Preparing the Climate Adaptive Water Resources Management in the Aral Sea Basin Project - TA-9782 UZB

Climate Change Risk Mapping of the Amu Darya river basin, Uzbekistan

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Preparing the Climate Adaptive Water Resources Management in the Aral Sea Basin Project - TA-9782 UZB

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Summary

Uzbekistan's water resources are highly sensitive to climate change, as changes upstream in the Amu Darya River basin will affect the flow variability and amounts coming from the source areas. Especially the water resources-intensive agricultural sector will need to transform into more resilient systems. As a response, the ADB-funded technical assistance "TA-9782 UZB: Preparing the Climate Adaptive Water Resources Management in the Aral Sea Basin", supports the government in enhancing the river basin planning in the Amu Darya River basin and preparing investments in representative irrigation and drainage areas, taking a long-term and knowledge-based approach to deliver climate adaptive solutions for water resources management.

This report presents the climate risks mapping for the Amu Darya River basin in Uzbekistan, focusing on water resources management, irrigation, agricultural production and the environment. Relevant datasets were collected on climate hazards and vulnerabilities which were comprehensively analyzed using a climate risk framework. Based on pre-screening, key hazards that were mapped in detail are: drought, heatwaves, floods, landslides, and erosion. The spatial risk information was used to visualize district and eco-zone risk scores.

The results show that drought risk is high for most districts. Key zones are parts of Kashkadarya, parts of Samarkand, Navoi, Bukhara, Karakalpakstan, and Khorezm. Heat waves are often compounded by drought, and risk levels are also high in most districts, often concurring with high drought risk levels. Also dust storms and wind erosion are hazards related to these risks. Landslide and erosion risk, mostly related to high rainfall extremes and soil and slope conditions, are high in particular Surkhandarya, Kashkadrya, and Samarkhand districts. River flood risk is limited to some districts only where peak flows in the tributaries of the Amu Darya river basin may cause damage to agricultural areas.

The produced risk maps are used as input into the discussions with the government and stakeholders on their priorities, adding local data, insights, and expert judgment. From these discussions, several areas were selected to conduct socio-economic surveys. This fieldwork aims to capture the key drivers for rural livelihood vulnerability (e.g., agricultural practice being vulnerable to climate stresses, and identifying the most important crops for livelihood and their vulnerability). Data collected from the survey will contribute to establishing a better picture of the vulnerability of rural livelihoods, identifying climate adaptation options, and defining an early project note.

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1 Introduction

1.1 Context of the assignment

Uzbekistan's water resources depend to a large extent on the Amu Darya River. The water resources of this transboundary river are practically fully allocated to different uses across the basin. This implies that Uzbekistan is highly sensitive to changes in upstream and in-country water availability. In particular, the country will be impacted by climate change, which will alter glaciers and snow cover, water availability, water uses and demands across the river basin. These changes in intra-annual and seasonal variability are therefore a threat to Uzbekistan's water security.

Besides, climate change will increase extreme events, which pose a risk to existing water resources infrastructures. Water users and uses, including the environment and the Aral Sea, will face the consequences in the next few decades if no action is taken. This is particularly the case for the agricultural sector, which will need to transform to more resilient systems at all levels.

As a response, the technical assistance TA-9782 UZB: Preparing the Climate Adaptive Water Resources Management in the Aral Sea Basin, approved in August 2019, is supporting the government in enhancing the river basin planning in the Amu Darya River basin. In addition to preparing investments in representative irrigation and drainage areas, it will undertake a long-term and knowledge-based approach to deliver climate adaptive solutions for water resources management. Two climate-responsive irrigation modernization subprojects were already prepared under this TA and approved by the government in 2021.

1.2 Overall approach of the assignment

In the context of this TA, this assignment has been commissioned to support the Ministry of Water Resources (MWR) in assessing climate change impacts in the Amu Darya River basin and identify, in a participatory manner, climate-resilient investment measures within the basin. The measures will be based on a basin-wide approach and government priorities on climate change and good international practice.

An explicit focus of the investments is to reduce vulnerability to climate change; therefore, measures (hard and soft) strengthening adaptation capacity will be prioritized. The assignment has three main tasks, as detailed in the schematic of the overall approach provided in Figure 1. These main tasks involve different engagements with stakeholders, at district and national levels, to validate:

- climate risk maps, to refine and confirm the maps;
- adaptation measures and their prioritization.

Importantly, consultations at district levels will be validated by a high-level workshop at the national level, with representatives from the Ministry of Water, other ministries and national agencies, and funding agencies. This will mainstream basin-level priorities for adaptation, which were captured from district priorities, to identify investment opportunities.

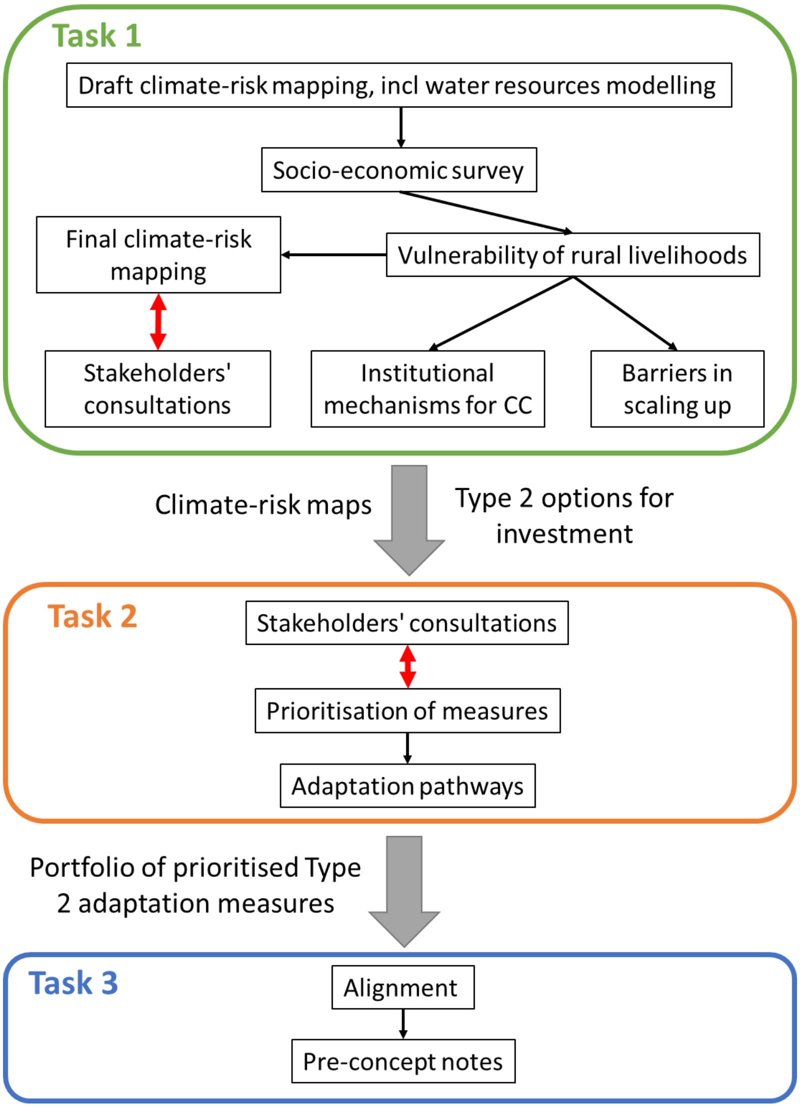

Figure 1. Schematic of the overall approach of the assignment. Engagements with stakeholders and feedbacks to validate results, at district and national levels, are represented with red arrows.

This report contributes to Task 1, which is about a basin-wide climate change risk and adaptation analysis. The report presents the climate risk maps in the Amu Darya River basin, focusing on water resources management, irrigation, and agriculture production.

1.3 Overall approach of task 1

The starting point of Task 1 is data collection for the generation of climate-risk maps, using mainly globally available data, existing data, complemented to the extent possible with local data obtained through the local consultant ICG. Using a climate risk framework, detailed hazard maps are produced, and risk maps at district and province levels. The importance of considering upstream-downstream links when identifying priority areas based on these climate-risk maps is illustrated with results from a water resources system model of the river basin.

The risk maps will subsequently serve in preparing the socio-economic survey, by identifying areas to conduct the survey. This fieldwork will aim to capture the key drivers for the vulnerability of rural livelihood (e.g., type of agricultural practice being vulnerable to climate stresses, identifying the most important crops for livelihood and their vulnerability). Data collected from the survey will contribute to establishing the current and future vulnerability of rural livelihoods. Identifying existing institutional mechanisms for climate change will also follow, along with analyzing barriers (e.g., economic, financial, legal, regulatory, institutional, capacity and knowledge) for scaling-up adaptation measures.

Finally, combining all these activities, potential adaptation measures (hard and soft) will be identified as investment options to address the issues identified. These adaptation measures will be integrated into a project concept note for a Climate Adaptation project (Type 2).

2 Methods and data

2.1 Approach to risk assessment

This report provides climate risks maps for the Amu Darya River basin, focusing on water resources management, irrigation, agriculture production and environmental assets. This task will identify hotspots of water resources-related challenges, areas, infrastructure, and activities in the Amu Darya basin at high risk due to climate change and water-related hazards. This includes natural hazards driven or strongly affected by hydrological and climatic conditions. The impact of climate change on these natural hazards is reflected in the occurrence probability at each level of intensity of extreme events. Different phenomena cover a wide range of time-and-space scales and are represented by various hazard indexes and models. Most climate-related hazard models simulate complex interactions between climatic and non-climatic factors such as land morphology and use, water management practices, and vegetation type.

Risk in this context refers to the potential to suffer severe loss of performance of a system, society, or community in a specific horizon, determined conceptually as a function of hazard severity, exposure, and vulnerability. In other words, risk for a particular activity is calculated as a function of the hazard occurrence at the location of the activity and its vulnerability. Figure 2 shows this conceptually, in which:

- Hazard (H) refers to the climate-related process that causes the impacts, loss of performance, social and economic disruption, and environmental degradation (such as droughts, floods, or dust storms)
- Exposure (E) refers to the people and physical assets (e.g., infrastructure, housing, crops, land, ecosystems, forests) situated in that location and therefore exposed to the hazard (e.g., irrigation districts, canals, cities).
- Vulnerability (V) refers to the degree of sensitivity to suffer impacts from a climate-related hazard and the degree of adaptive capacity to cope with the hazard (e.g., salinity levels – as high saline areas are more vulnerable to climate hazards then non-saline areas, irrigation requirements: higher irrigation requirements indicate higher sensitivity to water scarcity).

With this climate risk mapping approach, the key questions to be answered are:

1. Where in the river basin are the climate-related hazards and associated vulnerabilities highest for each eco-hydrological zone in the Amu Darya basin?
2. Which administrative districts associated with each eco-hydrological zone in the Amu Darya basin are at high climate change risk, considering the dominant climate hazards?

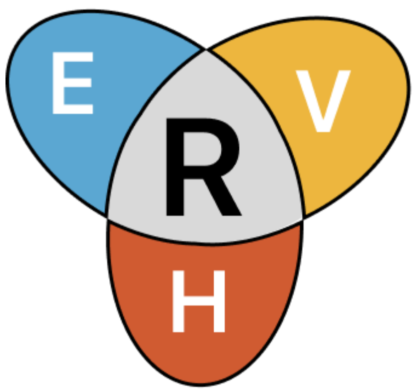

Figure 2. Risk (R) is defined as a function of Hazard (H), Exposure (E), and Vulnerability (V) components: R=f(H,E,V)

Climate change impacts on environmental and socio-economic systems are driven by (1) climate-related hazards: potentially harmful events of which the intensity and/or the frequency increases, and (2) long-term changes in temperature and precipitation, which cause an overall change in the hydro-climatic and (agro-)ecological regimes, and can cause increased water scarcity and consequently changes in the suitability, feasibility or performance of certain activities (for example a particular crop may be more productive under higher mean temperatures, or another crop may be less productive under lower mean precipitation). These long-term impacts on the overall system are essential for identifying adaptation investments and their potential lifetime.

Therefore, this risk mapping exercise is done in the following steps:

1. Data collection for climate-related hazards and vulnerabilities
2. Initial screening of hazards based on data availability and occurrence for each ecozone
3. Draft climate risk mapping for the key hazards
4. Final climate risk mapping, including insights and feedback from the stakeholder interactions to the extent relevant and feasible.

2.2 Approach to climate change impacts

Screening and assessing climate change impacts typically involves comparing baseline situations with future climate. It requires the construction of both baseline climate conditions and how climate may evolve based on emission scenarios. For each climate-related hazard, one or more climate indices (CI) can be associated (see Figure 3), representing the climate drivers affecting the historical period's baseline hazard rating. CI are products derived from essential climate variables, which summarize the past and projected climate change obtained from climate model data, reanalysis, and observations. They are used as a proxy to estimate the change in hazard rating compared to the baseline. The long-term (20-30 years) average of a CI variable is defined as the normal and is used as a baseline value. The anomaly of a CI is the variation relative to the climatological normal during a particular reference period (here taken as the 20-year period between 1995 and 2014).

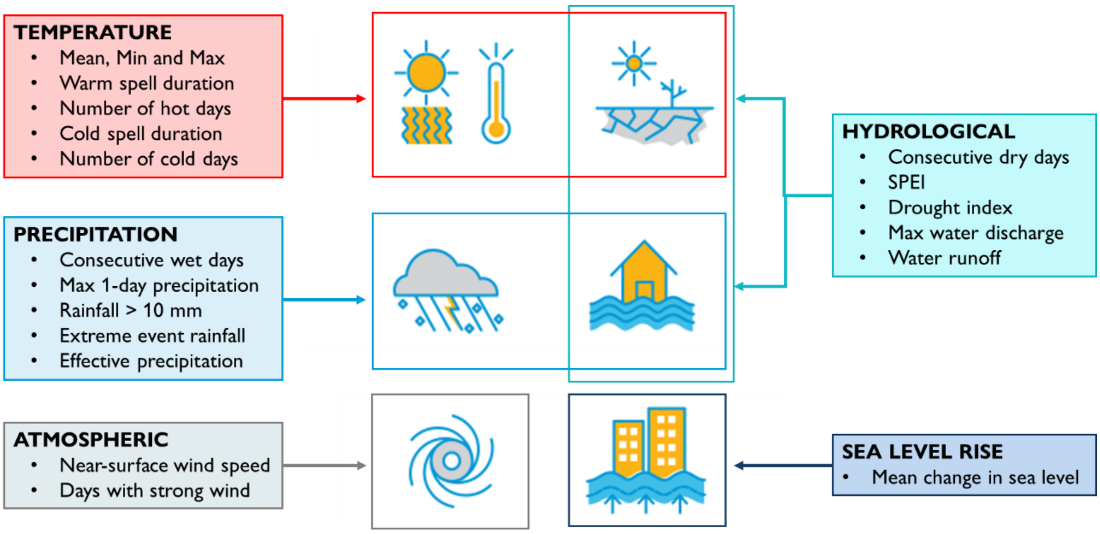

Figure 3. Climate Indices (CI) related to climate hazards (source: Amadio et al., 2022[1])

[1] Amadio, M., Hunink, J.E. Fourniadis, Y., 2022. ADB Climate and Disaster Risk Screening and Assessment Tool – Methodology. TA-9414, ADB.

Projections of future climates are provided by GCMs (Global Circulation Models) resulting from the Coupled Model Intercomparison Project Phase 6 (CMIP) activities and experiments. CMIP6 has led to a standard set of initial conditions, model simulations and a (more or less) comparable output. The potential future change in baseline hazard characteristics was identified from the CMIP6 ensembles. The CMIP6 multi-model ensemble was used to reduce the uncertainty of different climate models projections. The widely used shared socioeconomic pathway (SSP) scenarios, such as SSP2 (middle of the road) and SSP5 (fossil fuel development), were employed to assess the potential climate change impacts in the future.

The project will focus on three-time horizons in the future: (a) short-term (2020-2040) (b) mid-of-the-century (2040-2060) and (c) long-term (2080-2100). As the task involves identifying hotspots of water resources-related challenges in the Amu Darya basin, this report focuses on the long-term water-related future hazards driven by the (pessimistic) SSP5 pathway. This approach potentially exacerbates water resource-related challenges but ensures that hotspot areas are better discerned and identified.

An overview of the steps to derive the CI for future potential changes in hazard characteristics is outlined below:

- The aggregated baseline metrics for level-2 administrative units of Uzbekistan within the Amu Darya basin were calculated and normalized between 0-1 for each exposed feature.
- The anomalies (derived from the 1995–2014 CMIP6 reference period) for the associated extreme climate indices in the future were calculated for each time horizon and SSP's. The spatial anomalies were then also aggregated to level-2 administrative units.
- The aggregated data were transformed into categorical indexes between 0 and 1.
- The anomalies were then overlayed using an appropriate mathematical operator (i.e., addition) with the baseline hazard characteristics. The future hazard thus obtained was transformed into an index by normalizing between 0 and 1, to make it consistent with the baseline hazard categories (Figure 4).
- The future hazard indices were divided into priority categories for climate-resilient investments (i.e., 'very-low', 'low', 'medium', 'high' and 'very-high' priority categories).

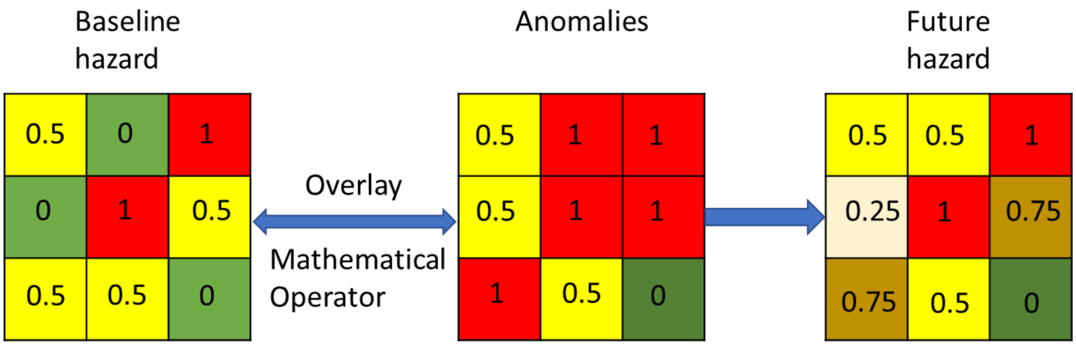

Figure 4. Methodological framework to assess future hazards. The mathematical operator used in this project is 'addition'.

The exposure to climate and geophysical hazards was calculated based on the data identified and collected. The exposure identification focused on the key water resources-dependent sectors, which are (a) agriculture, (c) water supply infrastructure, and (d) vital ecosystems and their services (e.g., south Aral Sea, Aral Sea delta, rivers, wetlands) (NDC, 2021). The United Nations Office for Disaster Risk Reduction defines critical infrastructure and facilities as the primary physical structures, technical facilities and systems which are socially, economically, or operationally essential to the functioning of a society or community, both in routine circumstances and in extreme circumstances of an emergency.

Similar to the hazards, the exposure layers were normalized between 0 to 1, transforming them into a priority index. Again, the vulnerabilities of the key sector will be prepared based on the data identified and collected in section 2.4. The vulnerability layers were also transformed into a priority index by normalizing between 0-1, similar to the hazards and exposure. Finally, the climate risk hotspot mapping is carried out by multiplying the hazard, exposure, and vulnerability score. The districts with the final risk score, on a scale of 0-1, for each ecozone are plotted to understand the risks among the districts in each ecozone.

2.3 Hazard datasets

For the risk mapping methodology, datasets were collected for all climate-related hazards for the A-D basin for which prior literature indicated some relevance for the study area (see Table 1). A pre-screening was done and five hazard categories (drought, landslides, erosion, heat waves, and river floods) were prioritized for the draft climate risk mapping assessment. The other relevant hazards (glacial lake outburst floods, dust storm / wind erosion, wildfire) may be included in the final climate risk assessment.

Most climate-related hazard models simulate complex interactions between climatic and non-climatic factors such as land morphology and use, water management practices, and vegetation type. Table 1 represents the most common metrics and models and/or the best available datasets to define the considered climate-related hazards for this assessment.

Table 1. Most relevant hazards identified for the A-D basin

Hazard	Baseline dataset	Baseline metric	Associated Climate Index
Drought	FAO Agricultural Stress Index[1]	Frequency of drought affecting >30% land	Standardized Precipitation Evapotranspiration Index (SPEI)
Rainfall-induced landslides	WB Global Landslide[2]	Average annual frequency of significant rainfall-triggered landslides per sq. km for 1980-2018	Annual maximum 5-day consecutive precipitation (Rx5day)
Rainfall-induced erosion	GloREDa Rainfall erosivity factor[3]	Rainfall erosivity above a certain threshold	Annual maximum 1-day precipitation (Rx1day)
Heat waves	VITO Global Heat Model[4]	20-years mean return value of temperature above a certain threshold	Warm spell duration (WSDI)
River floods	WRI Global Flood Model[5]	Water depth return period 100 year	not applicable

[1] https://data.apps.fao.org/catalog/organization/about/asis
[2] https://www.geonode-gfdrrlab.org/layers/rftl_aa_mean_1980_2018:hazard:rftl_aa_mean_1980_2018
[3] https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity
[4] https://www.geonode-gfdrrlab.org/layers/hazard:intensity_returnperiod20y
[5] www.wri.org/applications/aqueduct/floods

Hazard	Baseline dataset	Baseline metric	Associated Climate Index
Glacial Lake Outburst Floods	Remote sensing-based dataset[1]	Proximity indicator	Annual maximum 5-day consecutive precipitation (Rx5day)
Dust storms and wind erosion	Wind erosion risk potential[2]	Severity indicator	CMIP6 Wind speed projections
Wildfire	Fire Weather Index[3]	30-year return period intensity value	Warm spell duration (WSDI)

2.4 Vulnerability datasets

One or more vulnerability datasets were associated with each relevant hazard for the A-D basin, listed in Table 2. The vulnerability data was selected based on expert judgement and relevance and availability for the Amu Darya basin.

Table 2. Vulnerability datasets associated with each considered hazard.

Hazard	Vulnerability dataset	Metric
Drought, dust, and windstorms	WRI Aqueduct Water Risk[4]	Water Demand, measured as water withdrawals. Projected change in water withdrawals is equal to the summarized withdrawals for the target year, divided by the baseline year, 2010.
Rainfall-induced landslides	WUEMoCA dataset[5]	Inverse of Water Productivity (1/$ m^{-3}) for cotton, rice, wheat
Rainfall-induced erosion	WUEMoCA dataset	Inverse of Water Productivity (1/$ m^{-3}) for cotton, rice, wheat
Heat waves, Wildfire	WRI Aqueduct Water Risk	Water Stress, measured as the ratio of demand for water by human society divided by available water.
River floods, Glacial Lake Outburst Floods	WUEMoCA dataset	Net Irrigated Area (in ha)

Besides, several water management indicators were extracted from local data sources, by ICG, which are summarized in a parallel report. To support identifying the problematic districts and select priority sites to be included in the investment plan, the districts in the Amu Darya River basin were ranked according to the following water management conditions' indicators:

- Anti-seepage operations on the government's irrigation system.
- Anti-seepage operations on the on-farm irrigation system.

[1] Petrov, Maxim A., Timur Y. Sabitov, Irina G. Tomashevskaya, Gleb E. Glazirin, Sergey S. Chernomorets, Elena A. Savernyuk, Olga V. Tutubalina et al. "Glacial lake inventory and lake outburst potential in Uzbekistan." Science of the Total Environment 592 (2017): 228-242.
[2] Prepared by FutureWater using data sets available in Google Earth Engine
[3] https://www.geonode-gfdrrlab.org/layers/hazard:csiro_wf_max_fwi_rp30
[4] https://www.wri.org/aqueduct
[5] https://wuemoca.geo.uni-halle.de/app/

- Provision of the outlets on inter-farm canals with regulating structures.
- Provision of the on-farm outlets with regulating structures.
- Efficiency of the government's irrigation system.
- Water availability.
- Land areas with moderate and high salinity.
- Productivity of the irrigated lands.
- Water productivity.

Each indicator has a score from 1 to 10 (see Table 14 and Annex 2). The indicator 'Land areas with moderate and high salinity' should be assessed in descending order, the remaining indicators should be assessed in ascending order. The analysis was carried out in the context of administrative regions and the list of districts was compiled in ascending order by the sum of scores. The district with the lowest score represents the most problematic area and thus appears as the first in the list.

2.5 Exposure datasets

Likewise, as with vulnerability, one or more exposure datasets are associated with each relevant hazard for the A-D basin, which are listed in Table 3. The exposure data were selected based on expert judgement and relevance and availability for the Amu Darya basin.

Table 3. Exposure datasets associated to each considered hazard.

Hazard	Exposure dataset	Metric
Drought, Dust and windstorms, Rainfall-induced landslides, Rainfall-induced erosion, Heat waves, Wildfire, River floods, Glacial Lake Outburst Floods	– WUEMoCA dataset – Gridded Population of World Version 4[1]	– Net Irrigated Area (in ha) – Nr. inhabitants per km^2

[1] https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

3 Situation assessment

3.1 Water resources

The Amu Darya is the largest river in Central Asia, with a total length of about 2,550 km and a catchment area of 309,000 km². The Amu Darya starts from Tajikistan, before flowing along the border of Afghanistan with Uzbekistan, crosses Turkmenistan and returns to Uzbekistan again, before discharging into the Aral Sea (Figure 5). Most of the flow is created in Tajikistan, from glaciers and snow melting, and lost in the plain from Kerki (Turkmenistan) to Nukus (Uzbekistan), due to evaporation, infiltration, and irrigation (Sokolov, 2020)[1]. The high water use rates have led to a continuously decreasing inflow into the Aral Sea over the last decades, which caused it to reduce its extent and led to high environmental and socio-economic impacts in the region.

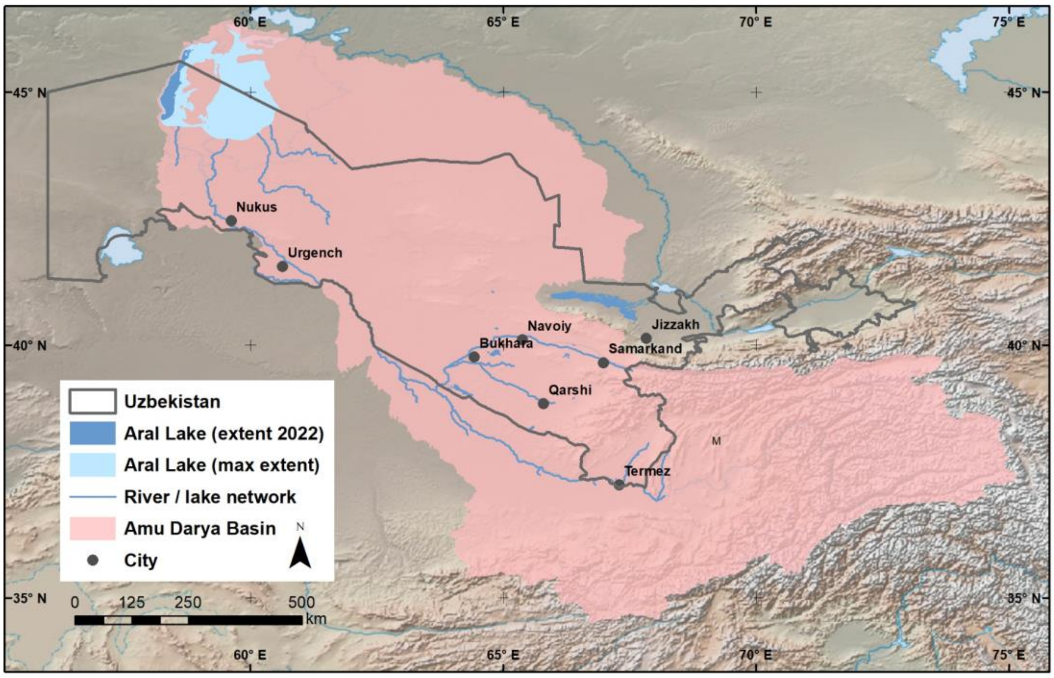

Figure 5. Amu Darya River basin

The average annual flow of the Amu Darya River basin is approximately 74 billion m^3/year (Bm^3/year), predominantly generated in Tajikistan (72%,Table 4). The seasonal peak of the flow occurs in late spring / early summer, while the minimum is in winter. This seasonal pattern favors water use for irrigation (Sokolov, 2020). Upstream reservoirs store water for the winter when hydropower demands are highest. This has the potential to lead to conflicts with downstream irrigation demand, although, if managed in a coordinated way, upstream storage development can also be an opportunity for downstream irrigation to mitigate the impacts of changing flow regimes due to climate change.

[1] Vadim Sokolov, *Handbook on Water Resources Management in Uzbekistan*, ed. Caroline Milow (Tashkent, Uzbekistan: GIZ, 2020).

Table 4: Average annual flow of the Amu Darya, period 1934-2011 (Source: ICG)

River basin	River flow generated in countries					Total for A-D
	Kyrgyzstan	Tajikistan	Uzbekistan	Turkmenistan	Afghanistan and Iran	
Pyanj	—	30,081	—	—	3,3	33,381
Vakhsh	1,654	18,4	—	—	—	20,054
Kafirnigan	—	5,575	—	—	—	5,535
Surkhandarya	—	—	4,841	—	—	4,841
Sherabad	—	—	0,228	—	—	0,228
Kashkadarya	—	—	1,222	—	—	1,222
Murgab	—	—	—	0,771	0,771	1,542
Tejen	—	—	—	0,488	0,489	0,977
Atrek	—	—	—	0,136	0,137	0,273
Afghanistan	—	—	—	—	6,167	6,167
Total (km^3)	1,654	54,056	6,291	1,405	10,814	74,22
Amu Darya River basin (%)	2,2	72,8	8,5	1,9	14,6	100

Over the last decades, the available water resources are declining. For the hydrological years 1989-90 to 2017-18, the availability was on average 60 km3/year (see Figure 6), significantly less than the long-term average annual flow (14 km3/year less).

