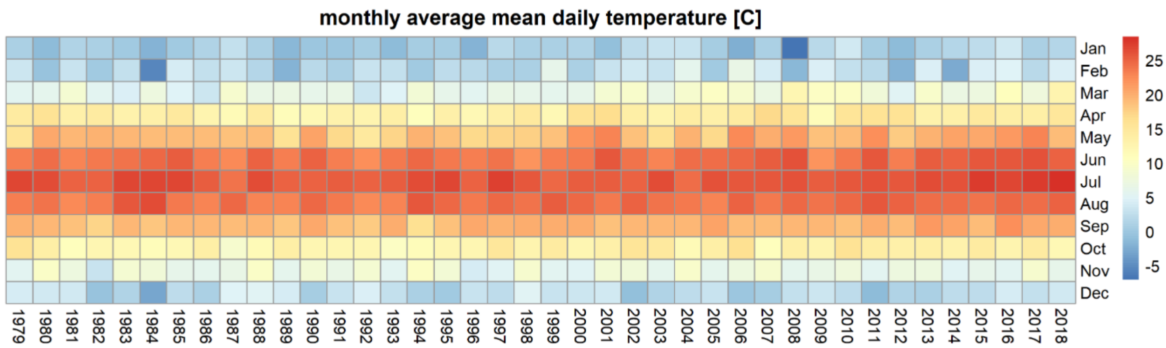

Figure 12. Seasonality in temperature from ERA-5 dataset for the Batabag area (Surkhandarya province).

2.3.2 Precipitation trends

21. Historical data on precipitation shows that average total annual precipitation is relatively higher at around 600mm for the Babatag sub-project area (Figure 8). A trend of decreasing total annual rainfall is evident for this period, but with lots of variability around this (Figure 14). The majority of rainfall occurs in the months October – May, with a period of dry conditions prevailing in June – September in which little rainfall occurs (Figure 15).

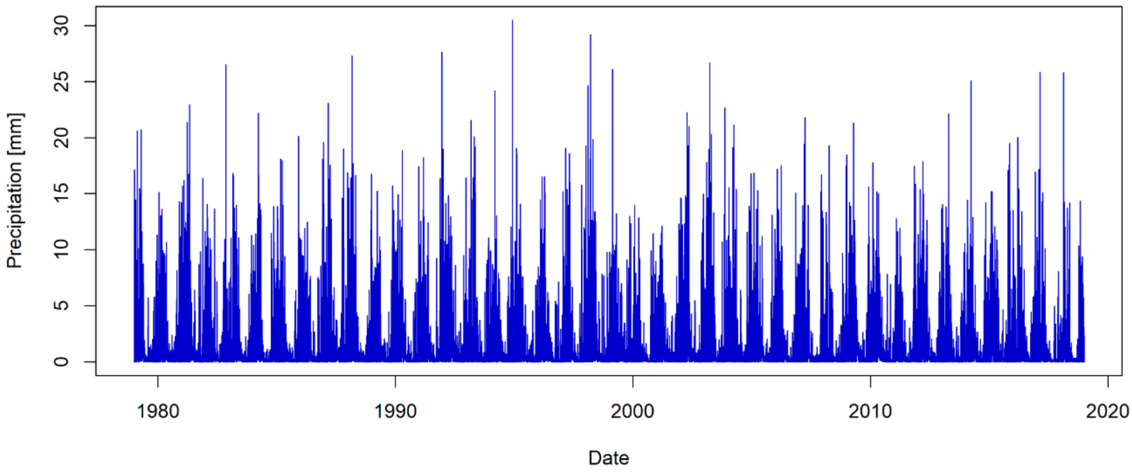

Figure 13. Daily precipitation from ERA-5 dataset for the Batabag area (Surkhandarya province).

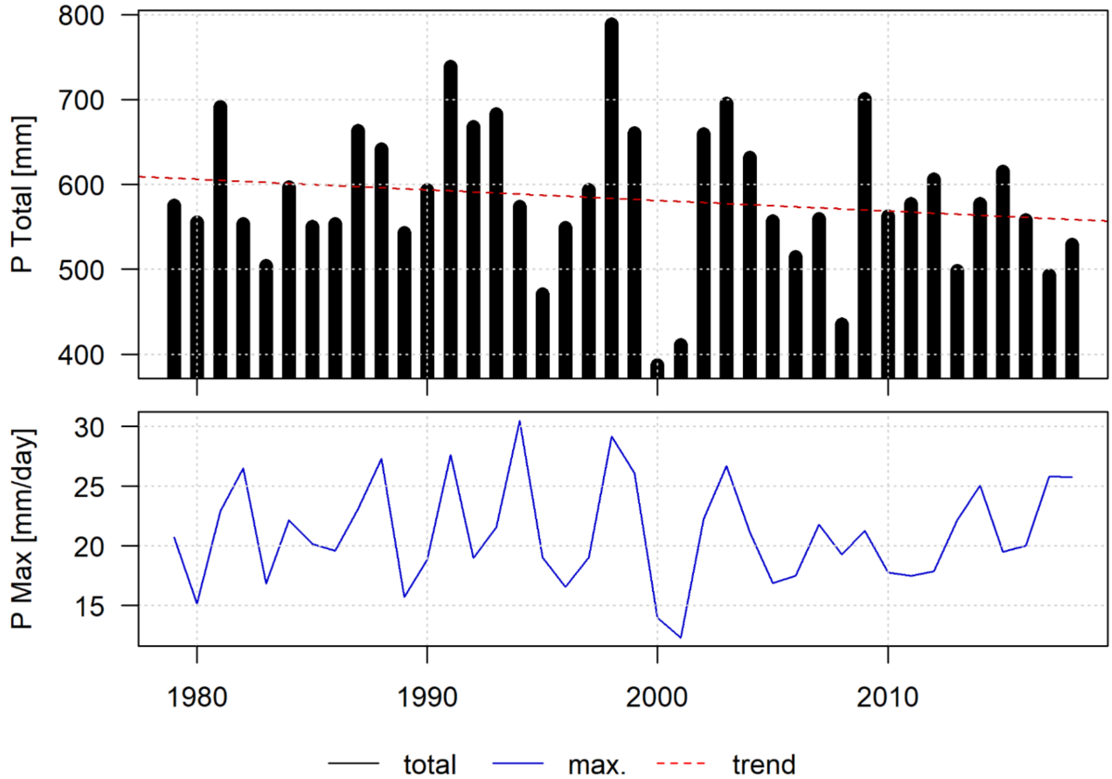

Figure 14. Total yearly and maximum daily precipitation from ERA-5 dataset with trendline for the Batabag area (Surkhandarya province).

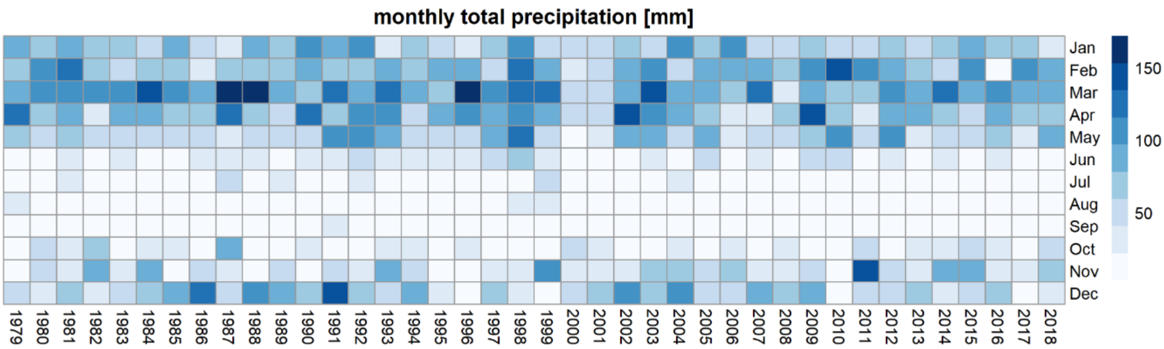

Figure 15. Seasonality of precipitation from ERA-5 dataset for the Batabag area (Surkhandarya province).

2.4 Drought events

22. A drought (dry period) frequency analysis was conducted to determine the drought hazard per project area based on ERA5 reanalysis data. This looked at the number of events per decade where average daily rainfall was less than 1mm for a consecutive period of days (20-150) for both proposed project areas. This allows meteorological drought frequency for the historical period to be characterized using a simple methodology.

23. Results show that the Jondor SP is more exposed to extended dry periods out of the two project areas, with dry periods of lengths greater than 150 days occurring on average 4 times per decade for the historical period. The Babatag SP is less exposed to extended dry periods, but still experiences considerable periods of low precipitation, with dry periods of lengths greater than 60 days occurring on average 2 times per decade for the historical period.

Table 2-1. Number of drought events per decade, for different drought period thresholds (number of days where precipitation is less than 1 mm)

Period pr. < 1mm (days)	Events per decade (Babatag)	Events per decade (Jondor)
30	9	20
60	2	12
90	0	9
150	0	4

2.5 Trends in Amu Darya flows

24. Both SPs are mainly reliant on water availability in the Amu Darya river. For the purpose of this CRVA, discharge data were analysed of Amu Darya over the last 30 years for two locations:

- Kerki station (just upstream of intake for Amu-Bukhara system), 1936 – 1989, daily data (source: GRDC) and from 1990-2018 annual (source BW Amu Darya)
- Inflows into Aral Sea (1992 – 2015, source BW Amu Darya)

25. Figure 2-1 shows the annual flow volumes derived for both stations. As can be seen, the amount of water that finally reaches the Aral Sea is only a fraction of what is measured upstream at Kerki, due

to the high water stress in this basin, and withdrawals to irrigated areas, including the Jondor SP area. Also, it is can be seen that there is clear downward trend for both points in the river, of approximately 0.5 km3/year. This trend is consistent among both points. Also, water scarce and wet years in both series generally coincide well.

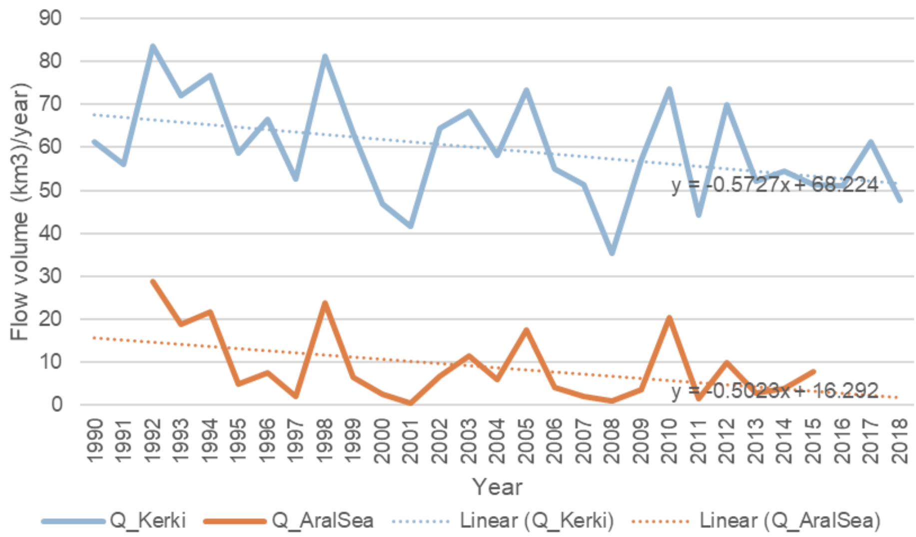

Figure 2-1. Annual flow volumes for two points in the Amu Darya river (Kerki and inflow into Aral Sea)

26. For the Kerki gauging station there is a clear monthly pattern in the 1936 – 1989 data. It can be seen in the below figure that this monthly pattern has not significantly changed over these decades.

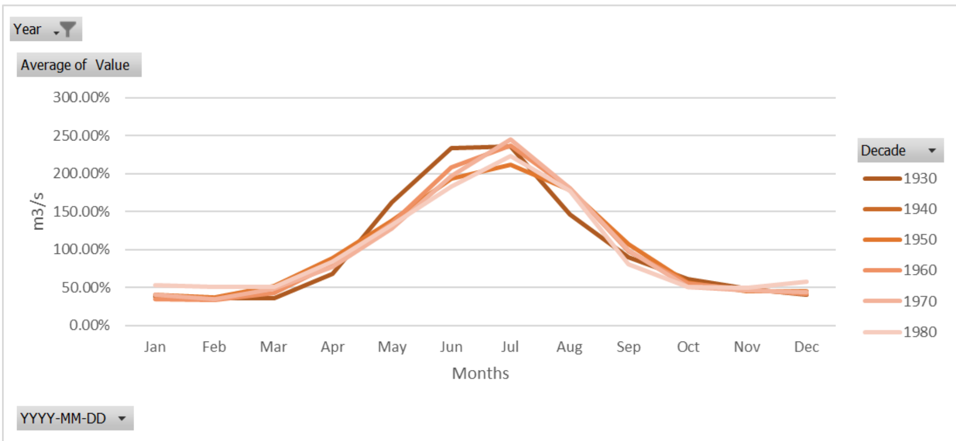

Figure 2-2 Monthly flows per decade relative to the mean annual flow (%) based on data from 1936-1989 for the Kerki station.

27. However, the absolute values for this period (before 1990) do show a downward trend of approx. 6 km^3 per decade, or 0.6 km^3 per year, as can be seen in Figure 2-3. This value is consistent with the reduction in flows over the last three decades.

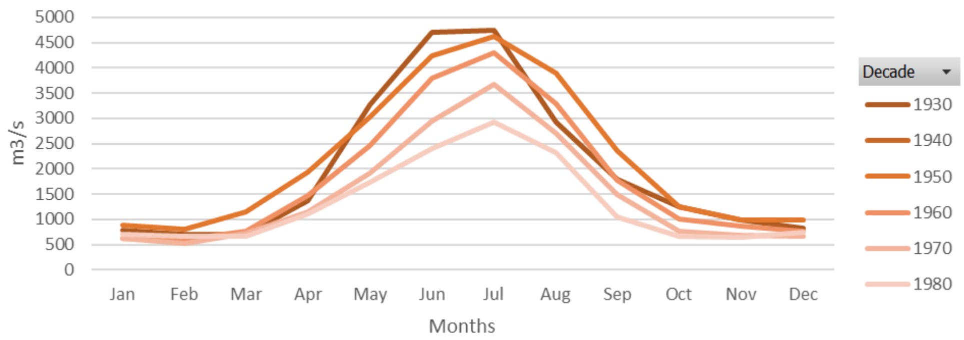

Figure 2-3 Monthly flows per decade (m^3/s) to the mean annual flow (%) based on data from 1936-1989 for the Kerki station.

28. To analyse whether these downward trends are mainly related to changes in water use upstream in the different countries tapping from this resource, or climate change-induced changed, data were obtained from the local consultants for Nurek reservoir inflows (main reservoir in the Vakhsh River in Tajikistan). Figure 2-4 shows mean monthly flows for a moving window of 10 years around a central year (1970 refers to 1966-1975, etc).

29. First of all, there is slight increase in annual flow volume for this point, although limited (a few percent). Probably more importantly, it can be seen from the figure that during the last two decades, the flows during spring were slightly higher than in 1970 and 1990.

30. Flows during 10-year window of 1976-1985 (1980) seem to be anomalous: winter flows were consistently higher for several years in that period, and summer flows were relatively lower. It is not clear if this is due to human interventions upstream or is related to a climate anomaly.

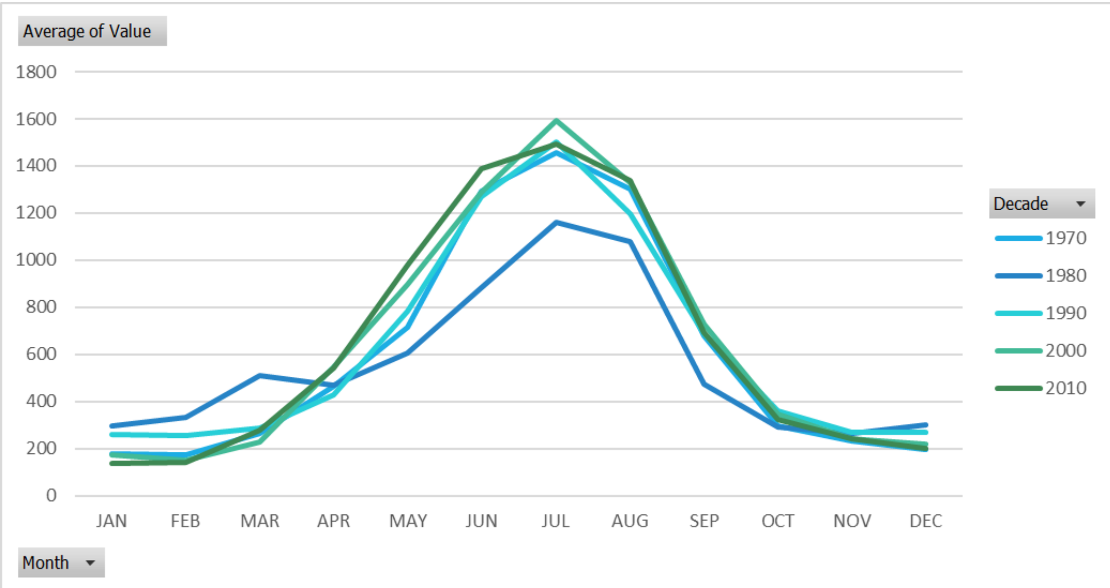

Figure 2-4 Monthly flows per decade (m^3/s) to the mean annual flow (%) based on data from 1966-2009 for Nurek reservoir inflow.

31. Thus, the downward trend observed in the downstream stations is not observed in the upstream Nurek location. This suggests that the downward trend is mainly due to changes in water use upstream, and changes in upstream climate do not influence notably. However, it is important to note that the Vaksh river is only on tributary of the Amu Darya, there are many more: some of them with high glacier/snow

regime, other less. In other words, the trends analyzed here for the Nurek location may be not representative for other upstream tributaries.

32. Another factor influencing downstream water availability is increased winter releases of water for hydropower in Tajikistan, with corresponding decreases in summer releases. This factor is set to increase in importance upon completion of new dams (mainly Rogun) in Tajikistan. Active storage capacity or Rogun is approximately 10 km3. Analyzed increases in water availability are in the order of 0.2 km2/year: it is thus evident that this potential increase in water availability will be totally counteracted during the filling period of the new Rogun dam.

3 Future Climate Projections

3.1 Climate projection dataset

3.1.1 Ensemble model projections

33. For the purpose of this CRVA, NASA-NEX[1] data is used to analyze future climate trends. This dataset is used to provide analysis of trends in terms of temperature and precipitation for the given area of interest. This product is used as it provides spatially gridded time series of temperature and precipitation outputted by 21 General Circulation Models with global coverage (see Table 3-1 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 3-1. Climate models included in NASA-NEX dataset.

Model	Research centre	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

3.1.2 Scenarios and future horizons

34. Two RCP scenarios are analyzed 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 represent a good

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

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

35. 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 3-2. 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)	21
	2060 (2045-2075)	21
RCP85	2030 (2015-2045)	21
	2060 (2045-2075)	21

3.1.3 Climate extremes indices

36. 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 standardized, comparable way.

37. For the purposes of this project, the indices described in Table 3-3 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 3-3. 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

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

3.2 Jondor SP

3.2.1 Average trends in temperature and precipitation

38. In terms of average climate trends, the climate model ensemble predicts a clear increase in mean temperature for the project area in the upcoming 60 years (Figure 16). 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 1-2°C are predicted by the climate model ensemble, for the longer-term horizon 2045-2075, this increases to around 2-4°C, with a larger spread in model predictions. 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.

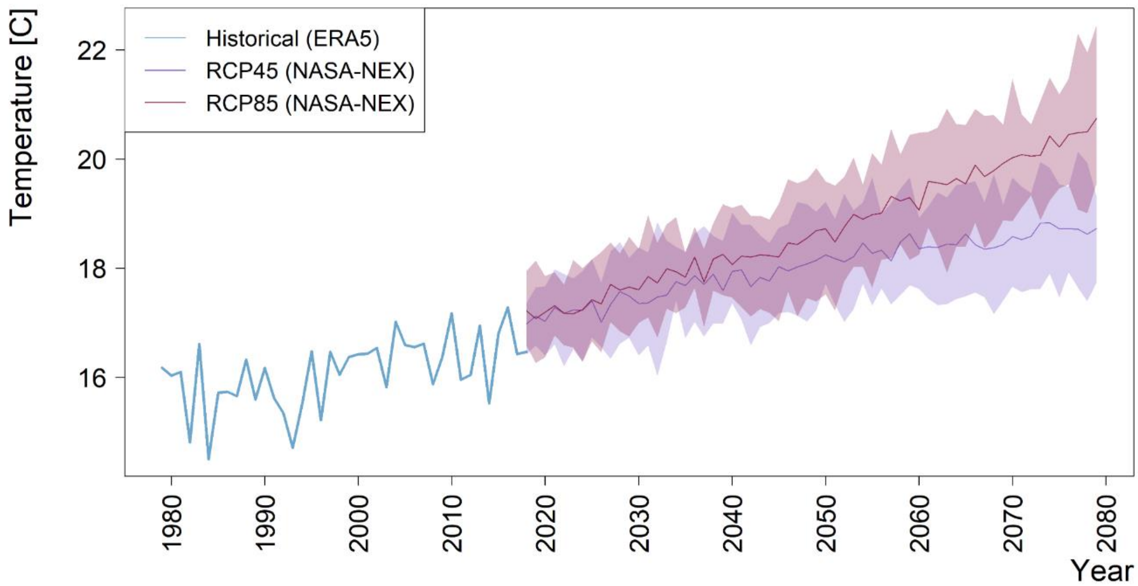

Figure 16. Time series of mean yearly temperature for the Jondor SP constructed using ERA5 dataset for the historical period (1979-2019), and NASA NEX (per model bias corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model predictions.

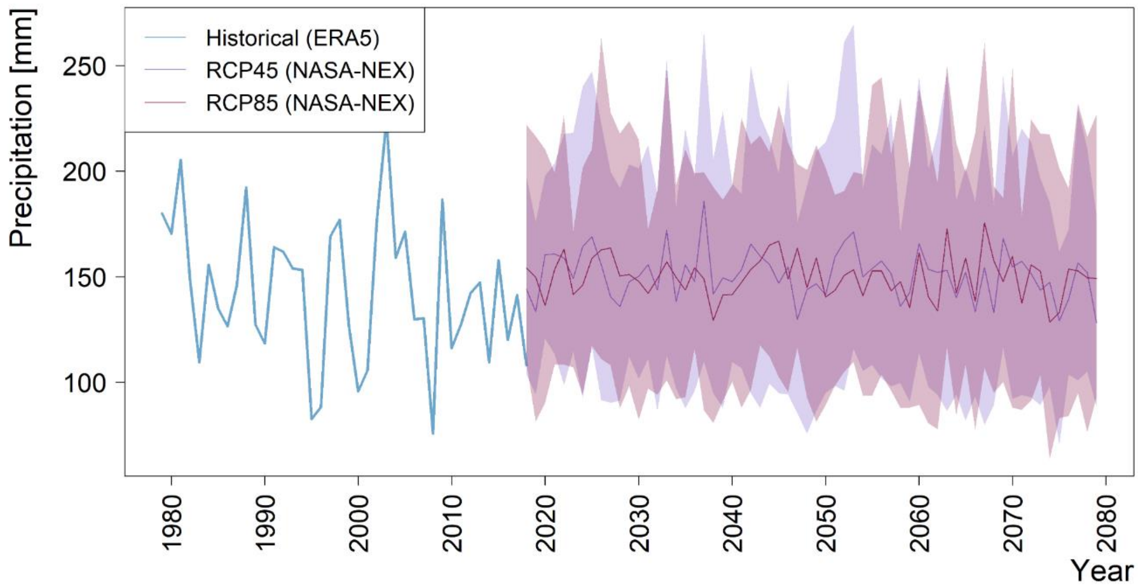

Figure 17. Time series of total yearly precipitation for the Jondor SP constructed using ERA5 dataset for the historical period (1979-2019), and NASA NEX (per model bias corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model predictions.

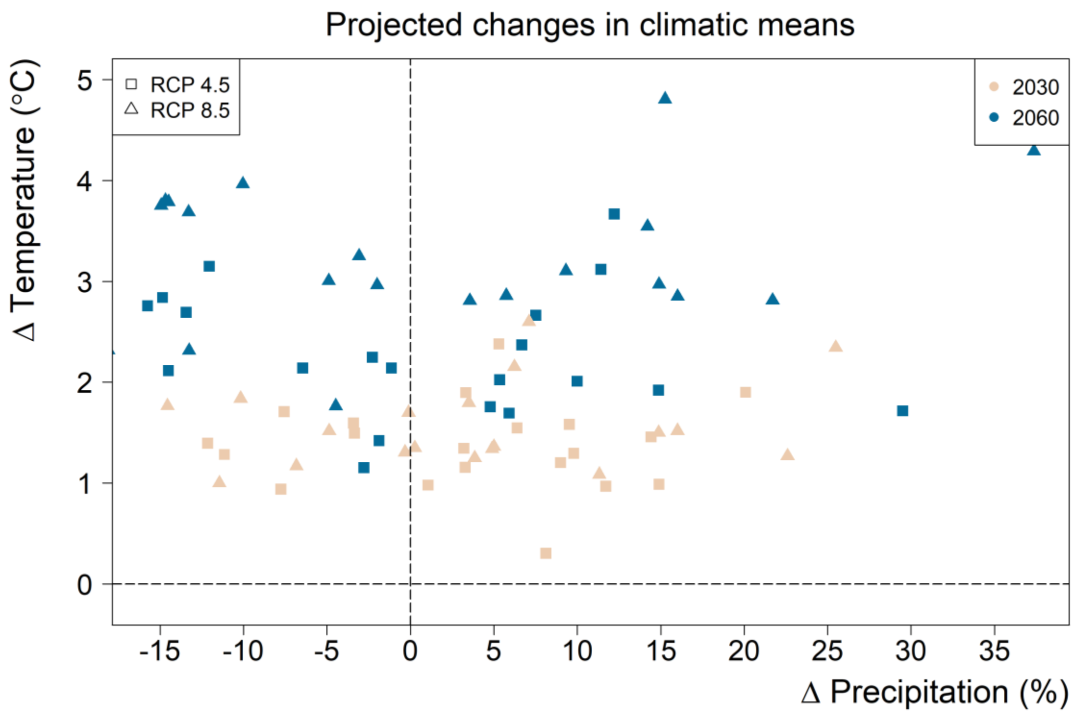

Figure 18. Average temperature and precipitation changes for the Jondor project area (Bukhoro province). These indicate the difference (Δ) between historical (1976-2005) and future (2015-2045; 2045:2075) time horizons for the two RCP scenarios.

3.2.2 Seasonality

39. In terms of seasonality, climate model ensembles predict a general increase in both minimum and maximum temperatures for all months. 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 may suggest that in the shorter term 2015-2045 there may be less rain in the wet part of the year (February – May).

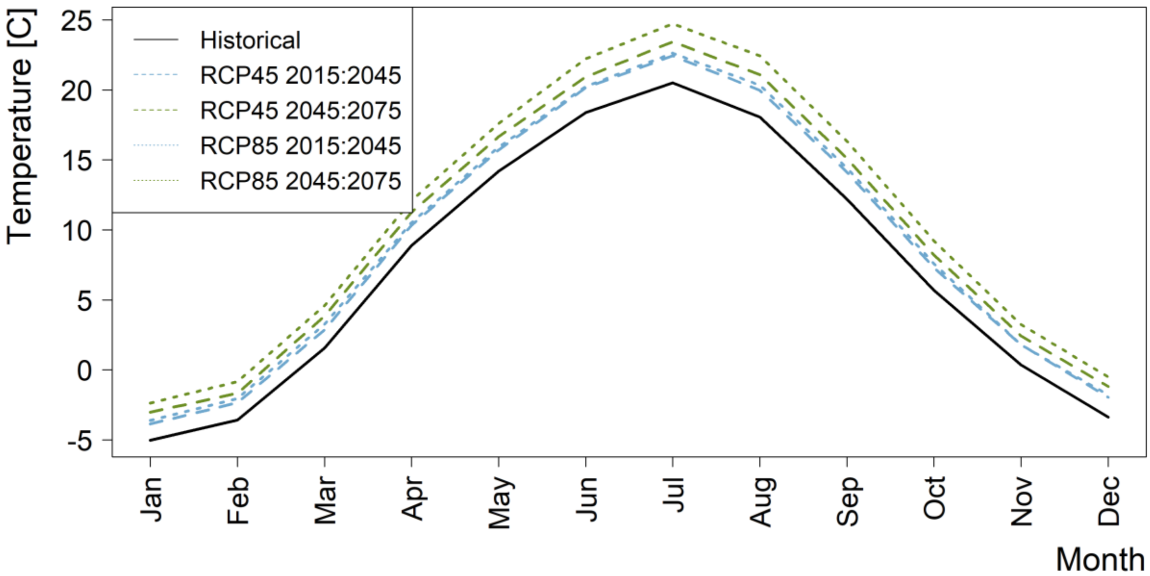

Figure 19. Average minimum daily temperature per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios.

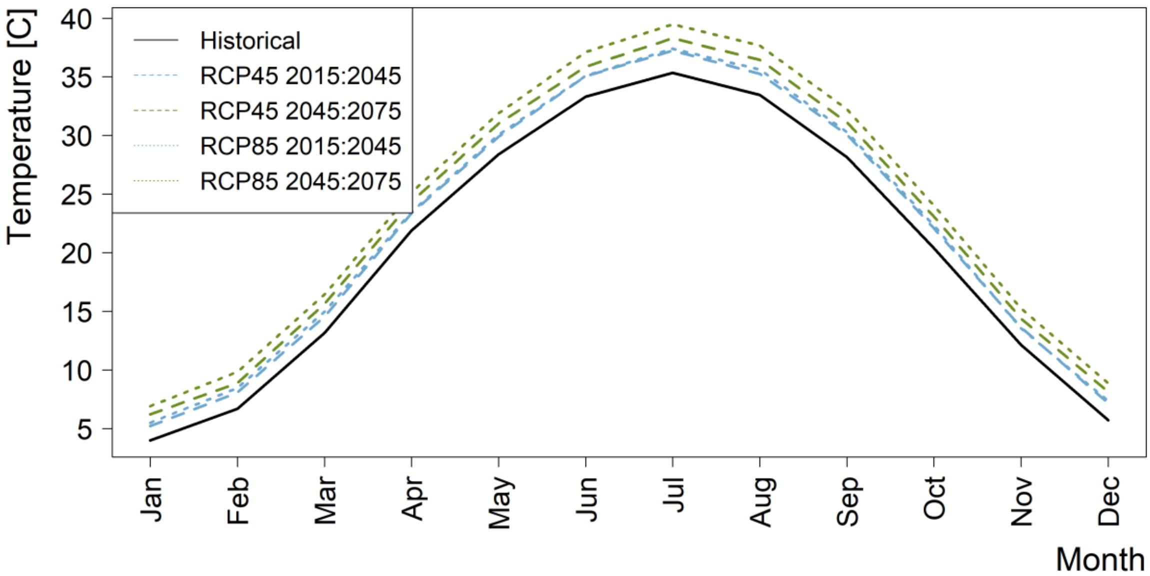

Figure 20. Average maximum daily temperature per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios.

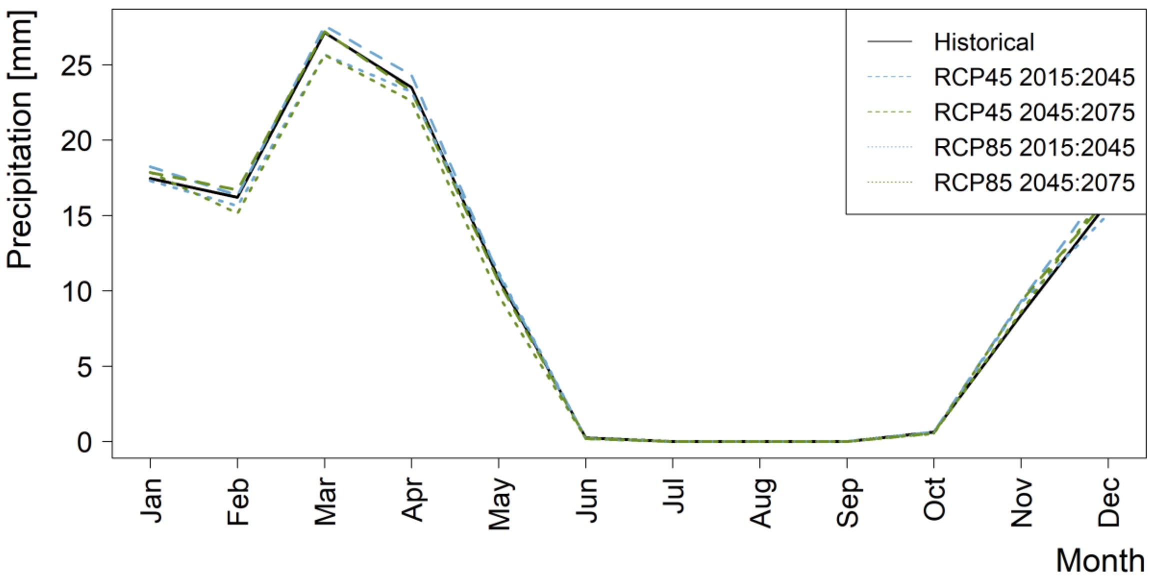

Figure 21. Average total monthly precipitation per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios. Shown for the Jondor project area (Bukhoro province).

3.2.3 Extreme Climate Trends

40. When extreme trends are considered, climate model ensembles show a fairly large amount of uncertainty. 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, appear to show some increase in the severity of drought events (CDD) for both future time horizons and RCP scenarios. Uncertainty regarding this is high, however, and the magnitude of change is relatively small.

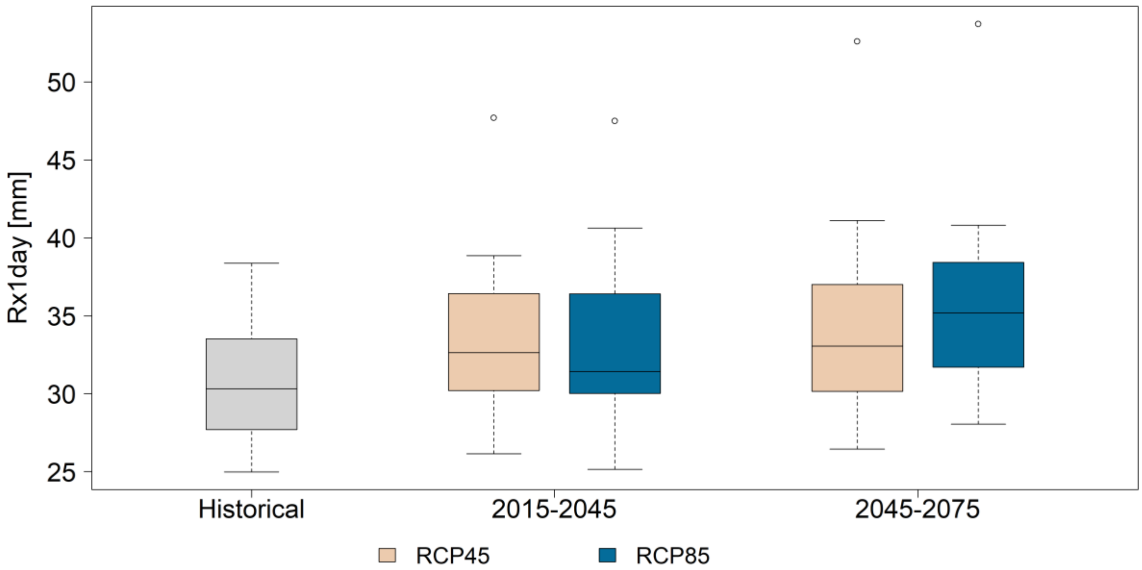

Figure 22. Boxplots indicating the spread in climate model predictions of average maximum rainfall in a day per year (Rx1day) for the historical (1976-2005) and future time periods under two RCP scenarios. Shown for the Jondor project area (Bukhoro province).

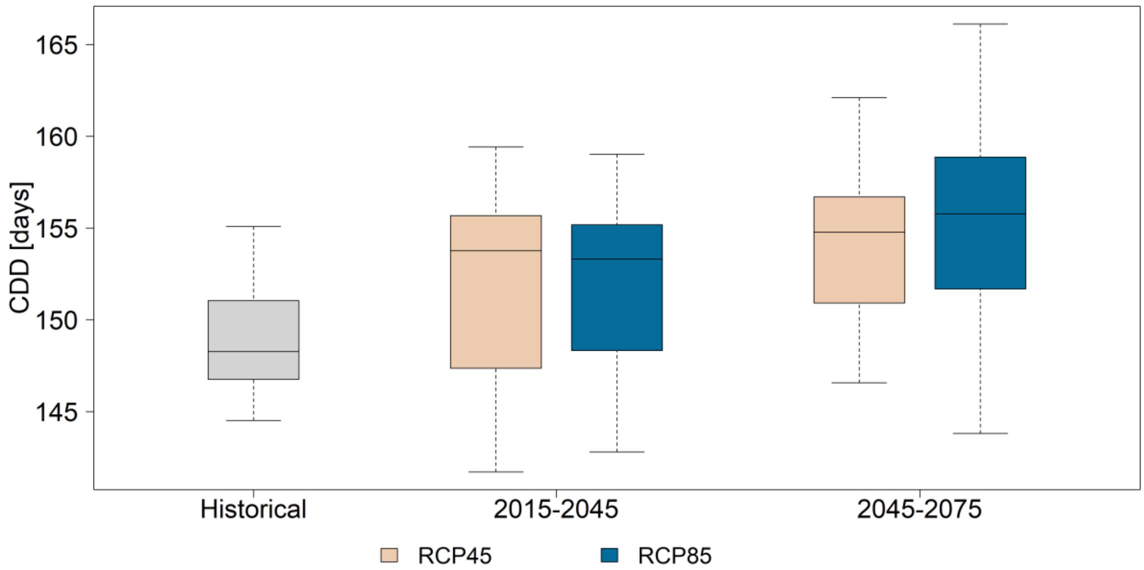

Figure 23. Boxplots indicating the spread in climate model predictions of average consecutive dry days per year (CDD) for the historical (1976-2005) and future time periods under two RCP scenarios. Shown for the Jondor project area (Bukhoro province).

3.2.4 Summary tables

41. 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 3-4 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 3-5 and Table 3-6 show the main statistics (median, 10^{th} percentile and 90^{th} 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 3-4. 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. Shown for the Jondor project area (Bukhoro province).