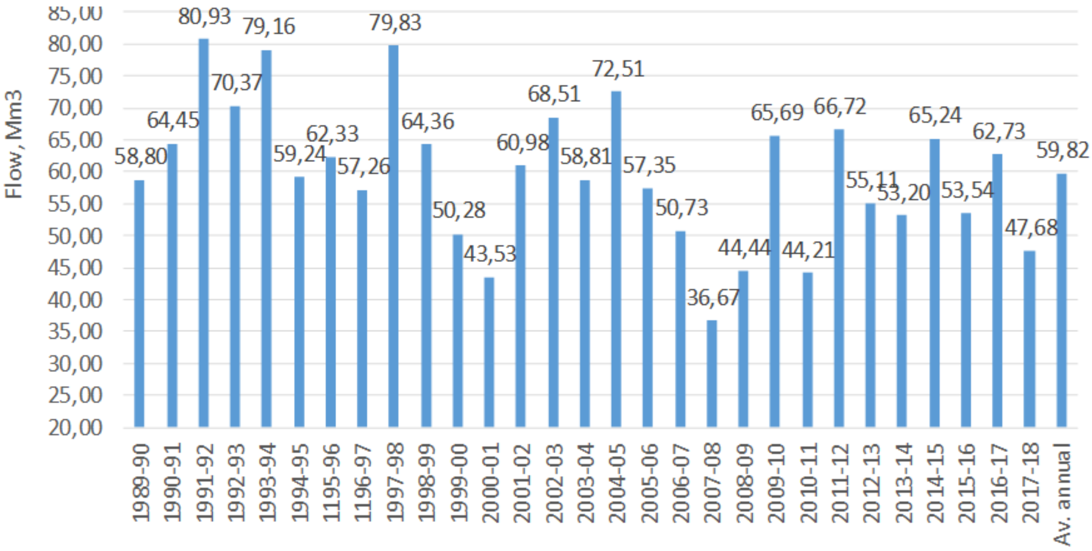

Figure 6. Total annual water resources of the Amu Darya river basin (source: BWO Amu-Darya, ICG)

In Uzbekistan, the annual water demand of all sectors amounted to 56 Bm^3 in 2019 (Khamidov et al. 2020[1]), but the actual water withdrawal was 20% less than this required amount (Khamraev et al. 2020[2]). Irrigation is the predominant water user from Amu Darya in Uzbekistan, and the sector plays a significant role in the country's economy, comprising 30% of the overall gross domestic product (Zorya et al., 2020[3]). About 80% of the arable land in the Amu Darya basin is irrigated. This leads in many areas to pressures

[1] M Kh Khamidov et al., 'Using Collector-Drainage Water in Saline and Arid Irrigation Areas for Adaptation to Climate Change', *IOP Conference Series: Earth and Environmental Science* 422, no. 1 (1 January 2020): 012121, https://doi.org/10.1088/1755-1315/422/1/012121.
[2] Khamraev, S.; Mukhamednazarov, L.; Sokolov, V.; Gayfulin, I. Irrigation and Drainage in Republic of Uzbekistan: History and Modern State; Ministry of Water Resources of the Republic of Uzbekistan: Tashkent, Uzbekistan, 2020; p. 27
[3] Zorya,Sergiy; Von Cramon-Taubadel,Stephan; Mu, Yali; Barrantes, Carlos. *Policy Dialogue on Agriculture Modernization in Uzbekistan : Study of Wheat and Flour Market Integration (English)*. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/528231635746914998/Policy-Dialogue-on-Agriculture-Modernization-in-Uzbekistan-Study-of-Wheat-and-Flour-Market-Integration

on the environment: salinization, water conflicts with environmental usage, and erosion, among others. Over the last years (since 2018), the Aral Sea area has not received the annual amount of water it requires according to national and international agreements (see Planned versus Actual in Figure 7) and a clear negative trend can be observed.

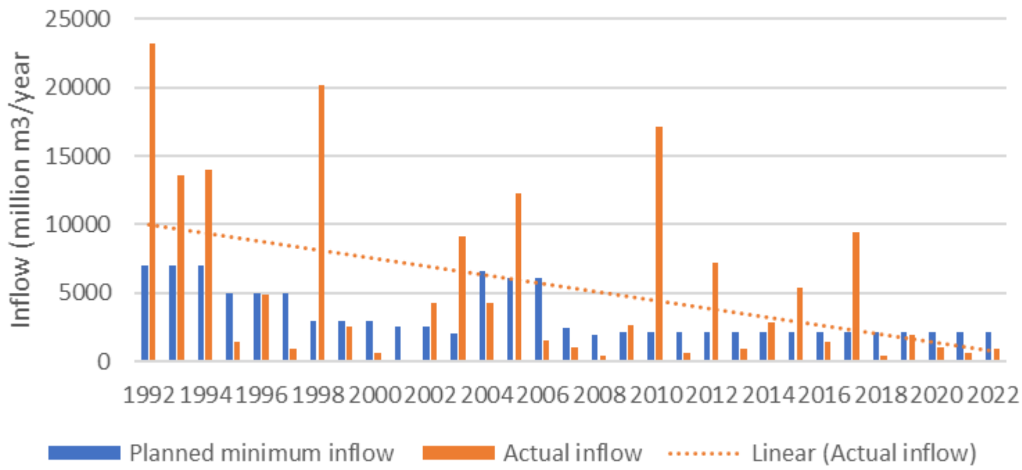

Figure 7. Water supply to the Aral Sea and the Amu Darya river estuary (source: cawater-info.net, ICG)

The average coverage of the water demand (water supplied versus the water demand) of the regions in the Amu Darya River basin during the off-irrigation season in 2018-2021 ranged from 74% in the Republic of Karakalpakstan to 96% in Bukhara region (see Annex 5). During the irrigation season these values range from 53% in the Kashkadarya region to 93% in Surkhandarya region (see Annex 5). The low water availability in Kashkadarya region is related to very low water availability of the regions receiving water from Kashkadarya and Zarafshan rivers.

3.2 Salinity

One of the most widespread environmental impacts of current water resources management and irrigation in the Amu Darya basin, are related to salinity. Current irrigation practices dissolve salts already in the soil and depending on the groundwater levels, this causes them to rise to the surface, affecting productivity.

In short:

- Areas with high ground waters level are especially observed in the downstream reaches of the Amu Darya River: Khorezm region and the Republic of Karakalpakstan
- Saline groundwater (with mineralization of 3-10 g/l) prevail in Kashkadarya, Bukhara regions and in the Republic of Karakalpakstan. In recent years, around half the area in Kashkadarya and Bukhara regions has saline groundwater. In Khorezm region, slightly saline ground waters prevail, with mineralization of 1-3 g/l, and covering more than 85% of the irrigated lands, and in recent years, an increase of groundwater mineralization was observed in this region.
- Substantial areas with moderately and heavily saline soils are observed in the downstream reaches of the Amu Darya River. In recent years, in Khorezm region the areas with moderately and heavily saline soils covered 41%, that in the Republic of Karakalpakstan 40% and in Bukhara region 23%.

Salinization hampers agricultural productivity in several ways. First, it increases water requirements. During the off-irrigation season, farmers try to flush salt out of the soil by applying large volumes to the fields before or after the growing season; a practice called leaching. Water for leaching accounts for one-third of total water use in highly salinized areas, such as Karakalpakstan. Second, salinity inhibits the growth of plants when the osmotic pressure of the soil-water solution in the root zone inhibits the ability of plants to absorb water. Salts can also hamper growth through ion toxicity, but the osmotic effect is more prevalent.

Salinity is managed in the Amu Darya river basin by monitoring (1) groundwater levels, (2) groundwater and surface water salinity, and (3) soil salinity at the district level. A river-basin approach to salinity management is not yet a reality in the Amu Darya river basin, although some initial discussions and knowledge exchange initiatives are currently going at the regional level.

Climate change impacts on salinity are not yet known either. Climate change affects salinity in the river basin through:

- Increased soil evaporation
- Groundwater levels
- Increased surface water evaporation
- Higher crop demands
- Changes in soil weathering and soil salinity processes
- Overall changes in the water and related salt fluxes at the river basin-level

Assessing these impacts would require a basin-level salinity balance which is not yet available. To prepare this, and assess climate change impacts, an exhaustive analysis of the available data is required. This can be used and included in a suitable water resources model that allows the simulation of solutes.

3.3 Water resources infrastructure

A quick summary of the water resources infrastructure is provided (source ICG):

- The major water intakes from the Amu Darya River are at Amu Zang canal, Karshi main canal, Amu Bukhara canal, Left Bank canal, Right Bank canal, Pakhta Arna, Suenli, Parallel and Dustlik canals. Amu Zang canal takes water from the Amu Darya River with 3 pumping stations with a total head of 147 m; Karshi main canal takes water from the Amu Darya River with 7 pumping stations with a total height of 132 m; Amu Bukhara canal takes water from the Amu Darya River with 2 pumping stations with a total height of 112 m.
- In general, 789 pumping stations with 2178 pumping units with a total discharge of 3323m3/s were constructed in the Amu Darya River basin to pump water from the sources and canals.
- There are 23 reservoirs in the Amu Darya River basin with a total useful capacity of 9,496 Mm3. There is one reservoir in Khorezm district (Tuyumayn), two in Bukhara (Kuyu Mazar and Tudakul), 13 in Kashkadarya region and 7 in Surkhandarya region
- In Bukhara, Kashkadarya and Surkhandarya regions, respectively 265, 1129 and 59 irrigation wells with a total capacity of 3.97 m3/s, 35.85 m3/s and 2.06 m3/s, are operated for irrigation purposes.
- In total, 12,234 km of canals are operated by the WMOs, of which 32% are lined. Actual efficiency of the irrigation systems during the irrigation season ranges from 0.72 in the Republic of Karakalpakstan to 0.82 in Surkhandarya region, and that during the off-irrigation season ranges from 0.74 in Bukhara to 0.80 in Kashkadarya regions.

3.4 Eco-hydrological Zones

The climate change impacts and related water management challenges in each part of the Amu Darya river basin depend on different factors related to the geographical, social and economic context. For example, the climate hazards and socio-economic vulnerability factors in the Surkhandarya region may be of different relevance, compared to the downstream Karapakalstan region. The underlying processes are largely controlled by the climate, hydrology, and ecology – in short: the environmental conditions of a region. For this reason, it can be useful to analyze climate change impacts per zone, depending on the dominant eco-hydrological properties of this zone.

To classify the A-D river basin (Uzbekistan) in these so-called eco-hydrological zones, a state-of-art global dataset was used, which uses several scientific criteria to classify the globe in different zones. The Ecoregions dataset subdivides the Earth into 846 terrestrial ecoregions (Dinerstein et al., 2017)[1] and is grouped into 14 biomes and 8 realms. Each ecoregion represents a distinct assemblage of biodiversity (all taxa, not just vegetation) whose boundaries include the space required to sustain ecological processes. Ecoregions provide a useful basemap for environmental planning because they draw on natural, rather than political, boundaries, and define distinct biogeographic assemblages and ecological habitats within biomes.

Using the boundaries of the Ecoregions 2017 dataset, the A-D basin was divided into five distinct eco-hydrological Zones (see Figure 8): Aral Sea, Lower, Mid, Riverine, and Upper.

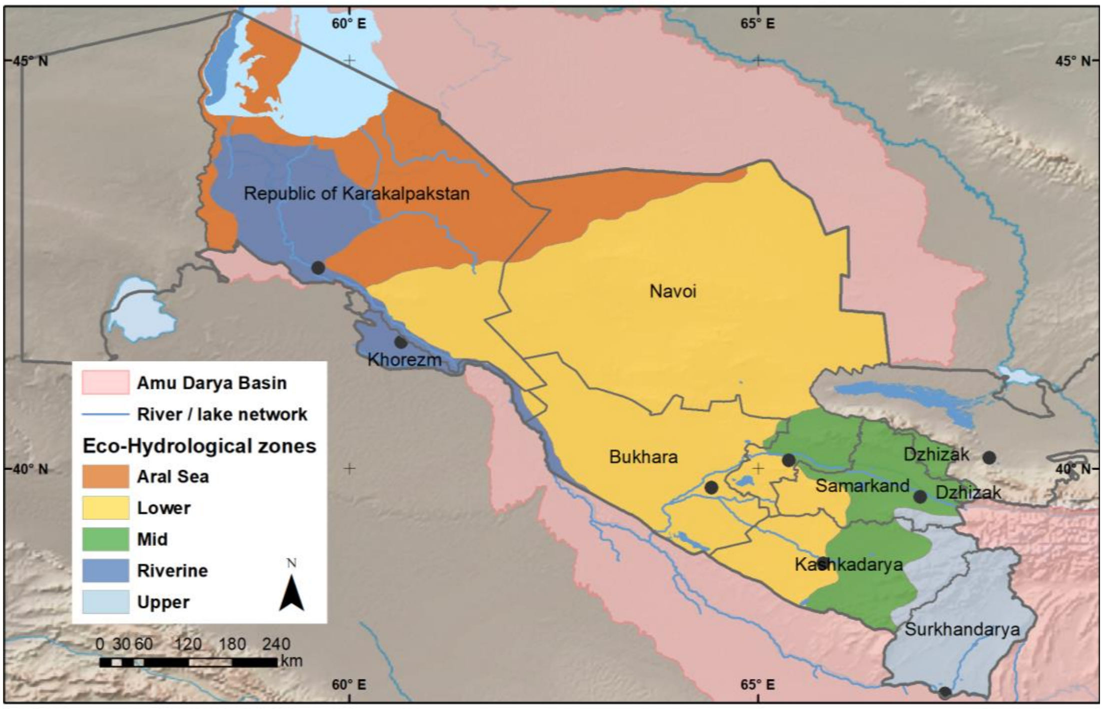

Figure 8. Amu Darya basin divided into five ecozones, based on RESOLVE Ecoregions 2017.

For each ecozone, a literature-, data- and expert-based screening was done on the relevant climate hazards and vulnerabilities (see Table 5). This pre-screening exercise is needed before the detailed risk mapping can be performed for the key hazards.

[1] Eric Dinerstein, David Olson, Anup Joshi, Carly Vynne, Neil D. Burgess, Erik Wikramanayake, Nathan Hahn, Suzanne Palminteri, Prashant Hedao, & Reed Noss. (2017). An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm. BioScience, 67(6), 534–545. https://academic.oup.com/bioscience/article-abstract/67/6/534/3102935

Table 5: Pre-screening of hazards and vulnerabilities per eco-hydrological zones of the Amu Darya (A-D) river basin (Uzbekistan)

Zone	Provinces	Relevant climate hazards	Relevant vulnerability factors
Upper basin	Surkhandarya, parts of Kashkadrya and parts of Samarkhand	• **Landslides** • Mudflows • **Soil erosion** • Some flood risk from glacial lakes • Droughts	• High water demands, and water withdrawals • Large irrigation systems which are mostly gravity or low pump lifts • Aged irrigation and drainage infrastructure • Relatively low soil salinity • Relatively lower aridity • Lack of accurate monitoring of intakes, and water accounting • Scope to crop high-value crops • Population density • Deterioration of river water quality due to upstream activities
Mid basin	Parts of Kashkadarya, parts of Samarkand, parts of Navoi	• **Landslides** • Mudflows • **Soil erosion** • Stream-bank erosion and deepening of the river bed • Some flood risk from glacial lakes • Droughts	• High pump lifts • Aged irrigation and drainage infrastructure • Low to moderate soil salinity requiring inefficient winter leaching • Surface and horizontal drains • Drainage is reused via the canal system and also disposed to lakes (some near full) and to A-D river. • Some scope to grow high value crops • Uncontrolled development of sand and gravel pits
Lower basin	parts of Kashkadarya, parts of Samarkand, most of Navoi, whole Bukhara and part of Karakalpakstan	• Increased mean temperature • **Heat waves** • **Droughts** • **Water scarcity**	• Gravity irrigation with aged irrigation and drainage infrastructure • Arid, shallow saline watertables high soil salinity • Low productivity and high poverty • Deep cut surface drainage discharging into A-D river • Water quality and river ecosystem health poor • Semi-arid desert ecosystems (plants and animals)
Riverine	Khorezm and part of Karakalpakstan	• Increased mean temperature • **Heat waves** • **Droughts** • **Water scarcity**	• Much reduced flows • Water quality (salinity) increasing from top to bottom • High sediment load and obstruction and pump offtake sites • Flooding does not seem to be important
Aral Sea	Most of Karakalpakstan	• Increased mean temperature • **Heat waves**	• Very arid and saline • Productive agriculture is difficult • Moderately high salinity A-D inflow

Zone	Provinces	Relevant climate hazards	Relevant vulnerability factors
		• **Droughts** • **Water scarcity** • Wind storms	• Ecosystem generally degraded, although some successful restoration efforts

The data- and literature-based pre-screening of hazards revealed that the dominant hazards (in bold in Table 5) are:

1. for the upper and the mid-eco-zone are **landslides** and **erosion** and to a minor extent **floods**, are currently the key hazards (in bold), affecting water resources infrastructure through sedimentation and issues related to high turbidities, and the loss of fertile soil.
2. For the lower, riverine and Aral Sea eco-zone, **heatwaves**, and **drought** are the key hazards affecting water supply infrastructure, the environmental areas, such as water and land productivity in several ways:
    a. heat waves affect crop health and crop productivity, and overall productivity of the agricultural value chain (health, processing facilities sensitive to heat, etc); they also alter the environmental system and its ecosystem service provision. Heat waves can also affect infrastructures which are not prepared for heat extremes
    b. Droughts affect crop productivity and environmental systems as water shortage reduces biomass and if frequent and/or severe can lead to long-term impacts

These hazards have been mapped in detail in the following sections. Another long-term climate impact is **water scarcity**: literature and data show this will further aggravate the current imbalance between water demand and supply, potentially leading to even further negative impacts on the environment and the Aral Sea.

3.5 Districts

The part of the Amu Darya basin in Uzbekistan encompasses seven (7) level-1 administrative regions (oblasts), which are further divided into ninety-nine (99) level-2 districts (tuman). For all districts in each eco-hydrological zone, the hazards to water resources and the associated vulnerabilities and exposures were analyzed and ranked. This approach allows for insights into prioritizing climate adaptation investments.

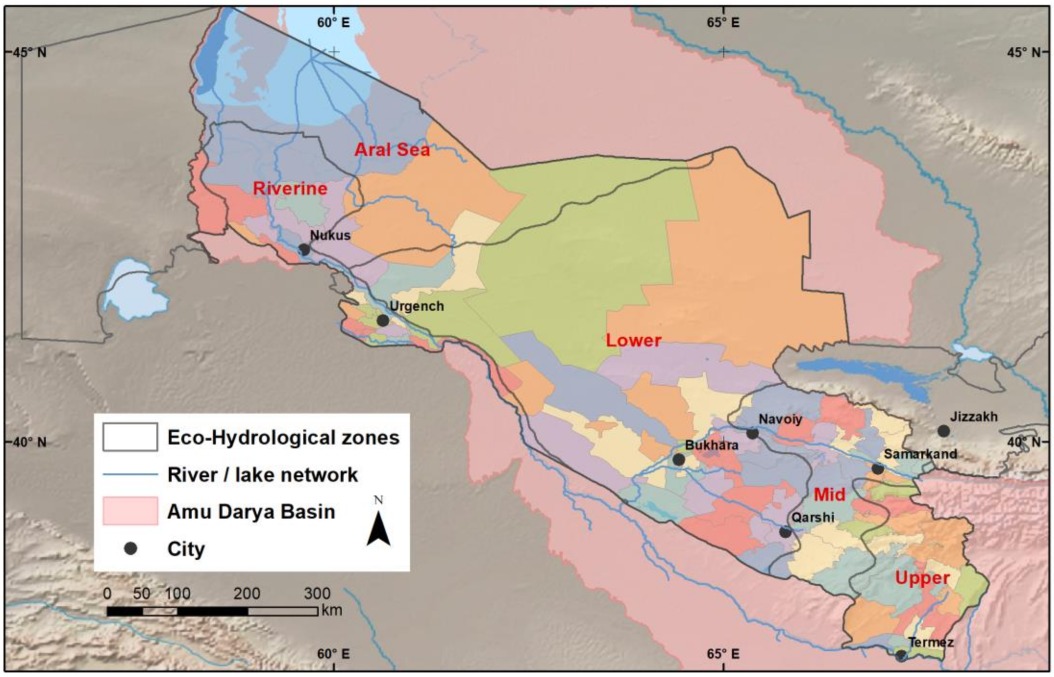

Figure 9. The ninety-nine (99) level-2 districts of Uzbekistan within the A-D basin

4 Climate Risk Mapping

This chapter presents the results of the risk mapping, based on the collected datasets, and for the key hazards discussed earlier (droughts, landslides, erosion, heat waves and floods). The risk mapping is presented following the risk framework-logic: First, the spatial baseline hazard metric is plotted. Second, the spatial future anomalies (compared to the historical period) are presented. Third, future hazard is calculated as explained in section 2.2 and presented for each hazard. Then in the fourth step, the used vulnerability and exposure datasets are mapped, and finally in the fifth step all maps are combined resulting in the risk map.

A rectangular extent, with sufficient buffer, was used to extract the data (baseline, anomalies, exposure, and vulnerabilities) to ensure no spatial gaps and inconsistencies in the analysis. Note however, for plotting purposes, the exact boundaries are used, which may have some effect on the edges of the boundaries.

4.1 Droughts

A drought is a period of abnormally dry weather long enough to cause a severe hydrological imbalance. Drought events can last from weeks to years. This can be due to reduced rainfall over a certain period, inadequate timing or ineffectiveness of precipitation, or a temporary negative water balance due to increased water demand or lack of water supply. Drought events are distinguished from water scarcity when the climatologically available water resources are insufficient to satisfy long-term average water requirements. These phenomena can aggravate each other, i.e., the severity and frequency of droughts can lead to water scarcity situations, while overexploitation of water resources can exacerbate the consequences of droughts.

4.1.1 Hazard (baseline)

As droughts are highly relevant for agriculture-related projects, a specific index was identified and used for the agricultural sector, the Agricultural Stress Index (ASI) developed by FAO. This index was considered to assess the baseline drought, describing the historical frequency of significant drought events. Drought events affecting agricultural areas often also impact non-agricultural systems (water supply and environment).

The ASI is an indicator that facilitates the early identification of cropped land with a high likelihood of water stress and is based on 10-day satellite data of vegetation status (NDVI) and land surface temperature at 1 km resolution. By monitoring vegetation indices across global crop areas during the growing season, with detailed land use maps and national crop statistics, ASI detects hotspots where crops and pastures may be affected by drought. ASI is an agriculture-based indicator, but for this study it can be interpreted as an indicator independent of the sector, assuming that when the agricultural sector is faced with water shortages due to lack of water supply, or reduced precipitation, this will typically also have an indirect impact on the environment and put pressure on domestic water supplies.

The ASI offers thresholds for the intensity variable (% of cropland affected by severe drought) and historical frequency as the number of years since 1984 surpassing the 30% or the 50% thresholds of the area affected. This study used the number of years since 1984 surpassing the 30% threshold of the area affected for baseline drought conditions (see Figure 10).

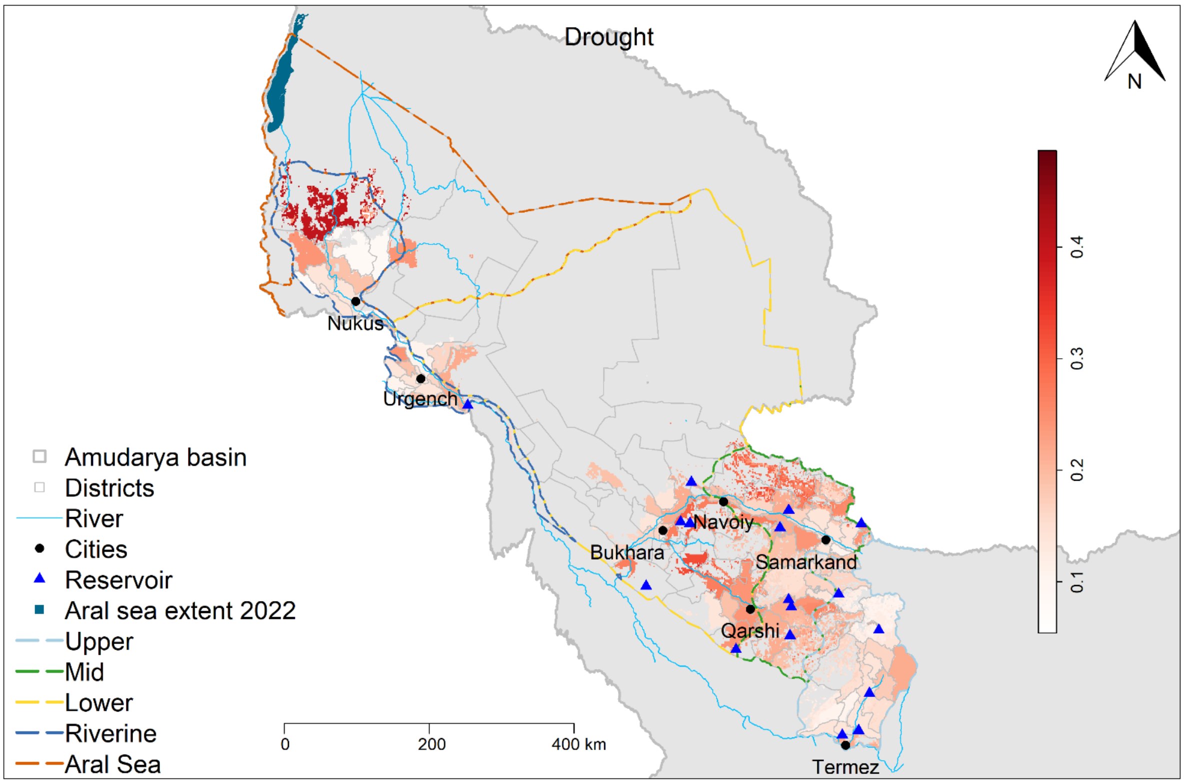

Figure 10. Baseline drought hazard (no. year > 30% threshold area affected) for Amu Darya basin

4.1.2 Hazard (future)

To derive the future drought hazard for the Amu Darya basin, the Standardized Precipitation Evapotranspiration Index (SPEI) is used as the associated Climate Index. SPEI is a multiscalar index (ranging between -5 and 5) frequently used to quantify drought and is based on a climate water balance. As opposed to some existing indices of climatological drought, SPEI incorporates multiple climatological factors including precipitation and temperature, which is imperative for assessing the influence of climate change on drought (Vicente-Serrano et al., 2010)[1]. The SPEI is designed to consider both precipitation and potential evapotranspiration (PET) in determining drought. SPEI uses a climatic water balance (i.e. difference of P and PET) obtained at various time scales (i.e. over one month, two months, three months, etc.). For example, to obtain the 12-month SPEI, a time series is first constructed by the sum of P and PET values difference from 11-months before to the current month. The precipitation (accumulated over a period of time) in the SPEI stands for water availability, while PET stands for atmospheric water demand. Thus, SPEI compares the highest possible evapotranspiration (what we call the evaporative demand by the atmosphere) with the current water availability. SPEI can measure drought severity according to its intensity and duration and identify the onset and end of drought episodes.

SPEI results should be interpreted as a relative measure of surface water surplus or deficit with respect to hydroclimate conditions of the reference period. SPEI can be calculated on a range of timescales from 1-48 months. SPEI drought is categorized into 5 classes as; (1) non-drought (in this class the value of SPEI is greater than -0.5), (2) mild (the value of SPEI is between -0.5 and -1), (3) moderate (SPEI is between -1.5 and -1), (4) severe (SPEI is between -2 and -1.5), and (5) extreme (Less than -2).

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[1] Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. *Journal of Climate*, *23*(7), 1696–1718. https://doi.org/10.1175/2009JCLI2909.1

In this project, we chose SPEI12 (also used by the World Bank) for the drought analysis. The 50th percentile of the muti-model (SSP5-8.5 GCM ensemble) anomalies, i.e., the difference in the future time slice and reference (1995–2014), were obtained from the climate knowledge portal of the World Bank[1].

As shown in Figure 11, Future SPEI anomalies show consistent moderate to severe drought patterns across Uzbekistan. By combining the drought baseline hazard with the SPEI anomalies, the future drought hazard priority index (-) for climate-resilient investment was constructed for the Amu Darya basin (see Figure 12).

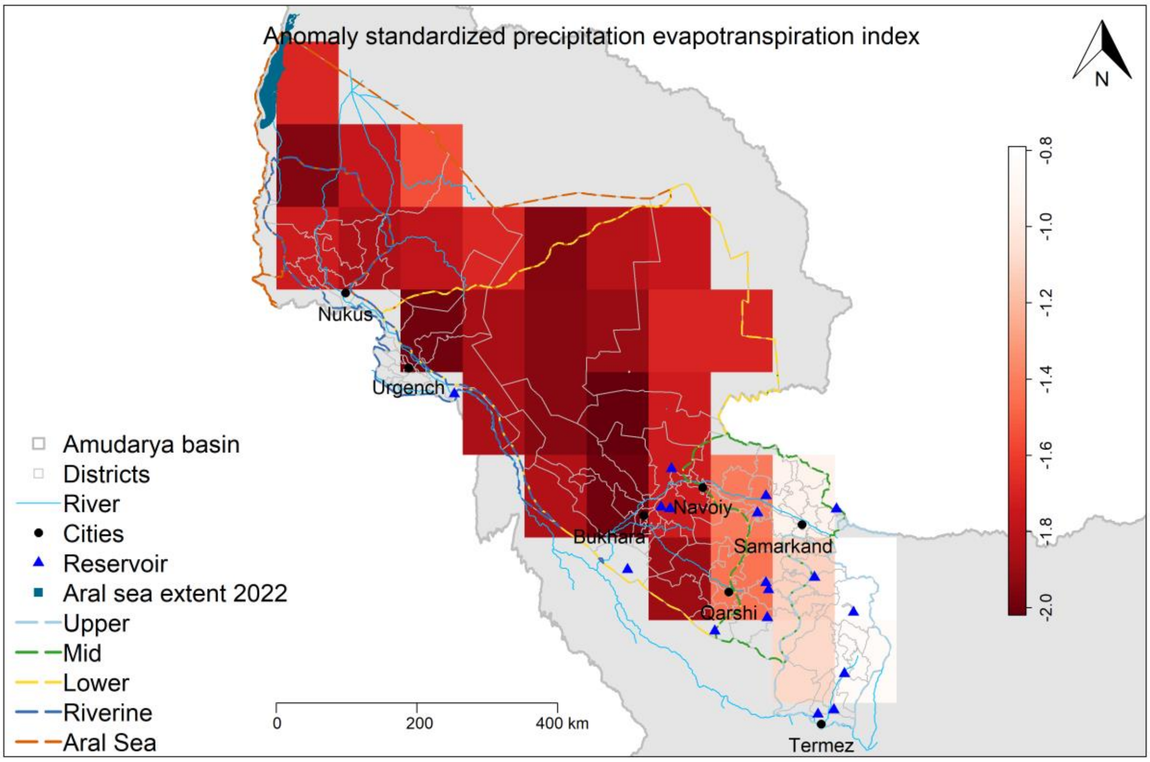

Figure 11. Future SPEI anomalies for the Amu Darya basin

[1] https://climateknowledgeportal.worldbank.org/download-data

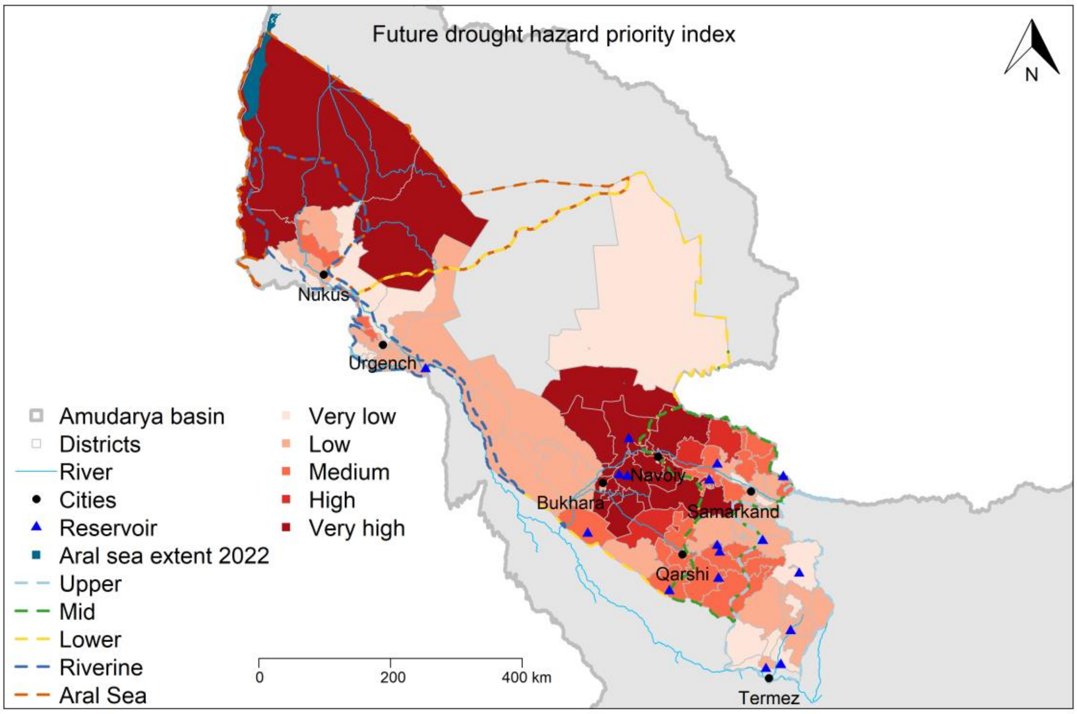

Figure 12. Future drought hazard priority index (-) for Amu Darya basin

4.1.3 Vulnerability

To quantify the drought vulnerability, the Aqueduct Water Risk dataset (Gassert et al., 2015)[1] developed by the Water Resources Institute (WRI)[2] was used, which provides decadal projections of water supply and demand using CMIP5 GCMs. The dataset includes 9 historic baseline and four future water risk indicators, with output at hydrological sub-basin scale. The 90th percentile of the GCM ensemble around 2070 was calculated for the four available future indicators:

- **Water stress**, an indicator of competition for water resources and is defined informally as the ratio of demand for water by human society divided by available water. Water stress measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Water withdrawals include domestic, industrial, irrigation, and livestock consumptive and non-consumptive uses. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users.
- **Water supply**, or total blue water (renewable surface water). Projected change in total blue water is equal to the mean around the target year divided by the baseline period of 1950–2010.
- **Water demand**, measured as water withdrawals. Projected change in water withdrawals is equal to the summarized withdrawals for the target year, divided by the baseline year of 2010. Since consumptive irrigation use varies based on climate, unique estimates of consumptive and non-consumptive agricultural withdrawal were estimated for each year.
- **Seasonal variability**, an indicator of the variability between months of the year. Increasing SV may indicate wetter wet months and drier dry months, and higher likelihood of droughts or wet periods.

[1] Gassert, F., Luck, M., Scientist, R., LLC, Is., Scientist, M. L. R., & LLC, Is. (2015). Aqueduct Water Stress Projections: Decadal Projections of Water Supply and Demand Using CMIP5 GCMs. https://www.wri.org/research/aqueduct-water-stress-projections-decadal-projections-water-supply-and-demand-using-cmip5
[2] https://www.wri.org/aqueduct

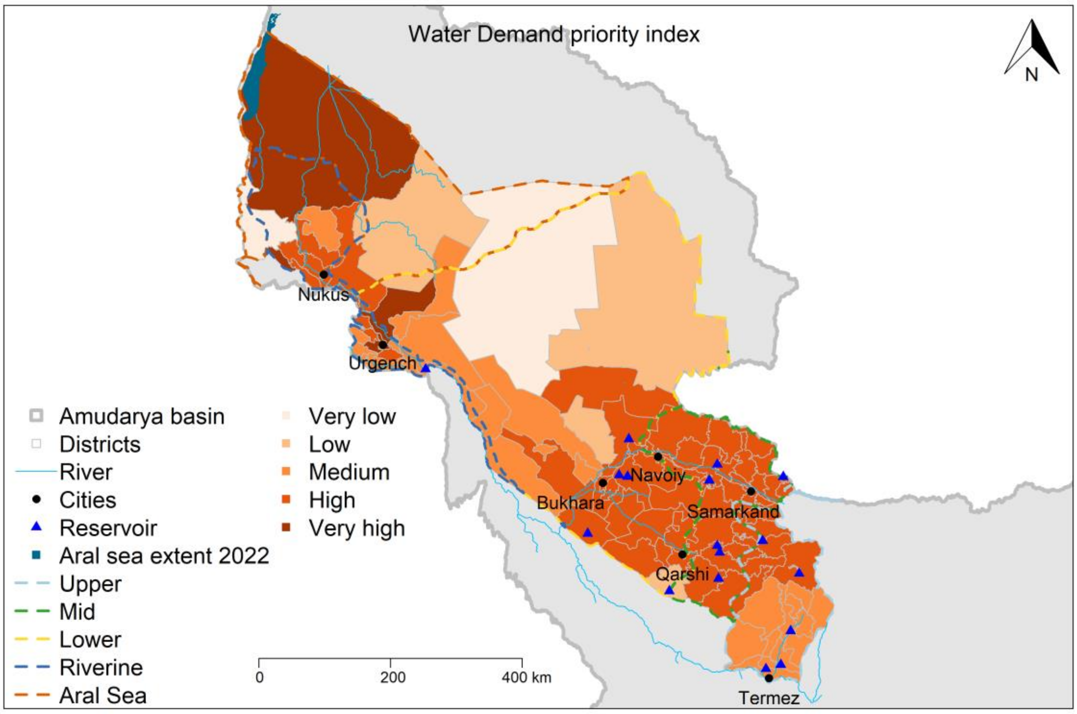

Figure 13. Future drought vulnerability priority index (-) for Amu Darya basin

For the Amu Darya basin the water demand indicator (Figure 13) was determined to be most suited as a vulnerability associated to drought hazard and is used in the future drought risk calculation.

4.1.4 Exposure

The online information tool WUEMoCA[1] (Water Use Efficiency Monitor in Central Asia) developed by Wuerzburg University constitutes a continuous and automated monitoring platform that provides free access to spatio-temporal agricultural geoinformation such as land use and crop types, yield estimations, and evapotranspiration assessments. This information is derived from open-source optical satellite remote sensing MODIS imagery and freely available global climate data. Applications include assessments of marginal lands with low productivity, the intensity of land use, the early estimation of harvest shortfalls, and the assessment of water use efficiencies.

WUEMoCA offers a suite of RS-driven key indicators (see Table 6 and Annex 3) on the state of the irrigated cropland use and water use efficiency in the Aral Sea Basin. It intends to provide agriculturally relevant information to regional users to support planning in water management institutions and organizations. The indicators are mainly relevant in:

- Estimating the performance of irrigated agriculture within and among the boundaries of an irrigation system, administrative divisions (e.g., provinces and districts), hydrographic units (e.g., hydro module zones), and transboundary and riparian countries and river catchments
- Comparing different irrigation systems, administrative divisions, hydrographic units, and transboundary and riparian countries and river catchments (by land use and cultivated crop types, crop productivity, water productivity, water use efficiency, and others),
- Identifying problem spots, respectively localities at risk, for instance in terms of drought, continuous water scarcity, and others.
- Identifying consistent trends of effective improvements and setting reasonable development goals.

[1] https://wuemoca.geo.uni-halle.de/app/

– Monitoring performance of irrigated agriculture over time (e.g., multi-annually, annually, inter-annually, and seasonally) and in space.

Table 6. Specification of indicators in WUEMoCA platform used for exposure and vulnerability

Indicator [Unit]	Description	Interpretation
Net irrigated area [ha]	Area equipped with irrigation infrastructure (active and passive irrigable cropland)	Reference area for crop-specific shares
Water Productivity (ET) [$ m^{-3}]	Economic revenue per m3 of water consumed, measured in crop-specific actual evapotranspiration (for cotton, rice, and wheat fields separately)	Allows comparisons of the monetary value of crops in relation to their water consumption.

For the drought hazard risk mapping, the Net irrigated area was transformed into a priority index climate-resilient investment and used as a measure of exposure (see Figure 14). Net irrigated area is defined as an area equipped with irrigation infrastructure, including fallow land (see Table 6). Other relevant exposure / vulnerability layers included in the WUEMoCA tool are in Annex 3.

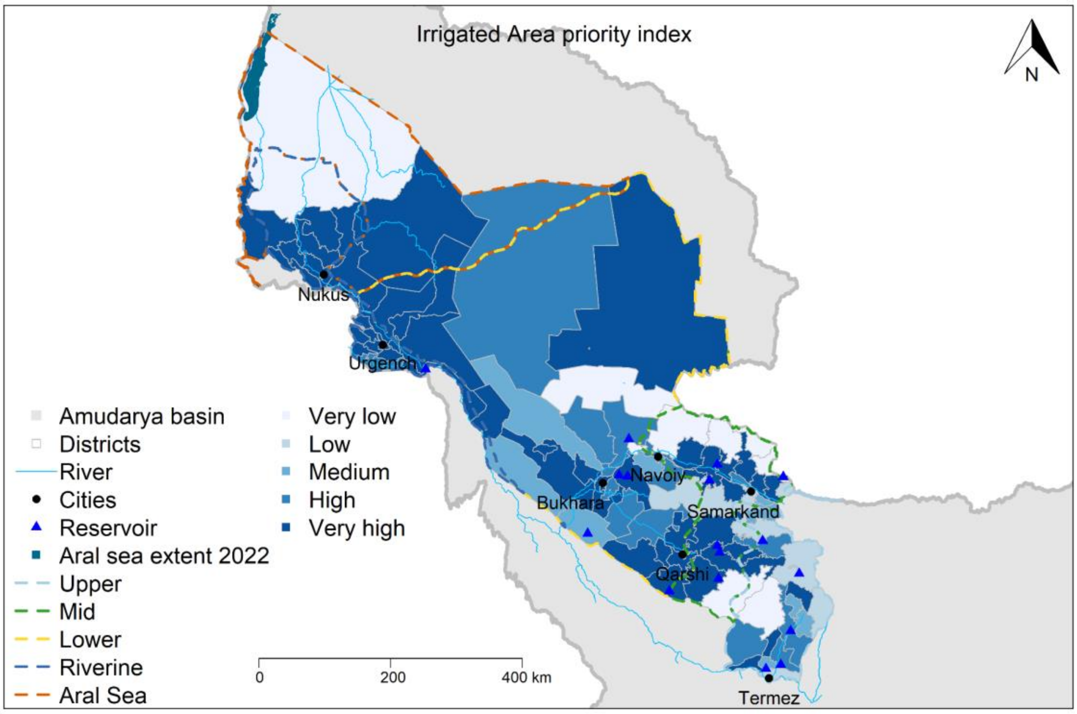

Figure 14. Exposure priority index (-) based on net irrigated area in Amu Darya basin (WUEMoCA)

Another measure of exposure used in the drought hazard risk mapping methodology is population estimates from the Gridded Population of World Version 4.11 (GPWv4)[1]. This dataset models the distribution of global human population for the years 2000, 2005, 2010, 2015, and 2020 on 30 arc-second (approximately 1km) grid cells. Population is distributed to cells using proportional allocation of population from census and administrative units. Population input data are collected at the most detailed spatial resolution available from the results of the 2010 round of censuses, which occurred between 2005 and 2014. The input data are extrapolated to produce population estimates for each modeled year. The

[1] https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

most recent population estimate for the Amu Darya basin was transformed into a priority index climate-resilient investment, aggregated to level-2 districts and used as an exposure layer (see Figure 15)

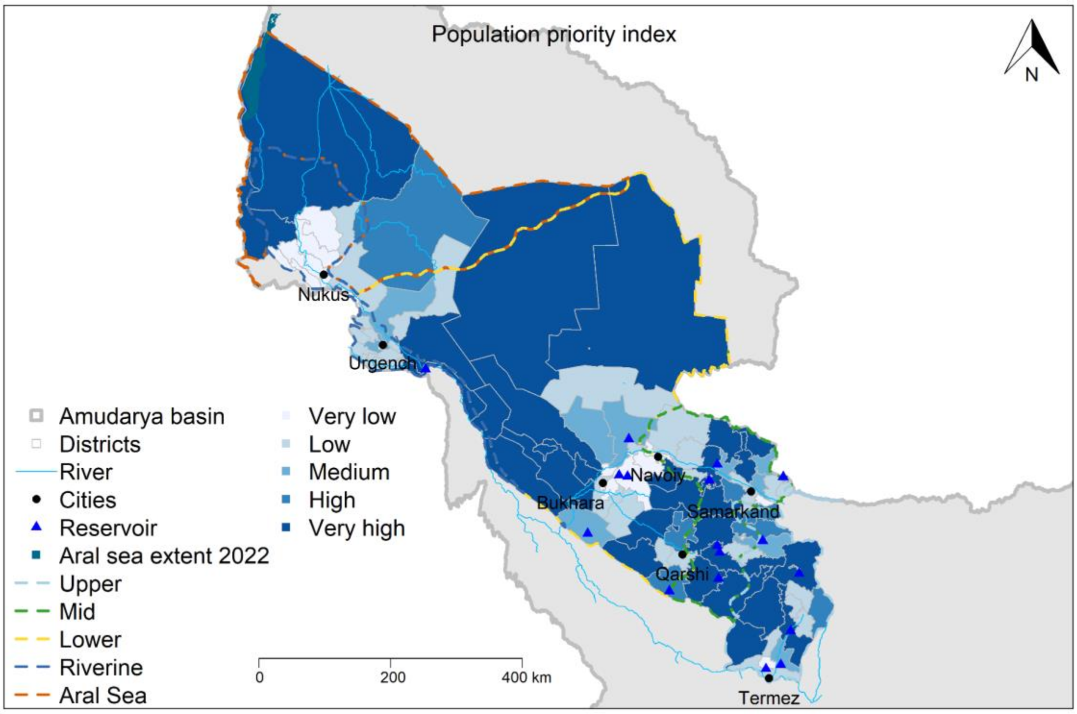

Figure 15. Exposure priority index (-) based on population estimates in Amu Darya basin for 2020 (GPWv4)

4.1.5 Risk

The risk calculation follows the methodology explained in section 2.1. The drought risk calculation entails the future drought hazard (Figure 12), vulnerability layer (Figure 13), and exposure layers (Figure 14 and Figure 15). Though the future drought hazard priority index is on the higher end (very high) for some districts of Bukhara, South of Navoi, Samarkand, and the Republic of Karakalpakstan, the final risk ranking illustrates that the drought risk is spatially varied and differs per ecozone (Figure 16). This is mainly attributed to the fact that the other components of the risk, i.e. exposure (irrigated area and population) and vulnerability (water demand), have different spatial patterns. The drought risks are lower for most of the districts in the upper and riverine (except for the Khazarasp district of Khorezm province) ecozones. The final district aggregated risk plots (radar plots) show that the drought risks are relatively higher for the mid, lower, and Aral sea ecozones. These results are in line with the assessment presented in Figure 16. Moreover, the top 10 drought risk-prone districts with the corresponding hazards, vulnerability, and exposure components are higher for the Kashkadarya, Samarkand and Republic of Karakalpakstan (see Table 7). The hazard and vulnerability priority indices are scaled from 0-1 and subsequently multiplied with the exposure layers to get the final ranking. The overall final risk scores (not shown in table) are then used to rank the risk as shown in Table 7. This approach is consistent throughout the report for other risks.

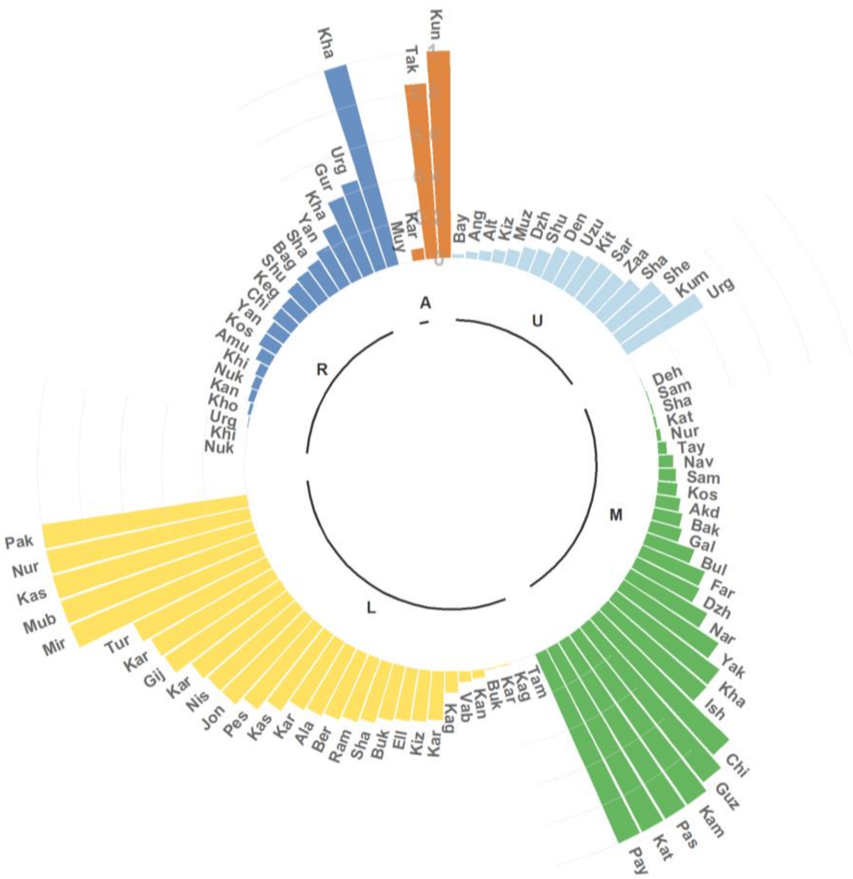

Figure 16. Drought risk radar plot ranking all districts in the five eco-hydrological zones (U=Upper, M=Mid, L=Lower, R=Riverine, A=Aral basin). Risk is scaled between 0-1 (low-high), and colours correspond to each ecozone. The three characters on top of the circular bar represent the first three letters of the district name.

Table 7. The zonal aggregates of the hazard, vulnerability, and exposure layers used in the drought risk calculation. The rows represent the top 10 drought risk districts as shown by the radar plot.

Zone	Province	District	Hazard index (0-1)	Vulnerability index (0-1)	Agricultural index (0-1)	Population index (0-1)
Riverine	Khorezm	Khazarasp	0.180	0.030	0.554	0.439
Lower	Kashkadarya	Mirishkar	0.176	0.036	0.783	0.308
Lower	Kashkadarya	Mubarek	0.371	0.039	0.383	0.338
Lower	Kashkadarya	Kasan	0.309	0.036	0.971	0.192
Lower	Samarkand	Nurabad	0.290	0.039	0.151	1.000
Lower	Samarkand	Pakhtachi	0.387	0.039	0.335	0.297
Aral basin	Republic of Karakalpakstan	Kungrad	0.378	0.009	0.700	0.848
Aral basin	Republic of Karakalpakstan	Takhtakupir	0.499	0.018	0.491	0.228
Lower	Republic of Karakalpakstan	Turtkul	0.226	0.024	0.523	0.303
Lower	Bukhara	Karaulbazar	0.520	0.039	0.327	0.121

4.2 Rainfall-induced Landslides

Rainfall-induced landslides and wet mass movement (e.g., mudflows) are caused by heavy precipitation and flooding (it does not include snow avalanches). Wet mass movements are affected by geological features (e.g., soil type and structure) and geomorphological setting (e.g., slope gradient). A commonly used intensity metric is frequency of occurrence of a significant landslide per sq. km. The severity of significant landslides is typically ranked by the annual frequency of occurrence of a significant landslide per sq. km. that accounts for susceptibility (slope, soil type) and probability of intense and long-lasting precipitation events that can trigger wet mass movements.

- Low hazard: < 0.005
- Moderate hazard: 0.005 – 0.01
- High hazard: > 0.01

4.2.1 Hazard (baseline)

Mudslides, also known as debris flows or mudflows, are a common type of fast-moving landslide that tends to flow in channels. Mudflows are amongst, according to data from the Centre of Hydrometeorological Service of the Republic of Uzbekistan (Uzhydromet), the most damaging and deadly natural hazards in Uzbekistan. The data suggest that mudflows were responsible for over 38 deaths and damaged approximately 3000 households and 5000 ha of agricultural crops over the decade (2005–2014) in Uzbekistan. However, the incidence of damage may be much larger as these events commonly occur in mountainous areas, in incised valleys and in areas of otherwise low relief.

The paper 'The role of synoptic processes in mudflow formation in the piedmont areas of Uzbekistan' by (Mamadjanova et al., 2018)[1] provides an overview of mudflow occurrences for the years 2005–2014 in areas with a high probability of mudflow passage in Uzbekistan (see Figure 17).

The main author of the paper was restricted from sharing the underlying data with a third party by the data provider Uzhydromet. A landslide / mudflow database with accurate GIS points of geological mass movements including landslides triggered by rainfall (mainly in the Tashkent Region) recorded by the State Committee of Uzbekistan for Geology is available upon official request when collaborating with Uzbek government bodies.

[1] Mamadjanova, G., Wild, S., Walz, M. A., & Leckebusch, G. C. (2018). The role of synoptic processes in mudflow formation in the piedmont areas of Uzbekistan. Natural Hazards and Earth System Sciences, 18(11), 2893–2919. https://doi.org/10.5194/NHESS-18-2893-2018

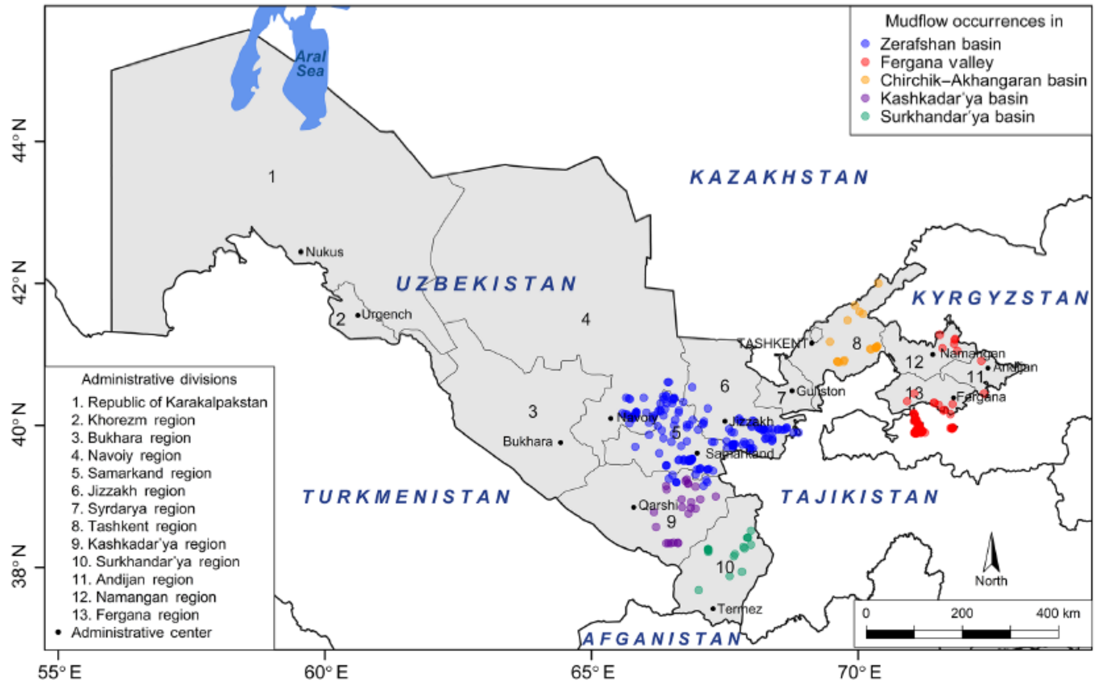

Figure 17. Mudflow occurrences for the years 2005–2014 in areas with a high probability of mudflow passage in Uzbekistan. Figure from (Mamadjanova et al., 2018)

For the baseline landslide hazard, the Global Landslide Hazard Map was considered, which presents a quantitative representation of landslide hazard. The dataset provides a systematic assessment of landslide hazards on a global scale. Landslides triggered by precipitation and earthquakes have been determined separately, and a combined qualitative landslide hazard assessment has been provided. The data provides frequency estimates for each grid cell on land between 60°S and 72°N for landslides triggered by seismicity and rainfall.

The component used here is the mean annual rainfall-triggered landslide hazard assessment from 1980 – 2018. Raster values represent the modelled average annual frequency of significant rainfall-triggered landslides per sq. km. Applications of this dataset include improved hazard screening based on frequency and severity, consistent national, regional, and global scale exposure assessment, and estimates of the annual expected impact on the population and the built environment. Figure 18 shows the baseline rainfall-induced landslide hazard map for the Amu Darya basin. Higher values indicate higher landslide hazards.

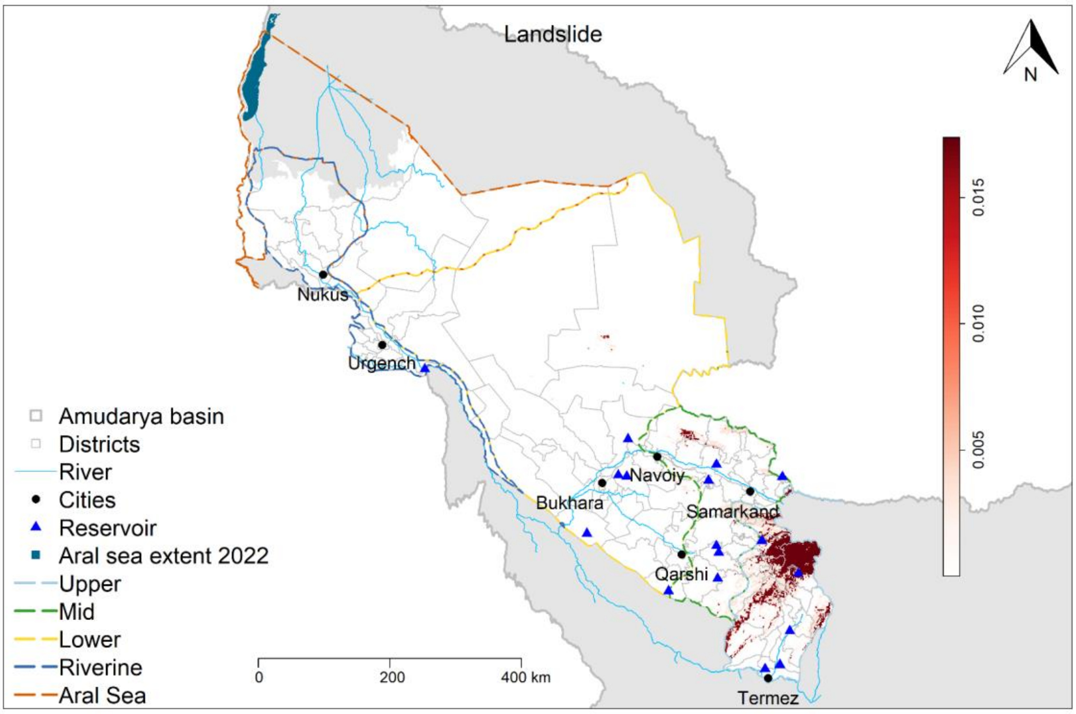

Figure 18. Baseline rainfall-induced landslide hazard (ann. freq. of rainfall-triggered landslides per sq. km) for the Amu Darya basin

4.2.2 Hazard (future)

To derive the future landslide hazard for the Amu Darya basin, the annual maximum 5-day consecutive precipitation (Rx5day) is used as the associated Climate Index. Rx5day denotes the maximum of a consecutive five-day precipitation amount within a considered time period. This climate index is a measure of heavy precipitation, with high values corresponding to a high chance of rainfall-induced hazards (e.g., flooding, landslides). An increase in this index with time means the chance of hazardous conditions will increase.

As shown in Figure 19, Future Rx5day anomalies (in mm) were calculated using Global Climate Model projections (90th percentile of SSP5-8.5 GCM ensemble) from the Coupled Model Intercomparison Project Phase 6 (CMIP6). By combining the baseline landslide hazard with the Rx5day anomalies, the future landslide hazard priority index (-) for climate-resilient investment was constructed for the Amu Darya basin (see Figure 20). This map is aggregated and gives a future landslide hazard indication at the district level; local topographic characteristics are accounted for in the baseline hazard dataset.

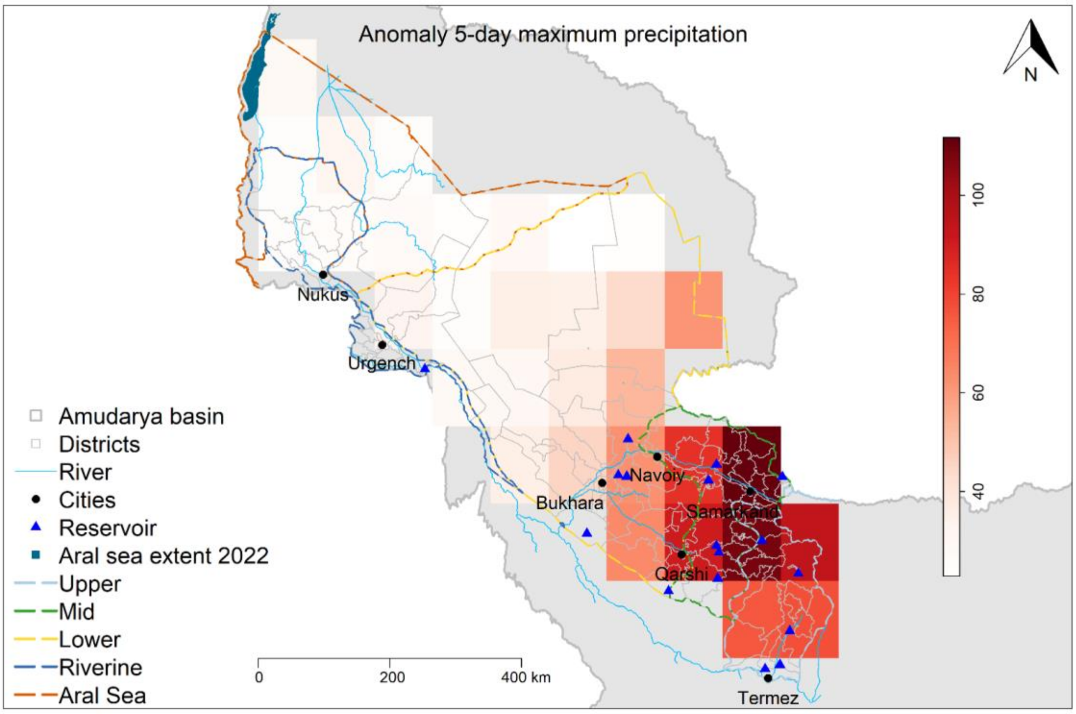

Figure 19. Future Rx5day anomalies (in mm) for Amu Darya basin

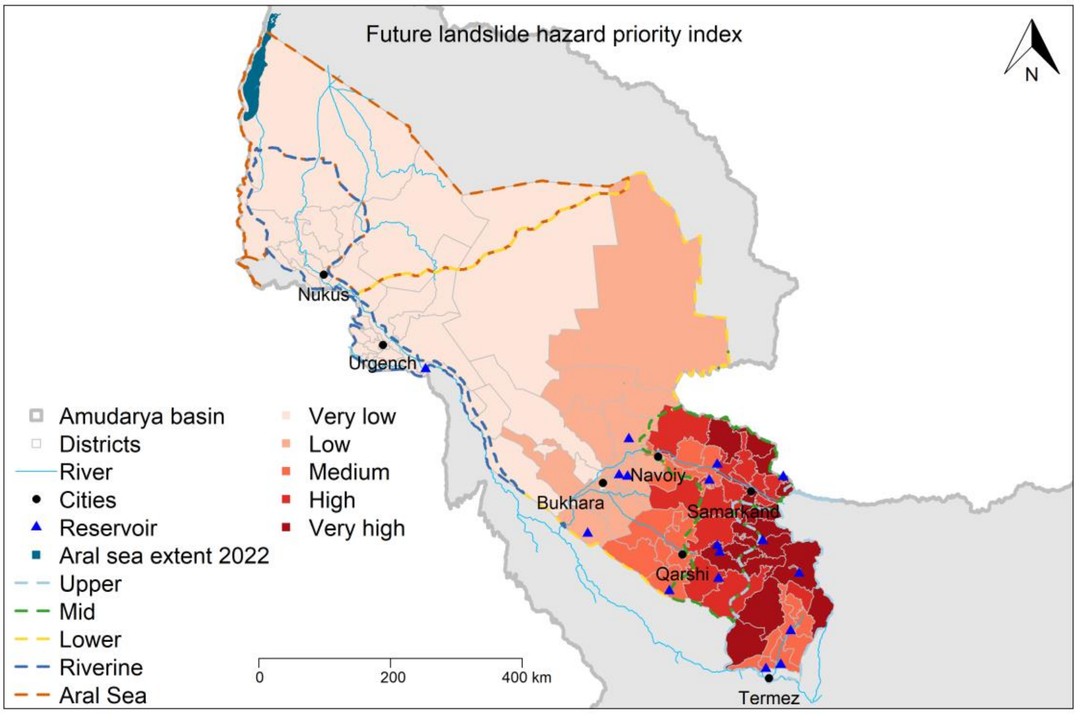

Figure 20. Future rainfall-induced landslide hazard priority index (-) for the Amu Darya basin

4.2.3 Vulnerability

For the landslide hazard risk mapping procedure, the Water Productivity (WP) indicators in the WUEMoCA dataset were considered as a measure of vulnerability (see Table 6). WP is defined as the economic revenue per m³ of water consumed, measured in crop-specific actual evapotranspiration (for cotton, rice, and wheat crops separately). Economic revenue is defined as crop harvest, calculated as crop yield multiplied by crop acreage.