		ACCESS1-0	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	11%	5%	-8%	23%	5%	2%	10%	1%	5%	-3%	16%	11%	-13%	3%	-6%	0%	9%	2%	6%	19%	-13%
	2060_RCP45	9%	2%	-13%	13%	11%	9%	9%	10%	12%	2%	11%	0%	-21%	-21%	-15%	-15%	5%	-4%	7%	28%	-1%
	2030_RCP85	-78%	5%	-23%	23%	12%	5%	5%	1%	5%	-4%	1%	-10%	-15%	-3%	-14%	5%	13%	8%	17%	15%	-6%
	2060_RCP85	-75%	-3%	-12%	39%	9%	6%	9%	11%	15%	-14%	-11%	-2%	-19%	-21%	-15%	-11%	11%	-1%	8%	24%	-4%
Tavg (oC)	2030_RCP45	1.88	1.48	1.55	2.21	1.44	1.29	1.59	1.62	2.50	1.10	1.02	0.38	1.90	1.80	1.67	1.88	1.57	1.57	1.62	1.22	1.71
	2060_RCP45	3.32	2.48	2.37	3.43	2.15	2.04	2.07	2.68	3.80	1.57	1.73	1.24	3.12	3.03	2.88	3.11	2.47	2.38	2.28	2.03	2.54
	2030_RCP85	2.35	1.76	2.11	2.66	1.73	1.52	1.37	1.75	2.73	1.31	1.40	1.12	2.05	2.01	1.98	2.13	1.60	1.56	1.63	1.35	1.79
	2060_RCP85	4.63	3.69	3.95	4.60	3.06	3.12	2.83	3.15	4.94	2.47	2.38	1.85	4.04	4.05	4.00	3.93	3.66	3.22	3.33	3.06	3.26

Table 3-5. Summary table showing statistics regarding spread in Climate Model (GCM) ensemble predictions for future changes in total annual precipitation in the Jondor SP.

	Median (%)	10th Perc. (%)	90th Perc. (%)	GCMs Dryer	GCMs Wetter
2030_RCP45	5%	-12%	19%	5	16
2060_RCP45	5%	-20%	13%	7	14
2030_RCP85	5%	-21%	17%	8	13
2060_RCP85	-2%	-21%	22%	12	9
Total	4%	-15%	16%	32	52

Table 3-6. Summary table showing statistics regarding spread in Climate Model (GCM) ensemble predictions for future changes in mean annual temperature in the Jondor SP.

	Median (ºC)	10th Perc. (ºC)	90th Perc. (ºC)	GCMs >2ºC	GCMs >4ºC
2030_RCP45	1.6	1.0	2.2	2	0
2060_RCP45	2.5	1.6	3.4	18	0
2030_RCP85	1.7	1.3	2.6	7	0
2060_RCP85	3.3	2.4	4.6	20	6
Total	2.1	1.3	3.9	47	6

3.3 Babatag SP

3.3.1 Average trends in temperature and precipitation

42. 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 24). 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 1-2°C are predicted by the climate model ensemble, for the longer-term horizon 2045-2075, this increases to around 1.5-4°C, with a larger spread in model predictions (Figure 26). 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 25). There is also little to differentiate the two RCP scenarios, with neither indicating any clear trend for the time period considered.

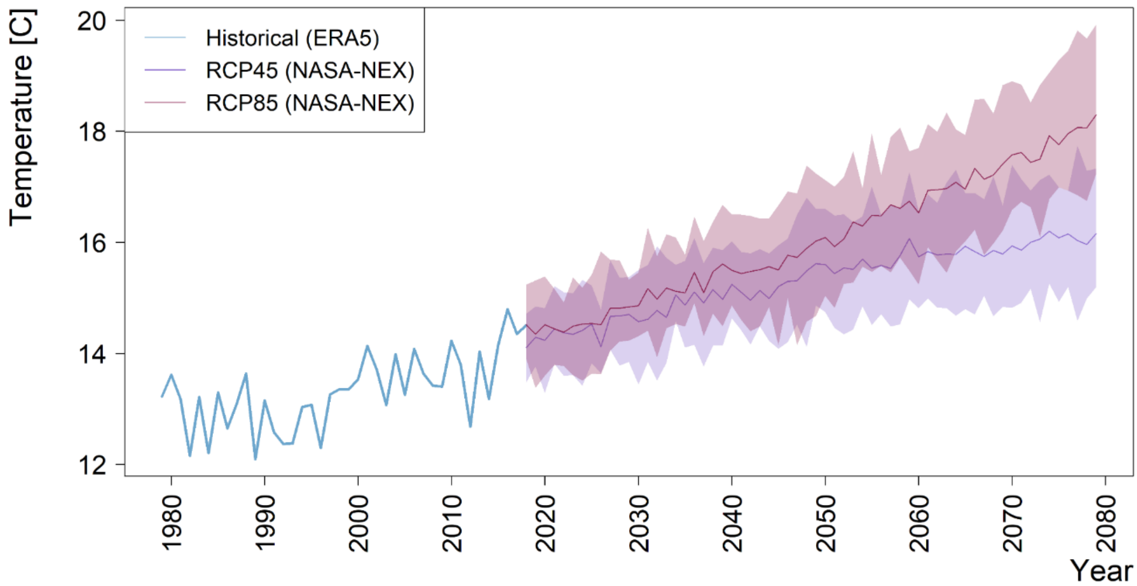

Figure 24. Time series of mean yearly temperature for the Batabag project area (Surkhandarya province) constructed using ERA5 dataset for the historical period (1979-2019), and NASA NEX (per model bias corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model predictions.

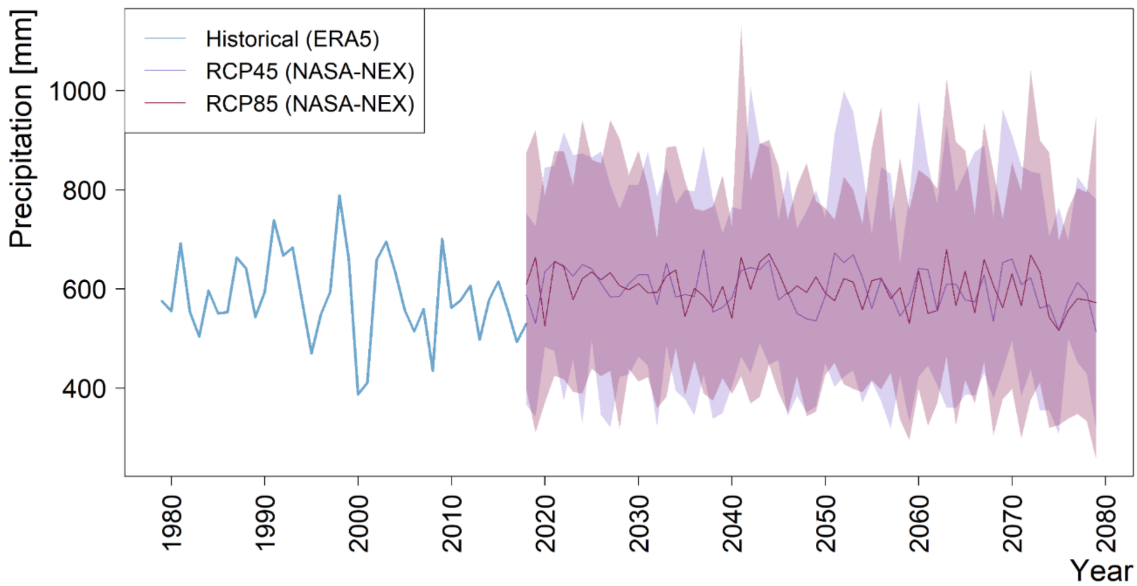

Figure 25. Time series of total yearly precipitation for the Batabag project area (Surkhandarya province) constructed using ERA5 dataset for the historical period (1979-2019), and NASA NEX (per model bias corrected) for the future period. Shaded areas show the 10th and 90th percentiles in the spread of model predictions.

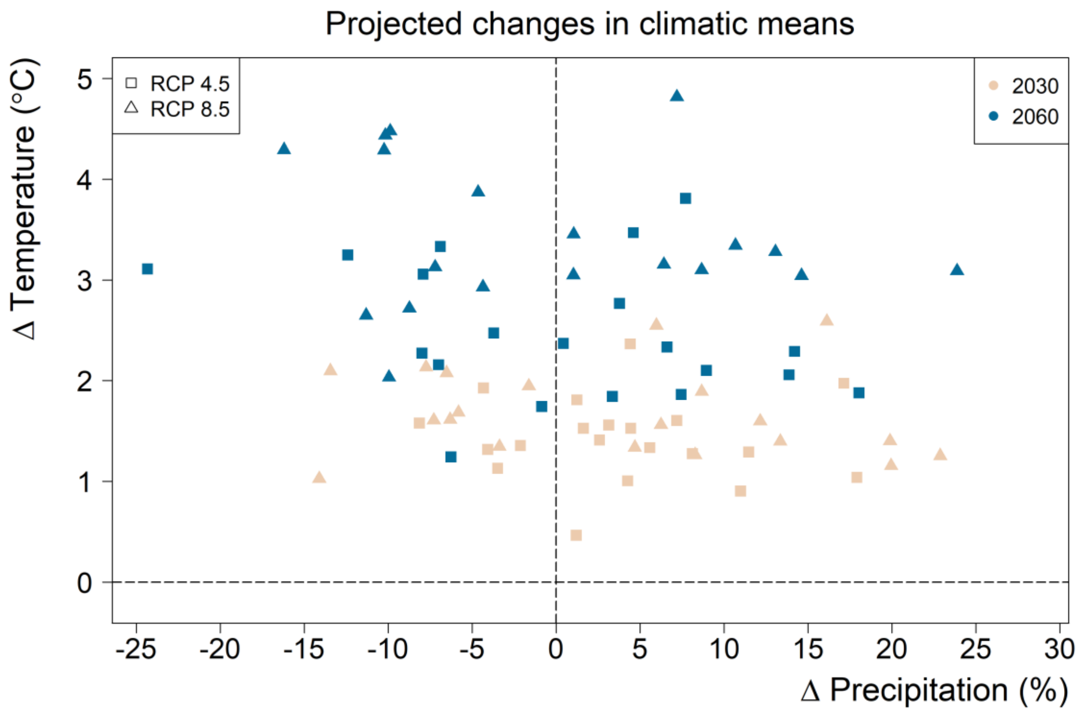

Figure 26. Average temperature and precipitation changes for the Batabag project area (Surkhandarya province). These indicate the difference (Δ) between historical (1976-2005) and future (2015-2045; 2045:2075) time horizons for the two RCP scenarios.

3.3.2 Seasonality

43. In terms of seasonality, climate model ensembles predict a general increase in both minimum and maximum temperatures for all months. A greater increase in temperatures is predicted in the longer term (2045-2075) timescale and under the higher RCP 8.5 scenario. Trends are again unclear in the seasonality of precipitation, but may suggest that climate change may lead to greater total precipitation in the wettest month (May) in future.

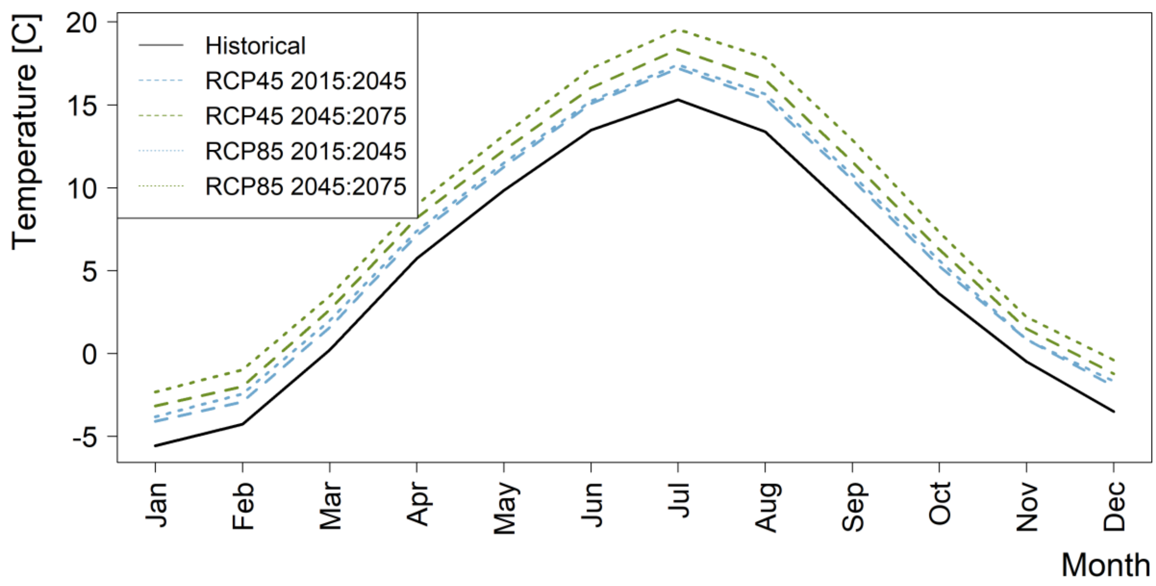

Figure 27. Average minimum daily temperature per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios. Shown for the Batabag project area (Surkhandarya province).

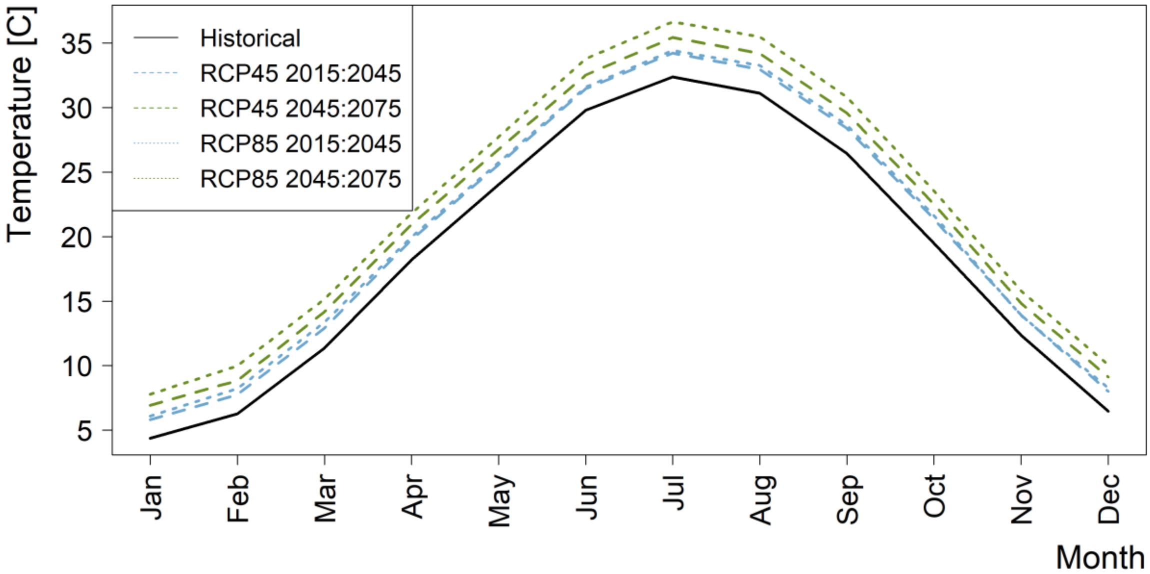

Figure 28. Average maximum daily temperature per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios. Shown for the Batabag project area (Surkhandarya province).

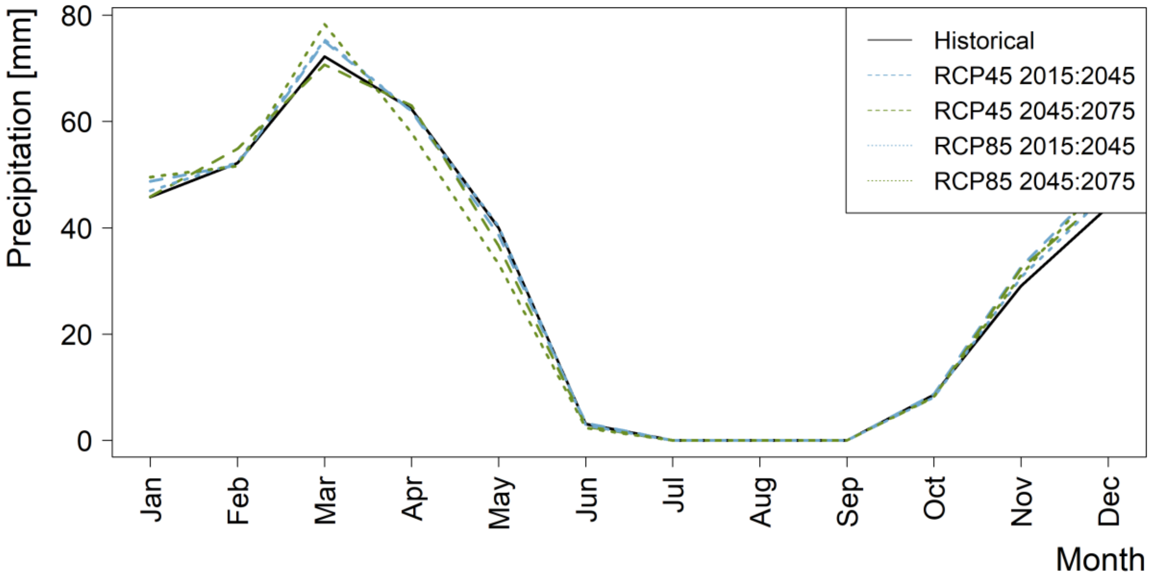

Figure 29. Average total monthly precipitation per month for historical (1976-2005) and future (2015-2045; 2045:2075) time horizons under the two RCP scenarios. Shown for the Batabag project area (Surkhandarya province).

3.3.3 Extreme Climate Trends

44. When extreme trends are considered, climate model ensembles show a fairly large amount of uncertainty. This is perhaps expected as climate models are inherantly limited in terms of predicting trends in extremes due to the stochastic nature of these events.

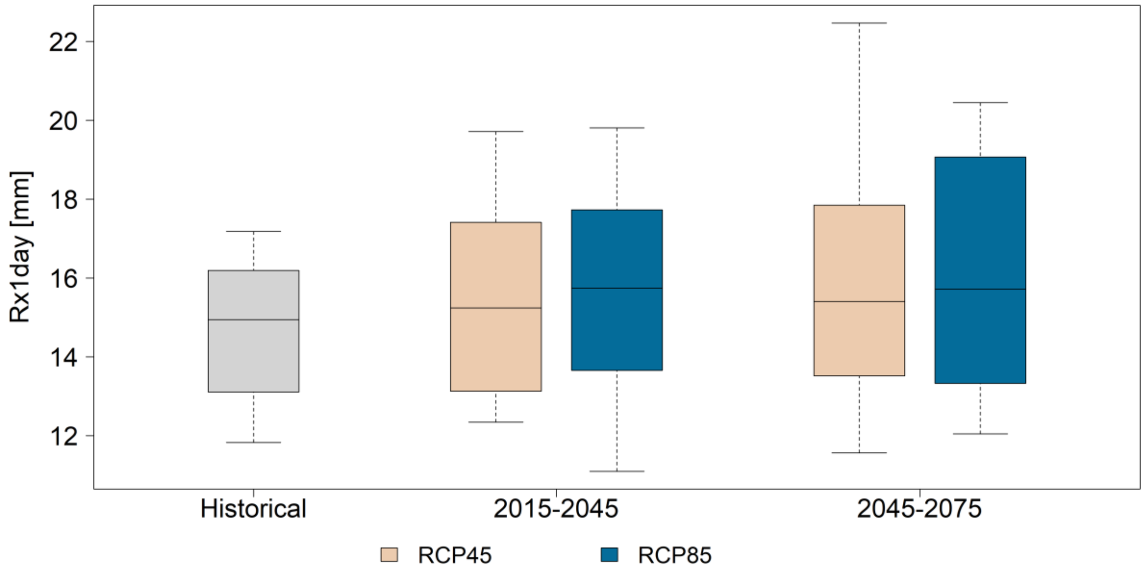

Figure 30. Boxplots indicating the spread in climate model predictions of average maximum rainfall in a day per year (Rx1day) for the historical (1976-2005) and future time periods under two RCP scenarios. Shown for the Batabag project area (Surkhandarya province).