Because productivity is an efficiency measure and it is the intention to use WP as a measure of vulnerability, the inverse of WP was calculated. The logic behind this vulnerability indicator is as follows: the lower the water productivity, the poorer livelihood conditions, and thus the less resources farmers have to cope with the impacts of climate-related hazards like landslides or erosion, and thus the more vulnerable they are. Figure 21, Figure 22, and Figure 23 depict the inverse of WP for cotton, rice and wheat, respectively, which were combined (by addition) into a single composite vulnerability priority index for the risk mapping procedure.

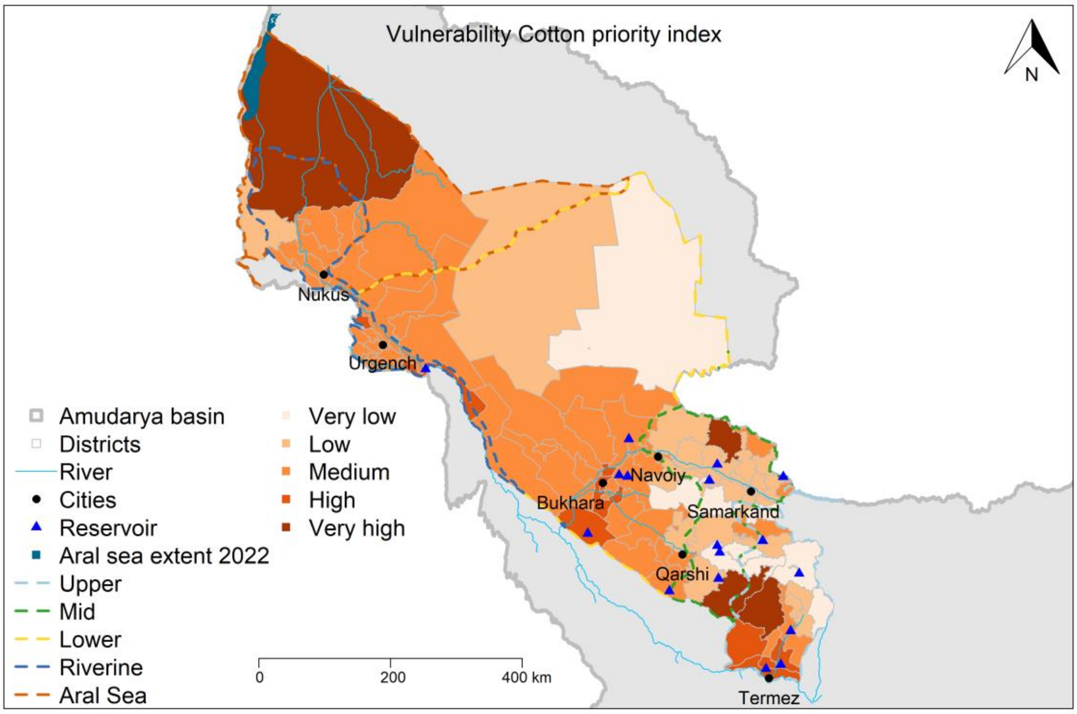

Figure 21. Vulnerability priority index (-) derived from the inverse of Water Productivity of cotton.

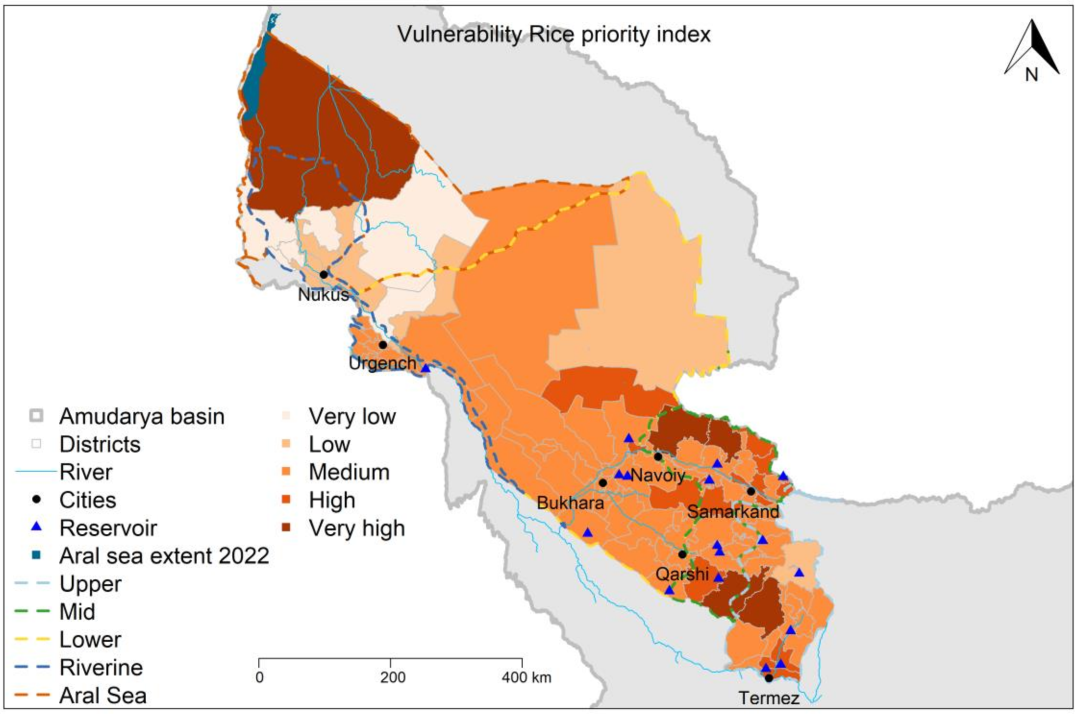

Figure 22. Vulnerability priority index (-) derived from the inverse of Water Productivity of rice

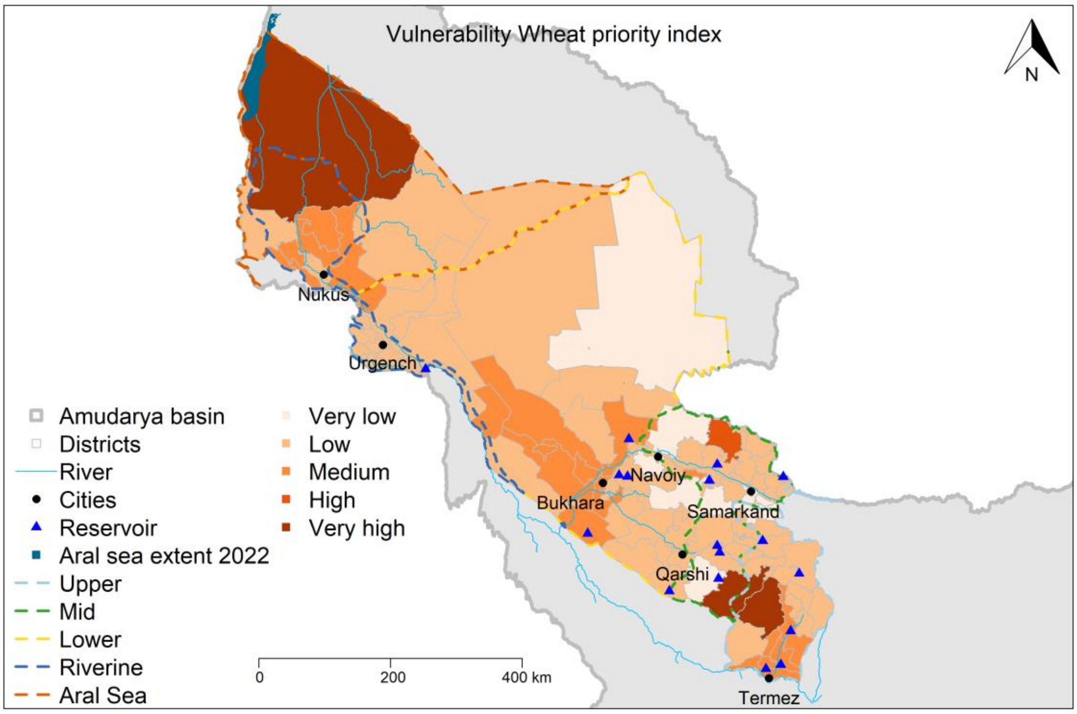

Figure 23. Vulnerability priority index (-) derived from the inverse of Water Productivity of wheat

4.2.4 Exposure

The priority index based on most recent population estimates for the Amu Darya basin from the Gridded Population of World Version 4.11 (GPWv4) was used as an exposure layer (see Figure 10). Higher population estimates correspond to higher hazard exposures.

The priority index based on Net irrigated area from WUEMoCA was also used to measure exposure (see Figure 15). Net irrigated area is defined as an area equipped with irrigation infrastructure, including fallow land (see Table 5). Larger irrigated areas mean more cropland is potentially exposed to climate-related hazards, in this case rainfall-induced landslides.

4.2.5 Risk

The risk calculation follows the methodology explained in section 2.1. The rainfall-induced landslide risk calculation entails the future rainfall-induced landslide hazard (Figure 20), vulnerability layer (Figure 21, Figure 22, and Figure 23), and exposure layer (Figure 14 and Figure 15). The future landslide hazard priority index is on the higher end (very high) for the districts of Samarkand, Surkhandarya, and Kashkadarya provinces. This aligns well with the final risk ranking and thus illustrates that the landslide risk is a localized phenomenon (Figure 24). The higher values are mainly attributed to the steep topography and higher precipitation in the southeastern regions selected for this study. The other risk components, i.e. exposure (irrigated area and population) and vulnerability (inverse water productivity for crops such as cotton, wheat, and rice) which have different spatial patterns may have some impact on spatial variability of the rainfall-induced landslide risks.

To curtail impacts of landslide only on the upper and mid ecozones, the vulnerability to the hazards for lower, riverine and Aral basin are neglected. The landslide risks are lower for most of the districts in the riverine, Aral, and lower (except for some districts in Kashkadarya province) ecozones. The final district aggregated risk plots (radar plots) show that the rainfall-induced landslide risks are relatively higher for the upper and mid ecozones. These results are in line with the assessment presented in Figure 24. Moreover, the top 10 rainfall-induced landslide risk-prone districts with the corresponding hazards, vulnerability, and exposure components are higher for the Samarkand, Surkhandarya, and Kashkadarya provinces (see Table 8).

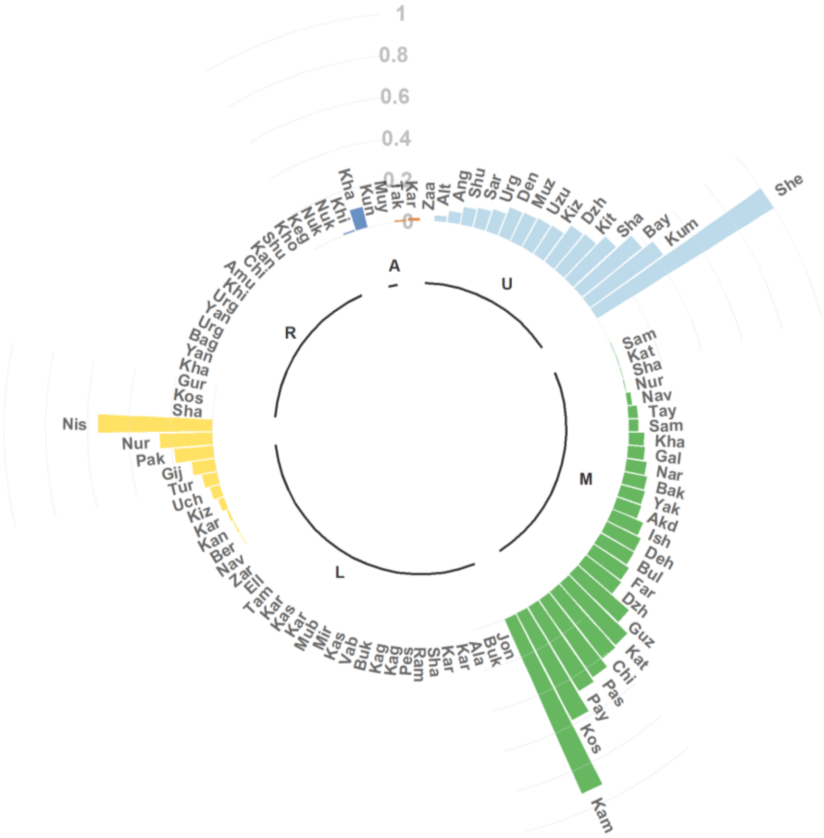

Figure 24. Landslide risk radar plot ranking all districts in the five eco-hydrological zones (U=Upper, M=Mid, L=Lower, R=Riverine, A=Aral basin). Risk is scaled between 0-1 (low-high) and colors correspond to each ecozone. The 3 characters on top of the circular bar represent the first 3 letters of the district name.

Table 8. The zonal aggregates of the hazard, vulnerability, and exposure layers used in the rainfall-induced landslide risk calculation. The rows represent the top 10 rainfall-induced landslide risk districts as shown by the radar plot.

Zone	Province	District	Hazard index (0-1)	Vulnerability index (0-1)	Agricultural area index (0-1)	Population index (0-1)
Upper	Surkhandarya	Sherabad	0.772	0.005	0.422	0.366
Mid	Kashkadarya	Kamashi	0.965	0.003	0.604	0.294
Mid	Samarkand	Koshrabad	0.573	0.077	0.017	0.447
Lower*	Kashkadarya*	Nishan*	0.353*	0.005*	0.865*	0.213*
Mid	Samarkand	Payarik	0.506	0.003	0.630	0.256
Mid	Samarkand	Pastdargom	0.486	0.003	0.925	0.189
Upper	Surkhandarya	Kumkurgan	0.401	0.005	0.431	0.272
Mid	Kashkadarya	Chirakchi	0.480	0.003	0.509	0.309
Mid	Samarkand	Kattakurgan	0.350	0.003	0.635	0.322

*Note:- As per the local experts, the district Nishan of Kashkadarya province is located in a very low-slope area, and landslides are very unlikely so it suggested to exclude Nishan from landslide related further consideration, survey and analysis.

4.3 Rainfall-induced erosion

The exposure of the Earth's surface to the energetic input of rainfall is one of the key factors controlling water erosion. Rainfall erosivity is among the main drivers of soil erosion, which is the most serious cause of global soil degradation. As such, rainfall erosivity is one of the most important input parameters for describing erosive processes and is essential for the definition of soil and water conservation practices in adapting agriculture to climate change. Since soil erosion is difficult to measure at large scales, models are required for estimating soil loss by water erosion at regional, national, and continental scales. Large-scale and global model predictions are of utmost importance, since soil erosion is, in addition to soil sealing, the major threat to soil sustainability and, consequently to water- and food security (Panagos et al., 2017).

4.3.1 Hazard (baseline)

For the baseline erosion hazard, the Global Rainfall Erosivity map (Panagos et al., 2017)[1] as part of the Global Rainfall Erosivity Database (GloREDa)[2] was considered. GloREDa contains erosivity values estimated as R-factors from 3,625 stations distributed in 63 countries worldwide. It results from an extensive data collection of high temporal resolution rainfall data from the maximum possible number of countries to have a representative sample across different climatic and geographic gradients. As a result, GloREDa provides global estimates of rainfall erosivity (in MJ mm ha^{-1} h^{-1} yr^{-1}) at high temporal resolution (30 arc-sec). A Gaussian Process Regression (GPR) model was used to interpolate single stations' rainfall erosivity values and generate the R-factor map. Figure 25 shows the baseline rainfall-induced erosion hazard map for the Amu Darya basin. Higher values indicate higher erosion hazards.

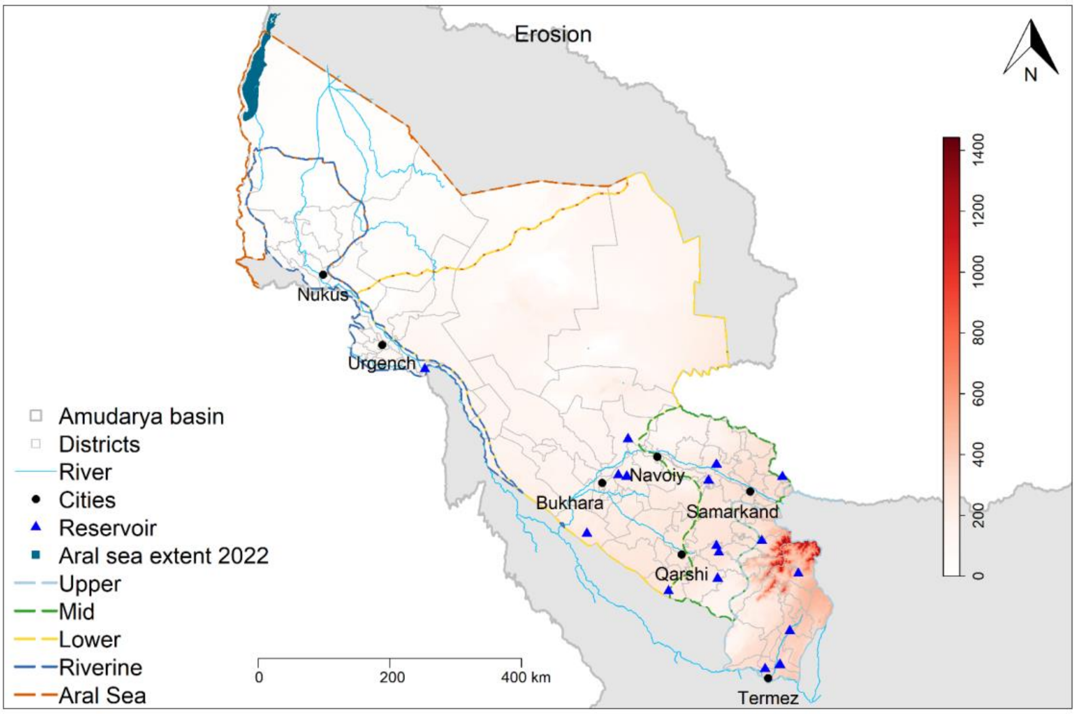

Figure 25. Baseline rainfall-induced erosion hazard map (in MJ mm ha-1 h-1 yr-1) for Amu Darya basin

[1] Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Lim, K. J., Yang, J. E., Ni, J., Miao, C., Chattopadhyay, N., Sadeghi, S. H., Hazbavi, Z., Zabihi, M., Larionov, G. A., Krasnov, S. F., Gorobets, A. v., Levi, Y., Erpul, G., Birkel, C., … Ballabio, C. (2017). Global rainfall erosivity assessment based on high-temporal resolution rainfall records. Scientific Reports 2017 7:1, 7(1), 1–12. https://doi.org/10.1038/s41598-017-04282-8

[2] https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity

4.3.2 Hazard (future)

The annual maximum 1-day consecutive precipitation (Rx1day) is used as associated Climate Index to derive the future erosion hazard for Amu Darya basin. Rx1day (in mm) denotes the maximum of one-day precipitation amount within a given time period. This climate index is a measure of heavy precipitation, with high values corresponding to a high chance of rainfall-induced hazards (e.g., flooding, landslides, erosion). An increase in this index with time means the chance of hazard conditions will increase.

As shown in Figure 26, Future R15day anomalies (in mm) were calculated using Global Climate Model projections (90th percentile of SSP5-8.5 GCM ensemble) from the Coupled Model Intercomparison Project Phase 6 (CMIP6). By combining the baseline landslide hazard with the Rx1day anomalies, the future landslide hazard priority index (-) for climate-resilient investment was constructed for the Amu Darya basin (see Figure 27). This map is aggregated and gives a future erosion hazard indication at the district level; local topographic characteristics are accounted for in the baseline hazard dataset.

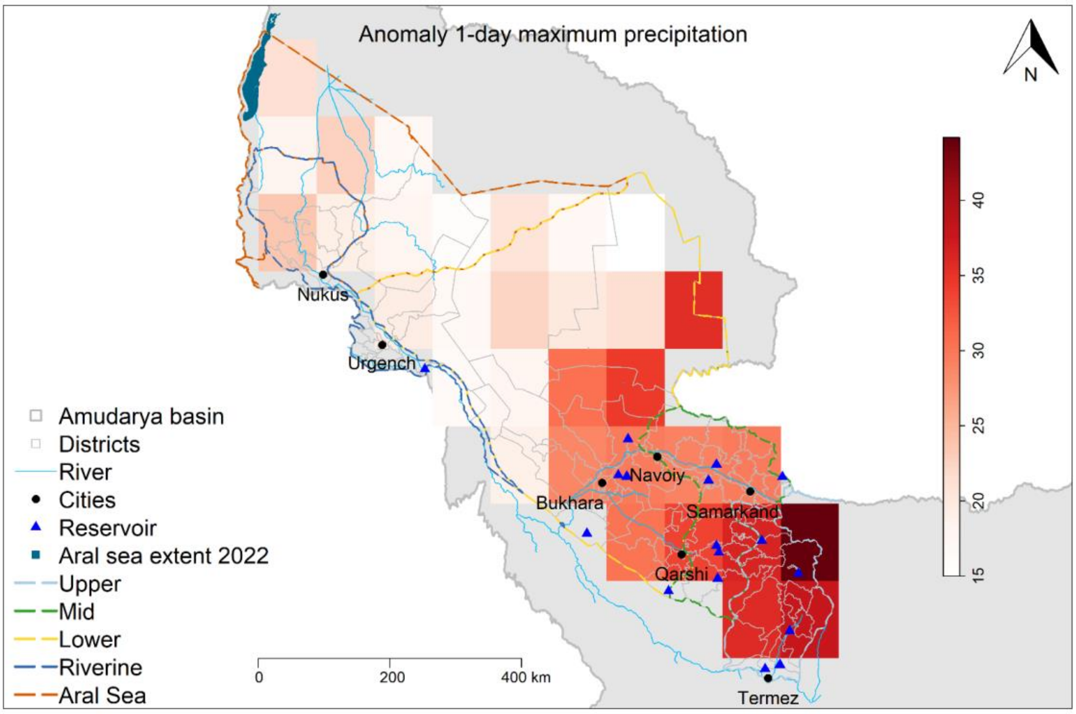

Figure 26. Future Rx1day anomalies (in mm) for Amu Darya basin

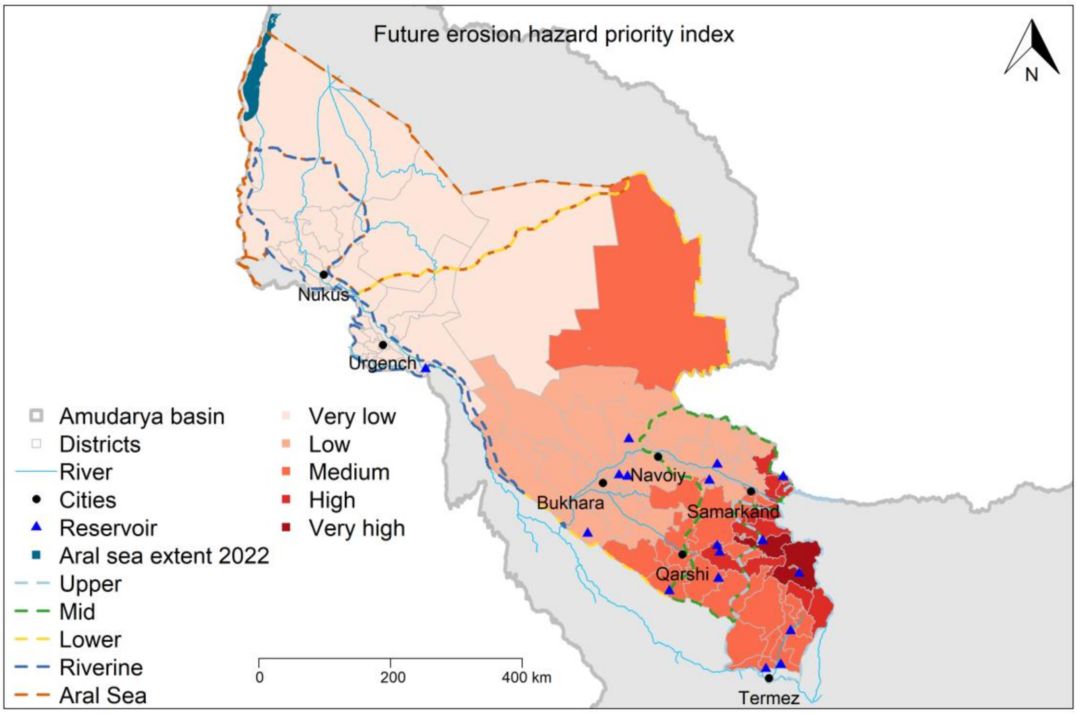

Figure 27. Future rainfall-induced erosion hazard priority index (-) for Amu Darya basin

4.3.3 Vulnerability

Like the landslide hazard, for the erosion hazard risk mapping procedure the Water Productivity (WP) indicators in the WUEMoCA dataset were also considered as a measure of vulnerability (see Table 6). Because productivity is an efficiency measure and WP is used as a measure of vulnerability, the inverse of WP was calculated and used as a vulnerability priority index (-). The logic behind this vulnerability indicator: the lower the water productivity, the poorer the farmers are and the less resources they must get a high productivity out of a drop of water, and thus the more vulnerable they are. Figure 21, Figure 22, and Figure 23 depict the priority indices derived from the inverse of WP for cotton, rice, and wheat respectively.

4.3.4 Exposure

The priority index based on the most recent population estimates for the Amu Darya basin from the Gridded Population of World Version 4.11 (GPWv4) was used as an exposure layer (see Figure 10). Higher population estimates correspond to higher hazard exposures.

The priority index based on Net irrigated area from WUEMoCA was also used to measure exposure (see Figure 15). Net irrigated area is defined as an area equipped with irrigation infrastructure, including fallow land (see Table 5). Larger irrigated areas mean more cropland is potentially exposed to climate-related hazards.

4.3.5 Risk

The risk calculation follows the methodology explained in section 2.1. The rainfall-induced erosion risk calculation entails the future rainfall-induced erosion hazard priority index (Figure 27), vulnerability layer (Figure 21, Figure 22, and Figure 23), and exposure layer (Figure 14 and Figure 15). Similar to the rainfall-induced landslide hazard, the future drought hazard is on the higher end (very high) for the districts of Samarkand, Surkhandarya, and Kashkadarya provinces. This aligns well with the final risk ranking and thus illustrates that the rainfall-induced erosion risk is a localized phenomenon (Figure 28). This is mainly attributed to the steep topography and higher precipitation in the southeastern parts of the regions selected for this study. The other risk components, i.e. exposure (irrigated area and population) and vulnerability (inverse water productivity for crops such as cotton, wheat, and rice), which have different spatial patterns, may have some impact on the spatial variability of the rainfall-induced erosion risks. The erosion risks, similar to landslide risks, are lower for most of the districts in the riverine, Aral, and lower (except for some districts in Kashkadarya province) ecozones.

The final district aggregated risk plots (radar plots) show that the rainfall-induced erosion risks are relatively higher for the upper and mid ecozones. These results are in line with the assessment presented in Figure 28. Moreover, the top 10 rainfall-induced erosion risk-prone districts with the corresponding hazards, vulnerability, and exposure components are higher for the Samarkand, Surkhandarya, and Kashkadarya provinces (see Table 14).

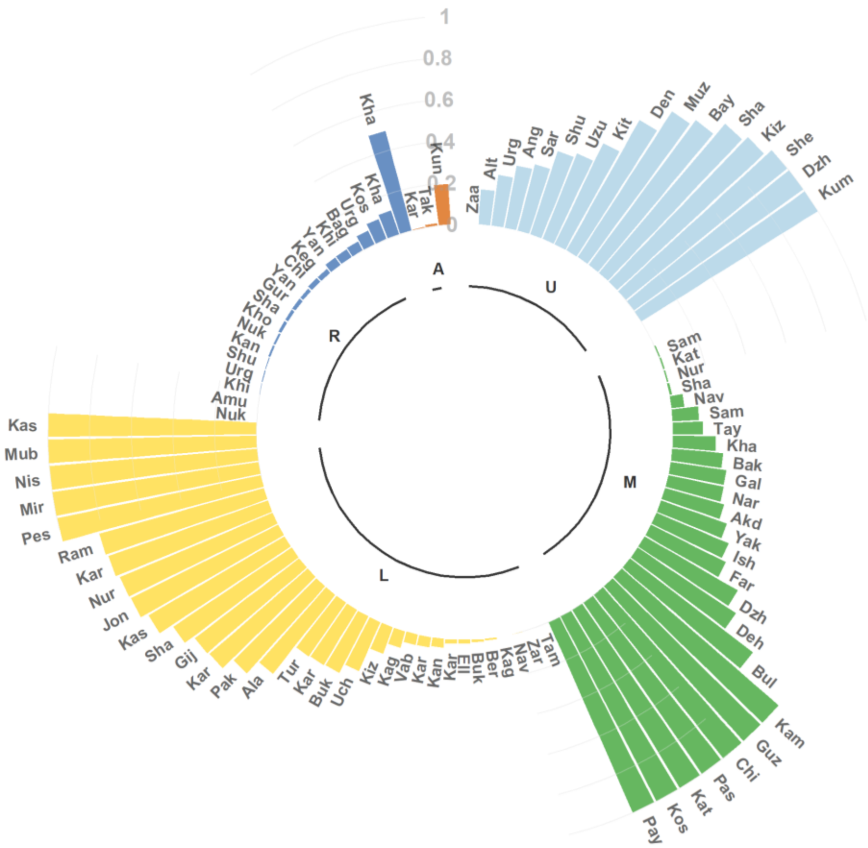

Figure 28. Erosion risk radar plot ranking all districts in the five eco-hydrological zones (U=Upper, M=Mid, L=Lower, R=Riverine, A=Aral basin). Risk is scaled between 0-1 (low-high) and colors correspond to each ecozone. The 3 characters on top of the circular bar represent the first 3 letters of the district name.

Table 9. The zonal aggregates of the hazard, vulnerability, and exposure layers used in the rainfall-induced erosion risk calculation. The rows represent the top 10 rainfall-induced erosion risk districts as shown by the radar plot.

Zone	Province	District	Hazard index (0-1)	Vulnerability index (0-1)	Agricultural area index (0-1)	Population index (0-1)
Upper*	Surkhandarya*	Sherabad*	0.486*	0.005*	0.422*	0.366*
Upper	Surkhandarya	Dzharkurgan	0.555	0.008	0.355	0.141
Upper	Surkhandarya	Kumkurgan	0.566	0.005	0.431	0.272
Mid	Kashkadarya	Kamashi	0.783	0.003	0.604	0.294
Mid	Kashkadarya	Guzar	0.451	0.003	0.436	0.286
Mid	Kashkadarya	Chirakchi	0.477	0.003	0.509	0.309
Mid	Samarkand	Pastdargom	0.351	0.003	0.925	0.189
Mid	Samarkand	Kattakurgan	0.313	0.003	0.635	0.322
Mid	Samarkand	Koshrabad	0.340	0.077	0.017	0.447

*Note:- As per the soil cover atlas of the Republic of Uzbekistan, water erosion was practically not observed in the Sherabad district of Surkhandarya province so it is suggested to exclude the Sherabad district from erosion related further consideration, survey and analysis.

4.4 Heat waves

A heat wave is a period of unusually hot weather (maximum, minimum and daily average temperature) over a region persisting for at least three consecutive days during the warm season compared to the normal climate patterns of a region. In contrast, warm spells are defined as a persistent period of abnormal warm weather and can occur at any time of the year (not only in the warm season). Changes in precipitation patterns coupled with heat stress conditions can impact on agricultural yields, posing implications for food security.

Extreme temperatures are measured by Wet Bulb Globe Temperature (WBGT °C), the Universal Thermal Climate Index (UTCI °C) or comparable heat indices. The occurrence of extreme temperatures is driven by changes in mean temperature and temperature amplitudes, and is influenced by land use (e.g., changes in forest cover) and urban development (heat islands). Air humidity affects how the extreme temperature is tolerated; vulnerability to extreme temperature is highly dependent on the considered exposure. Wet Bulb Globe Temperature (WBGT) is a commonly adopted measure of heat stress in direct sunlight, which considers temperature, humidity, wind speed, sun angle and cloud cover (solar radiation).

4.4.1 Hazard (baseline)

For the baseline heat wave hazard, the Heat Stress Map[1] developed by the research organization VITO in 2016 was considered, which provides 10 km raster grid of Temperature (WBGT °C). The WBGT has obvious relevance for human health, but it is relevant in all kinds of projects and sectors, including infrastructure related, as heat stress affects personnel and stakeholders, and therefore the design of buildings and infrastructure. WBGT is provided as the 20-years mean return value of temperatures.

[1] https://www.geonode-gfdrrlab.org/layers/hazard:intensity_returnperiod20y

According to heat stress studies (Willett & Sherwood, 2012)[1] the WBGT can be divided into the following heat stress hazard intensity categories:

- Low hazard: < 28 °C
- Moderate hazard: 28 – 32 °C
- High hazard: > 32 °C

Figure 29 shows the baseline heat wave hazard map for Amu Darya basin. Higher values indicate higher heat wave hazard.

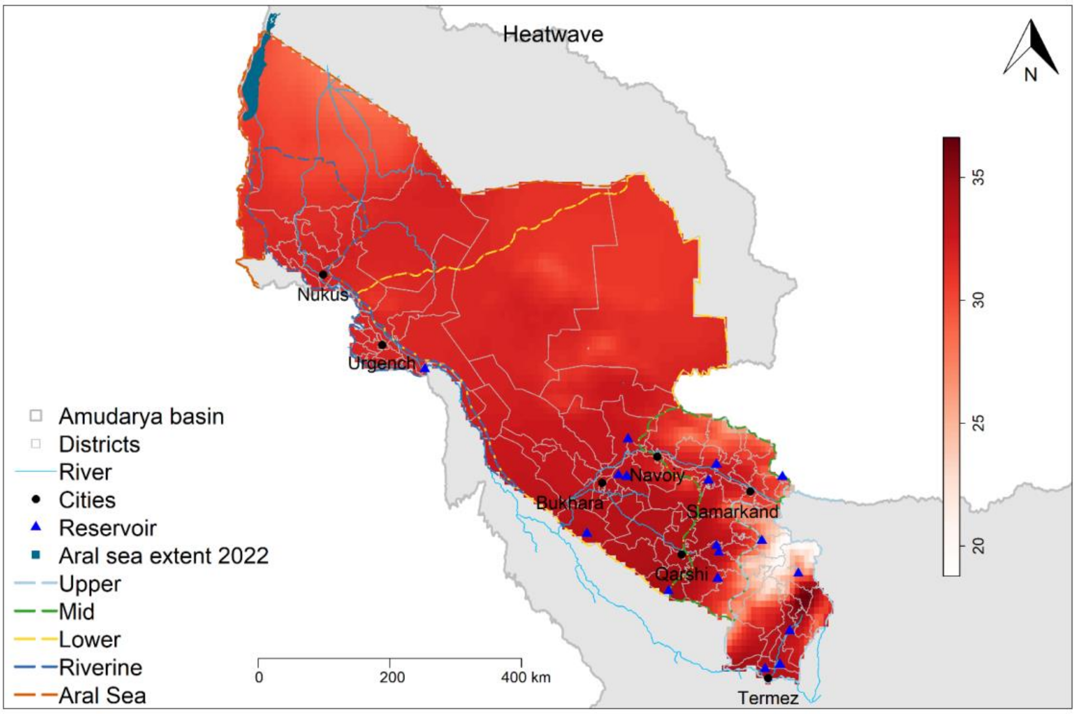

Figure 29. Baseline heat wave hazard map (in WBGT °C) for Amu Darya basin

4.4.2 Hazard (future)

The Warm Spell Duration Index (WSDI) is used as the associated Climate Index to derive the future heat wave hazard for Amu Darya basin. WSDI is defined as the number of days each year which are part of a 'warm spell'. A warm spell is defined as a sequence of 6 or more days in which the daily maximum temperature exceeds the 90th percentile for a 5-day running window surrounding this day during a reference period, here taken as 1995 – 2014.

As shown in Figure 30, Future WSDI anomalies (in days) were calculated using Global Climate Model projections (90th percentile of SSP5-8.5 GCM ensemble) from the Coupled Model Intercomparison Project Phase 6 (CMIP6). By combining the baseline heat wave hazard with the WSDI anomalies, the future heat wave hazard priority index (-) for climate-resilient investment was constructed for the Amu Darya basin (see Figure 31).

[1] Willett, K. M., & Sherwood, S. (2012). Exceedance of heat index thresholds for 15 regions under a warming climate using the wet-bulb globe temperature. *International Journal of Climatology*, *32*(2), 161–177. https://doi.org/10.1002/JOC.2257

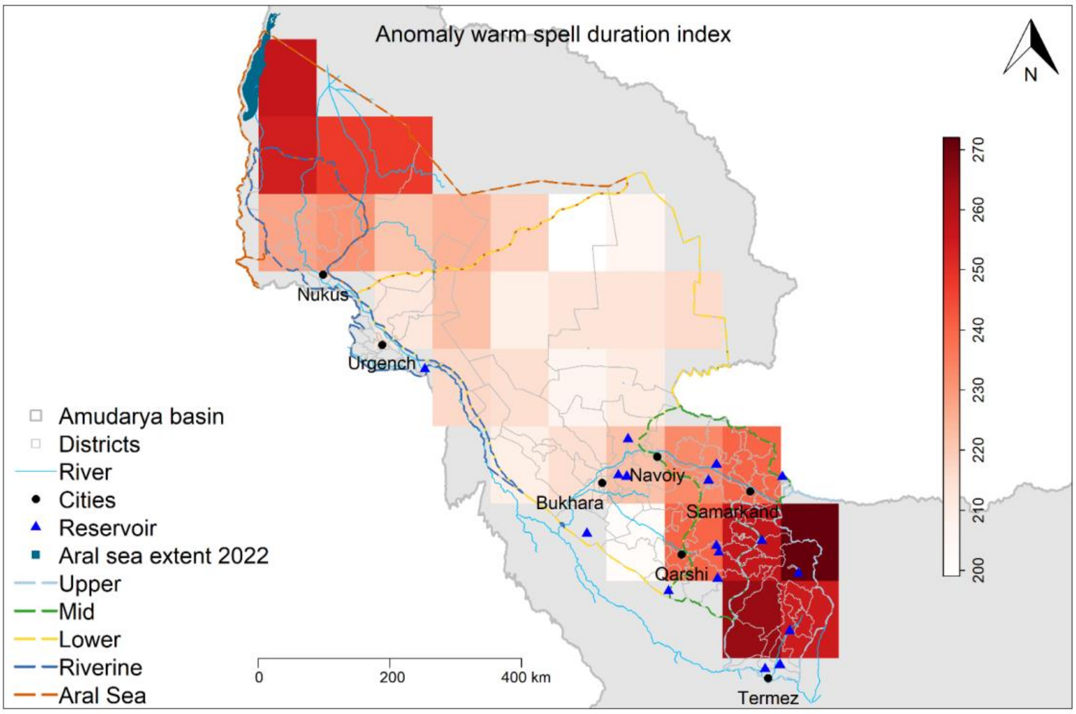

Figure 30. Future WSDI anomalies (in days) for Amu Darya basin

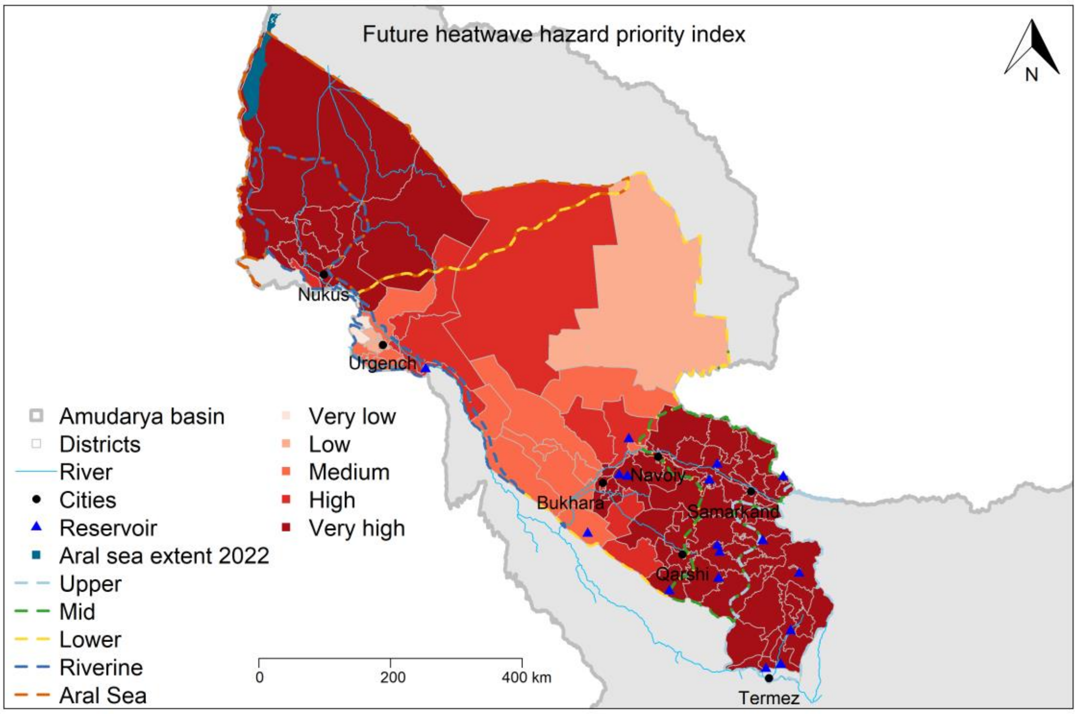

Figure 31. Future heat wave hazard priority index (-) for Amu Darya basin

4.4.3 Vulnerability

For the heat wave hazard risk mapping procedure, the Water Stress indicator of the Aqueduct Water Risk dataset (Gassert et al., 2015) developed by WRI[1] was considered as a measure of vulnerability. Water stress indicates competition for water resources and is defined informally as the ratio of demand for water by human society divided by available water. Higher values indicate more competition among users. The GCM mean ensemble of water stress projections was linearly extrapolated to the 2070 horizon and zonally aggregated at the 90th percentile for the level-2 administrative districts in the Amu Darya basin. Figure 32 shows future heat wave vulnerability priority index (-) for the Amu Darya basin, derived from the water stress indicator.

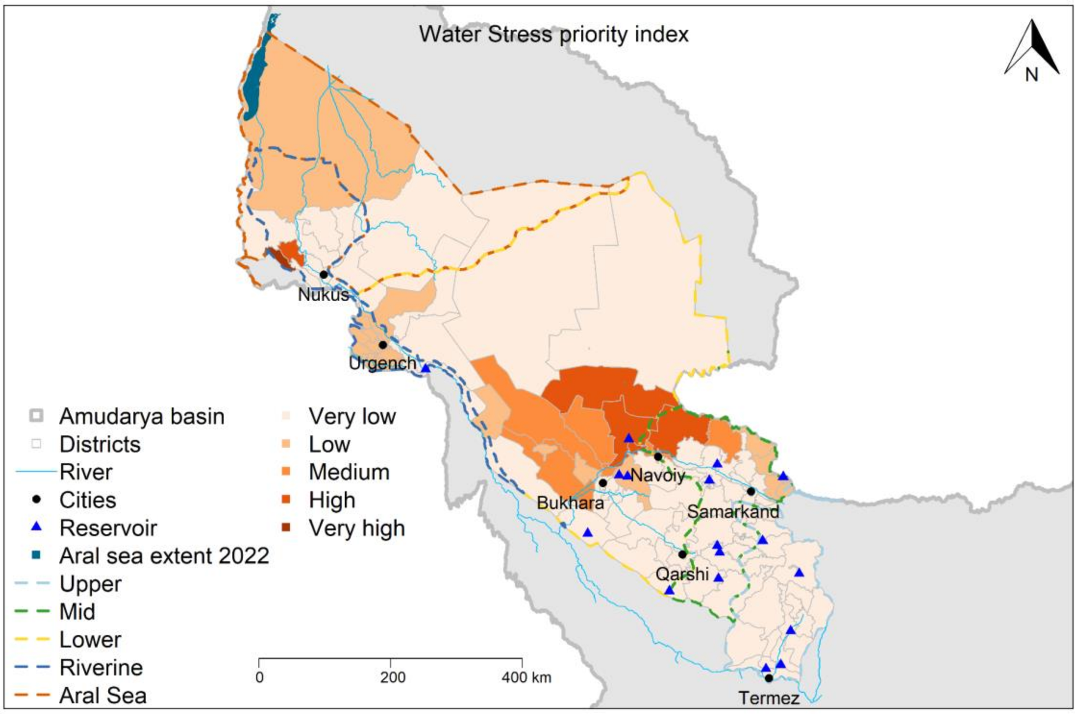

Figure 32. Future heat wave vulnerability priority index (-) for Amu Darya basin

4.4.4 Exposure

The priority index based on the most recent population estimates for the Amu Darya basin from the Gridded Population of World Version 4.11 (GPWv4) was used as an exposure layer (see Figure 10). Higher population estimates correspond to higher hazard exposures.

The priority index based on Net irrigated area from WUEMoCA was also used to measure exposure (see Figure 15). Net irrigated area is defined as an area equipped with irrigation infrastructure, including fallow land (see Table 5). Larger irrigated areas mean more cropland is potentially exposed to climate-related hazards.

4.4.5 Risk

The risk calculation follows the methodology explained in section 2.1. The heatwave risk calculation entails the future heatwave hazard priority index (Figure 31), vulnerability layer (Figure 32), and exposure layer (Figure 14 and Figure 15). In contrast to the previous hazards, i.e., rainfall-induced landslide,

[1] https://www.wri.org/aqueduct

rainfall-induced erosion, and drought, the future heatwave hazard is spatially consistent. It is on the higher end (high to very high) for most of the districts. This aligns well with the final risk ranking and thus illustrates that the heatwave is a widespread and large-scale phenomenon (Figure 33). The other components of risk, i.e., exposure (irrigated area and population) and vulnerability (water stress), which have different spatial patterns, could impact the spatial variability of the heatwave risks. The final district aggregated risk plots (radar plots) show that the heatwave risks are relatively higher for the lower, riverine and Aral Sea ecozones. These results are in line with the assessment presented in Figure 33. Moreover, the top 10 heatwave risk-prone districts with the corresponding hazards, vulnerability, and exposure components are higher for the Khorezm and the Republic of Karakalpakstan provinces (see Table 10).

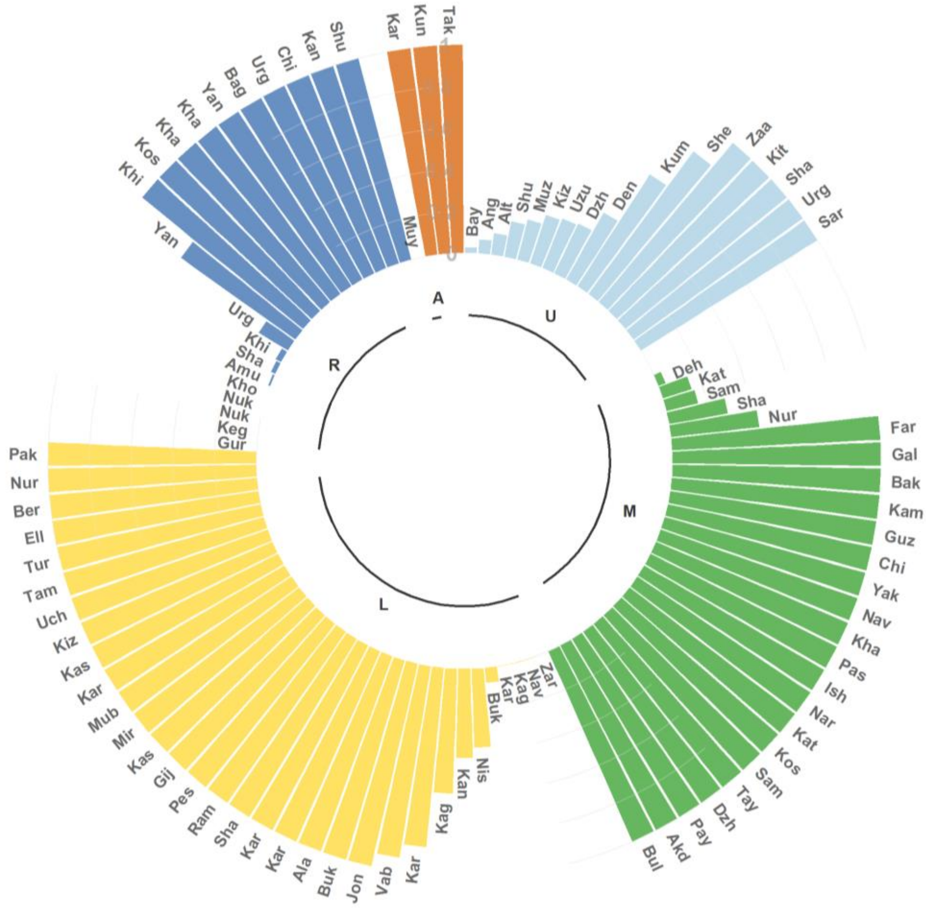

Figure 33. Heat waves risk radar plot ranking all districts in the five eco-hydrological zones (U=Upper, M=Mid, L=Lower, R=Riverine, A=Aral basin). Risk is scaled between 0-1 (low-high) and colors correspond to each ecozone. The 3 characters on top of the circular bar represent the first 3 letters of the district name.

Table 10. The zonal aggregates of the hazard, vulnerability, and exposure layers used in the heatwave risk calculation. The rows represent the top 10 heatwave risk districts as shown by the radar plot.

Zone	Province	District	Hazard index (0-1)	Vulnerability index (0-1)	Agricultural area index (0-1)	Population index (0-1)
Riverine	Khorezm	Khiva	0.163	0.228	0.346	0.073
Riverine	Khorezm	Koshkupir	0.148	0.228	0.533	0.107
Riverine	Khorezm	Khazarasp	0.185	0.067	0.554	0.439
Riverine	Khorezm	Khanka	0.158	0.204	0.577	0.120
Riverine	Khorezm	Yangiarik	0.164	0.228	0.345	0.085
Riverine	Khorezm	Bagat	0.170	0.228	0.432	0.091

Riverine	Khorezm	Urgench	0.112	0.205	0.541	0.127
Riverine	Republic of Karakalpakstan	Chimbay	0.293	0.149	1.000	0.027
Riverine	Republic of Karakalpakstan	Kanlikul	0.265	0.786	0.720	0.009

4.5 Fluvial floods

Flooding is among the most serious and dangerous of all global risks, causing loss of life and damage to property, livelihoods, and economies. Flooding is also likely to intensify in the coming decades due to climate change. Additionally, economic growth and urbanization are putting more and more assets and people into food-prone areas. (Ward et al., 2020)[1]. The assessment of flood hazard involves high-resolution outputs computed by hydrological and inundation models over a Digital Elevation Model (DEM). The resulting flood hazard maps describe the extent of floodable area around the drainage or river network and the associated maximum water depth according to event occurrence probability (return period), river network statistics and DEM. For river floods, the scenario with 100 years return period can be considered a conservative reference to define the baseline hazard level. The thresholds for the intensity variable (water depth in meters) are typically defined as:

- Low hazard: < 0.5 m
- Moderate hazard: 0.5 – 1 m
- High hazard: > 1 m

4.5.1 Hazard (baseline)

For flooding, future hazard projections are already available so it was not needed to consider baseline flooding conditions. It was thus also not needed to construct future flooding projections using an associated climate index.

4.5.2 Hazard (future)

The global flood maps available from the online platform Aqueduct Floods, developed by the Water Resources Institute (WRI), were considered for constructing the future flooding hazard priority index for climate-resilient investment. Aqueduct Floods provides model estimates of riverine and coastal flood risks (based on flood extent and flood inundation depth scenarios for different return periods) under both current baseline conditions and future projections in 2030, 2050, and 2080. In addition to providing hazard maps and assessing risks, Aqueduct Floods enable its users to conduct a comprehensive cost-benefit analysis to evaluate the value of dike food protection strategies.

The future 100-year return period flood hazard (expressed in inundation depth in meter) under the CMIP5 scenario RCP8.5 was used to derive the future flood hazard priority index (-). It is constructed based on the GCM mean ensemble of flood hazard projections and was zonally aggregated to the 90th percentile for the level-2 administrative districts in the Amu Darya basin (see Figure 34).

As can be seen from the flood hazards map, the districts with high a high hazard priority index, are related to tributaries of the Amu Darya (Zerafshan, etc). The results show that extreme rainfall in these tributaries lead to flooding events in the riverine zones of these tributaries. The Samarkand flood that happened in 2022 confirms that this is a risk already being faced today – but with potential to increase

[1] Ward, P. J., Winsemius, H. C., Kuzma, S., Bierkens, M. F. P., Bouwman, A., Moel, H. de, Loaiza, A. D., Eilander, D., Englhardt, J., Erkens, G., Gebremedhin, E. T., Iceland, C., Kooi, H., Ligtvoet, W., Muis, S., Scussolini, P., Sutanudjaja, E. H., Beek, R. van, Bemmel, B. van, … Luo, T. (2020). *Aqueduct Floods Methodology*. https://www.wri.org/research/aqueduct-floods-methodology

in the future. This result is based on 1:100 year return period events, so relatively rare, intense events, but with sufficient potential for harm to be considered in investment planning.

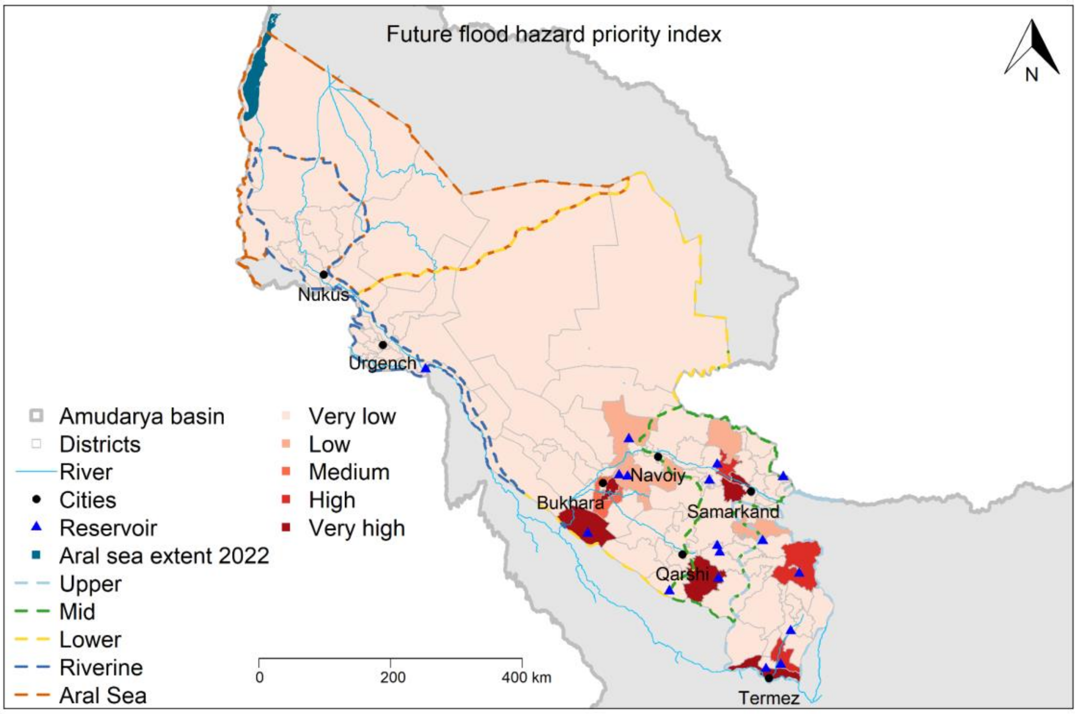

Figure 34. Future flood hazard priority index (-) for Amu Darya basin

4.5.3 Vulnerability

Due to the lack of flood-specific vulnerability, the capacity of the livelihoods and infrastructure to cope with the impacts of floods has been assumed to be homogeneous over the study area, for this analysis at the district level. A spatial expression of sensitivity to floods would require spatial data on flood mitigation infrastructure, and potentially a social flood preparedness index. As these are not available, this has not been considered.

4.5.4 Exposure

The priority index based on the most recent population estimates for the Amu Darya basin from the Gridded Population of World Version 4.11 (GPWv4) was used as an exposure layer (see Figure 10). Higher population estimates correspond to higher hazard exposures.

The priority index based on Net irrigated area from WUEMoCA was also used to measure exposure (see Figure 15). Net irrigated area is defined as an area equipped with irrigation infrastructure, including fallow land (see Table 5). Larger irrigated areas mean more cropland is potentially exposed to climate-related hazards.

4.5.5 Risk

The risk calculation follows the methodology explained in section 2.1. The flood risk calculation entails the future flood hazard (Figure 34), and exposure layer (Figure 14 and Figure 15). In contrast to the heatwave hazard, the future flood hazard priority index is on the higher end for only a few districts of Surkhandarya, Bukhara and Samarkand (high to very high). This aligns well with the final risk ranking and thus illustrates that flooding in this region is mostly an issue for southeastern regions (Figure 35).

The other component of risk, i.e., exposure (irrigated area and population), may impact the spatial variability of the flood risks. The final district aggregated risk plots (radar plots) show that the flood risks are relatively lower for all the regions except for the few districts in the upper and mid ecozones. These results are in line with the assessment presented in Figure 35. Moreover, the top 10 flood risk-prone districts with the corresponding hazards, vulnerability, and exposure components are higher for the Samarkand and Surkhandarya provinces (see Table 11).

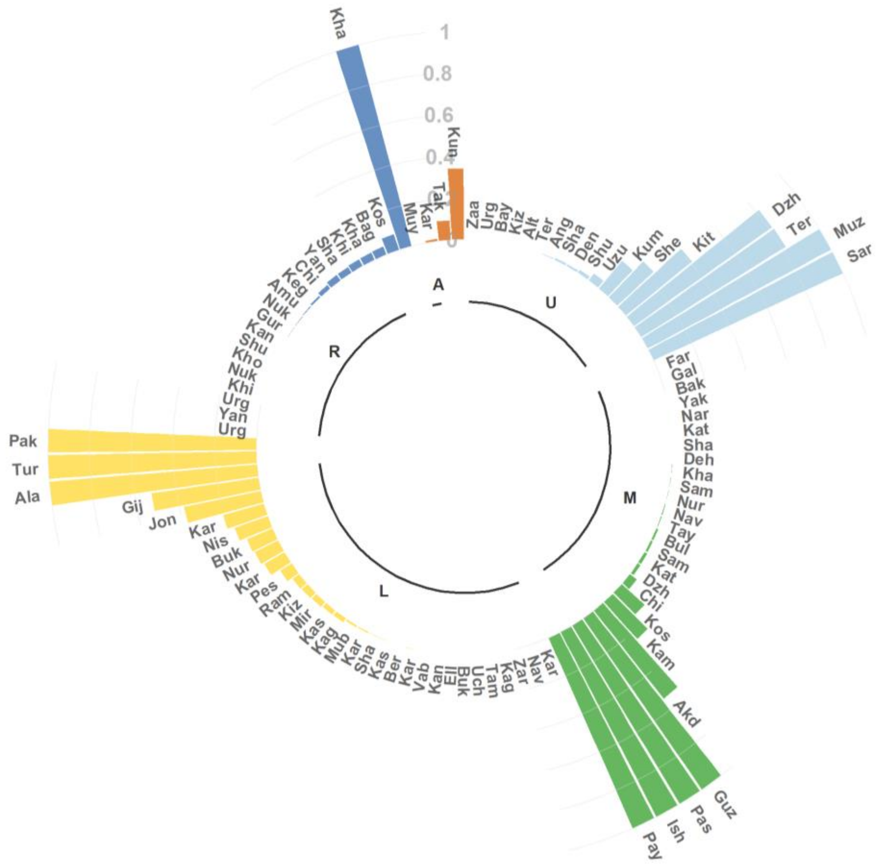

Figure 35. Flood risk radar plot ranking all districts in the five eco-hydrological zones (U=Upper, M=Mid, L=Lower, R=Riverine, A=Aral basin). Risk is scaled between 0-1 (low-high) and colors correspond to each ecozone. The 3 characters on top of the circular bar represent the first 3 letters of the district name.

Table 11. The zonal aggregates of the hazard, vulnerability, and exposure layers used in the flood risk calculation. The rows represent the top 10 flood risk districts, as the radar plot shows.

Zone	Province	District	Hazard index (0-1)	Agricultural area index (0-1)	Population index (0-1)
Upper	Surkhandarya	Muzrabad	0.317	0.496	0.072
Upper	Surkhandarya	Sariasiya	0.070	0.164	0.441
Riverine	Khorezm	Khazarasp	0.012	0.554	0.439
Mid	Kashkadarya	Guzar	0.130	0.436	0.286
Mid	Samarkand	Pastdargom	0.078	0.925	0.189
Mid	Samarkand	Ishtikhan	0.054	0.514	0.167
Mid	Samarkand	Payarik	0.017	0.630	0.256

Zone	Province	District	Hazard index (0-1)	Agricultural area index (0-1)	Population index (0-1)
Lower	Bukhara	Alat	0.156	0.298	0.129
Lower	Republic of Karakalpakstan	Turtkul	0.017	0.523	0.303

4.6 Other climate hazards

4.6.1 Glacial lake outburst flood (GLOF)

A glacial lake outburst flood (GLOF) is a type of outburst flood caused by the failure of a dam containing a glacial lake. The recent paper 'Glacial lake inventory and lake outburst potential in Uzbekistan' by (Petrov et al., 2017)[1] provides an inventory for glacial lakes with outburst potential. Based on a total of 7 main variables (i.e., lake type, dam type, freeboard, connection, drainage type, possibility for lake impact) and 3 sub-variables (dam width, width-to-height ratio, dam length) for dam geometry, the outburst potential assessment has been realized for 242 lakes considered in the inventory (see Figure 36).