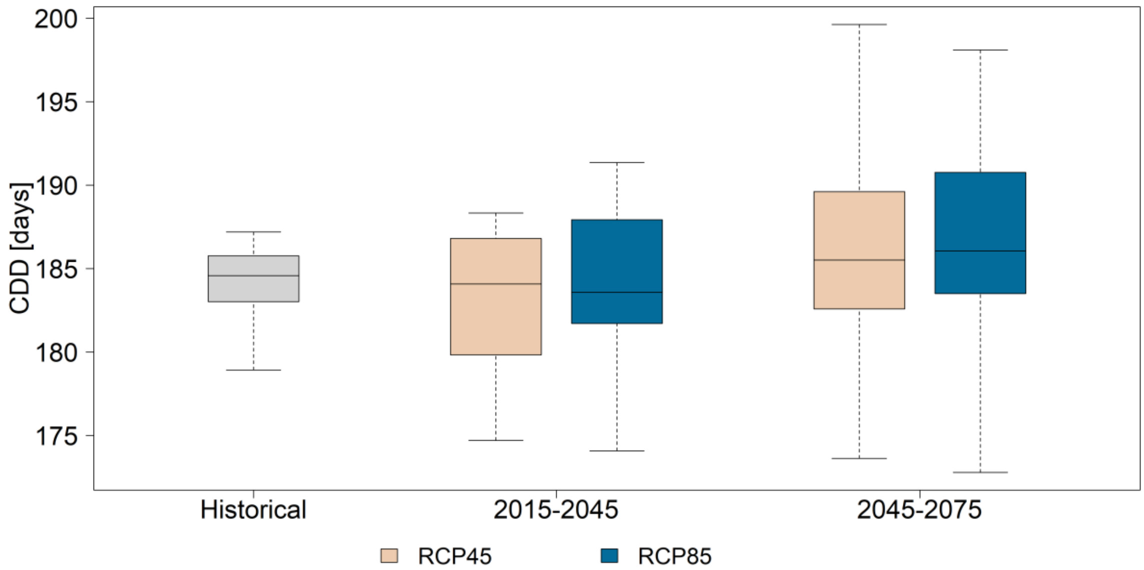

Figure 31. Boxplots indicating the spread in climate model predictions of average consecutive dry days per year (CDD) for the historical (1976-2005) and future time periods under two RCP scenarios. Shown for the Batabag project area (Surkhandarya province).

3.3.4 Summary tables

45. 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 3-7 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 3-8 and Table 3-9 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 3-7. 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. Shown for the Batabag project area (Surkhandarya province).

		ACCESS1-0	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	21%	4%	7%	17%	-2%	2%	5%	-4%	0%	2%	16%	2%	-7%	-9%	0%	4%	6%	-1%	0%	22%	-6%
	2060_RCP45	29%	5%	-3%	5%	7%	9%	15%	6%	4%	4%	9%	-3%	-9%	-33%	-9%	-15%	-1%	-3%	7%	18%	-10%
	2030_RCP85	1%	9%	-10%	14%	4%	7%	8%	-5%	2%	-1%	-3%	-12%	-9%	-12%	-8%	6%	19%	12%	19%	22%	-10%
	2060_RCP85	31%	-3%	-1%	27%	6%	-5%	7%	12%	5%	-4%	-8%	-8%	-13%	-25%	-11%	-11%	11%	1%	4%	25%	-2%
Tavg (oC)	2030_RCP45	1.88	1.57	1.75	2.22	1.61	1.38	1.51	1.64	2.49	1.24	0.98	0.59	2.15	2.07	1.72	1.66	1.43	1.50	1.72	1.20	1.69
	2060_RCP45	3.16	2.64	2.66	3.72	2.34	2.20	2.28	2.83	3.93	1.88	1.92	1.37	3.65	3.41	3.25	3.30	2.50	2.34	2.37	2.11	2.57
	2030_RCP85	2.18	1.77	2.32	2.83	1.85	1.61	1.50	1.76	2.67	1.48	1.72	1.14	2.32	2.22	2.33	1.91	1.55	1.47	1.60	1.35	1.90
	2060_RCP85	4.46	3.85	4.07	4.90	3.29	3.25	3.12	3.41	4.93	2.84	2.73	2.15	4.71	4.59	4.75	4.31	3.41	3.30	3.45	3.28	3.35

Table 3-8. Summary table showing statistics regarding spread in Climate Model (GCM) ensemble predictions for future changes in total annual precipitation in the Babatag project area (Surkhandarya province).

	Median (%)	10th Perc. (%)	90th Perc. (%)	GCMs Dryer	GCMs Wetter
2030_RCP45	2%	-7%	21%	7	14
2060_RCP45	4%	-14%	17%	9	12
2030_RCP85	2%	-11%	19%	9	12
2060_RCP85	-1%	-12%	26%	11	10
Total	2%	-11%	19%	36	48

Table 3-9. Summary table showing statistics regarding spread in Climate Model (GCM) ensemble predictions for future changes in mean annual temperature in the Jondor SP .

	Median (ºC)	10th Perc. (ºC)	10th Perc. (ºC)	GCMs >2ºC	GCMs >4ºC
2030_RCP45	1.6	1.0	2.2	4	0
2060_RCP45	2.6	1.9	3.7	18	0
2030_RCP85	1.8	1.4	2.6	7	0
2060_RCP85	3.4	2.8	4.9	21	8
Total	2.3	1.4	4.0	50	8

4 Climate Impact Assessment

4.1 Approach

4.1.1 Climate risks

46. This chapter identifies and assesses the principal climate risks for the two irrigation systems of the subprojects (SPs). Based on projected changes, and identified potential impacts, climate risks are evaluated and rated. This assessment reveals, through a combination of field and stakeholder information, quantitative analysis, and expert judgement, the extent to which the climate poses a threat to the SPs, and for which climate risks adaptation measures should be considered.

47. To prioritize risks, impacts need to be assessed, either quantitively or qualitatively. Risk has two aspects: the consequences of impacts and the likelihood of impacts. Based on information available and projections, both can be classified as negligible, low, medium and high. Table 4-1 shows the concept behind this risk classification.

Table 4-1. Risk classification matrix explaining the concept behind the climate risk classification (based on UKCIP)

		Consequences of impact occurring		
		Low	**Medium**	**High**
Likelihood	**High**	Medium	High risk and priority	
of impact	**Medium**		Medium	
occurring	**Low**	Low risk and priority		Medium

48. To identify the potential impacts to be included in the risk assessment, information gathered during and after the inception phase from the local partners, field visits and available documentation and data on the area were used. From this process, the following potential impacts were identified:

1. **Reduced water availability**
2. **Increased water demands**
3. **Increased water shortages**
4. **Increased crop heat-stress**
5. **Increased salinization**
6. **Increased flooding**
7. **Increased erosion and landslides**
8. **Increased sedimentation issues**

The risk level that these potential impacts may have on the project are discussed and analyzed in this chapter.

4.1.2 Impacts on water resources

49. To assess climate impacts on the water resources of the two I&D SPs (Jondor and Babatag), an impact model can assess responses to different climate projections. Such an impact model can range from a simple equation or Excel-based model, towards a complex simulation system with multiple coupled comprehensive and physically based models. Given the wide range of uncertainties in climate projections, a balance between data availability and model complexity should be found.

50. An impact model needs to be based on the current situation (baseline) and requires certain verification to test if it reproduces the climate response of the system. When this is the case, the model inputs (rainfall, temperature, flows) can be altered to assess the performance under the range of future

climates. Various performance metrics can be calculated which can then be tabulated or visualized using so-called Climate Response Surfaces[1], among others.

51. Figure 4-1 shows the different steps for the water resources analysis. Climate model projections are assessed based on a multi-model climate ensemble (presented in the previous chapter) – these are used to modify the inputs of the impact model. Both subprojects are highly reliant on external water inputs from the Amu Darya river basin. Thus, realistic ranges for future flows have been assessed and ingested by the impact model to assess the sensitivity of the system to these changes.

52. The impact model then analyzes the water balance, demands, supplies and finally water shortage for the wide range of possible future climates and flows. For the full range, performance metrics are analyzed that characterize how the system would respond. Then, using visual (Climate Response Surfaces) and/or statistical methods, an approximation of the future probable performance can be assessed, using the spread in climate models.

53. Details on the water resources simulation model, specifications, assumptions and data sources are given in Annex 1

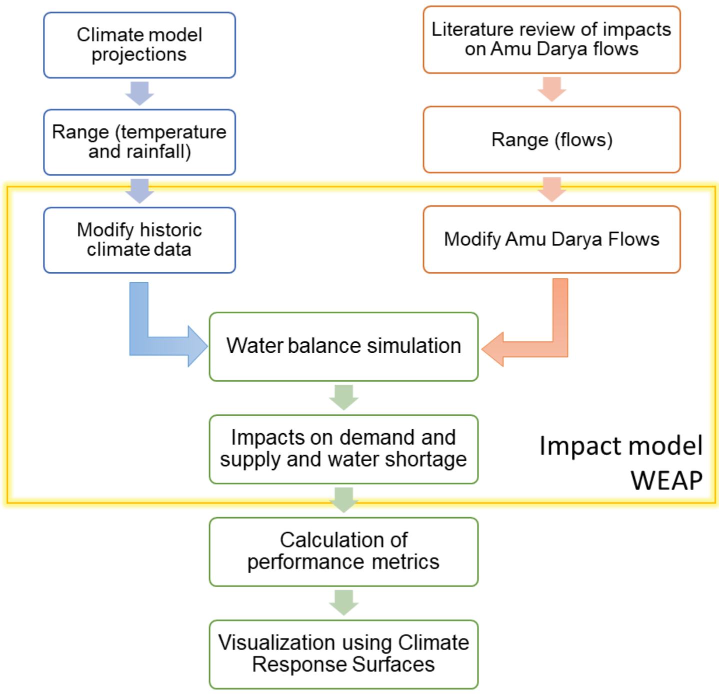

Figure 4-1. Steps for the water resources impact analysis.

54. Performance metrics are used to characterize how the systems respond to the range of future climates. To calculate these performance metrics, a number of variables are used, simulated for representative periods of 30 years to ensure that the interannual variability is captured. These variables are:

1. River discharge
2. Water demands
3. Water supplies
4. Water shortage (= unmet demand)

[1] Ray, Patrick A., and Casey M. Brown. Confronting climate uncertainty in water resources planning and project design: The decision tree framework. The World Bank, 2015.

55. For this climate risk assessment three performance metrics were assessed. Obviously, many more metrics can be calculated (for example related to the drought period length or maximum unmet demand as an indicator of drought severity), but a selection has been made as the main purpose of this climate risk assessment is to prioritize the climate risks and link them with consequent adaptation activities.

Table 4-2. Performance metrics used in the climate impact assessment

Performance indicator	Definition	Comments	Calculation
Coverage (%)	Percent of demand met with a supply for the subproject	Coverage is the inverse of the (irrigation) water supply deficit	Average unmet demand divided by the average total demand.
Reliability (%)	Describes how often the system succeeds under one specific climate realization.	Success means that the demand is met in all months within the year. Failure means a positive water deficit (unmet demand) for a particular month.	1 minus the number of months that the water supply is lower than the demand, divided by the total number of months in the full simulation period
Water Stress Index (%)	Describes how stressed the river basin is	The water stress index is a proxy for the level of water stress a basin experiences, including the subproject as well as the downstream demands.	The index is calculated here by dividing the total withdrawals (including downstream) by the total water availability.

4.2 Reduced water availability

4.2.1 Current state of knowledge

56. Both subprojects are highly dependent on water resources coming from the upstream Amu Darya basin. Thus, this means that these projects are not only sensitive to changes in climate in their immediate vicinity, but also in upstream areas of the basin. Indeed, the Amu Darya experiences complex discharge regimes based on precipitation but also on snowmelt coming from the high-altitude Pamir mountain range.

57. The response to climate change of the Asia's high mountain basins, and especially the glaciers, have been a focus of public and scientific debate over the last decade. Uncertainties in their current and future state are of major concern because they play a major role in the hydrological cycles of many river basins originating in Asia's high mountains, including those in Central Asia. In the IPCC's AR4 an erroneous statement made clear that the knowledge of High Asia's cryosphere and its role in hydrology was insufficient. Since then, numerous scientific studies in this region have been conducted to assess the current and future status of the cryosphere (Bolch et al., 2012; Gardelle et al., 2012; Kääb et al., 2012; Kargel et al., 2011; Radić et al., 2013) A first large scale hydrological modeling assessment using AR4 climate change scenarios indicated decreasing flows around 2050 for most meltwater-dependent river basins in Asia (Immerzeel et al., 2010).

58. However, advancing research has led to new insights regarding the future runoff in glacierized basins such as the Amu Darya and Syr Darya. In 2013, a detailed high-resolution study in two glacierized basins in the Indus and Brahmaputra basins was conducted using the latest AR5 climate change scenarios (Immerzeel et al., 2013). This study showed that glacier melt water is likely to increase until around halfway the 21st century whereafter a decrease is expected. This is in contrast to the earlier results, where a decrease was already projected for 2050 (Immerzeel et al., 2010).

59. Another global scale study quantifying the global response of glacier runoff to twenty-first century climate change (Bliss et al., 2014) includes the Central Asian region and shows a slightly different picture for this area, when compared to the western part of South Asia. According to this study, the glacier-originated runoff increases until ~2050-2060 for western South Asia, and begins to decrease afterwards. This is consistent with the findings by (Lutz et al., 2014). For Central Asia (not included in the study by (Lutz et al., 2014)) (Bliss et al., 2014) don't find the same increase in glacier-originated runoff during the first half of the 21st century. The glacier-originated runoff stays rather constant or decreases slowly during the first half of the 21st century before it decreases more rapidly during the second half of the 21st century.

60. It is uncertain what causes this difference in response. The current climates of the Central Asian and the South Asian region differ substantially (Bookhagen and Burbank, 2010). The climate in South Asia is dominated by the monsoonal precipitation regime with the bulk of the precipitation falling during June, July, August and September. The climate in the Pamir and Karakoram mountain ranges is much more influenced by westerly streams bringing precipitation during the winter months (Kapnick et al., 2014). This largely seems to explain the differences in trends in glacier changes during the last decades, with glaciers generally retreating in South Asia, whereas some glaciers are expanding in the Pamir and Karakoram region. This phenomenon is referred to as the "Karakoram anomaly" (Hewitt, 2005) or, more recently, the "Pamir-Karakoram anomaly" (Gardelle et al., 2013) .

61. The dynamics of each the sub-basins of the Pamir mountain range that feed into the Amu Darya river are different and depend on the relative contributions of the different flow types (baseflow, direct runoff, snow and glacier-originated flow. For example, Figure 4-2 shows the projections for each of these flows for the Nurek reservoir inflow. This makes the response very dependent and uncertain. For example, Kure et al. (2013b, 2013a) analyze the climate impacts and hydrologic response. For some tributaries and for the near horizon (next decades) they find an increase in flows, 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 analyzed in the referred scientific publication.

62. Other studies (scientific and technical reports) have been published over the last decades on the hydrological impacts of climate change in the Amu Darya basin. The most relevant ones are (in chronological order):

- 2011: "Modelling the impact of global change on the hydrological system of the Aral Sea basin" (Aus der Beek et al., 2011)
- 2012: "Climate Change Impacts on the Upstream Water Resources of the Amu and Syr Darya River Basins" (Immerzeel et al., 2012; Lutz et al., 2012)
- 2013: "Glacier systems and seasonal snow cover in six major Asian river basins: Water storage properties under changing climate" (Savoskul and Smakhtin, 2013a, 2013b)
- 2013: "Hydrologic impact of regional climate change for the snowfed and glacierfed river basins in the Republic of Tajikistan" (Kure et al., 2013b, 2013a)
- 2013: "Reducing the Vulnerability of Uzbekistans's Agricultural Systems to Climate Change – World Bank report" (Sutton et al., 2013)
- 2014: "The Impact of Climate Change on the Water Resources of the Amu Darya Basin in Central Asia" (White et al., 2014)
- 2014: "Third National Communication of the Republic of Tajikistan under the United Nations Framework Convention on Climate Change" (Kayumov and Novikov, 2014)
- 2015: "Assessment of the Role of Glaciers in Stream Flow from the Pamir and Tien Shan Mountains" (World Bank, 2015)
- 2016: ""The Third National Communication of the Republic of Uzbekistan under the UN Framework Convention on Climate Change" (Taryannikova, 2016)
- 2017: "Climate change impacts in Central Asia and their implications for development" (Reyer et al., 2017)
- 2018: "Impacts of Climate Change in Central Asia" (Mannig et al., 2018)

- 2020: "Simulation of the Potential Impacts of Projected Climate Change on Streamflow in the Vakhsh River Basin in Central Asia under CMIP5 RCP Scenarios."(Gulakhmadov et al., 2020)

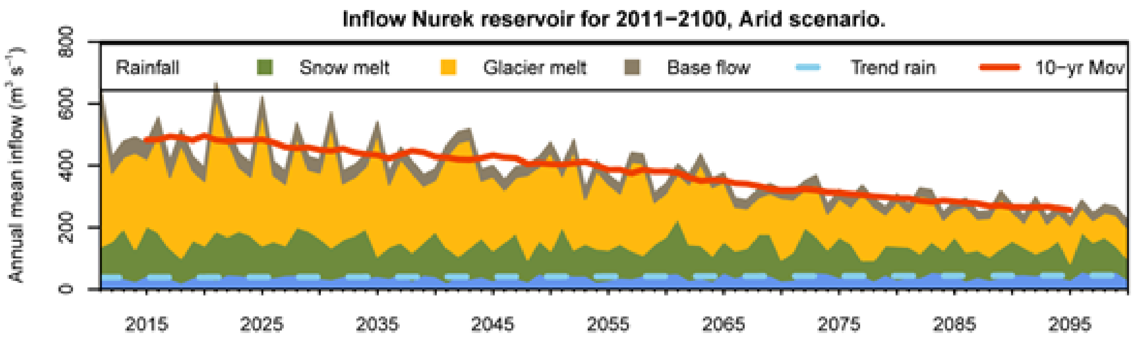

Figure 4-2. Sources (rainfall, snow, glacier and baseflow) of the river flow entering the Nurek reservoir, for one climate scenario, showing the influence of reduced glacier-flow (source: from data in FutureWater report Lutz et al., 2012)

4.2.2 Climate projections for Amu Darya upstream of the subprojects

63. A straightforward analysis of climate change trends was performed for the upstream area of the Amu Darya basin. 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 and is shown in relation to project areas in Figure 32.