The dataset is available in CSV format, but unfortunately, the provided coordinates (UTM projection zone 42 on a WGS84 ellipsoid) could not be matched to the locations of the lakes. Attempts to contact the main author of the paper failed, and the issue could thus not be resolved. Annex 1 lists the full inventory of lakes with GLOF potential, but the analysis has not included these data due to incorrect coordinates.

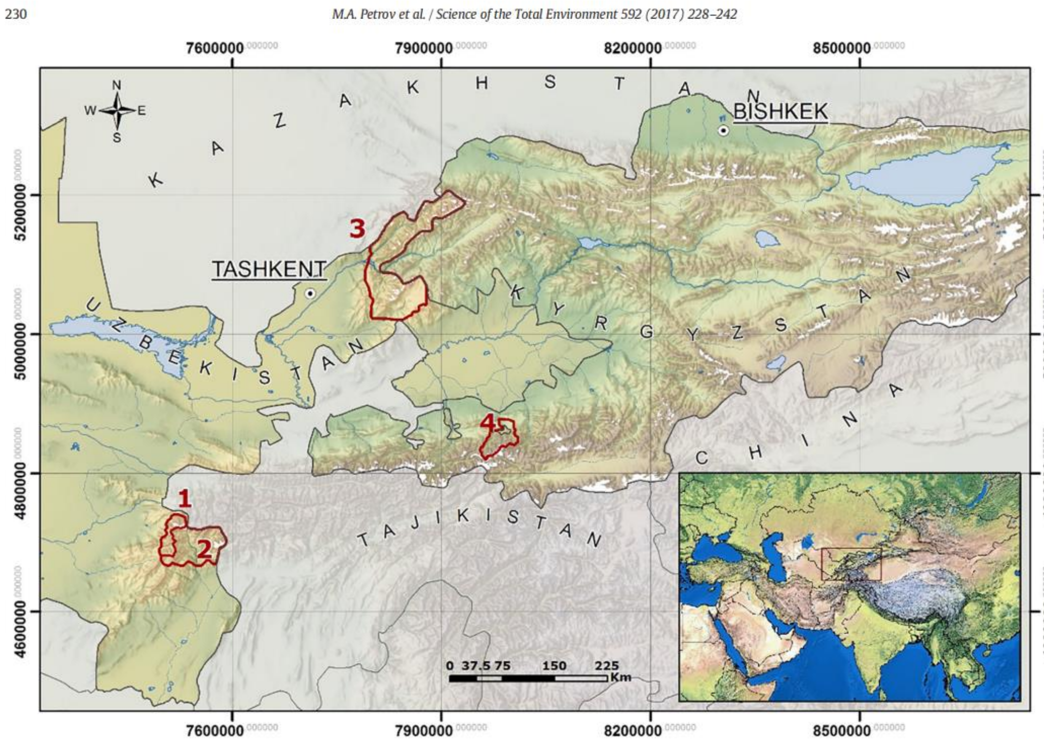

Figure 36. Regions of Uzbekistan in which mountain lakes have been analyzed: Kashkadarya (1), Surkhandarya (2), Tashkent (3) – Shakhimardan (4). Figure from (Petrov et al., 2017)

[1] Petrov, M. A., Sabitov, T. Y., Tomashevskaya, I. G., Glazirin, G. E., Chernomorets, S. S., Savernyuk, E. A., Tutubalina, O. v., Petrakov, D. A., Sokolov, L. S., Dokukin, M. D., Mountrakis, G., Ruiz-Villanueva, V., & Stoffel, M. (2017). Glacial lake inventory and lake outburst potential in Uzbekistan. *Science of The Total Environment*, *592*, 228–242. https://doi.org/10.1016/J.SCITOTENV.2017.03.068

4.6.2 Dust storms and wind erosion

Increasing desertification because of aridity and land degradation has amplified the number of dust storm events in Uzbekistan. Water shortages and increasing aridity caused by climatic changes coupled with land degradation problems have aggravated the desertification processes. As a result, a desert expanding over 60,000 km^2, has formed at the bottom of the former Aal Sea and is now an additional source of sand and dust storms in the country[1]. As a major consequence, this has resulted in increased dust storm events.

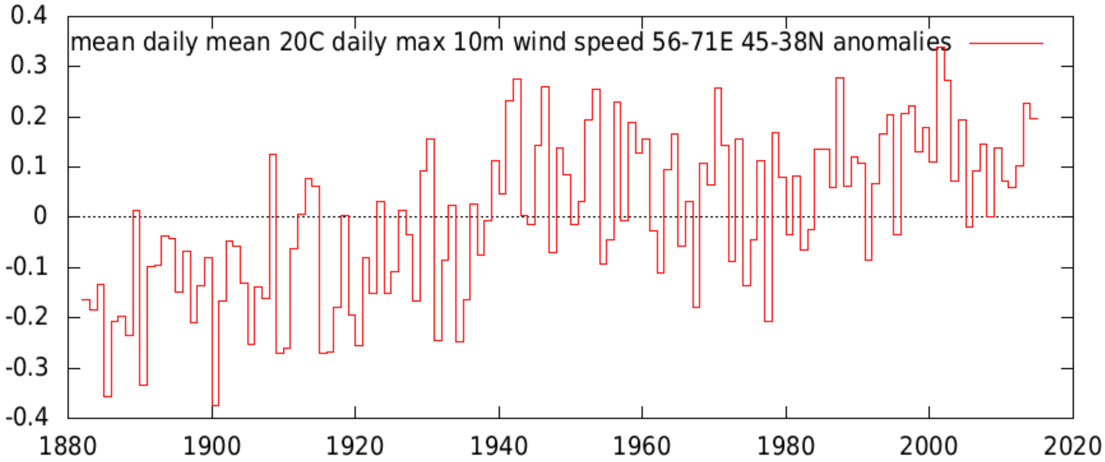

Figure 37. Wind speed anomaly for Uzbekistan (1880-2014) (Source: NOAA-CIRES).

The western part of Uzbekistan is particularly susceptible to dust storms, as Figure 38 illustrates. The map shows the wind erosion hazard (or risk) for Uzbekistan, based on the wind's erosivity and surface erodibility. Erosivity is expressed by max wind speeds at 10m heights measured[2], while erodibility is expressed as a combination of land cover[3] and soil type[4] (and texture). The expected substantial increase in air temperatures across Uzbekistan, is expected to lead to more prolonged periods of drought. This is likely to contribute to increased aridity and desertification in the country, which may also increase the occurrence of dust storms.

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[1] https://kun.uz/en/news/2022/02/05/sand-and-dust-storms-of-aralkum-yearly-carry-out-up-to-75-million-tons-of-sand-dust-and-salt

[2] Abatzoglou, J.T., S.Z. Dobrowski, S.A. Parks, K.C. Hegewisch, 2018, Terraclimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015, Scientific Data 5:170191, doi:10.1038/sdata.2017.191

[3] Buchhorn, M. ; Lesiv, M. ; Tsendbazar, N. - E. ; Herold, M. ; Bertels, L. ; Smets, B. Copernicus Global Land Cover Layers-Collection 2. Remote Sensing 2020, 12Volume 108, 1044. doi:10.3390/rs12061044

[4] Tomislav Hengl. (2018). Soil texture classes (USDA system) for 6 soil depths (0, 10, 30, 60, 100 and 200 cm) at 250 m (Version v02) [Data set]. Zenodo. 10.5281/zenodo.1475451

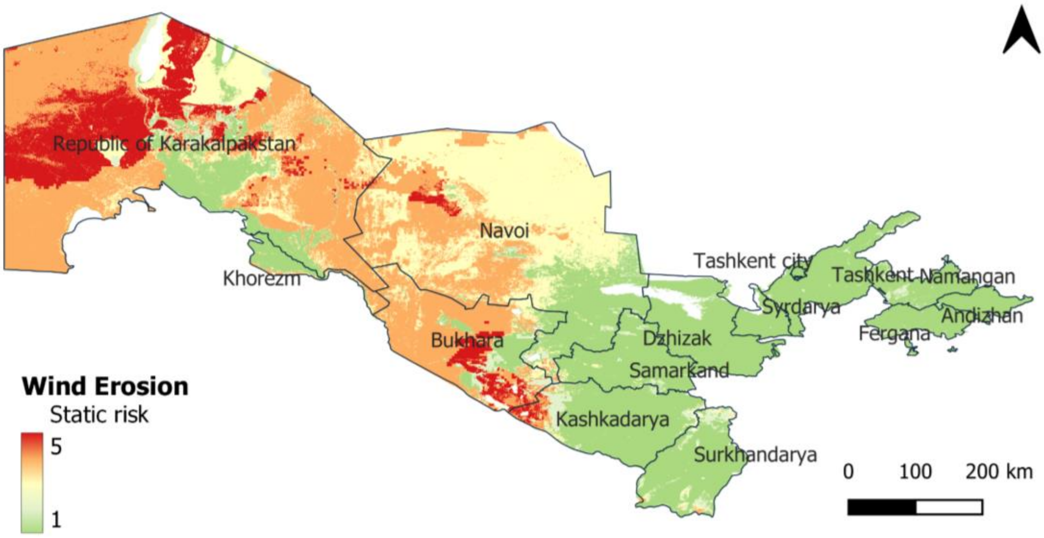

Figure 38. Wind erosion risk (Low-1 to High-5) for Uzbekistan, based on historical wind records, land cover and soil texture.

4.6.3 Wildfire

The wildfire hazard across Uzbekistan is classified as high[1], indicating a greater than 50% probability of weather conditions causing a significant wildfire. The extent of the wildfire hazard zone is also likely to increase in the future, posing a serious risk for major infrastructure developments.

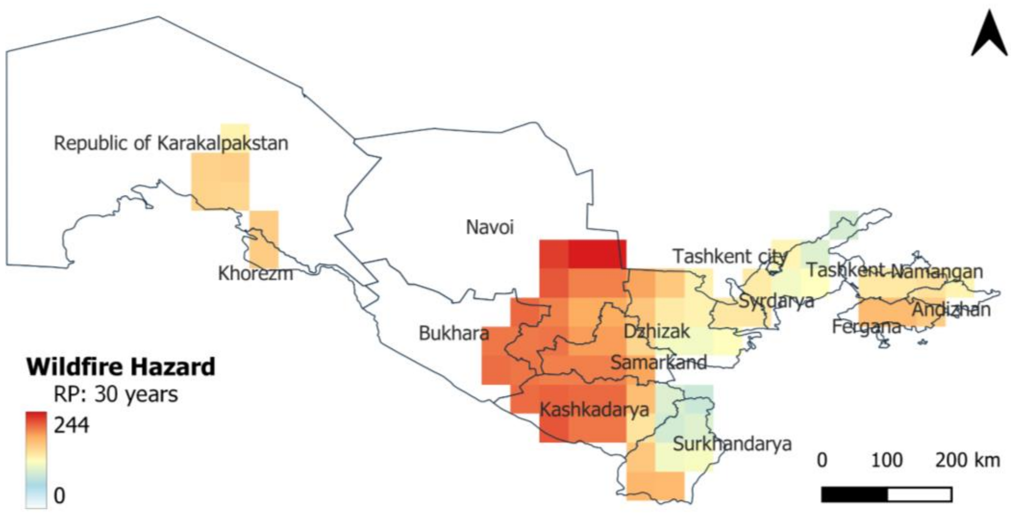

Figure 39. Wildfire hazard across Uzbekistan (Source: Global Facility for Disaster Reduction and Recovery, GeoNode).

As the wildfire hazard map[2] shows (Figure 39), the highest hazard is found in the regions of Samarkand and Kashkadarya followed by Andizhan. The approach to classifying wildfire hazard levels used is based solely on fire weather index climatology. Fire weather indices are used in many countries to assess both the onset of conditions that will allow fires to spread and the likelihood of fire at any point in the landscape.

[1] [2] https://thinkhazard.org/en/report/261-uzbekistan/WF
[2] https://www.geonode-gfdrrlab.org/layers/hazard:csiro_wf_max_fwi_rp30

The method presented uses statistical modelling (extreme value analysis) of a 30-year fire weather climatology to assess the predicted fire weather intensity for specific return period intervals (here 30 years RP). These intensities are classified based on thresholds using conventions to provide hazard classes that correspond to conditions that can support problematic fire spread in the landscape if an ignition and sufficient fuel were to be present.

4.7 Climate Risk Summary

To allow a quick comparison of the five main hazards that were mapped in detail, this summary section reflects the risk maps and radar plots all together in a panel. Looking at this overview (see Figure 40), it is evident that there is a high spatial heterogeneity across the ecozones and districts considered in this study. For example, risks to heatwaves show large-scale patterns across ecozones and are consistently on the higher end (high to very high) of the distribution for most of the districts. The drought risks are similar to the heatwave risks, but the magnitude of the drought risk is lower than that of the heatwave. Whereas the risk to landslide and erosion hazards are localized processes and therefore higher for the upper and mid ecozones except for the erosion hazard which is relatively higher in the lower ecozone.

The radar plots confirm the pre-screening analysis, which indicated erosion and landslide hazard to be dominant in the upper and mid-eco-zone, while the other three hazards are dominant in the other three eco-zones. To prioritize areas of intervention, these priorities and the risk scores should be considered and can back up or complement information the government and local stakeholders have on other aspects, not considered here, of relevance for climate adaptation. Also, upstream-downstream linkages should be considered in prioritizing adaptation measures, as is exemplified in the next section.

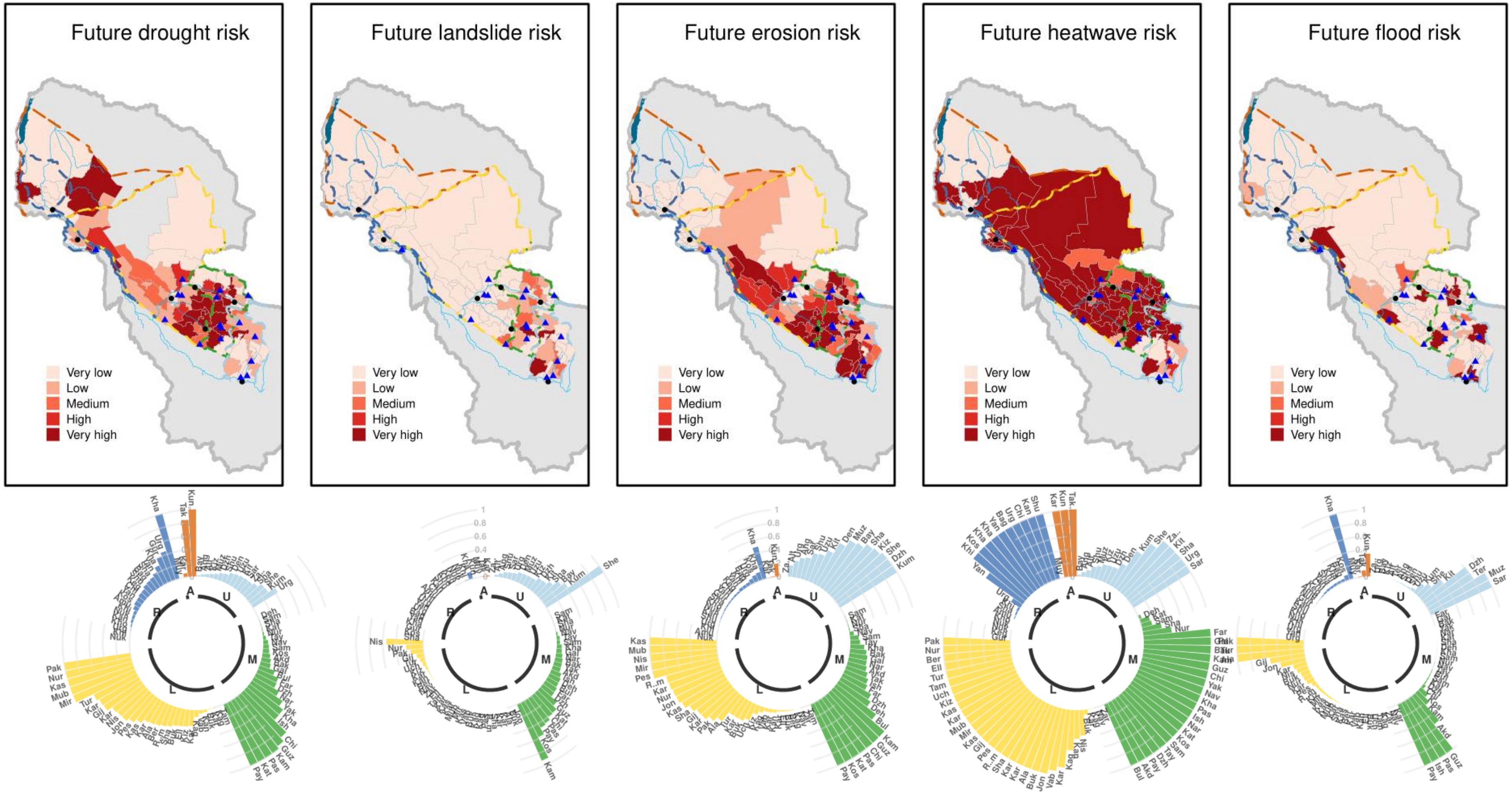

Figure 40. Final risk plot for the five hazards and corresponding radar plot summary

5 Recommendations

5.1 Selection of survey sites

The analysis presented in this report is based on the datasets described in section 2, collected mostly from public domain datasets, and complemented with local expert inputs where feasible. The climate hazard and vulnerability data were comprehensively analyzed using a climate risk framework.

The international and national experts and the Ministry of Water Resources discussed the risk mapping outputs. From this discussion, three districts in the Amu Darya basin have been selected as a priority for a detailed survey. The selection of these districts is justified as follows:

- They cover upstream and dowsntream ecozones,
- All key hazards are covered
- Overall, they have typically relatively high hazard scores, as well as vulnerability and exposure
- For this reason, their risk ranking compared to the other districts is overall relatively high

The Kitab district of Kashkadarya province, located in the Upper ecozone, was found to be relatively highly vulnerable to landslides, heat waves, and floods. The Gurlen district was found to be relatively highly vulnerable to drought hazards, while the Kanlikul district was highly vulnerable to heatwave hazards compared to other hazards. Table 14 provides insights into the relative climate risks faced by these three selected districts in the Amu Darya basin. The proposed socio-economic survey should help to inform targeted adaptation strategies to mitigate these risks in these districts or elsewhere.

Table 12. A heatmap showing the risk ranking of the three selected districts for the detailed socio-economic survey. The red (yellow) color indicates relatively high risk (relatively low risk)

District	Province	Ecozone	Drought	Landslide	Erosion	Heatwave	Flood
Kanlikul	Republic of Karakalpakstan	Aral Sea					
Gurlen	Khorezm	Riverine					
Kitab	Kashkadarya	Upper					

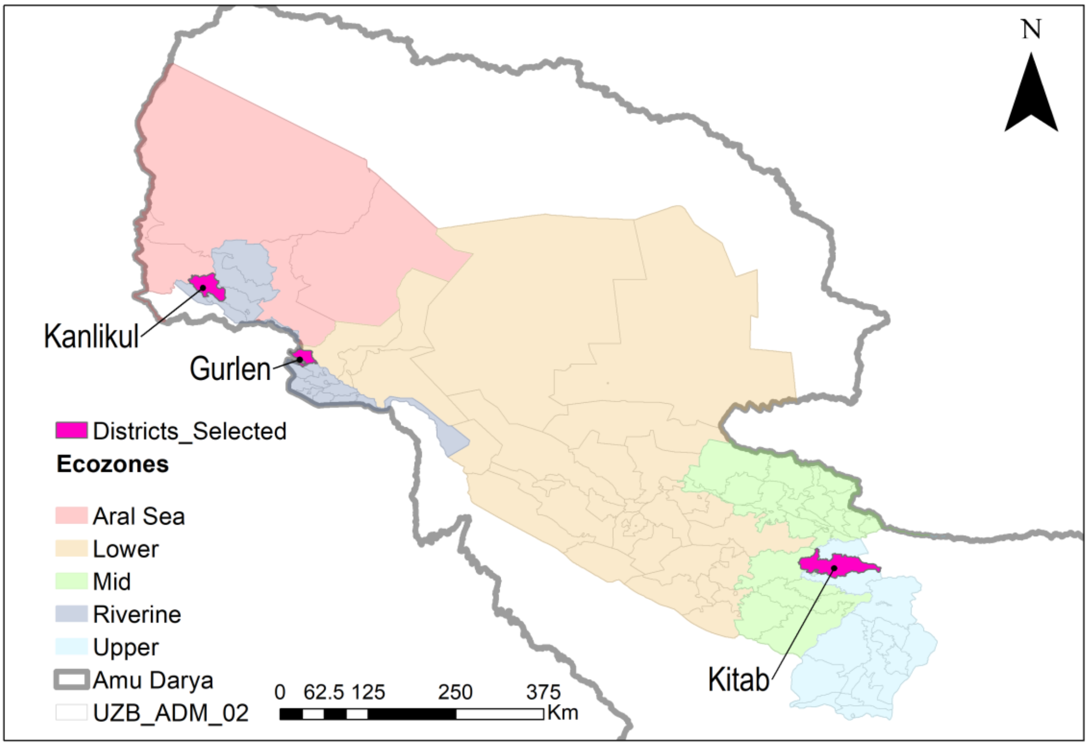

Figure 41. Final selected districts for the detailed socioeconomic survey

For the projects currently being executed under the present TA (see Introduction), also a socio-economic survey was performed (Jondor district – Bukhara oblast, and for the Babatag irrigation system: Kukurgan and Djarkurgan districts in the Surkhandarya oblast). These were for this reason excluded from the selection of districts.

5.2 Consideration of upstream-downstream links

A river basin perspective is needed to identify adaptation options that bring optimal resilience benefits. Such an approach makes sure that options are prioritized that benefit downstream water resources, and at the same time bring more resilience to upstream areas. Water-related hazards and related adaptation measures in the upstream tributaries of the Amu Darya (e.g., droughts or erosion) can have notable positive or negative impacts on downstream areas. To assess these impacts, a water resources system model is a suitable tool to be used. Such a water resources system model simulates the water supply and demand of the different areas, considering the infrastructures and allocation rules in place, all in one integrated analytical tool at the river basin level.

To demonstrate the relevance of considering these upstream-downstream linkages for water resources risk analysis and for adaptation planning, an exploratory modelling exercise is presented here for the Amu Darya river basin. Based on exploratory modelling scenarios, the impact of upstream changes through adaptation interventions is exemplified on downstream water resources.

The model scenarios presented hereafter focus on how impacts of interventions upstream of a primary water storage reservoir have notable impacts downstream. Note that these interventions can be a mix of infrastructure investments and more soft measures, like sustainable catchment management options, nature-based solutions or management solutions.

An existing water resources system model for the Aral Sea basin was adapted to demonstrate these upstream-downstream relations. The model was developed with the Water Evaluation And Planning (WEAP[1]), hereafter called the WEAP-Aral model. It was developed for a regional study of the entire Aral Sea basin (i.e., Syr Darya and Amu Darya river basin)[2].

A few key model specifications of the WEAP-Aral model (see Figure 42 for a schematic representation of the model) are:

- Hydrological flows were used from simulations using the glacio-hydrological model SPHY.
- Calibrated with 10-year data (2000-2010) of reservoir inflows and outflows.
- Includes 8 principal reservoirs in the basin (in Uzbekistan: Surkhandarya, Gissarak, Chimkurgan, and Tyuyamuyn)
- 11 agricultural demand sites and 11 domestic/industrial demand sites (in Uzbekistan: Surkhandarya upstream, Surkhandarya downstream, Kashkadarya upstream, Kashkadarya downstream, Zerafshan valley, Urgenc/Nukus/Aral Sea area)
- 22 return flow links representing drainage going back to the river system

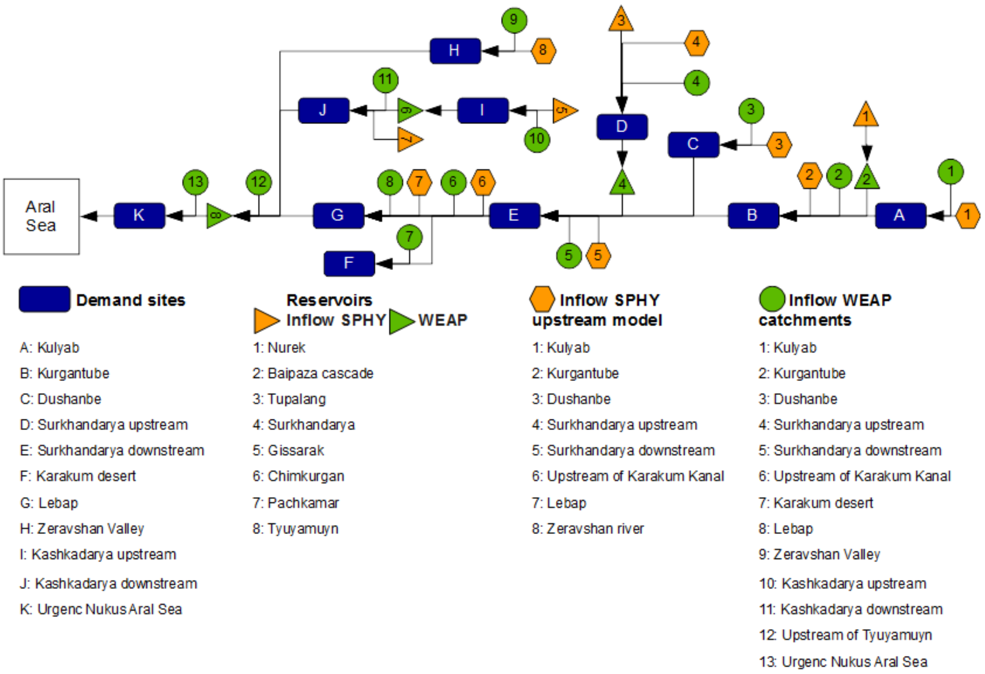

Figure 42. The water resources system schematization for the Amu Darya river basin of the WEAP-Aral model

The WEAP-Aral model was slightly adapted for this study (see Figure 43 for a screenshot of the model, including eco-hydrological zones, and a schematic indication of the upstream and downstream areas). Modelling activities carried are:

- Adjust the model to only simulate the Amu Darya river basin, excluding the Syr Darya.
- Consistency checks.
- Set up for impact analysis of changes in upstream flows and storage.
- Model runs.
- Impact analysis.

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[1] http://weap21.org/
[2] Hunink, J.E., A.F. Lutz, P. Droogers. 2014. Regional Risk Assessment for Water Availability and Water-related Energy Sector Impacts in Central Asia. FutureWater Report 196. Download link

As mentioned, the model used here was not built for this study specifically and, as such, comes with a number of limitations, which are primarily::

a. The model was built for a regional (Aral Sea basin) study, so was not designed nor calibrated for more detailed studies at the sub-basin level.
b. The model was built with limited data for calibration (2000-2010) and only for the key reservoirs in the region
c. The climate projections used were from the prior generation of climate models (CMIP5)
d. The focus of the model was regional hydropower production versus regional agricultural water demand, rather than assessing impacts at the sub-basin level or for specific agricultural zones or districts

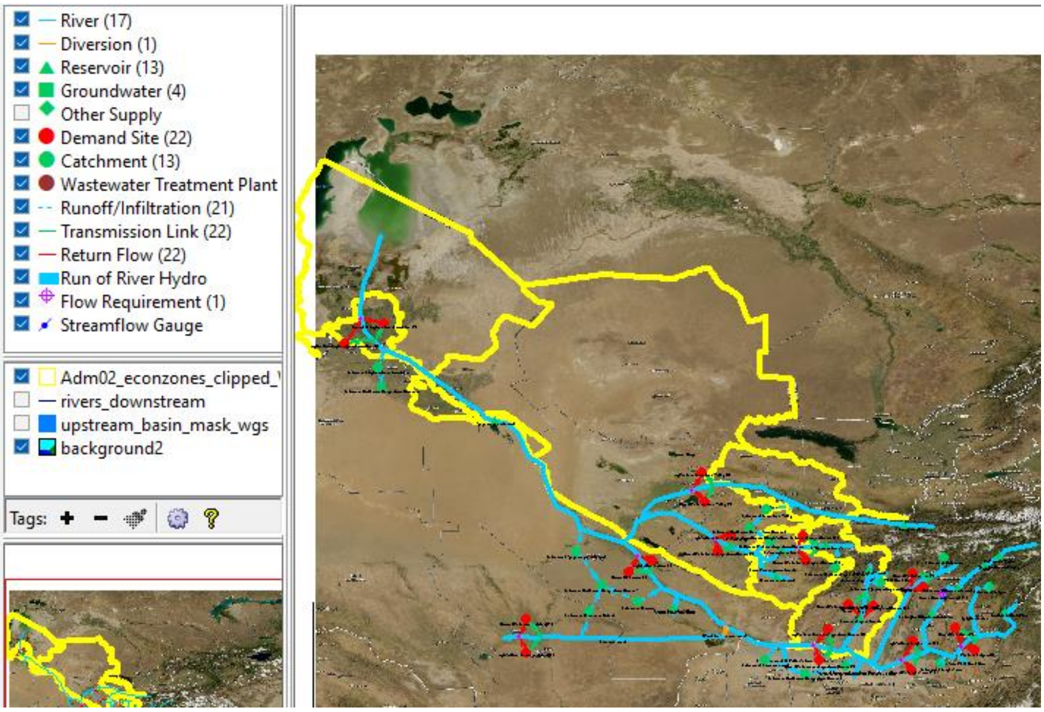


Figure 43. Screenshot of the WEAP-Aral model (Hunink et al., 2014[1]), slightly adapted for this study.

The model was run for three exploratory adaptation scenarios, and a reference (=business-as-usual) scenario. The scenarios, including the related hazards and examples of related adaptation measures, are summarized in

Table 13. Summary table of the exploratory adaptation scenarios

Scenario name	Related hazards	Examples of typical adaptation measures	Scenario implementation
Reference	All	Business as usual (no adaptation)	-
Drought Mitigation	Drought	Improved agricultural practices, improved cropping cycles and patterns, improved water allocation mechanisms, etc	Reduced demands downstream by 10%
Sedimentation Mitigation	Erosion and landslides	Catchment interventions reducing erosion, improved agricultural practices	Reservoir capacity loss due to

[1] Hunink, J.E., A.F. Lutz, P. Droogers. 2014. Regional Risk Assessment for Water Availability and Water-related Energy Sector Impacts in Central Asia. FutureWater Report 196. Download link

Scenario name	Related hazards	Examples of typical adaptation measures	Scenario implementation
		reducing erosion, measures reducing mudflow hazard, etc	sedimentation was reduced by 50%
Flood Mitigation	Flood	Buffer for flood mitigation in reservoirs, nature-based solutions upstream of reservoir, etc	20% of the storage capacity is reserved for buffering floods

The scenarios were run as follows:

- over a 10-year future period (2031-2040),
- assuming a moderate climate change scenario (RCP4.5).
- focus on the Kashkadarya tributary of the Amu Darya river (Figure 43),
- scenario assumptions applied to the Gissarak reservoir and the Chimkurgan reservoir in this tributary.

The impacts are analyzed on the downstream water resources in this tributary: flows, and water supplies.

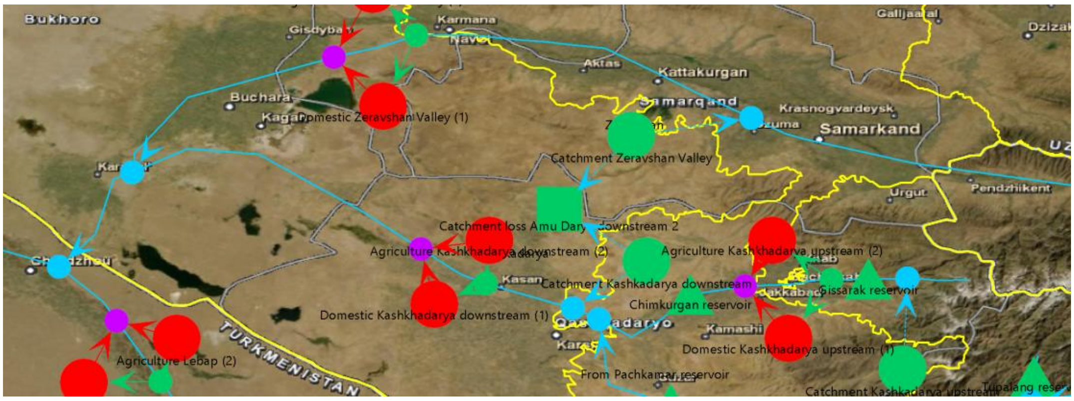


Figure 44. Zoom of the schematic of the Kashakdarya tributary in the WEAP-Aral model.

<u>**Drought mitigation**</u>

The results of this scenario demonstrate that implementing measures that reduce water demands downstream (e.g., smart climate agriculture, improved salt leaching practices, real water savings measures) can considerably reduce the gap between supply and demand. Figure 45 shows how the coverage (= the percentage of the demand met by a supply) increases relative to the business-as-usual (reference) scenario. This increase obviously depends on the climate conditions in each season and year, as seen in the simulation outputs: for some years and months, increases of up to 10% in coverage can be seen compared to the reference scenario.

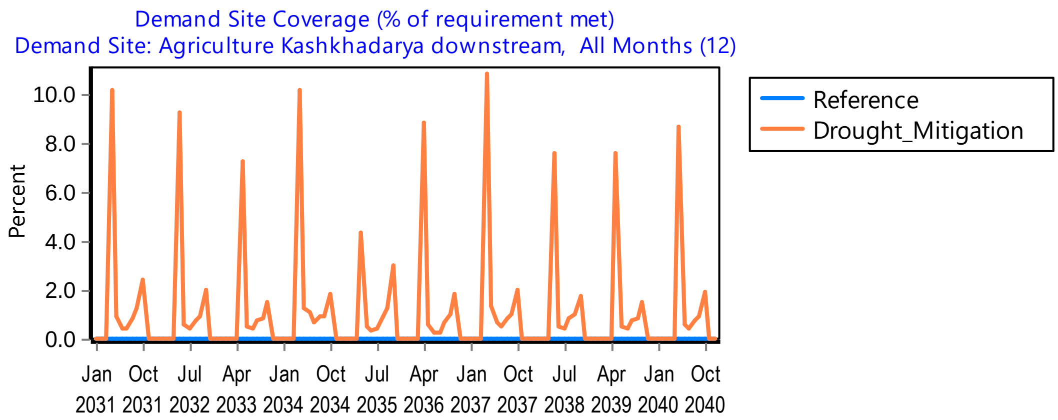


Figure 45: Change in water demand coverage (percentage of the demand being covered) compared to the Reference (without drought mitigation).

The impacts of droughts on crop production can also be reduced by improved reservoir management, reduced sedimentation, and other measures related to natural or artificial storage. The scenario on Sedimentation Mitigation presented afterward demonstrates this.

Sedimentation mitigation

The results of this scenario (Figure 46) show that the two reservoirs (Gissarak and Chimkurgan) have more capacity to store water in the winter when the sedimentation in the reservoir is reduced. This is only a factor in the wetter years (for example, the year 2038 in Figure 46). Obviously, this additional water stored in the reservoir becomes available for use during the vegetation period and can be supplied to the agricultural areas and other uses downstream of the reservoir.

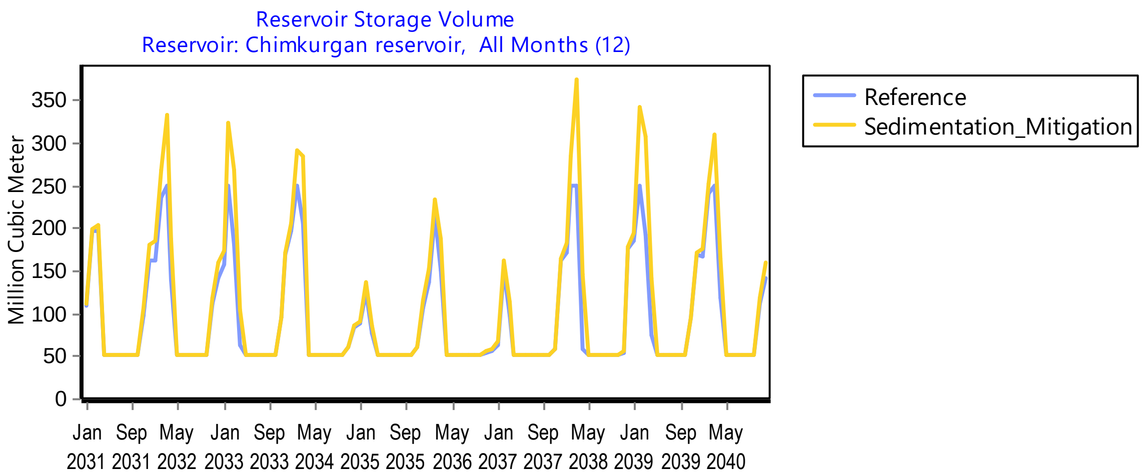


Figure 46: Water stored in the Chimkurgan reservoir, with and without (Reference) sediment mitigation.

Currently, there is an imbalance between water supply and demand for the agricultural areas in the Amu Darya river basin. The water resources system model simulates this imbalance. Currently, the model is not sufficiently up-to-date to accurately estimate the absolute amount corresponding to this imbalance. However, the model can be used to check whether the reduced sedimentation can potentially be used to reduce the imbalance.

Indeed, under this scenario, this imbalance is reduced: Figure 47 shows that unmet demand can be reduced in some years more than others, and typically in May/June, depending on whether there was a water surplus for storage or not.

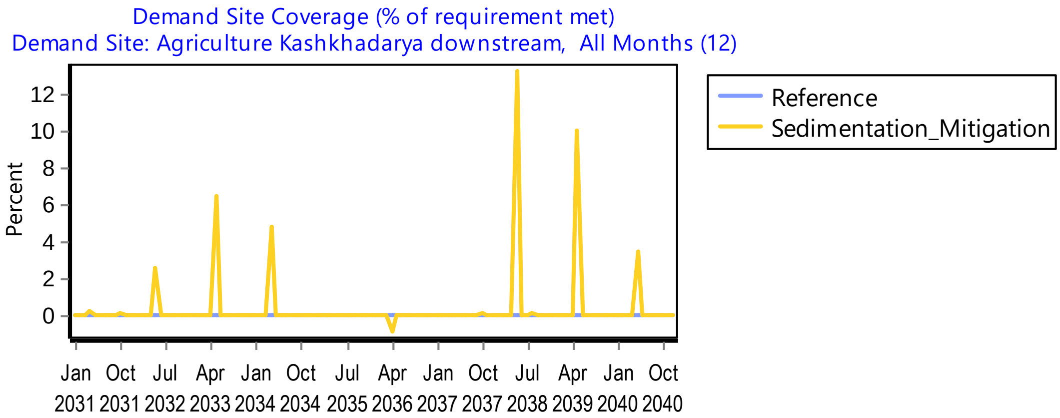


Figure 47: Change in mean monthly water demand coverage (percentage of the demand being covered) compared to the Reference (without sedimentation mitigation).

Flood mitigation

The simulation scenario, which includes adaptation measures for reducing flood risk (Flood Mitigation), shows clearly that the peak flow in the high-flow season (around April) reduces considerably (Figure 48). In order words, the adaptation interventions in this scenario (for example by improved reservoir release rules, better forecasting of flood peaks, optimized buffering reserves for flood regulation, potentially also combined with upstream natural flood retention measures), flows can be regulated better, and the increasing flood risk due to climate change can be mitigated to a certain degree.

This result shows that improved management of reservoirs (through hard infrastructure, soft measures (management, early warning, etc), and/or nature-based solutions can lead to benefits for flood risk, while also creating benefits for more reliable water supplies and overall increased water security.

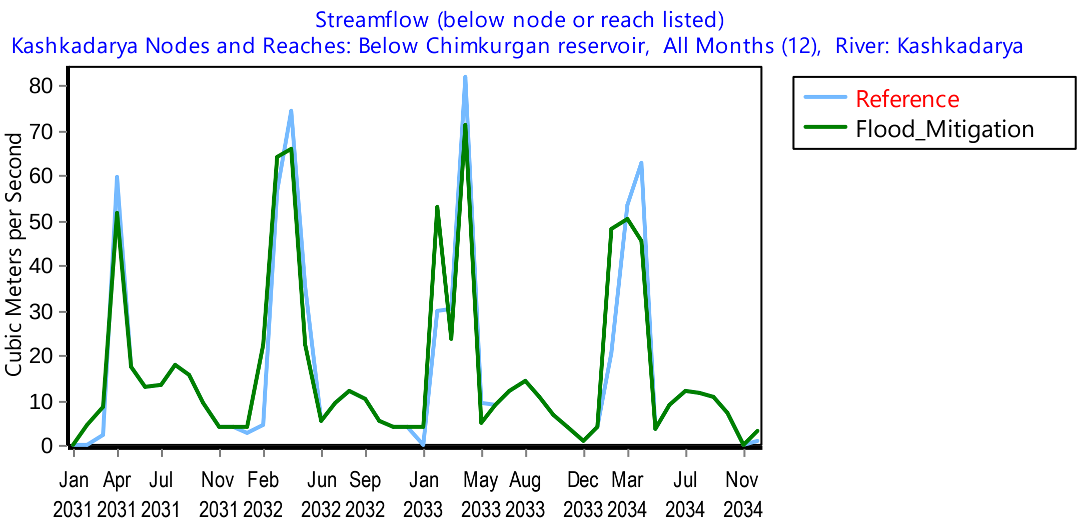


Figure 48. Results for the Flood Mitigation scenario: streamflow below the Chimkurgan reservoir for the Reference and the Flood Mitigation scenario

Annex 1 – Dataset of GLOF potential in Uzbekistan

ID	X	Y	Z	Area (m2)	Basin	Region	Dam type	Lake type	Drainage	Connection	Freeboarc	Dam_Wid	Dam_Height	Events	Hazard	Criteria
Ak01	7510680	4712110	3651	26370	Aksu	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	rock-falls, avalanches, yes	23	High
Ak02	7510670	4711960	3651	1971	Aksu	Kashkadarya	moraine-dammed lake	periglacial	underground drainage	cascade	1	35	100	No	20	Medium
Ak03	7510650	4719070	3668	8639	Aksu	Kashkadarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Ak04	7511800	4719890	3880	8572	Aksu	Kashkadarya	rock-dammed lake	proglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Ak05	7513230	4720190	3825	1110	Aksu	Kashkadarya	moraine-dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Ak07	7515640	4721280	3618	4014	Aksu	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	no	19	Medium
Ak08	7524920	4733900	2777	2210	Aksu	Kashkadarya	Landlisde dammed	extraglacial	underground drainage	cascade	1	N/D	N/D	No	21	Medium
Ak09	7585650	4697590	3902	5255	Aksu	Kashkadarya	rock-dammed lake	proglacial	underground drainage	single	1	N/D	N/D	No	21	Medium
Ak10	7525040	4733250	2825	1158	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak11	7525290	4732040	2920	1903	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak12	7525390	4731380	2960	2598	Aksu	Kashkadarya	Landlisde dammed	extraglacial	underground drainage	cascade	1	N/D	N/D	No	21	Medium
Ak13	7525540	4730770	2990	3493	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak14	7525610	4730250	3025	3042	Aksu	Kashkadarya	Landlisde dammed	extraglacial	underground drainage	cascade	1	N/D	N/D	No	21	Medium
Ak15	7525730	4730000	3037	1886	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak16	7525580	4729710	3051	8776	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak17	7525750	4728590	3079	6192	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak18	7525780	4728210	3102	4451	Aksu	Kashkadarya	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ak19	7521460	4726150	3646	20851	Aksu	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No	19	Medium
Ak20	7525910	4727670	3133	9408	Aksu	Kashkadarya	Landlisde dammed	extraglacial	underground drainage	cascade	1	N/D	N/D	No	21	Medium
Ak21	7521300	4722300	3961	317	Aksu	Kashkadarya	ice-dammed lake	supraglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	25	High
Ak22	7524140	4722010	3669	149	Aksu	Kashkadarya	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall, avalanche	23	High
Ak23	7528790	4726000	3944	4786	Aksu	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine, rock	19	Medium
Ak24	7529700	4723120	3742	18357	Aksu	Kashkadarya	ice-debris dammed lake	proglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall, rock-fall, avalanche	22	High
Ak25	7529960	4722820	3767	29509	Aksu	Kashkadarya	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Ak26	7530420	4722920	3759	1040	Aksu	Kashkadarya	moraine-dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	Yes, ice-fall	24	High
Ak27	7530520	4723050	3754	12977	Aksu	Kashkadarya	rock-dammed lake	periglacial	drainless	cascade	12	600	400	rock-falls, lake inside of bedrock, yes	14	Low
Ig01	7513060	4678760	3817	1508	Igrisuv	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	avalanches, rock-falls, yes	21	Medium
Ig03	7513870	4679480	3876	177	Igrisuv	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	fulfilled it flows easely, no	21	Medium
Ig04	7513870	4679410	3874	531	Igrisuv	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	fulfilled it flows easely, no	21	Medium
Ki01	7512860	4681250	3701	775	Kashkadarya	Kashkadarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No	23	High
Ki02	7514340	4680940	3792	328	Kashkadarya	Kashkadarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, hard to see any dam	21	Medium
Ki03	7515080	4680760	3750	2262	Kashkadarya	Kashkadarya	ice-dammed lake	supraglacial	underground drainage	single	1	N/D	N/D	Ice falls from bedrocks	25	High
Ta01	7511470	4701340	3732	2743	Tanhizdarya	Kashkadarya	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	"	23	High
Ta02	7522850	4730670	3688	7675	Tanhizdarya	Kashkadarya	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, avalanche, ice-fall	25	High
Ta03	7908790	5203870	3671	1597	Tanhizdarya	Kashkadarya	moraine-dammed lake	proglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	20	Medium
Ta04	7515910	4700360	3668	84708	Tanhizdarya	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	ice-falls,avalanches, rock-falls, yes	23	High
Ta05	7517100	4702130	3750	131	Tanhizdarya	Kashkadarya	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No	20	Medium
Ta06	7517940	4702720	3854	719	Tanhizdarya	Kashkadarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	19	Medium
Sh01	7983590	4848720	3779	15260	Shakhimardan	Shakhimardan	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	19	Medium
Sh02	7987340	4840830	4056	12392	Shakhimardan	Shakhimardan	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Sh03	7987780	4840820	4040	3949	Shakhimardan	Shakhimardan	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Sh04	7998250	4856520	1765	105194	Shakhimardan	Shakhimardan	Landlisde dammed	extraglacial	underground drainage	cascade	4	600	240	Yes, rock-fall	17	Medium
Sh05	7997650	4857540	1746	85442	Shakhimardan	Shakhimardan	Landlisde dammed	extraglacial	underground drainage	cascade	14	600	300	No, cascade	15	Low
Ka01	7538160	4721480	3684	1751	Mogiendarya	Surkhandarya	rock-dammed lake	proglacial	underground drainage	cascade	20	600	300	Yes, ice-fall	17	Medium
Ka02	7538620	4721690	3680	34072	Mogiendarya	Surkhandarya	rock-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Ka03	7537720	4721620	3743	36633	Mogiendarya	Surkhandarya	rock-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Sa01	7516530	4671880	3665	433	Sangardakdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	60	700	350	No	12	Low
Sa02	7516730	4672000	3660	1441	Sangardakdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine, rock	19	Medium
Tu01	7576130	4698760	3741	236	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Tu04	7579190	4695820	3856	269	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Tu04	7583860	4696170	3759	817	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Tu05	7583510	4695880	3753	160	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Tu05	7583540	4696990	3684	219	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, rock-fall	23	High
Tu06	7581760	4701450	3787	4003	Tupalangdarya	Surkhandarya	rock-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No	18	Medium
Tu07	7586660	4699570	3531	1274	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Tu08	7584730	4697650	3885	1768	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Tu09	7585650	4697590	3902	388	Tupalangdarya	Surkhandarya	ice-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	27	High
Tu10	7585700	4697550	3902	192	Tupalangdarya	Surkhandarya	ice-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	27	High
Tu11	7589020	4700420	3822	374	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	26	High
Tu12	7589030	4700470	3822	118	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No	21	Medium
Tu13	7589750	4703100	3741	12245	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No	21	Medium
Tu14	7589960	4702760	3757	19728	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No	21	Medium
Tu15	7589450	4701980	3899	359	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	3	150	60	Yes, ice-fall, avalanche	16	Medium
Tu16	7591070	4702120	3964	165	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	Yes, Ice falls	24	High
Tu17	7591290	4702280	3991	783	Tupalangdarya	Surkhandarya	ice-dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	Yes, Ice falls	25	High
Tu18	7591070	4702610	3946	212	Tupalangdarya	Surkhandarya	ice-dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, avalanche	25	High
Tu19	7585960	4711040	3678	6500	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Tu20	7590400	4709570	3840	1436	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	surface drainage	cascade	1	N/D	N/D	No	23	High
Tu21	7591630	4710090	3957	2733	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	26	High
Tu22	7590550	4709160	3925	3252	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	surface drainage	cascade	1	N/D	N/D	No	23	High
Tu23	7591670	4710200	3964	479	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No, solid moraine	23	High
Tu24	7592420	4710370	4059	5061	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	underground drainage	single	8	250	150	Yes, Ice-fall	19	Medium
Tu25	7591610	4710720	3956	23547	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, avalanche, ice-fall, rock-fall	23	High
Tu26	7582470	4722920	3759	2172	Tupalangdarya	Surkhandarya	rock-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes	22	High
Tu27	7562620	4709510	2395	41958	Tupalangdarya	Surkhandarya	Landlisde dammed	extraglacial	underground drainage	single	1	N/D	N/D	Yes, rock-fall, avalanche	21	Medium
Tu28	7558810	4712860	3588	6701	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine, rock	19	Medium
Tu29	7559770	4714260	3648	4231	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall, avalanche	25	High
Tu30	7562260	4717720	3601	9141	Tupalangdarya	Surkhandarya	rock-dammed lake	proglacial	surface drainage	single	1	N/D	N/D	solid moraine, no	19	Medium
Tu31	7562770	4720830	3702	942	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Tu32	7558590	4723800	3789	19731	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	solid moraine, no	19	Medium
Tu33	7558760	4723290	3808	1226	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	solid moraine, no	19	Medium
Tu34	7554820	4721730	3973	1432	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Tu35	7554500	4721910	3998	2896	Tupalangdarya	Surkhandarya	ice-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	27	High
Tu36	7554620	4721630	3981	4029	Tupalangdarya	Surkhandarya	moraine-dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Tu37	7555830	4720570	3791	1412	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	surface drainage	single	1	N/D	N/D	ice-fall, yes	22	High
Tu38	7555220	4719060	3954	2284	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Tu39	7555240	4718500	3945	2764	Tupalangdarya	Surkhandarya	ice-dammed lake	supraglacial	underground drainage	single	3	200	140	Yes, ice-fall	19	Medium
Tu40	7557810	4718870	3669	942	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	2	100	100	Yes, ice-fall	18	Medium
Tu41	7548220	4714470	3805	1850	Tupalangdarya	Surkhandarya	rock-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	bedrocks, no	18	Medium
Tu42	7553290	4716970	3793	1722	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Tu43	7552710	4722020	3915	21892	Tupalangdarya	Surkhandarya	rock-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	cascade trigger, yes	22	High
Tu44	7553150	4721950	3940	16662	Tupalangdarya	Surkhandarya	Landlisde dammed	proglacial	surface drainage	cascade	4	140	55	avalanches, landslides, yes	17	Medium
Tu45	7539700	4721430	3613	36506	Tupalangdarya	Surkhandarya	moraine-dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-falls, rock-falls	24	High
Tu46	7527520	4721790	3555	1209	Tupalangdarya	Surkhandarya	rock-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, rock-fall, avalanche	22	High
Tu47	7522210	4720850	3900	10033	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	surface drainage	single	1	N/D	N/D	avalanche, ice-falls, yes	21	Medium
Tu48	7516290	4705340	3683	2740	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Tu49	7517110	4704890	3727	312	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	22	High
Tu50	7517180	4704870	3728	312	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	8	N/D	N/D	No, solid moraine	20	Medium
Tu52	7518130	4704160	3756	291	Tupalangdarya	Surkhandarya	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Tu53	7518730	4703690	3791	4388	Tupalangdarya	Surkhandarya	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, avalanches, rockfalls&icefalls	24	High
Tu54	7520350	4702550	3743	3975	Tupalangdarya	Surkhandarya	ice-debris dammed lake	supraglacial	underground drainage	single	90	600	120	Yes, avalanches, icefalls rock falls	16	Medium
Tu55	7520950	4703500	3777	1837	Tupalangdarya	Surkhandarya	rock-dammed lake	proglacial	surface drainage	single	1	N/D	N/D	rock-falls, ice-falls, yes	21	Medium
Tu56	7520990	4705630	3613	4879	Tupalangdarya	Surkhandarya	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	20	Medium
Tu57	7526490	4705780	3548	26194	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	no	21	Medium
Tu58	7526150	4704640	3650	52538	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No, solid moraine, rock	23	High
Tu59	7514720	4677740	3738	5593	Tupalangdarya	Surkhandarya	rock-dammed lake	periglacial	surface drainage	single	10	200	350	rock-falls, yes	12	Low
Tu60	7525900	4704150	3669	8505	Tupalangdarya	Surkhandarya	moraine-dammed lake	proglacial	underground drainage	cascade	1	12	80	No, solid moraine	23	High
Tu61	7514790	4677210	3843	335	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	avalanches, yes	21	Medium
Tu62	7526610	4705110	3569	6382	Tupalangdarya	Surkhandarya	moraine-dammed lake	proglacial	underground drainage	cascade	4	250	120	No, solid moraine	16	Medium
Tu63	7527090	4706280	3421	24944	Tupalangdarya	Surkhandarya	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	rock-falls, yes	21	Medium
Tu64	7527710	4705910	3402	1082	Tupalangdarya	Surkhandarya	Landlisde dammed	periglacial	underground drainage	single	50	300	400	No, solid moraine	14	Low

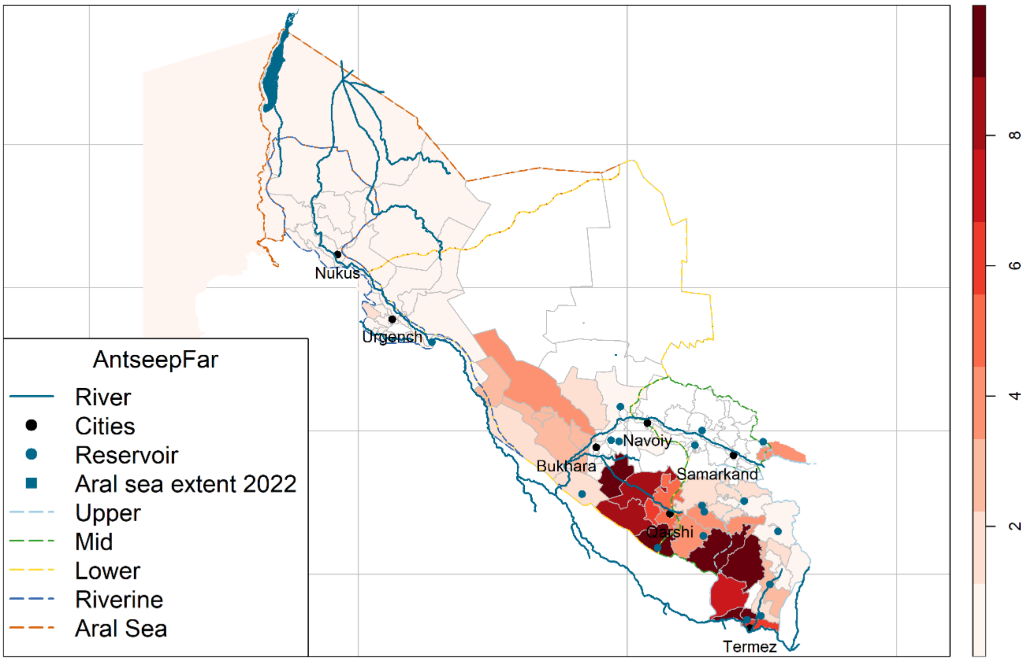
Ah01	7856520	5076990	3666	88032	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, avalanche, rock-fall	23	High
Ah02	7855290	5074060	3540	3626	Angren	Tashkent	moraine-dammed lake	extraglacial	underground drainage	cascade	3	200	100	Yes, avalanche, rock-fall	17	Medium
Ah03	7854870	5074220	3549	5776	Angren	Tashkent	moraine-dammed lake	extraglacial	underground drainage	cascade	2	200	100	Yes, avalanche, rock-fall	17	Medium
Ah04	7855320	5073520	3536	1114	Angren	Tashkent	moraine-dammed lake	extraglacial	underground drainage	single	10	150	80	No, solid moraine	14	Low
Ah05	7850760	5066200	2791	13520	Angren	Tashkent	moraine-dammed lake	extraglacial	surface drainage	cascade	1	250	180	No, solid moraine	16	Medium
Ah06	7850210	5066280	2766	108264	Angren	Tashkent	moraine-dammed lake	extraglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	20	Medium
Ah07	7846890	5066800	3343	1562	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Ah08	7847090	5066610	3360	10110	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	150	100	Yes, avalanche, rock-fall	19	Medium
Ah09	7848470	5065220	2873	177055	Angren	Tashkent	moraine-dammed lake	extraglacial	surface drainage	cascade	4	350	200	No, solid moraine	12	Low
Ah10	7849090	5065820	2870	4943	Angren	Tashkent	moraine-dammed lake	periglacial	drainless	single	10	200	400	solid moraine, no	12	Low
Ah11	7838020	5056250	3461	3311	Angren	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Ah12	7836780	5057550	3625	220	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Ah13	7837100	5056990	3537	2557	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, avalanche	25	High
Ah14	7837060	5056860	3537	1187	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, avalanche	25	High
Ah15	7836950	5056580	3538	13601	Angren	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Ah16	7837600	5056020	3507	4338	Angren	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Ah17	7836120	5051760	3481	809	Angren	Tashkent	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	20	Medium
Cha01	7829770	5050250	3357	564	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Cha02	7830810	5049650	3513	1242	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	19	Medium
Cha03	7831340	5049390	3498	1636	Chatkal	Tashkent	ice-debris dammed lake	proglacial	underground drainage	single	10	230	300	Yes, avalanche	18	Medium
Cha04	7831890	5054880	3265	14392	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha05	7831850	5054310	3374	2963	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha06	7832080	5053730	3396	37582	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha07	7831770	5053280	3508	548	Chatkal	Tashkent	moraine-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	26	High
Cha08	7833130	5051800	3460	7461	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Cha09	7833180	5051580	3452	5877	Chatkal	Tashkent	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	22	High
Cha10	7833770	5050630	3485	5746	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha11	7833930	5050420	3477	4474	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha12	7835580	5056930	3466	4211	Chatkal	Tashkent	rock-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	20	Medium
Cha13	7835620	5056530	3513	6762	Chatkal	Tashkent	moraine-dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	22	High
Cha14	7836200	5058400	3593	250	Chatkal	Tashkent	ice-dammed lake	proglacial	underground drainage	cascade	35	600	200	Yes, avalanche,rock-fall	21	Medium
Cha15	7836100	5058350	3597	994	Chatkal	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	30	380	200	Yes, ice-fall	19	Medium
Cha16	7836200	5059180	3539	662	Chatkal	Tashkent	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	22	High
Cha17	7836810	5059350	3519	609	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Cha18	7836030	5061250	3397	1379	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall, avalanch	25	High
Cha19	7836780	5061050	3470	10028	Chatkal	Tashkent	rock-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No, solid moraine	22	High
Cha20	7837160	5060770	3525	399	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No, solid moraine	23	High
Cha21	7836520	5061480	3363	7053	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha22	7835920	5061830	3347	466	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha23	7835840	5061830	3345	2360	Chatkal	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	21	Medium
Cha24	7837980	5062880	3374	5882	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid morain	21	Medium
Cha25	7838440	5062730	3343	2694	Chatkal	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No	21	Medium
Cha26	7838930	5062740	3269	7533	Chatkal	Tashkent	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	20	Medium
Cha27	7838240	5058460	3545	627	Chatkal	Tashkent	ice-dammed lake	supraglacial	underground drainage	cascade	6	200	100	No, solid moraine	17	Medium
Cha28	7838430	5058630	3560	1242	Chatkal	Tashkent	ice-dammed lake	supraglacial	underground drainage	cascade	1	N/D	N/D	No, solid moraine	25	High
Cha29	7838430	5059180	3469	63435	Chatkal	Tashkent	ice-debris dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	22	High
Cha30	7839040	5059580	3456	14143	Chatkal	Tashkent	ice-debris dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	19	Medium
Ko01	7839600	5118160	1736	17335	Koksuv	Tashkent	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, landslide	21	Medium
Ko02	7844480	5127280	2040	177883	Koksuv	Tashkent	Landlisde dammed	extraglacial	surface drainage	cascade	1	N/D	N/D	Yes, rock-fall, landslide	21	Medium
Ko03	7857630	5134850	3264	3519	Koksuv	Tashkent	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	19	Medium
Ko04	7850760	5142000	3511	4542	Koksuv	Tashkent	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall	21	Medium
Ko05	7831260	5114440	1628	5165	Koksuv	Tashkent	Landlisde dammed	extraglacial	underground drainage	single	40	500	200	No	11	Low
Oy01	7884940	5152520	3447	2393	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy02	7886330	5152710	3636	358	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy03	7885510	5152800	3537	2834	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy04	7881350	5161920	3489	4579	Pskem	Tashkent	moraine-dammed lake	proglacial	underground drainage	single	7	400	225	Yes, ice-fall	16	Medium
Oy05	7879720	5174090	3147	629	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy06	7881580	5177140	3224	134	Pskem	Tashkent	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	20	Medium
Oy07	7886760	5179220	2292	5118	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	cascade	7	200	100	No	13	Low
Oy08	7886570	5178970	2299	1505	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	cascade	3	150	250	No	15	Low
Oy09	7885620	5176820	2366	30361	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	cascade	25	1600	150	Yes, rock-fall	17	Medium
Oy10	7888380	5179180	2282	2491	Pskem	Tashkent	Landlisde dammed	extraglacial	surface drainage	cascade	1	175	110	No	13	Low
Oy11	7889920	5176900	2421	30476	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	cascade	10	200	150	No	15	Low
Oy12	7892745	5168535	3657	1437	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No	21	Medium
Oy13	7893120	5167900	3602	4163	Pskem	Tashkent	ice-debris dammed lake	proglacial	surface drainage	single	1	N/D	N/D	yes, ice-fall	22	High
Oy14	7896400	5167140	3553	699	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy15	7896260	5166970	3548	170	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy16	7896610	5166660	3552	1473	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	20	630	300	No, solid moraine	13	Low
Oy17	7896670	5166980	3573	207	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy18	7898560	5167940	3449	1281	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Oy19	7900190	5166040	3520	478	Pskem	Tashkent	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	20	Medium
Oy20	7904010	5168860	3741	9740	Pskem	Tashkent	rock-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall, rock-fall	20	Medium
Oy21	7901310	5181340	3340	622	Pskem	Tashkent	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No	19	Medium
Oy22	7903510	5180220	3481	808	Pskem	Tashkent	ice-debris dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	No	24	High
Oy23	7903410	5180270	3470	743	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No	23	High
Oy24	7903270	5187660	3464	677	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No	21	Medium
Oy25	7908030	5187010	3534	1263	Pskem	Tashkent	ice-dammed lake	supraglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall, rock-fall	23	High
Oy26	7908010	5187110	3530	670	Pskem	Tashkent	ice-dammed lake	supraglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall, rock-fall	23	High
Oy27	7907210	5184270	3700	11870	Pskem	Tashkent	ice-debris dammed lake	periglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall, rock-fall	21	Medium
Oy28	7908020	5182140	3567	4288	Pskem	Tashkent	ice-dammed lake	supraglacial	surface drainage	single	1	N/D	N/D	Yes, ice-fall, rock-fall	23	High
Oy29	7913210	5176520	3624	4462	Pskem	Tashkent	ice-debris dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	No	24	High
Oy30	7912850	5177730	3416	2829	Pskem	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	Yes. avalanches	23	High
Oy31	7913350	5189160	3506	1280	Pskem	Tashkent	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	19	Medium
Oy32	7914080	5182760	3714	2472	Pskem	Tashkent	moraine-dammed lake	periglacial	surface drainage	single	1	N/D	N/D	Yes, rock-fall	21	Medium
Oy33	7916860	5193750	3595	3608	Pskem	Tashkent	ice-debris dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	Yes, rock-fall	23	High
Oy34	7917480	5192540	3762	1153	Pskem	Tashkent	ice-dammed lake	supraglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	27	High
Oy35	7916680	5193940	3569	2860	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	12	250	100	No	15	Low
Oy36	7917430	5196040	3448	3816	Pskem	Tashkent	ice-dammed lake	supraglacial	underground drainage	single	7	400	300	Yes, ice-fall, rock-fall	17	Medium
Oy37	7917980	5199100	2783	394976	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	12	800	800	Yes, avalanche, rock-fall	19	Medium
Oy38	7920390	5195000	3291	6521	Pskem	Tashkent	Landlisde dammed	periglacial	underground drainage	cascade	1	N/D	N/D	No	22	High
Oy39	7919010	5192490	3648	5403	Pskem	Tashkent	ice-debris dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	Yes, ice-fall	24	High
Oy40	7920100	5192390	3511	3672	Pskem	Tashkent	ice-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	No	25	High
Oy41	7920180	5192920	3474	1106	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No	23	High
Oy42	7920980	5187350	3383	22563	Pskem	Tashkent	Landlisde dammed	periglacial	surface drainage	single	1	N/D	N/D	Yes, avalanche	20	Medium
Oy43	7926720	5187390	3600	1340	Pskem	Tashkent	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Oy44	7927480	5185690	3845	867	Pskem	Tashkent	ice-dammed lake	supraglacial	underground drainage	single	1	N/D	N/D	Yes, avalanche	25	High
Oy45	7515360	4699600	3986	4084	Pskem	Tashkent	ice-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	27	High
Oy46	7932910	5190350	3941	183	Pskem	Tashkent	ice-dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	Yes, ice-fall, landslide, cascade	25	High
Oy47	7932350	5190350	3863	407	Pskem	Tashkent	ice-debris dammed lake	proglacial	underground drainage	cascade	10	350	250	Yes, rock-fall	18	Medium
Oy48	7933130	5191120	4088	10333	Pskem	Tashkent	rock-dammed lake	proglacial	surface drainage	single	1	N/D	N/D	Yes, avalanche	21	Medium
Oy49	7928420	5191850	3692	569	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No	21	Medium
Oy50	7929360	5192650	3768	527	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Oy51	7929330	5192780	3771	2100	Pskem	Tashkent	ice-debris dammed lake	proglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	24	High
Oy52	7929060	5192880	3753	388	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Oy53	7929060	5192930	3752	374	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Oy54	7929080	5193030	3752	949	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Oy55	7928900	5193140	3755	957	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High
Oy56	7929810	5194690	3971	20826	Pskem	Tashkent	ice-dammed lake	proglacial	underground drainage	cascade	2	160	220	Yes, ice-fall	21	Medium
Oy57	7929650	5194100	3905	13851	Pskem	Tashkent	ice-debris dammed lake	proglacial	surface drainage	cascade	1	N/D	N/D	No, solid moraine	22	High
Oy58	7918490	5202660	3640	3373	Pskem	Tashkent	moraine-dammed lake	periglacial	surface drainage	cascade	1	N/D	N/D	Yes, ice-fall, rock-fall	23	High
Oy59	7913170	5202320	3466	1229	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No	23	High
Oy60	7913520	5202490	3538	806	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No	23	High
Oy61	7914160	5202600	3610	1482	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	No	23	High
Oy62	7913790	5203030	3583	10558	Pskem	Tashkent	rock-dammed lake	periglacial	surface drainage	cascade	1	220	70	Yes, rock-fall, cascade	16	Medium
Oy63	7913500	5202940	3530	8160	Pskem	Tashkent	rock-dammed lake	periglacial	surface drainage	cascade	14	350	120	Yes, avalanches, cascade	16	Medium
Oy64	7911120	5202200	3319	2840	Pskem	Tashkent	moraine-dammed lake	extraglacial	underground drainage	single	1	N/D	N/D	No	20	Medium
Oy65	7933080	5190180	3983	1599	Pskem	Tashkent	ice-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, avalanche	27	High
Oy67	7887980	5189980	3445	4324	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, ice-fall	23	High
Oy68	7852744	5168051	3125	6869	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	10	300	200	Yes, ice-fall	15	Low
Oy69	7826844	5149472	1525	74771	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	single	40	700	400	Yes, rock-fall	13	Low
Ps01	7822290	5119930	3177	314	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	0	N/D	N/D	No	21	Medium
Ps02	7824230	5117730	3275	143	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	0	N/D	N/D	No	21	Medium
Ps03	7834140	5122940	3378	1929	Pskem	Tashkent	ice-debris dammed lake	periglacial	underground drainage	single	1	N/D	N/D	Yes, avalanche	23	High
Ps04	7833520	5140350	1554	26874	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	single	3	400	160	Yes, landslide, avalanche	13	Low
Ps05	7839790	5139670	1711	264474	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	single	21	400	600	Yes, avalanche	15	Low
Ps06	7854010	5145770	2354	78873	Pskem	Tashkent	moraine-dammed lake	extraglacial	surface drainage	single	1	N/D	N/D	No, solid moraine	18	Medium
Ps07	7855120	5146250	2398	262107	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	cascade	25	900	350	Yes, rock-fall	15	Low
Ps08	7854420	5143060	2704	9267	Pskem	Tashkent	Landlisde dammed	extraglacial	underground drainage	cascade	12	600	200	Yes, avalanche	15	Low
Ps09	7859970	5140780	3211	6885	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	single	1	N/D	N/D	No, solid moraine	21	Medium
Ps10	7861070	5146750	3475	3704	Pskem	Tashkent	moraine-dammed lake	proglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	26	High
Ps11	7861060	5147080	3451	3123	Pskem	Tashkent	moraine-dammed lake	periglacial	underground drainage	cascade	1	N/D	N/D	Yes, ice-fall	25	High