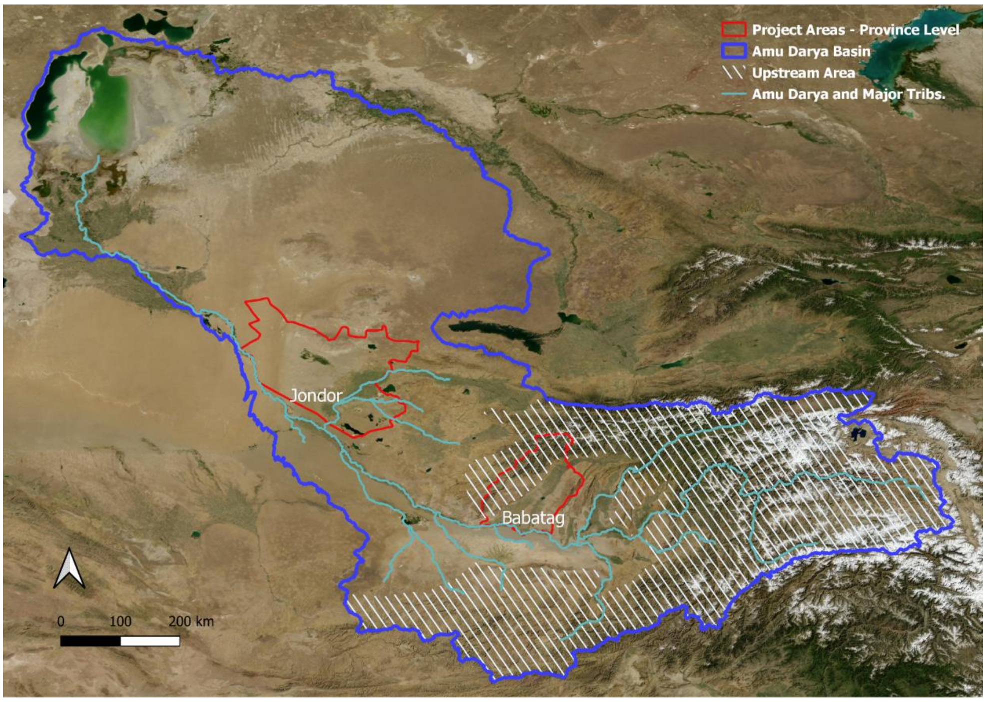

Figure 32. Amu Darya Basin, upstream area and major channels in relation to proposed project areas.

64. Projected changes in temperature and precipitation in in the upstream area were analysed using the NASA-NEX dataset described in Section 3.1.1. This analysis shows changes in annual mean temperatures in the range of around 1-2.5°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 (Figure 33). In terms of precipitation, model predictions are uncertain, but on average show a trend of increasing annual precipitation of around 5-15%.

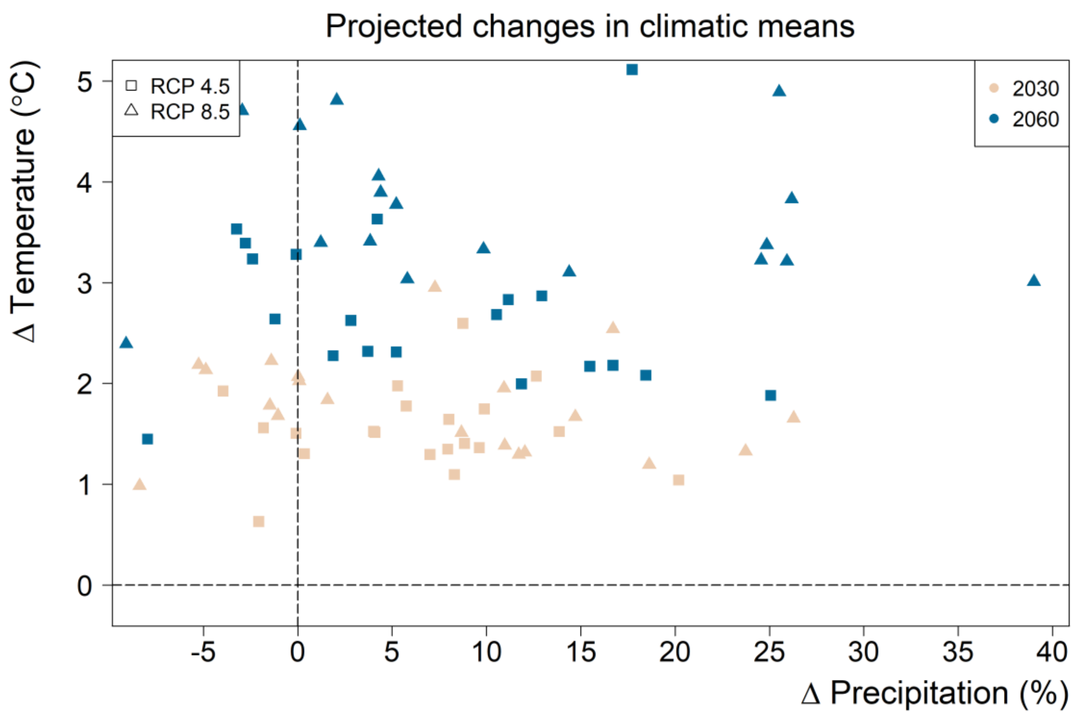

Figure 33. Average temperature and precipitation changes in Amu Darya upstream region.

4.2.3 Impacts on flows

65. As discussed before, the changing climate is likely to lead to complex changes in discharge dynamics originating from upstream areas. Increases in average temperatures are likely to lead to increased discharge in the short term due to increased snowmelt. But this is based on a finite amount of snow and may therefore lead to reduced discharge from this source in the longer term. Increased precipitation will also increase discharge in these areas. In combination, it is therefore likely that climate change may at least temporarily lead to certain increases in total annual flow volumes originating from upstream areas, alongside impacting the seasonality of runoff. Many factors (biophysical and human-induced) determine how this increased short-term runoff may translate to discharge in the **lower** parts of the basin. Therefore, it is by no means certain that this could lead to increased flow in the vicinity of project areas.

66. Several of the referred publications give an indication of the expected relative flow change in the Amu Darya river. In Table 4-3 this has been summarized and the relative change predictions been categorized, indicating how many studies fall into each of the three categories (slight increase, slight decrease, and more moderate to severe decrease). As can be seen, for the next 30 years, there is no real consensus on hydrologic response to climate change in the Amu Darya. For the next half of the century, most studies agree that there will be moderate to severe decrease. Please note however that these studies have different approaches, some of them focusing purely on changes in upstream hydrologic response, not considering downstream demands and downstream trends.

Table 4-3. Change in Amu Darya flows predicted by several studies

Change	Number of studies	References
Next 30 years (< 2050)		
Increase approx. +10%	3	(World Bank, 2015) (Kayumov and Novikov, 2014) (Gulakhmadov et al., 2020)
Slight decrease up to -10%	2	(Kure et al., 2013b, 2013a) (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)		
Increase approx. +10%	1	(Gulakhmadov et al., 2020)
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., 2013b, 2013a); (White et al., 2014); (Taryannikova, 2016); (Mannig et al., 2018)

67. The referenced studies coincide 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 in section 2.6). 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. As was analyzed for the purpose of this CRVA, it appears that this shift is already occurring (see Figure 2-4).

68. How this seasonal shift propagates to the downstream flow regime at the subproject intake locations is not at all straightforward. For the water resources simulation done to look at impacts on water shortages (see hereafter), a simple assumption was used: a maximum 20% relative increase was assumed in the first half of the year (Jan-Jun) and a 20% decrease for the second half of the year (Jul-Dec).

69. Another likely impact of climate change is that the interannual variability will increase, as the over-year buffering effect of glaciers will diminish. For the water resources simulation, it was assumed that the coefficient of variation (standard deviation divided by the average of mean annual flows) increases from 20% to a maximum of 30% in the future.

4.2.4 Low water availability risk for the subprojects

70. The analysis done on flow data for a downstream location (Kerki) and an upstream location (Nurek reservoir inflow) in section 2.5 showed that (i) over the last decades a slight increase in flows is seen for the upstream location, while (ii) there is a much more consistent decrease in flows for the downstream location. This suggests that increases in water demands (induced by climate change but probably more significant by increase in water use and population growth) over the last decades have cancelled out the small increase in water availability.

71. For the future there are no accurate predictions on water use in the Amu Darya basin. There are some factors though that suggest that upstream demand will increase:

- Increasing temperatures upstream leading to higher crop water requirements and natural vegetation

- Increasing temperatures upstream may enable new areas to become appropriate for cropping
- Likely construction of Rogun dam, with approx 10 km^3 of active storage. Filling, evaporation, as well as operations will likely have a considerable impact on downstream flows

72. Overall, it seems unlikely that water availability will increase for the subproject locations, even for the following decades. Flows will either remain stable for the next decades or may also suffer moderate reductions. Thus, the additional risk due to climate change for lower water availability for both SPs is estimated to be **high.**

4.3 Increased water demand

73. The combination of higher temperatures and lower precipitation will lead to increases in consumptive water use by natural vegetation, and an increase in crop water requirements. The water resources assessment framework calculates the demand based on the typically used equations for crop water requirements (FAO-56-based), considering both temperature as well as effective rainfall, and assumptions or data on efficiencies. The cropping scheme was implemented in the model (see details in Annex 1), considering three crop types: winter wheat, cotton and a third crop category that bundles the other crops that are cultivated in the area.

74. For a range of increased temperatures and changes in precipitation amounts, the changes in demand were assessed. Figure 4-3 shows the Climate Response Surface for the irrigation demand of Jondor SP, for the range of temperature and precipitation change. As can be seen from Figure 4-3, the temperature change influences largely the demand change, while the precipitation change has hardly any effect. For the Jondor SP, rainfall amounts are currently very low (approximately 100mm annual), so rainfall effectively used for evapotranspiration almost negligible in most months. Also for Babatag SP, rainfall amounts during the cropping seasons are low, thus predicted changes in rainfall do not have a significant effect on crop water requirements

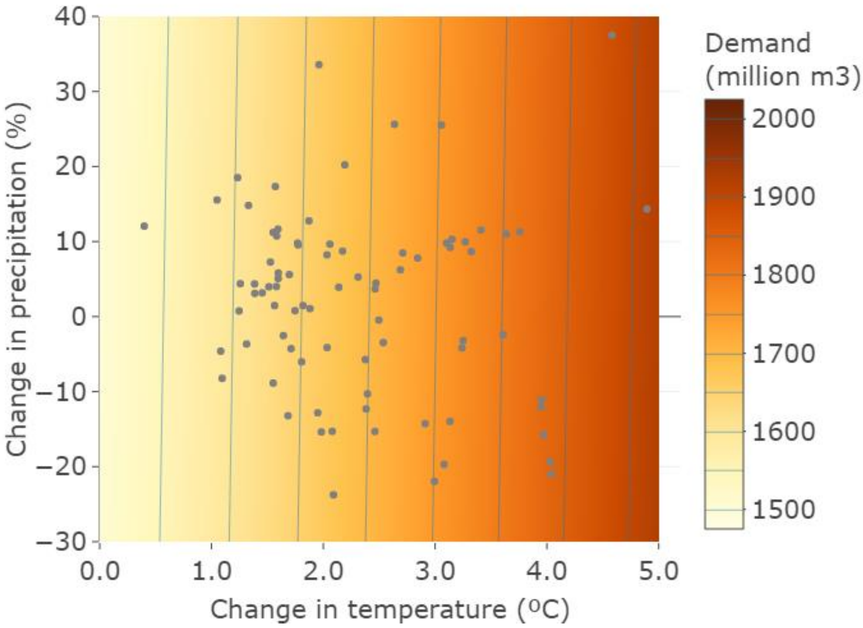

Figure 4-3. Climate response surface showing the impact on irrigation demand for Jondor SP of changes in temperature and precipitation. The dots show the projections for the two RCP scenarios, 21 models, and two horizons included in the study (see section 3.1.2)

Table 4-4 shows the number of climate models that predict an increase in demand for different thresholds for both Jondor as well as Babatag SP (resp. more than 5%, 10% and 15% increase). As can be seen, for example, an increase of 5% or more is extremely likely (21 models out of a total of 21). On the other hand, an increase of more than 15% is for the 2030 horizon unlikely (0 models out of 21).

Table 4-4. The number of climate models per RCP scenario and horizon from which an irrigation demand increase above a certain threshold is estimated.

Scenario/horizon	Increase > 5%	Increase > 10%	Increase > 15%
rcp45			
2030	20	6	0
2060	21	19	7
rcp85			
2030	21	10	0
2060	21	21	18

75. From the previous it can be concluded that the risk for increased water demand due to climate change is **high**: increases of around 10% can be expected and they are **very likely,** both for Jondor SP as well as Babatag SP.

4.4 Increased water shortages

76. Considering the climate trends, trends in Amu Darya flows and the climate projections for the project area as well as upstream, it is likely that more frequent water shortages in the future may occur for the subprojects, under current management conditions. The water resources simulation model (WEAP, see Annex 1) was used to dynamically simulate the main climate-driven factors that affect that performance of the subproject. Based on project demand and water availability, WEAP simulates a water supply for the subproject. As demand is hardly sensitive to the projected rainfall changes, the water shortage analysis has focused on changes in Amu Darya flows, in combination with changes in the temperature at the subproject areas.

77. The model runs for 30-year periods to make sure that interannual variabilities are considered. Based on the model outputs, water shortages (frequency, amounts, etc) are calculated. For the range of future climates, the performance metrics (see section 4.1.2) are assessed and visualized. Figure 4-4 shows the Climate Response Surfaces for Jondor SP, for four metrics (see detailed definition in section 4.1.2):

1. Unmet Demand
2. Coverage (Demand Met / Total Demand)
3. Supply Reliability (number of months with shortage / total number of months)
4. Water Stress Index (basin-level supplies divided by basin-level availability)

78. The Climate Response Surfaces show that the metrics are principally influenced by changes in Amu Darya flows. However, also temperature change will have an impact on the shortages (amount and frequency). Table 4-5 selects the values from the surfaces for the “most likely” value (median in case of temperature, -10% change for Amu Darya flows) and an optimistic and a pessimistic value. The following can be concluded:

1. Coverage and Reliability slightly influenced by temperature change – something to consider in design of adaptation measures. Both metrics are varying a few percent, depending on the future climate.
2. Flow changes have a large impact on the performance of the system: both coverage as well as reliability are influenced considerably, and difference between the pessimistic and optimistic value is about 25 to 30% for both metrics.

3. The Water Stress Index gives an indication of the stress on the water resource, considering competing demands downstream, and is thus a proxy for the potential for conflicts with other use(r)s. The value for this index indicates already an extreme stress level (typically above 40% is considered severe). Temperature change at the project level does not have a significant impact, but flow change does. Please note that the influence of temperature and demand change in downstream areas is not considered in this analysis.

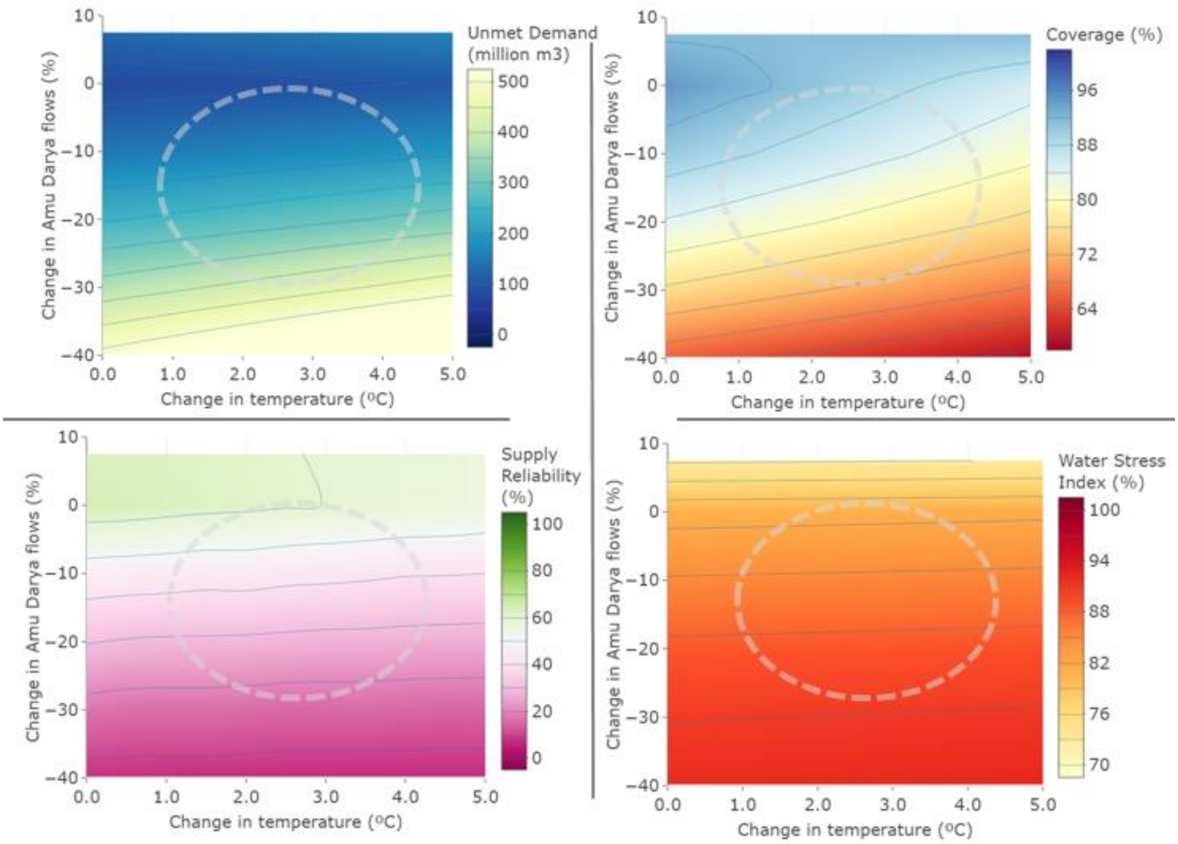

Figure 4-4. Climate Response Surfaces for Jondor SP: Left-upper: Unmet Demand; Right-upper: Coverage; Left-below: Reliability; Right-below: Water Stress Index. The grey circle gives a rough indication of where the most likely climate futures are.

Table 4-5. Values for the three performance metrics for Jondor SP, for different temperature and flow change values (median, pessimistic and optimistic)

	Coverage	**Reliability**	**Water Stress Index**
Temperature (ºC)			
Median (+2.1 ºC)	91%	62%	81%
Optimistic (10th perc)	93%	63%	81%
Pessimistic (90th perc)	87%	58%	81%
Amu Darya flow			
Most likely (-10%)	90%	46%	85%
Optimistic (+10%)	92%	64%	73%
Pessimistic (-30%)	75%	17%	91%

79. The outcomes from the water resources simulation for Jondor SP are also indicative for Babatag SP: even though the water resources situation is somewhat different, given the fact that water demand changes and water availability changes are similar among both SPs, it can be expected that the climate sensitivity of the project is rather similar to Jondor SP.

80. For Babatag SP, satellite imagery was used to visualize how a particular drought event affects the spatial patterns of vegetation and crop vigor (satellite sensors measure greenness among others). The year 2008 was a relatively dry year, both in terms of precipitation as well as Amu Darya flows. Figure 4-5 shows how the greenness of the vegetation deviates from the mean vegetation (based on a 20-year period) for the cropping season of 2008. It can be seen that the non-irrigated areas in the northern part of the image have a brownish color – indicating a negative anomaly in greenness and thus a drought impact. In the irrigated area, a patchy pattern is seen: brownish colors indicating a negative anomaly, and greenish colors indicating a positive anomaly. The dominant color is brown though, indicating that most farmers were negatively impacted that year by drought. This analysis illustrates the use of satellite data for the monitoring of project performance and water productivity.

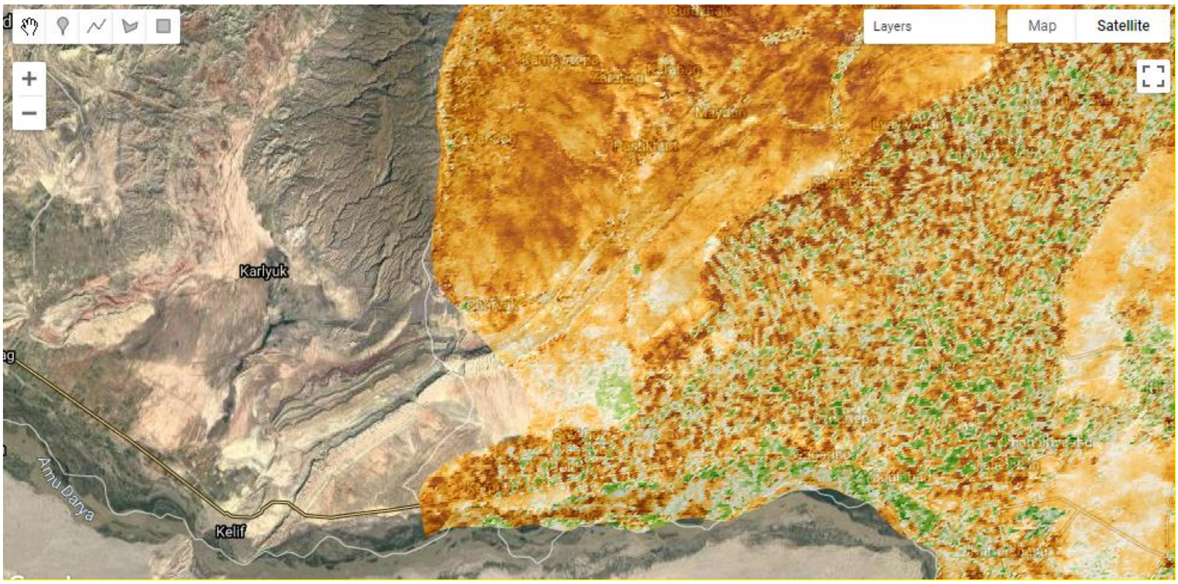

Figure 4-5. Map of vegetation greenness anomaly for a drought year (2008), for the Batabag SP area (source: Google Earth Engine).

81. From the analysis presented, it can be concluded that the climate risk for increased water shortages over the next decades is **high**: the impacts on the irrigation system performance are **high** and the likelihood for changes in demand and reduced water availability is very **high**. This holds for both SPs

4.5 Increased crop heat-stress

82. Another climate impact that may affect the subproject profitability is related to increased temperature extremes, affecting the productivity of crops (for example heat waves, increased diseases). Some scientific literature is available on this climate risk to crop productivity but still there are also important knowledge gaps in this field. Specifically for the region, the World Bank commissioned a study in 2013 on crop yield impacts, which included partially temperature-related stresses (Hunink and Droogers, 2011; Sutton et al., 2013). For this climate risk assessment, a few crop-specific climate indicators are analyzed, and available literature reviewed to further describe this risk.

83. The most relevant crops are cotton and winter wheat. Both are affected by changes in temperature, with growth placed under significant stress if significant changes in maximum and minimum temperatures occur. A summary of the temperature related characteristics of these crops is found below

(Table 4-6), alongside a selection of other crops (potato, alfafa) which may be cultivated as part of diversification plans for Uzbekistan's agriculture. Crop specific considerations should also be taken into account. Regarding Cotton, diurnal cycles are important – when night temperatures exceed 21 ºC, respiration rates increase markedly and substantial photosynthate is lost to respiration (FAO, 2012). Winter wheat requires a cold period or chilling (vernalization) during early growth for the full growth cycle to eventually occur.

Table 4-6 – Crop specific temperature related parameters for growth. Taken from FAO (2012).

Crop	Growing season	Heat tolerance level	No growth / chilling
Winter Wheat	October - August	34	5
Cotton	April - September	40 (day), 27 (night)	20 (day), 12 (night)
Potato	April - September	35	1
Alfafa	April - September	45	5

84. Extreme high and extreme low temperatures may exert stresses on crops for example through surpressing pollination and minimising degree days required for full biomass to occur. Climate change is (as mentioned in previous sections) likely to exert an influence on extreme temperatures and therefore may lead to increased crop stress into the future. Conversely, it may lead to increased crop production through warming temperatures minimising stress associated with extreme low temperatures. To quantify the impacts of climate change on crop growth in relation to heat stress, the thresholds detailed in Table 4-6 are therefore considered in relation to climate model predictions for future temperature changes, alongside historical reanalysis data for context.

85. Table 4-7 shows – per crop – anticipated future changes change in high temperature related heat stresses (given the large uncertainties and the explorative approach taken, numbers are shown as multiples of 10). An increase in the number of days with which the heat thresholds are breached is evident for both RCP scenario´s and time horizons and all crops with the exception of alfalfa (which has a very high temperature tolerance). This suggests that climate change (especially a under a worst case (RCP85) scenario), will exert a negative impact on crop yield due to heat stress. This is especially evident in relation to cotton and potato, with winter wheat less affected due to its differing growing season. Still, wheat may also be impacted by heat extremes as was analyzed scientists that predicted for several sites in Central Asia with similar climate conditions, hot temperatures to cause issues for flowering (flower sterility) on the long-term (Sommer et al., 2013).

Table 4-7. Jondor SP: changes in the frequency with which daily maximum temperatures will exceed heat stress threshold per crop during the growing season.

	Change in heat stress (days per growing season)	
Crop	2030-horizon	2060-horizon
Wheat	10	20
Cotton	0	40
Potato	20	30
Alfafa	0	0

86. In Babatag SP very similar maximum temperatures are observed as in Jondor (reaching up to 46ºC-47ºC – see Volume II and III of the main report). Also, temperature projections extracted from the climate model ensemble are very similar. Thus, it can be reasonably expected that Babatag SP is as vulnerable as Jondor SP is to this climate risk.

87. Table 4-8 details the change in low temperature related crop growth impacts. A significant decrease in the number of days with which this threshold is breached is evident for all RCPs, time

horizons and crops. This suggests that climate change may also have some beneficial effects in terms of reducing the days per growing season in which crop growth will be negatively affected by extreme low temperatures. Scientific analysis elsewhere confirms these conclusions for wheat for analysis across Central Asia (Sommer et al., 2013).

Table 4-8– Changes in the frequency with which daily minimum temperatures will be lower than the no growth threshold per crop in the average growing season for several time horizons and return periods (numbers given as multiples of 10).

Crop	Change in cold stress (days per growing season)	
	2030-horizon	2060-horizon
Wheat	-10	-20
Cotton	-10	-30
Potato	-10	-10
Alfafa	-10	-10

88. In Babatag SP temperature projections extracted from the climate model ensemble do not deviate significantly from those from Jondor SP, and similar cropping periods and temperatures are observed. Thus also for Babatag SP, positive impacts of increased minimum temperatures on vegetative growth can be expected. This means: less frost damage and faster early growth (emergence to flowering) for Babatag SP, as is the case for Jondor SP.

89. Overall, for **Jondor SP and Babatag SP**, the additional risk due to climate change for heat-related impacts on crop performance is considered **high** (high impacts and very likely). The reduced number of frost-days and low temperatures will probably only partially counterbalance these negative impacts.

4.6 Increased salinization

90. Secondary (i.e. caused by human intervention) salinization affects most of the irrigated lands in Uzbekistan, causing decreasing productivity. Principal factors driving this hazard are shallow groundwater tables and malfunctioning drainage. Salinization is managed intensively by the government-supported Ameliorative Expedition, concerned with drainage and controlling high water tables and salinity. Salinity is a major issue in Jondor SP. For Babatag SP, due to favorable groundwater levels and drainage, no significant salinity issues are reported.

91. Soil salinization is affected by climate change in that higher temperatures and evaporation rates increase the accumulation of salts (including sodium, phosphorus, calcium and magnesium) in the surface soil layers through capillary action. A positive effect of climate change may be higher rainfall, which contributes to leaching out accumulated salts through increased drainage. How these factors will play out will depend on each region. It appears likely though that soil salinization hazard will increase for Jondor SP, probably less for Babatag SP.

92. For Jondor SP, another factor that may cause issues in the future are changes in water availability for the leaching activities during the non-vegetative period. Currently about 20% of total water use (see Figure 4-6) is used for leaching.

93. The demand for leaching was simulated in the water resources simulation performed to assess water shortage risks, presented previously. Temperature-related effects on water demand were not included in this simulation, as they are highly uncertain. Figure 4-6 shows how coverage (percent demand satisfied) for the demand for leaching used in the non-vegetative period reduces with reduced water availability in the Amu Darya. Currently coverage is approximately 90%. This could slightly increase if flows go up by approx. 10%. A reduction of 20% in flows in the Amu Darya (as a cause of

climate change and/or increased upstream water consumption and demands) would decrease the coverage with 10% to approx. 80%.

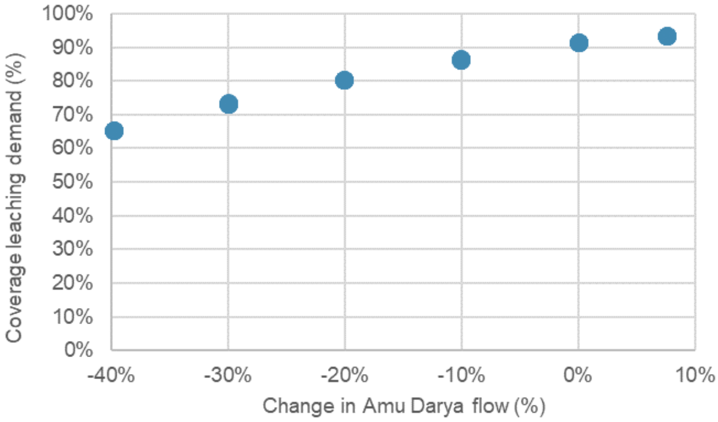

Figure 4-6. Jondor SP: coverage of leaching demand as a function of changing water availability from Amu Darya

94. Summarizing: Jondor SP is currently highly exposed to salinization. This risk is managed currently by various activities but mainly by leaching measures using water resources from the Amu Darya. As these resources may reduce in the future, additional risk due to climate change for salinization is classified as **high**. For Babatag SP this risk is estimated to be **low.**

4.7 Increased flooding

95. Local experts and stakeholders have indicated that flooding issues are currently not a key concern in the Jondor SP area. This is confirmed by the observed incidences of flooding from the global public-domain Dartmouth Flood Observatory dataset. Figure 4-7 shows only one pluvial flooding event recorded in the database for the Jondor area

96. For the Batabag SP, no flooding events have been recorded in this same database. Field information however indicated that nowadays local pluvial floods occur occasinally that cause some issues issues with sedimentation in the canals.

97. Both SPs are not exposed to flooding events originating from the rivers (Amu Darya and reaches), due to their location and altitude. Overall, the climate risk for flooding for the two SPs can be classified as **negligible**.

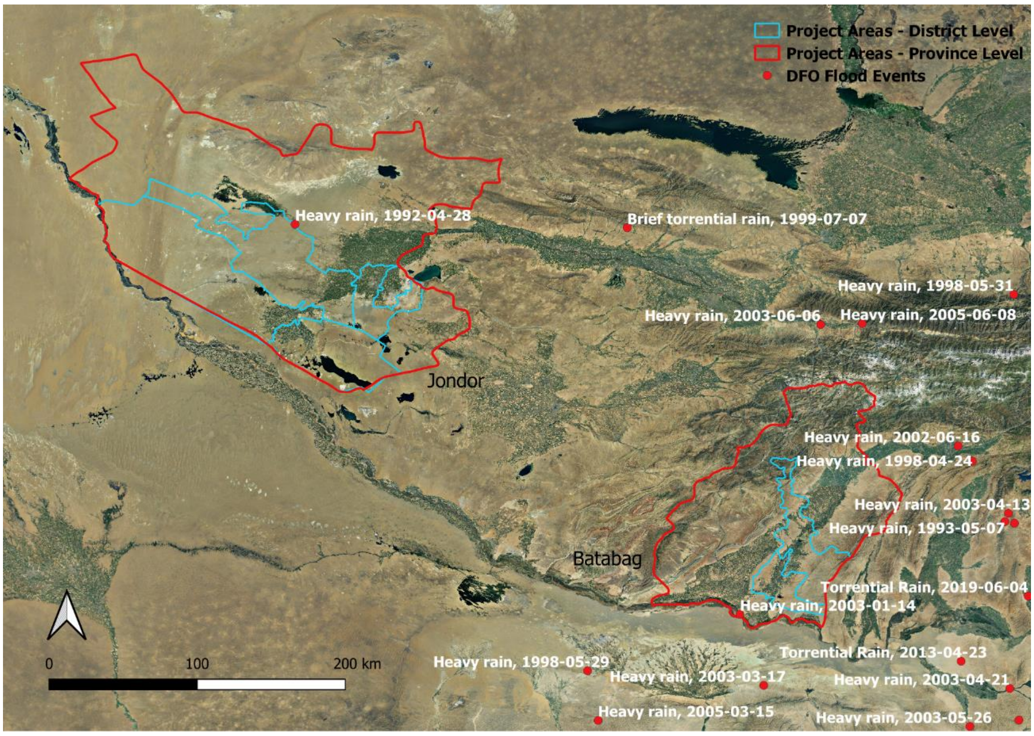

Figure 4-7. Recorded flood events from the Dartmouth Flood Observatory database in the area of the proposed projects.

4.8 Increased erosion and landslides

98. Uzbekistan faces a wide range of challenges related to land degradation. A key factor driving land degradation can be soil erosion. It is reported that about 80 tons per ha of irrigated croplands are lost each year in Uzbekistan. Wind erosion affects more than 50% of farmlands and 19% of the irrigated area is affected by water erosion (Aw-Hassan et al., 2015). The principal negative impact is the loss of fertile land, affecting the productivity of the irrigation system.

99. For Jondor SP, stakeholders did not report facing issues with soil erosion or landslides. Indeed, landslides are unlikely to be an issue of concern given the gentle slopes dominating the areas. Soil erosion may still to some extent be an issue, mainly driven by wind, but apparently not recognized as a factor affecting productivity nowadays.

100. For Babatag SP, it is reported that the soils are quite sensitive to erosion, particularly in the sloping terraces. Erosion of soils from some of the downslope aligned furrows was observed (see Vol III of the main report).

101. Data from the global dataset presented in Figure 4-8 confirms that landslides can also be an issue of concern in Batabag SP. Stakeholders have indicated that sedimentation of the canals due to sediments entering the infrastructure from the slopes is currently is an issue of concern.

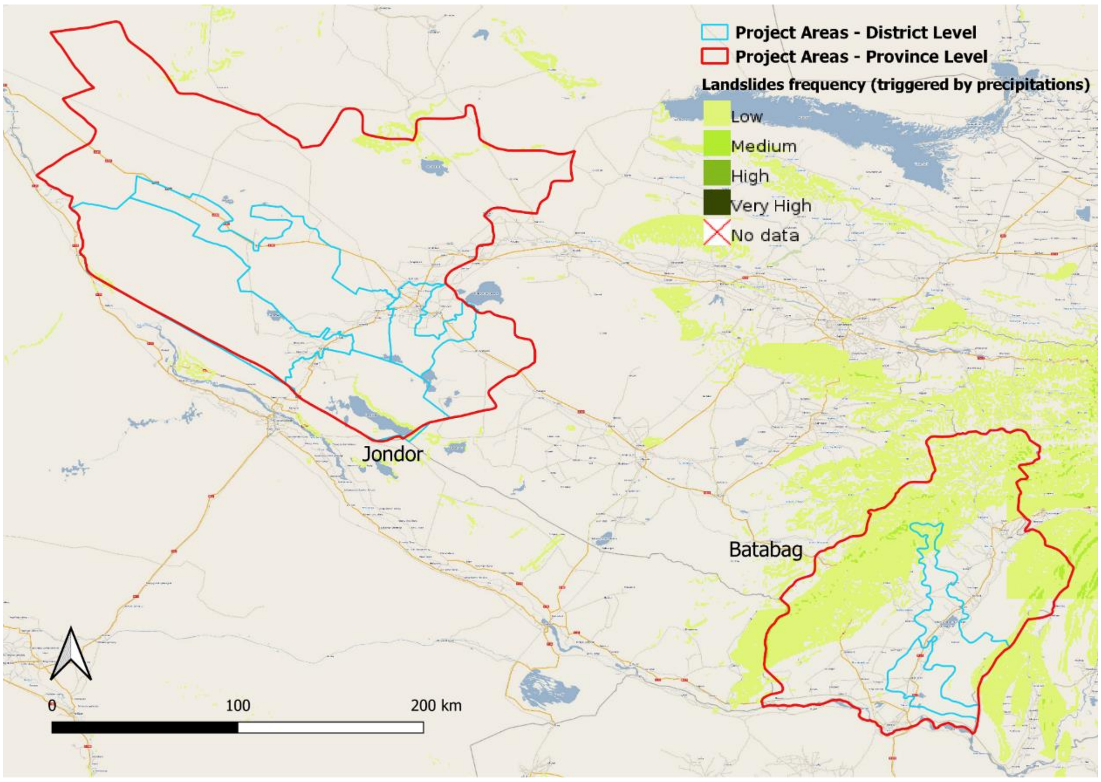

Figure 4-8. Landslide hazard to the two project areas taken (source: Global Risk Data Platform)

102. Overall, for Jondor SP, the additional risk due to climate change for erosion is classified as **low**, as current impacts of erosion are reported to be low and it is **likely** that climate change will not change this considerably.

103. For Babatag SP, erosion and landslides are already causing **some** issues, productivity losses and costs related to sedimentation of infrastructure. It is **very likely** that the drivers of erosion (high rainfall events and wind) will increase in the future. Thus, this risk is classified as **medium.**

4.9 Increased sedimentation issues

104. The Amu Darya river has high sediment loads during the flood seasons. This is causing issues in the Babatag SP mainly, due to poorly designed infrastructure. It is reported that the sediment concentrations of the Amu Darya vary are about 500 mg/l during low flows (winter) rising to over 3,000 mg/l during spring and early summer floods (see Vol III).

105. Also for Jondor SP, sedimentation issues are currently an issue of concern. Reportedly, canal cleaning is required 3-4 times (on-farm canals) per year compared to 1-2 times per year in other regions of Uzbekistan, because of high sediment loads, possibly partly because sediment loads are lower in the lower reaches of Amu Darya (see Vol II).

Figure 4-9. Main canal of Babatag SP showing silt in bed and spoil banks along main canal

106. Sediment loads in the Amu Darya rivers are mainly governed by the flood peaks. As discussed earlier in the report, climate change will affect the hydrological regime of the Amu Darya, changing the peak towards earlier in the season. Peaks on the long-term are also likely to increase, as more water will originate from direct runoff, instead of from snow or glaciers. Thus, it appears very likely that sediment loads will increase over the next decades. Another factor to consider is also the negative trends in land degradation upstream in the Amu Darya, causing more sediment to enter the river.

107. Overall, the additional risk due to climate change for sedimentation of infrastructure to occur in the future is classified as **high,** for both Jondor SP as well as Babatag SP: infrastructure is currently highly exposed to this hazard and climate projections indicate that sediment loads are very likely to increase the driving climate variables.

4.10 Jondor SP: Prioritized Climate Risks

108. The following table shows a summary of the key climate risks as were identified, assessed and classified in the previous sections.

Table 4-9. Jondor SP: summary of key climate risks

Potential impact	Related Project Components	Anticipated Change	Relevance and risk to Jondor SP
Reduced water availability	Canal system, irrigated areas	Climate and upstream demands and regulation affecting flow regime in Amu Darya	**High** Principal source of water supply at risk thus productivity loss
Increased water demands	Irrigated areas, irrigation system, pumping systems	Increase in mean, minimum and maximum temperatures predicted by climate model ensemble	**High** Water demands already not fully covered today; further reduction may cause productivity loss
Increased water shortages	Irrigated areas, irrigation system	Combination climate and non-climate factors affecting water availability and demand	**High** Shortages due to poor infrastructure and negative trends in water availability, putting profitability at risk
Increased crop heat-stress	Irrigated areas, irrigation system	Increased minimum and maximum temperatures	**High** Crops may suffer considerably during summer from heat stress; some crops may not be feasible anymore
Increased salinization	Irrigated areas	Increased evaporation and changes in rainfall	**Medium** Highly exposed but reasonable capacity to manage risk, but will need further risk management
Increased flooding	Irrigated areas, canal system	Increase in rainfall extremes	**Negligible** Not a significant hazard in this area
Increased erosion and landslides	Irrigated areas	Wind velocities and rainfall extremes increase	**Low** Low exposure to this hazard, and will not significantly increase in the future
Increased sedimentation	Canals, pumping stations	More extreme rainfall leading to increased flooding peaks in Amu Darya	**High** Costs to mitigate sedimentation issues in canals and other infrastructure will further increase

4.11 Babatag SP: Prioritized Climate Risks

109. The following table shows a summary of the key climate risks as were identified, assessed and classified in the previous sections.

Table 4-10. Babatag SP: summary of key climate risks

Potential impact	Related Project Components	Anticipated Change	Relevance and risk to Jondor SP
Reduced water availability	Canal system, irrigated areas	Climate and upstream demands and regulation affecting flow regime in Amu Darya	**High** Principal source of water supply at risk thus productivity loss
Increased water demands	Irrigated areas, irrigation system, pumping systems	Increase in mean, minimum and maximum temperatures predicted by climate model ensemble	**High** Water demands already not fully covered today; further reduction may cause productivity loss
Increased water shortages	Irrigated areas, irrigation system	Combination of reduced water availability and increased demand	**High** Shortages due to poor infrastructure and negative trends in water availability, putting profitability at risk
Increased crop heat-stress	Irrigated areas, irrigation system	Increased minimum and maximum temperatures	**High** Crops may suffer considerably during summer from heat stress; some crops may not be feasible anymore
Increased salinization	Irrigated areas	Increased evaporation and changes in rainfall	**Low** Groundwater tables and drainage cause low exposure to this hazard.
Increased flooding	Irrigated areas, canal system	Increase in rainfall extremes	**Negligible** Not a significant hazard in this area
Increased erosion and landslides	Irrigated areas	Wind velocities and rainfall extremes increase	**Medium** Erosion causes soil loss and landslides issues with sediment affecting infrastructure
Increased sedimentation	Canals, pumping stations	Increased flooding peaks in Amu Darya	**High** Costs to mitigate sedimentation issues in canals and other infrastructure will further increase

5 Climate Adaptation

5.1 Introduction

110. The climate risks identified in the previous chapter for the two subprojects (SPs) urge for project activities that manage and address these risks. The project proposes a wide range of integrated adaptation activities, at different levels (system, farm and institutional). This chapter links the climate risks that were identified with the proposed activities.

111. The climate risks that the project activities should address are those that were prioritized as "medium" or "high" in the climate risk assessment. The prioritized risks that follow from the climate risk assessment are (see summary tables in previous chapter):

I. **Reduced water availability**
II. **Increased water demands**
III. **Increased crop heat-stress**
IV. **Increased salinization issues** (Jondor SP)
V. **Increased erosion and landslides** (Babatag SP)
VI. **Increased sedimentation of infrastructure**

These risks are linked with the project activities in the sections below, and described per Output of the project:

- Output 1: infrastructure development and investments to modernize the main conveyance system
- Output 2: on-farm water management improvements, by introducing several state-of-the-art physical and management technologies
- Output 3: Institutional strengthening for sustainable water resources management, including among others information systems for monitoring compliance and procedures for volumetric measurement.

112. Besides, specific climate adaptation activities are proposed that are financed by requested climate finance (ADF-13). These activities focus on specific risks and make use of novel technologies (remote sensing-based).

5.2 Output 1: Modernized Main Canal Water Supply Systems

113. This project output that focuses on the main canal system, should reduce water that is currently lost from the system by leakage and which becomes non-utilizable and non-recoverable. This is especially relevant for Babatag SP, due to the high salinity in the groundwater degrading the water quality of the return flows considerably. Also, the project output aims at better monitoring and control of water supplies and thus more reliable water supplies, especially under a more variable climate and water availability regime.

114. More specifically, the following project components should address the climate risks related to **(I) reduced water availability, (II) increased water demands** and resulting increased occurrence of water shortages**:**

a. Upgrading of the main canals to provide a reliable level of service along the canal, by re-sectioning and targeted lining.

b. Upgrading of control structures, offtakes, and other minor infrastructure along the main canals so that water is supplied from offtakes more reliably

c. Construction of improved measurement and canal control systems by installing a SCADA system on the main canals to measure flow and depth so that climate adaptive levels of service can be better maintained, and uncontrolled losses minimized

115. The mentioned project components may also reduce to some extent the climate risk of **(IV) increased salinization** issues, as also during the non-vegetative period, water for leaching can be supplied more efficiently to the land.

116. For the identified climate risk **(VI) Sedimentation of infrastructure**, the project invests in mud flow structures for the Babatag canal. For the Jondor SP the project does not include a component that addresses this issue, as the ongoing Amu Bukhara project also financed by ADB includes sediment exclusion structure works at the pumps for the Amu Darya river.

5.3 Output 2: Modernized Interfarm Canal Systems and On-farm Management

117. Output 2 targets the interfarm and on-farm level. Also at this level, **(I) reduced water availability, (II) increased water demands** and resulting increased occurrence of water shortages are key climate risks that need to be addressed by adaptation activities. The project activities that respond to these risks are:

a. Re-sectioning and modernization of interfarm canals, to provide a reliable level of service from main canal to farms so that irrigated agriculture

b. Introduction of modern climate resilient irrigation technologies that are internationally standard practices for improving productivity and enable higher value crops (buried pipe distribution system, precision land levelling, drip irrigation).

118. Further on, the **(IV) salinization** climate risk is addressed by the following project component:

c. Drainage works for salinity improvement: undertaking targeted cleaning of the Collector Drain Network for better water table and salinity control

119. The main aim of the on-farm interventions is to promote on-demand water supply so farmers can better adapt to more variable water availability and supplies from the main canal system, due to climate change. More accurate and on-demand supplies will enable crop diversification, if supported by adequate capacity building measures (see Output 3), reducing the related **socio-economic vulnerabilities**.

120. Another key risk at this level that was prioritized is **(III) crop response to heat extremes.** This is also addressed by the same project components leading to a more flexible and reliable water supply system and thus enabling farmers to choose more heat-tolerant varieties. This risk is further addressed in Output 3 (see next section).

5.4 Output 3: Policy and institutional strengthening

121. For both SPs, the interventions proposed under Output 3 should increase the adaptive capacity of management and planning arrangements and strengthen the institutions and farmers to better adapt to climate change. Project components included in Output 3 address **all prioritized climate risks**. These components are:

a. Increased capacity for modernized water allocation and use, by strengthening the capacity and approaches of WMO and WCA for preparing, implementing and monitoring climate adaptive cropping patterns and water allocation plans.

b. Establishment of improved asset and MOM arrangements, by strengthening the capacity and approaches of WMO and WCA for asset management and MOM of irrigation systems so that systems well managed, operated and maintained to minimise the impacts of climate change and particularly increasing crop water demands.

c. Increased capacity for improved salinity and water quality management, by improving approaches of the Jondor BISA Ameliorative Expedition, WMO and WCA to manage water tables and salinity through more efficient use of water

d. Institutional strengthening of WMO, WCA and farmer groups, by raising WMO, WCA and farmer groups knowledge of climate change and strengthen their governance practices and the successful implementation of new WCA arrangements.

122. More specifically, for the prioritized climate risk **(VI) erosion and landslides,** capacity building activities to WCAs will include training and provision of guidelines for irrigation layout and whole farm planning that considers design and slopes that reduce erosivity.

123. Climate risk **(III) Crop response to increased occurrence of heat extremes** is covered by the project as capacity building activities will provide training on heat-stress and heat-tolerance aspects, e.g. heat-tolerant crops, linking with scientific knowledge centres on this topic, heat-stress reducing technologies and agronomic practices (e.g. application of macronutrients, application of growth regulators, anticipating the date of sowing, etc).

124. Capacity building activities will also promote the abandonment of the quota system and other **measures to promote more flexible cropping decisions**, thus increasing the climate resilience of the farmers and as such as also lead to reduced **risks (I) – (IV)**.

125. For climate risk **(III) salinization**, an integrated approach will be promoted for salinity and drainage management that focuses among others on adapting to existing soil and water salinity and mitigating the potential development of salinity. This includes: accurate irrigation scheduling (Howell, 2003); permanent raised bed (Akbar et al., 2007); and soil conservation and management practices, such as reduced tillage, the incorporation of crop residues, gypsum and manure application, crop rotation and cover crops to increase soil organic matter, soil water holding capacity and infiltration.

126. Output 3 (3a) will focus on reducing a key driver of climate risk of both SPs: **inequitable service levels and water distribution**, depending on the location in the system. For example, typically farmers at the tail-ends of the systems have lower reliable water supply, as was confirmed in the socio-economic survey. To enable equity and uniformity of water distribution, spatial information on water use and productivity is key. **Remote sensing technologies** can provide this spatial information on water consumption and productivity, updated each cropping season. Thus, a key adaptation activity included in the project is to use remote sensing technologies to evaluate performance and to regularly update water allocations. Currently such information is not available to irrigation system managers in Uzbekistan, while being essential for an adaptive response to climate change. This project component will address the prioritized **risks (I) – (IV)**

5.5 Adaptation costs

127. For this project, a certain fraction of the project costs can be attributed to climate adaptation. Different methods can be used to calculate climate adaptation costs. The MDB common methodology for tracking adaptation finance is based on three steps, which are (i) establish **context** (justification), (ii) **intent** and (iii) define **logical connections** between climate risks and adaptation. The climate vulnerability **context** is provided in this CRVA. The general vulnerability context is one of increasing water stress as a result of climate change, which poses a major challenge to Uzbekistan to maintain and expand upon recent economic developments in agriculture. The project-specific context is summarized in Chapter 2 – 4 of this CRVA.

128. There is an explicit **intent** of the ADB and the Ministry of Water Resources (MWR) to incorporate climate adaptation aspects in the preparation of water resources projects over the next decades. Currently, the National Water Sector Development Concept 2030 is being prepared jointly and to be approved in 2020. It aims at prioritization and phasing of interventions over a 10-year period, supporting long-term sustainable water resources management, addressing climate risks. The project closely aligns with the government's priorities on adapting to climate change, currently being worked out in the National Adaptation Plan and specified in the Intended Nationally Determined Contributions submitted to UNFCC, listing several adaptation measures in the agriculture and water management sector that are integrated in this project, especially those aiming at diversification of food crops production pattern, improvement of water management practices and land husbandry.

129. **Logical connections** are established in this CRVA between the identified project-specific climate risks and the project activities addressing these risks (see previous sections of this Chapter). Many of these activities will generate direct benefits after implementation, independent of climate change. But the activities have been designed for long-term performance: considering likely productivity decrease and water scarcity increases in the future. Thus, the full benefit of these activities can be expected on the long-term, with increased climate change risks. These additional benefits on the long-term, can be associated with an incremental investment cost.

130. Guidance for tracking climate adaptation finance developed by the "MDB Working Group on tracking climate finance"[1] and related guidance developed by ADB[2] suggests estimating, if possible, adaptation costs by calculating incremental costs of activities that can demonstrate an adaptation benefit beyond good development (or, in other words, the differentiating elements of development operations). However, this is not always possible, because some activities do not have associated incremental costs, such as water allocation mechanisms or the selection of more drought-resistant crops so they withstand future climate change impacts.

131. In that case, when it is not possible to estimate incremental cost or investment directly from project budgets, for example because of the before-mentioned reasons, the guidance suggests applying a proportion of the project cost or investment corresponding to adaptation activities to represent the incremental amount. The proportion can be estimated based on climate impact assessment and the relative impact of climate change on the performance of the project.

132. For the current project, calculating incremental costs of climate adaptation in the preferred approach (with climate change versus without climate change) is cumbersome because:

a. There are multiple, compounding climate change risks that affect the project: for example heat stress-impacts or increased salinization also impact demands and shortages, etc;

b. The project proposes a large number of activities that are predicated on climate change, and thus do not have any incremental costs associated, e.g. those related to climate smart agriculture, water allocation governance, etc

133. For this reason, the proportional approach was applied for the engineering project components, and 100% of project costs were assigned to climate adaptation for those activities that were predicated on climate change or those where climate change adaptation is central (e.g. those related to water allocation).

134. From the climate impact analysis presented in this report, it followed that water supply deficits will likely increase by around 20% within the project lifetime, due to a combination of increased crop water requirements, increased demands upstream in the river basin, and more variable (and possibly also

[1] The 2020 Joint Report on Multilateral Development Banks' Climate Finance, Annex B.
[2] A Guidance Note on Tracking Climate Finance in Urban and Water Sectors

lower) supplies. Besides, several other climate risks were identified and rated as high, for example increased crop heat stress. Climate change (reduced variability, increased demands, increased heat stress) have been considered in the design of the project components. Given the compounding nature of these risks, and the likely relative impacts, a proportion of 30% was assumed to be an appropriate value to be used for calculating climate adaptation finance.

135. The below table shows the adaptation finance for each of the relevant project activities and its justification. This table can also be found in the Linked Document "Climate Change Assessment" (Appendix 11 of the project documents).

Table 5-1. Adaptation activities, estimated adaptation costs and justification

Adaptation Activity	Target Climate Risk	Estimated Adaptation Costs ($ million)	Adaptation Finance Justification
Output 1: Modernized Main Canal Water Supply Systems			
More extensive upgrading of the main canals by re-sectioning and targeted lining.	(i) reduced water availability, (ii) increased water demands	30.2	To prevent the performance of the canal system to be compromised by increased variability of water supply and demands under future climate change, extra sections and works are needed (30% proportion of the activity cost)
More extensive upgrading of control structures, offtakes, and other minor infrastructure along the main canals	Idem	0.3	To enable the distribution system to deal with increased variability of water supply and demands under future climate change, extra control structures and offtakes are required (30% proportion of the activity cost)
Construction of extra improved measurement and canal control systems by installing SCADA system	Idem	0.4	To be able to measure and control under increased variability of water supply and demands, additional capacity is needed for the measurement and control system (30% proportion of the activity cost)
Output 2: Modernized Interfarm Canal Systems and On-farm Management			
More extensive re-sectioning and modernization of interfarm canals	(i) reduced water availability, (ii) increased water demands	9.2	To prevent the performance of the canal system to be compromised by increased variability of water supply and demands under future climate change, extra sections and works are needed (30% proportion of the activity cost)
Introduction of climate resilient irrigation technologies (buried pipe distribution system, precision land levelling, drip irrigation).	Idem	7.2	Costs for introducing climate resilient irrigation technologies to counteract future climate change impacts on productivity (100% of costs)
More extensive cleaning and works for drainage and salinity improvement	Increased salinization issues	1.0	Additional cost from need for extra sections and works, required to offset future climate change impacts on supply and productivity (30% proportion of the activity costs)
Output 3: Policy and institutional strengthening			
Capacity building on implementing and monitoring climate adaptive cropping patterns and water allocation plans.to WMO and WCA	Reduced water availability; Increased water demands; Increased crop heat-stress; Increased salinization issues; Increased erosion and sedimentation	3.6	Addressing and improving climate resilience is the primary goal of this activity (100% of costs).

Adaptation Activity	Target Climate Risk	**Estimated Adaptation Costs** ($ million)	Adaptation Finance Justification
Establishment of improved climate-resilient asset and MOM arrangements,	Idem	0.4	Addressing and improving climate resilience is the primary goal of this activity (100% of costs).
Capacity building on climate resilient and improved salinity and water quality management	Idem	0.5	Addressing and improving climate resilience is the primary goal of this activity (100% of costs).
Institutional strengthening of WMO, WCA and farmer groups, implementing climate resilient governance practices and new WCA arrangements.	Idem	0.6	Addressing and improving climate resilience is the primary goal of this activity (100% of costs).
Preparation of water sector strategy	Idem	0.9	Addressing and improving climate resilience is the primary goal of this activity (100% of costs).

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Annex I. Assessment tool WEAP

Model specifications

A standardized approach to climate change impact and vulnerability assessment does not exist yet. Various methods and guidelines exist and ADB, amongst others, are in the process of refining the approach to climate risk assessment[1, 2, 3, 4].

Various water resources impact tools exist and appropriate selection of the most relevant is essential for the success of a climate risk assessment (Figure 0-1). Conventional supply-oriented catchment simulation models are not adequate for exploring the full range of climate change impact analysis. Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side management, regarding climate change impact analysis. WEAP incorporates these values into a practical tool for water resources planning by balancing supply and demand. Moreover, WEAP is very scalable and therefore able to incorporate processes into detail where necessary and scoping where possible.

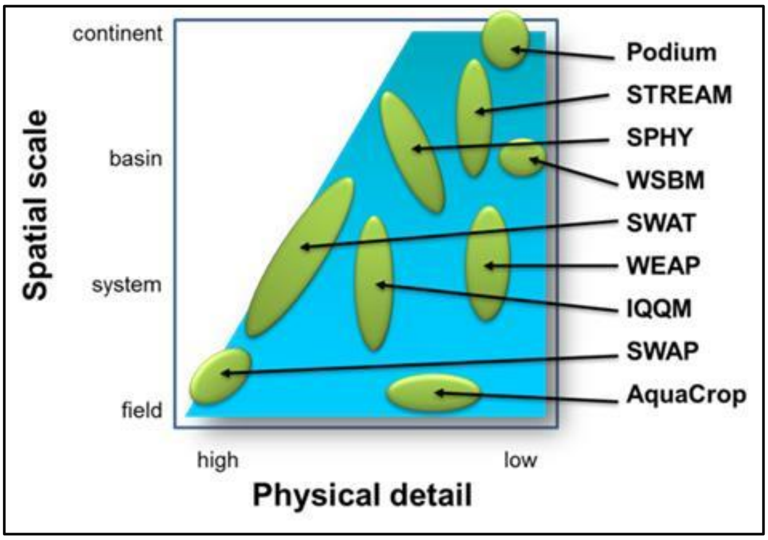

Figure 0-1: Relation between spatial scale and physical detail in water resources simulation tools. The green ellipses given an indication of where the key strengths are in this space for a few well-known water resources models[5]

A detailed discussion on WEAP can be found in the WEAP manual which can be freely downloaded from the WEAP website (http://www.weap21.org/). In summary, WEAP have the following features:

- Integrated Approach: Unique approach for conducting integrated water resources planning assessments.

[1] Asian Development Bank (ADB). 2017. Guidelines for Climate Proofing Investment in the Water Sector: Water Supply and Sanitation. https://www.adb.org/sites/default/files/ institutional-document/219646/guidelines-climate-proofing-water.pdf.
[2] Asian Development Bank (ADB). 2014. “Climate Risk Management in ADB projects.”
[3] Asian Development Bank (ADB). 2012. Addressing Climate Change and Migration in Asia and the Pacific. Asian Development Bank. http://www.adb.org/publications/addressing-climate-change-and-migration-asia-and-pacific.
[4] Economic Commission for Europa. 2009. Guidance on Water and Adaptation to Climate Change. https://www.unece.org/fileadmin/DAM/env/water/publications/documents/ Guidance_water_climate.pdf.
[5] Droogers and Bouma, 2014. Simulation modelling for water governance in basins. International Journal of Water Resources Development. p. 475-494.

- Stakeholder Process: Transparent structure facilitates engagement of diverse stakeholders in an open process.
- Water Balance: A database maintains water demand and supply information to drive mass balance model on a link-node architecture.
- Simulation Based: Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and in-stream water quality under varying hydrologic and policy scenarios.
- Policy Scenarios: Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.
- User-friendly Interface: Graphical drag-and-drop GIS-based interface with flexible model output as maps, charts and tables.
- Model Integration: Dynamic links to other models and software, such as QUAL2K, MODFLOW, MODPATH, PEST, Excel and GAMS. Links to all other models can be developed quite easily since WEAP can read and write plain text files similar as SWAT, SPHY, SWAP, Mike11, HEC-HMS, HEC-RAS and Geo-SFM.

Model input data

The WEAP framework is rather flexible in terms of data requirements: it allows to setup the analysis in a more conceptual mode or a more physically based one. Typically, a mixture will be used based on the questions to be answered and data availability. The accuracy of the climate risk assessment for a specific area depends on the availability of data and the way the system is conceptualized. The climate sensitivities need to be captured well enough. For this purpose, two things are important to mention: the uncertainty in climate models is typically much higher than the uncertainty in model parameters[1]. Related to this, one can distinguish between "absolute" accuracy and "relative" accuracy. "Absolute" accuracy relates to how well the model represents reality; "relative" accuracy relates to the performance of comparing different scenarios. It has been shown that for water and climate studies, even if "absolute" accuracy is low, "relative" accuracy can be still high[2].

Availability and access to good quality of data is essential for water resources impact analysis using WEAP. Required input data can be divided into the following main categories:

- Model building
  - Static data[3]
    - Land use, land cover
    - Irrigation area and efficiencies
    - Cropping practices
  - Dynamic data
    - Climate (rainfall, temperature, reference evapotranspiration)
    - Evapotranspiration by crops and natural vegetation
    - Water demands
    - Reservoir releases
- Climate change impact
  - Precipitation changes
  - Temperature changes
  - Flow changes

[1] Her, Y., Yoo, S., Cho, J. et al. Uncertainty in hydrological analysis of climate change: multi-parameter vs. multi-GCM ensemble predictions. Sci Rep 9, 4974 (2019). https://doi.org/10.1038/s41598-019-41334-7
[2] Droogers, P., A. Van Loon, W. Immerzeel. 2008: Quantifying the impact of model inaccuracy in climate change impact assessment studies using an agro-hydrological model. Hydrology and Earth System Sciences 12: 1-10
[3] Nota that static data can still vary over longer time frames, but are fairly constant over days/weeks

For adaptation scenarios, model parameters following from the static data can be modified – for example increasing the irrigation efficiencies. Each of the above categories can be refined depending on availability and accessibility of data. The WEAP framework is flexible in level of details of data availability. A typical example is that water demands can be included as a total amount of water but can be also estimated by WEAP using for example the population, their daily required intake and daily and/or monthly variation. Similarly, climate data can be entered at annual, monthly, 10-days or daily level.

The following table shows the main data inputs and parameters with its corresponding value and/or source

Variable	Static / Spatial Resolution / Location / Time Period	Value / Data source
Climate		
Temperature	Dynamic, 9 km, 1980-2019	ECMWF ERA5 Land
Precipitation	Dynamic, 9 km, 1980-2019	ECMWF ERA5 Land
Temperature	Dynamic, 2005-2099	21-model ensemble NASA-NEX
Precipitation	Dynamic, 2005-2099	21-model ensemble NASA-NEX
Land use		
Irrigated area	Static	Max: 56,000 ha, BW Amu Darya)
Cropping pattern	Monthly pattern	Jondor: Wheat: 29%; Cotton: 65%; Other: Intercropped in summer
Practices and infrastructure		
Irrigation efficiency	Static	0.6 (assumption, see below)
Canal losses Jondor	Static	15% (not included in Irrigation efficiency)
Internal reservoir storage capacity Jondor	Static	179 million m3 (proportional to Jondor irrigated area)
Flows		
Amu Darya flows	Station Kerki, 1936 – 1980, daily	GRDC
Amu Darya flows	Station Kerki, 1990 – 2018, annual	BW Amu Darya
Inflow Aral Sea	1992 – 2015	BW Amu Darya
Demands		
Planned allocation	2005-2019, monthly	BISA
Actual allocation	2005-2019, monthly	BISA
Downstream demands		Estimated assuming the 80-percentile of flows is allocated
Aral Sea flow requirements		5 km3/year (median of inflow of last 30 years)

No reliable data is available on irrigation efficiency for the study area. For this analysis, a value of 0.6 was assumed, excluding the losses in the Jondor canal (15%). If Jondor canal losses are included, the value for the overall efficiency is 0.6*(1-0.15)=0.51. This value is similar as what is provided by the remote sensing-based portal WUEMoCA (Water Use Efficiency Monitor in Central Asia)[1], which presents the annual values in Figure 0-2.

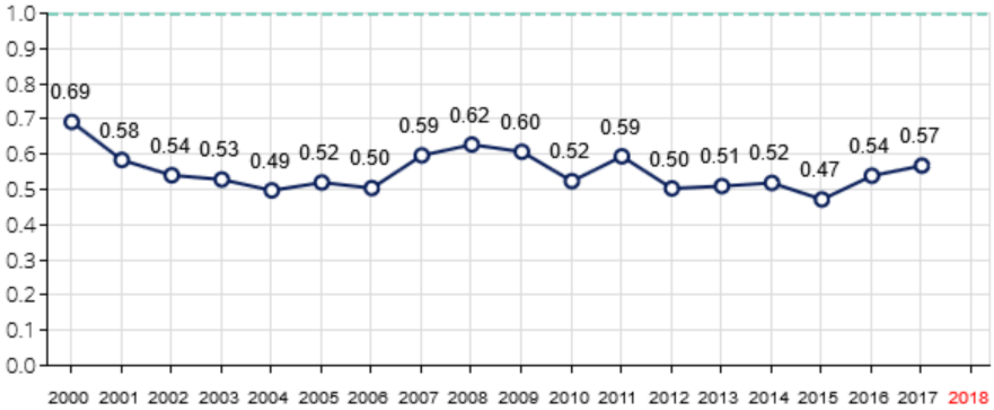

Figure 0-2. Annual values for the irrigation efficiency for the Bukhara province (source: WUEMoCA)

The crop water requirements are calculated in WEAP according to the FAO-56 procedures. Potential evapotranspiration is calculated using the modified Hargreaves formula[2] for each timestep. Then a monthly crop coefficient (see Figure 0-3) is applied to calculate the crop water requirements (ETc) for each timestep.

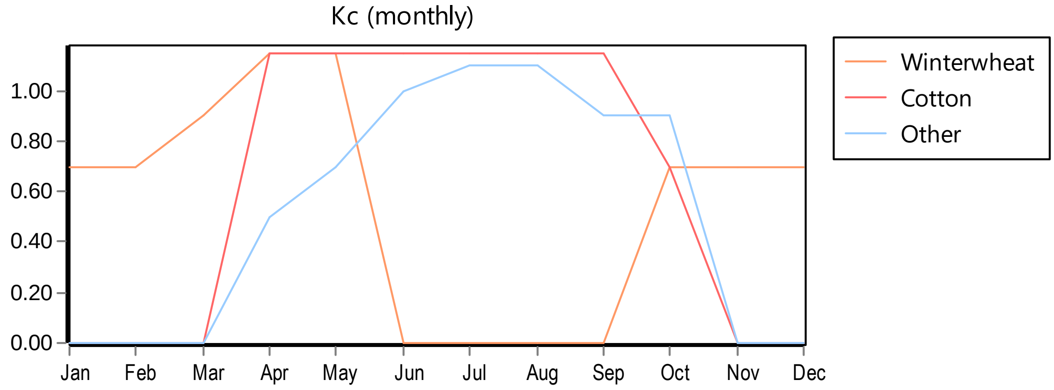

Figure 0-3: Monthly crop coefficient (kc) to calculate crop water requirements for each timestep using FAO-56 approach

According to the sector review performed by the local agronomist, approx.. 3% of the collected drainage water is reused within the Jondor SP area, 20% of the collected drainage water is diverted outside the area, and the rest (77%) flows back to the Amu Darya river. Also this was included in the WEAP model parameters.

Model setup and performance

A few screenshots that show how the Jondor and Batabag systems were incorporated in the WEAP software and related data input fields are shown below. **Figure 0-4** shows the different demand nodes: for irrigation of the Jondor scheme (*I_Jon*), a separate demand node for the leaching requirements (*LR_Jon*), downstream demands (*I_KerkiDS*) and flow requirements for the Aral Sea (*FR_AralSea*).

[1] http://wuemoca.net/app/
[2] Droogers P., R.G. Allen. 2002. Estimating reference evapotranspiration under inaccurate data conditions. Irrigation and Drainage Systems 16: 33-45

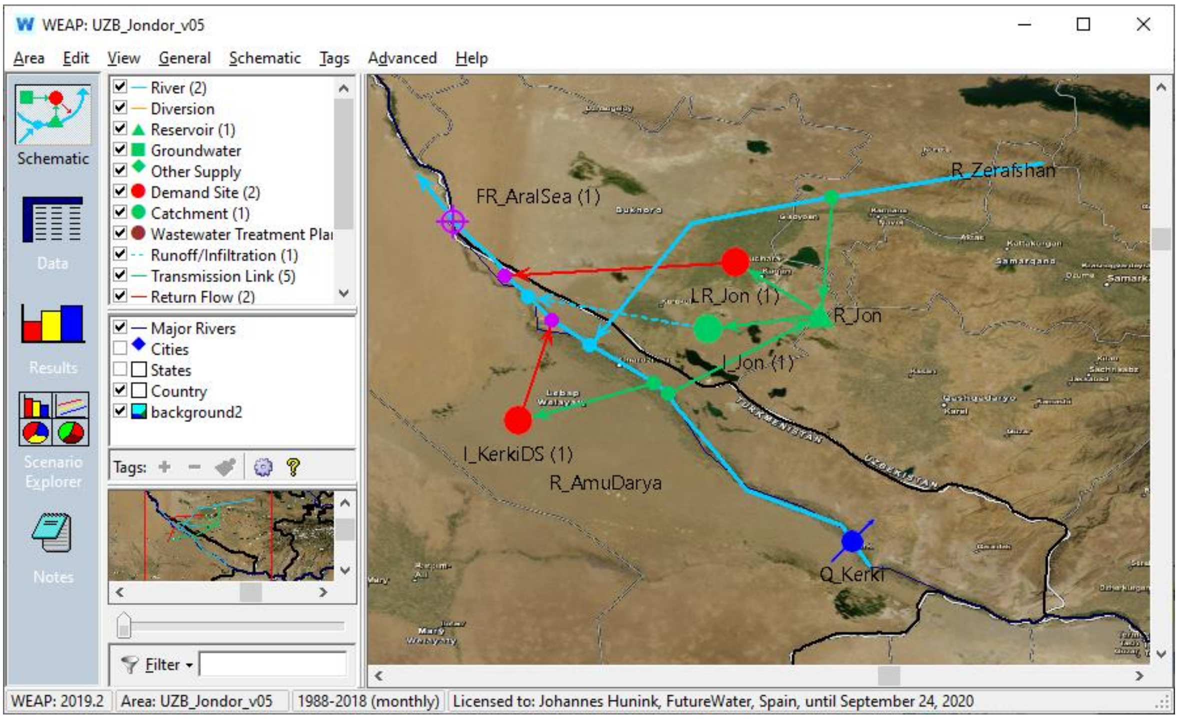

Figure 0-4: Schematization of the Jondor SP.

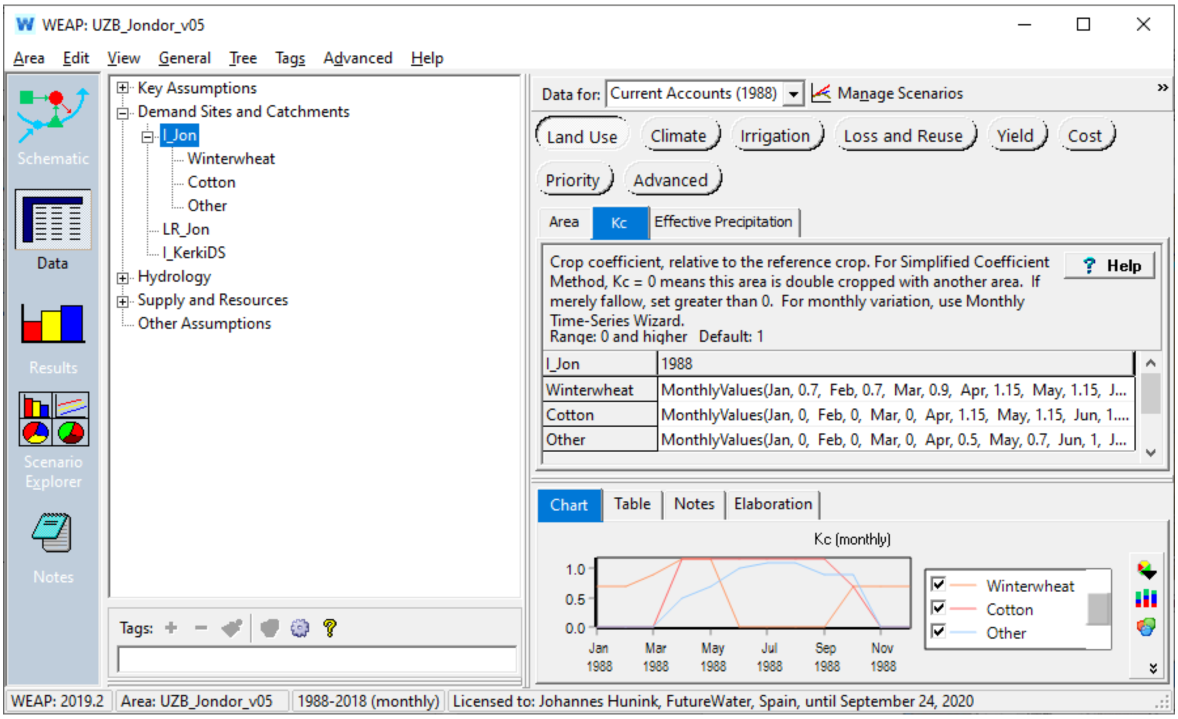

Figure 0-5: Most relevant input fields for the irrigation demand node

To evaluate how the model response compares with the data that was obtained (and not as used directly as input, but instead simulated by the model itself), several variables are compared in Table 0-1. As can be seen, the modelled values are very close or similar as the data that was obtained from the system. Differences can be due to limitations in the model, but also to errors in the data. Overall, from this can be concluded that the model performs well, given also the considerations previously discussed on relative accuracy, and can be used for the climate impact assessment.

Table 0-1. Simulated versus obtained data for a several model output variables for the Jondor SP setup

Variable	Simulated data	Obtained data
Aral sea inflow from Amu Darya (km3)	5	6
Total annual demand (km3)	2.6	2.3
Mean annual leaching demand (km3)	0.6	0.6
Peak demand (month)	July	July

For the current situation (no climate change) the following mean monthly and annual demands are estimated (based on a 30-year simulation period) for the three crop types and leaching (LR). As can be seen, most of the crop water demand is for cotton currently.

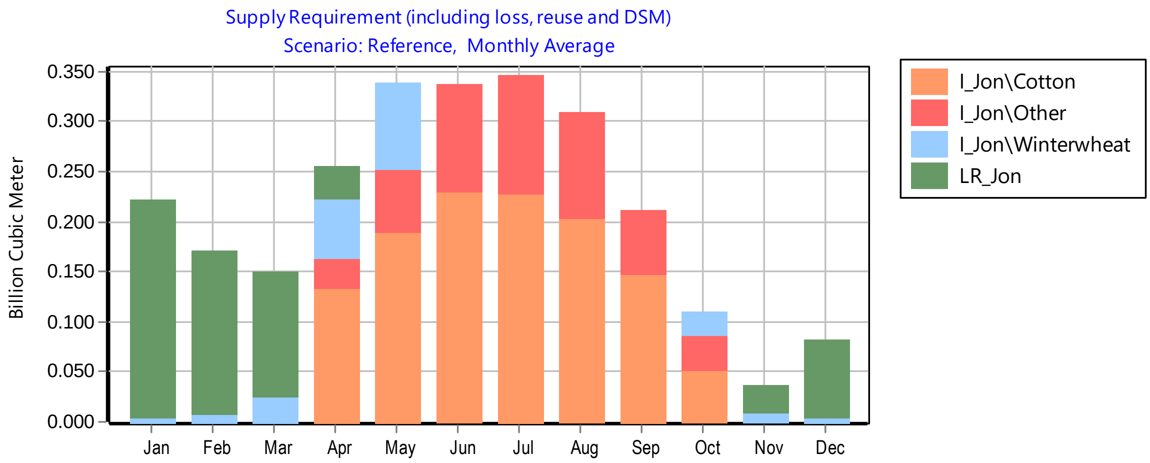

Figure 0-6. Current mean monthly water demand for the Jondor scheme, as estimated by the WEAP model and based on 30-year simulation (I_Jon – irrigation water requirements; LR_Jon –water requirements for leaching)

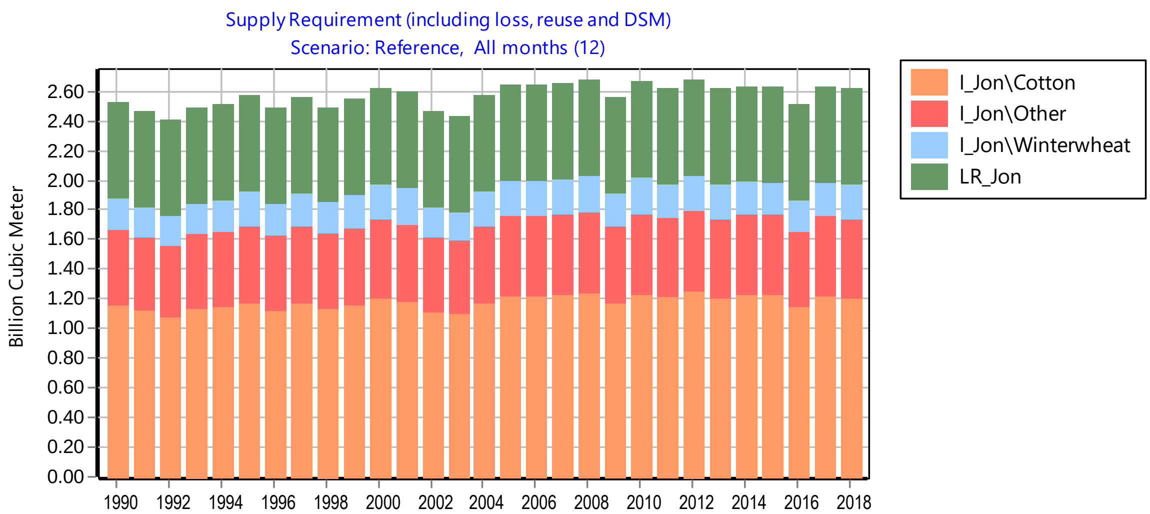

Figure 0-7. Annual water demand for the Jondor scheme, as estimated by the WEAP model and based on 30-year simulation (I_Jon – irrigation water requirements; LR_Jon –water requirements for leaching)