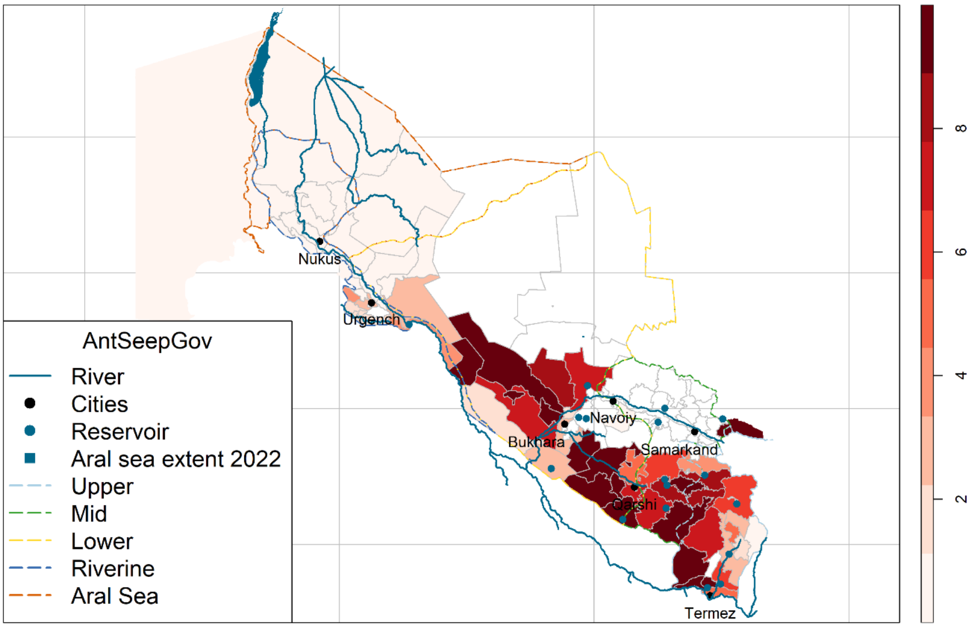
Annex 2 – Water management indicators

Table 14. Ranking of districts according to water management conditions (table 11 on p31 TA-9782 УЗБ)

Regions	Districts	Anti-seepage operations on the government’ s irrigation system	Anti-seepage operations on the on-farm irrigation system	Provision of the outlets on inter-farm canals with regulating structures	Provision of the on-farm outlets with regulating structures	Water availability	Land areas with moderate and high salinity	Productivity of the irrigated lands	Water productivity	Sum of scores
Khorezm	Gurlen	0	0	0	0	6	5	6	4	21
Karakalpakstan	Muynak	0	0	3	3	9	2	5	2	24
Khorezm	Kushkupir	2	0	0	2	7	5	4	4	24
Karakalpakstan	Kanlikul	0	0	8	2	6	7	2	2	27
Karakalpakstan	Takhtakupir	0	0	6	4	7	8	1	2	28
Khorezm	Yangibazar	0	0	0	3	7	7	7	4	28
Karakalpakstan	Kegeyli	0	0	10	3	10	3	1	2	29
Khorezm	Bogot	2	0	0	0	7	9	9	2	29
Karakalpakstan	Nukus	0	0	7	4	10	7	1	1	30
Khorezm	Shavat	4	2	0	0	7	6	7	4	30
Karakalpakstan	Karauzak	0	0	10	4	7	8	1	1	31
Khorezm	Yangiarik	2	0	0	0	7	7	9	6	31
Karakalpakstan	Turtkul	3	0	5	3	8	7	4	2	32
Karakalpakstan	Buzatov	0	0	8	7	8	3	4	2	32
Khorezm	Urganch	3	0	0	2	7	6	9	5	32
Khorezm	Khiva	2	0	2	0	7	7	9	5	32
Khorezm	Honka	5	0	2	0	7	8	7	4	33
Karakalpakstan	Beruniy	0	0	10	3	9	6	5	2	35
Karakalpakstan	Amu Darya	0	0	6	4	9	7	6	3	35
Karakalpakstan	Takhiatosh	0	0	10	4	10	6	3	2	35
Karakalpakstan	Shumanoy	0	0	10	4	9	8	2	2	35
Khorezm	Tuprokala	3	0	10	0	6	8	5	3	35
Karakalpakstan	Ellikkala	0	0	10	5	7	7	4	3	36
Karakalpakstan	Kungirot	0	0	8	9	8	7	2	2	36
Karakalpakstan	Chimboy	0	0	10	7	8	6	3	3	37
Surkhandarya	Shurchi	2	0	0	7	7	10	6	6	38
Karakalpakstan	Khzhayli	0	0	10	9	8	8	3	2	40
Khorezm	Khazorasp	4	0	8	0	7	6	10	5	40
Surkhandarya	Uzun	0	0	5	3	8	10	8	6	40
Surkhandarya	Bandikhan	9	4	0	4	10	9	4	3	43
Surkhandarya	Altynsay	5	0	4	10	5	10	5	6	45
Kashakdarya	Koson	5	5	10	8	5	9	3	3	48
Surkhandarya	Jargurgan	6	2	10	0	8	10	7	5	48
Kashakdarya	Guzar	7	4	10	4	5	9	5	5	49
Surkhandarya	Baysun	7	10	3	0	6	10	10	3	49
Surkhandarya	Sherabad	10	7	2	6	5	9	5	5	49
Bukhara	Bukhara	3	0	8	8	5	8	10	8	50
Bukhara	Korakul	2	2	6	8	6	9	10	7	50
Bukhara	Olot	3	2	8	8	5	8	9	7	50
Bukhara	Vobkent	2	0	10	8	6	9	10	8	53
Kashakdarya	Shakhrisabz	8	0	10	6	4	10	7	8	53
Surkhandarya	Kyziric	10	6	10	10	5	7	3	3	54
Bukhara	Shofirkon	8	2	8	7	7	8	9	6	55
Bukhara	Gijduvan	7	0	8	8	6	8	10	8	55
Kashakdarya	Karshi	7	5	10	10	5	10	4	4	55
Kashakdarya	Muborak	9	8	10	8	5	8	3	4	55
Surkhandarya	Kumkurgan	3	3	9	9	6	10	8	7	55
Surkhandarya	Muzrabad	10	9	10	6	5	8	4	3	55
Bukhara	Jondor	7	3	7	8	6	8	10	7	56

Kashakdarya	Kamashi	8	4	10	5	4	10	7	9	57
Kashakdarya	Kasbi	10	6	10	7	5	10	5	4	57
Kashakdarya	Nishon	10	9	10	7	6	9	3	3	57
Surkhandarya	Termez	5	6	8	7	7	10	8	6	57
Bukhara	Romitan	10	3	10	7	6	8	9	6	59
Kashakdarya	Kitob	4	2	10	10	3	10	10	10	59
Kashakdarya	Mirishkor	10	8	10	10	6	10	2	3	59
Kashakdarya	Chirokchi	6	2	10	5	6	10	10	10	59
Kashakdarya	Yakkabog	9	2	10	10	4	10	5	9	59
Surkhandarya	Denau	3	2	9	10	5	10	10	10	59
Surkhandarya	Sariassia	6	0	10	10	5	10	10	8	59
Bukhara	Korovulbozor	10	9	10	8	6	9	4	4	60
Bukhara	Kogon	9	2	10	8	6	9	10	7	61
Bukhara	Peshku	9	4	10	8	6	8	10	7	62
Surkhandarya	Angor	10	10	10	10	6	10	6	5	67
Kashakdarya	Dehkonobod	10	9	10	7	2	10	10	10	68

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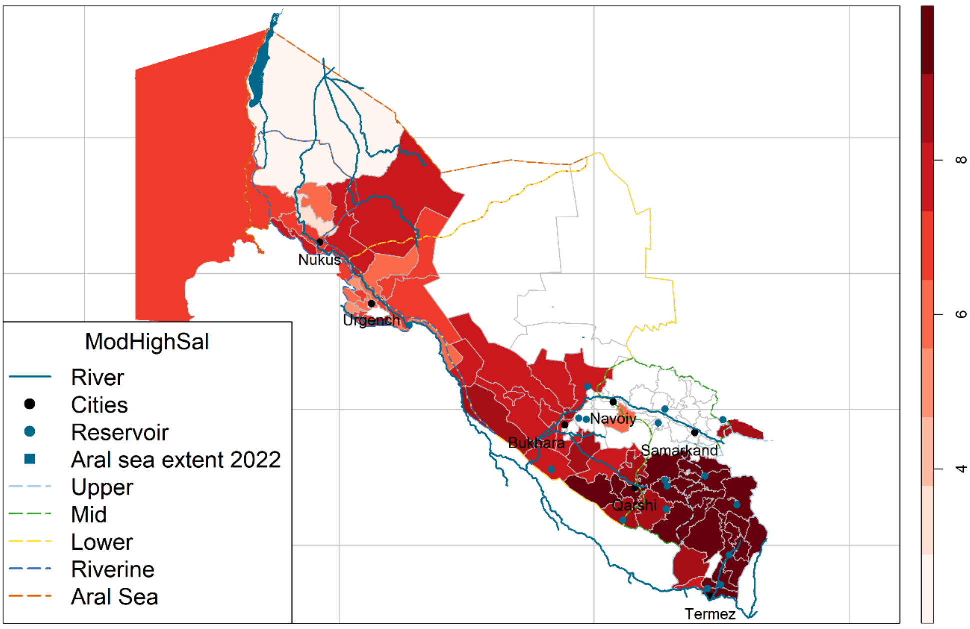
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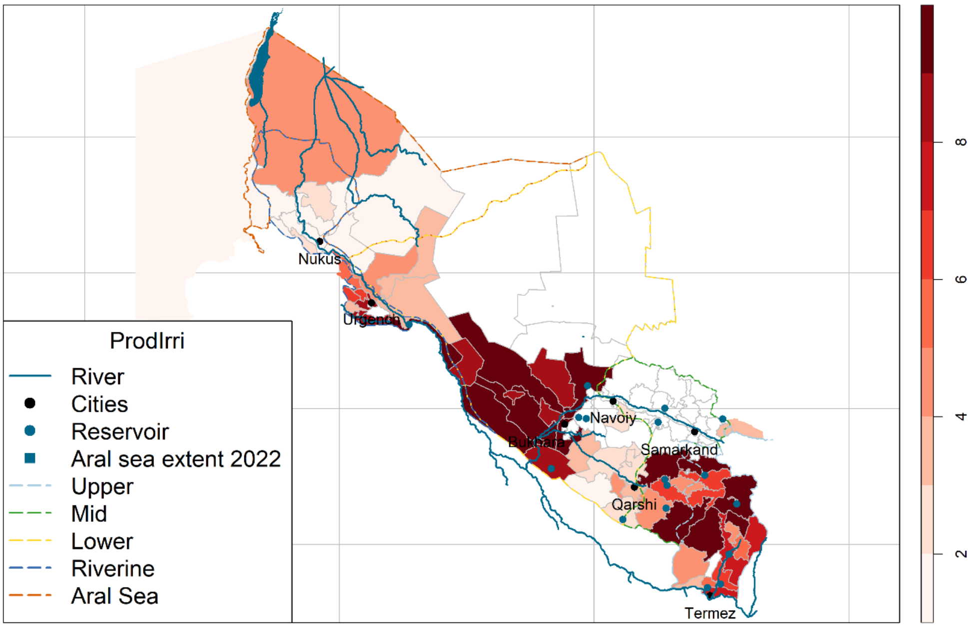
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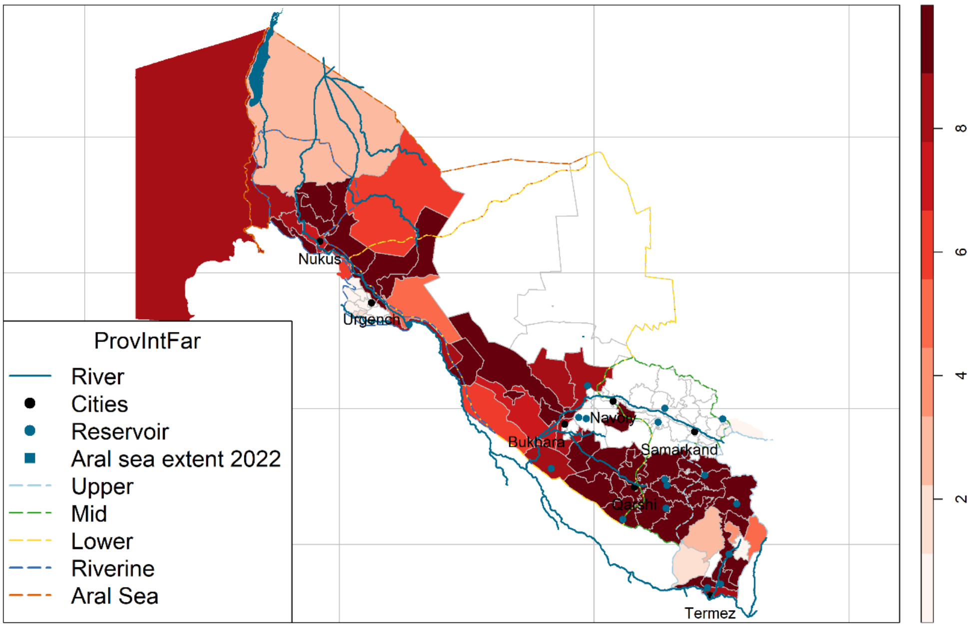
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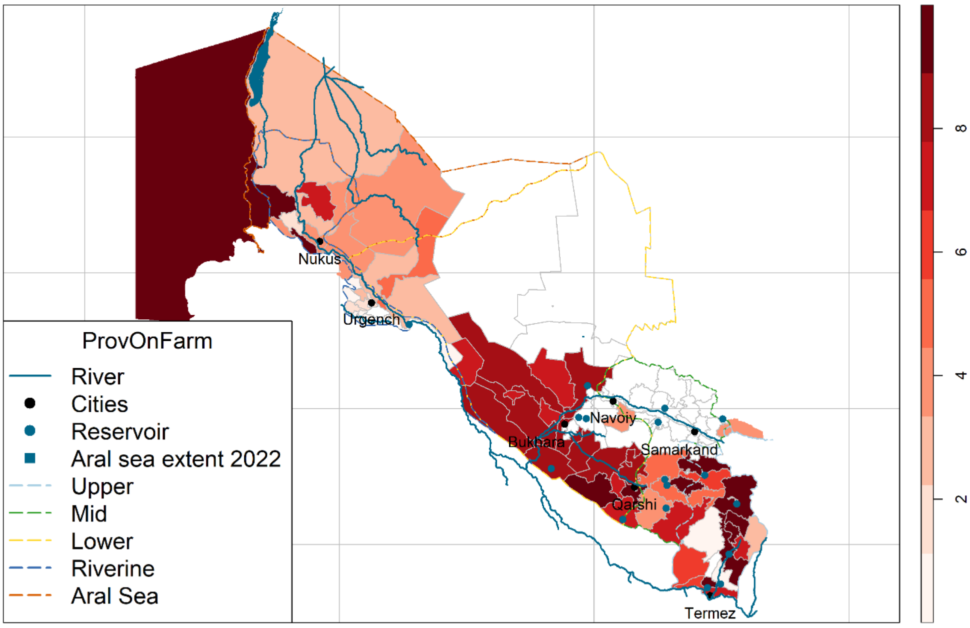
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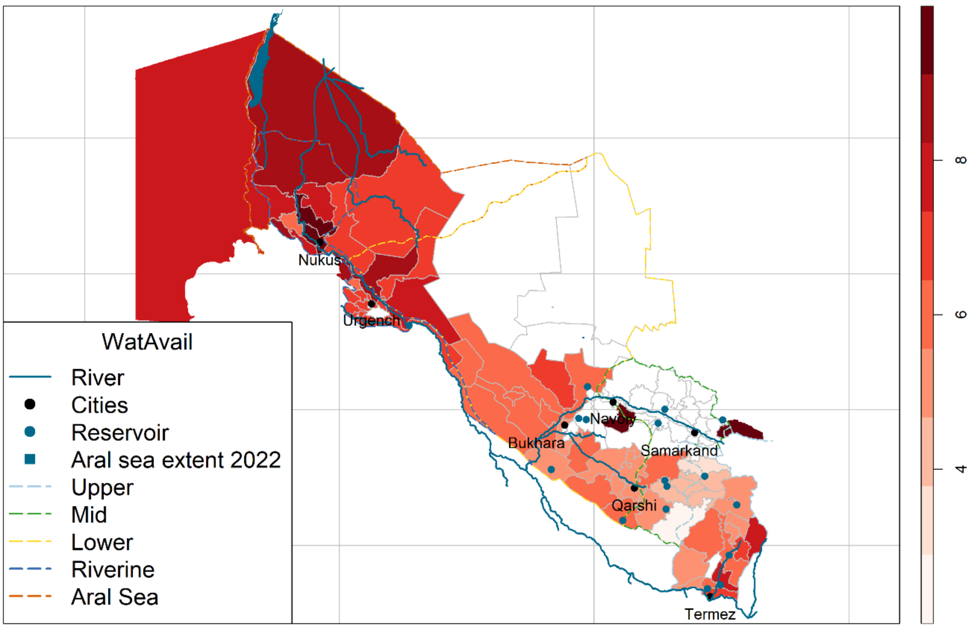
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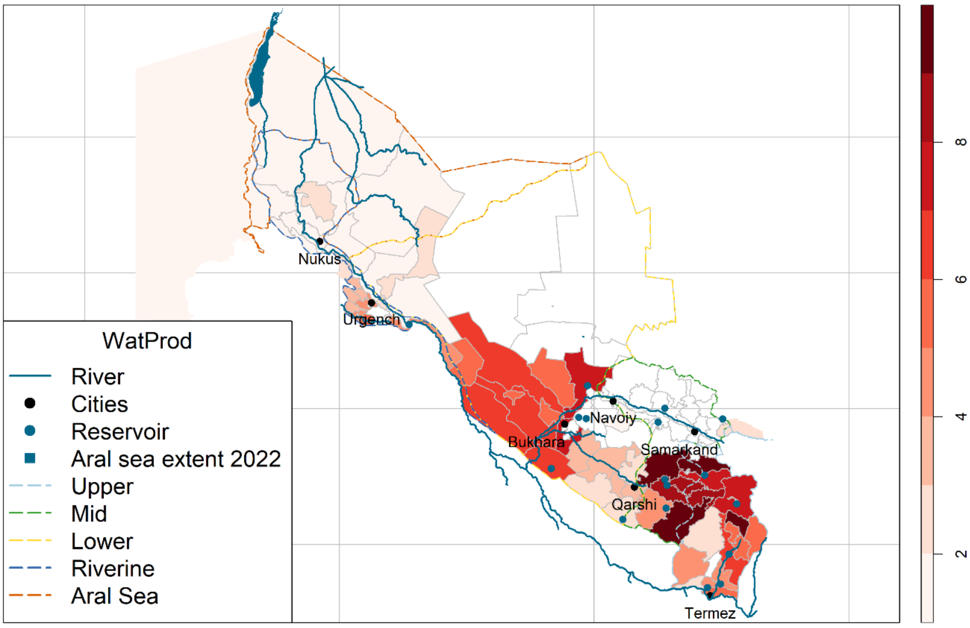
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Annex 3 - WUEMoCA indicators

WUEMoCA - Water Use Efficiency Monitor in Central Asia

Overview of WUEMoCA indicator acronyms - Information as of September 2019

WUEMoCA indicators

● = **RS-based** (based on remote sensing data from MODIS; Moderate Resolution Imaging Spectroradiometer, operated by NASA)
● = **climate data** (radiation, temperature, precipitation, humidity)
● = **user input/statistics** (crop prices, water intake, yield, groundwater, rainfall)
= "on-the-fly" calculation possible with user input ("User Polygon Toolbox")

Indicator [unit]	Acro-nym	Short description	Crop-specific	Aggrega-tion level	Data source	User input / statistics
Land use indicators (RS-based *)						
Net irrigated area [ha]	F_{ir_n}	Area equipped with irrigation infrastructure, including fallow land	-	all levels	●○○	-
Crop acreage [ha]	F_{ir_f}	Crop-specific area under irrigation (double usage is counted twice)	each crop and sum of all	all levels	●○○	-
Land use area [%]	U_{ir}	Area share of crop acreage F_{ir_f} in net irrigated area F_{ir_n}	each crop and sum of all	all levels	●○○	-
Temporarily unused irrigable land [%]	*FP*	Area share of fallow land in net irrigated area F_{ir_n}	-	all levels	●○○	-
Crop type diversity [-]	*CD*	Variety of different crop types (spatially)	-	all levels	●○○	-
Multi-annual Land use indicators (RS-based *)						
Fallow land frequency [-]	*FLF*	Average number of years in which land was not cultivated	-	regular raster	●○○	-
Land use rotation [-]	*LUR*	Average number of land use alternations, including fallow land	-	regular raster	●○○	-
Major land use [-]	*MLU*	Predominant crop type based on average frequency	-	regular raster	●○○	-
Productivity indicators (RS-based *)						
Farm crop output [t]	P_{ir_f}	RS-based estimated crop harvest (crop yield Y_f * crop acreage F_{ir_f})	cotton, rice, wheat	all levels	●●○	-
Crop yield [t ha^{-1}]	Y_f	RS-based estimated crop harvest P_{ir_f} per ha crop acreage F_{ir_f}	cotton, rice, wheat	all levels	●●○	-
Total productivity [$]	G_p	RS-based crop-specific total economic revenue (crop harvest P_{ir_f} * crop price)	cotton, rice, wheat and sum of them	user polygon	●●●	crop price
Productivity per hectare [$ ha^{-1}]	P_f	RS-based crop-specific economic revenue G_p per ha crop acreage F_{ir_f}	cotton, rice, wheat and average of them	user polygon	●●●	crop price
Quantity per water consumed [kg m^{-3}]	Y_w	RS-based crop-specific harvest P_{ir_f} per m^3 surface water consumed	cotton, rice, wheat	user polygon	●●●	crop water intake
Productivity per water consumed [$ m^{-3}]	P_w	RS-based crop-specific economic revenue G_p per m^3 surface water consumed	cotton, rice, wheat and average of them	user polygon	●●●	crop price, crop water intake
Productivity indicators (statistic-based)						
Farm crop output [t]	*Prod* P_{ir_f}	Statistical actual crop harvest (crop yield *Prod* Y_f * crop acreage F_{ir_f})	each crop	user polygon	○○●	crop yield
Crop yield [t ha^{-1}]	*Prod* Y_f	Statistical actual crop harvest *Prod* P_{ir_f} per ha crop acreage F_{ir_f}	each crop	user polygon	○○●	crop yield
Total productivity [$]	*Prod* G_p	Statistical crop-specific economic revenue (crop harvest *Prod* P_{ir_f} * crop price)	each crop and sum of all	user polygon	○○●	crop yield, crop price
Productivity per hectare [$ ha^{-1}]	*Prod* P_f	Statistical crop-specific economic revenue *Prod* G_p per ha crop acreage F_{ir_f}	each crop and average of all	user polygon	○○●	crop yield, crop price
Quantity per water consumed [kg m^{-3}]	*Prod* Y_w	Statistical crop harvest *Prod* P_{ir_f} per m^3 surface water consumed	each crop	user polygon	○○●	crop yield, crop water intake
Productivity per water consumed [$ m^{-3}]	*Prod* P_w	Statistical crop-specific economic revenue *Prod* G_p per m^3 surface water consumed	each crop and average of all	user polygon	○○●	crop yield, crop price, crop water intake
Specific water supply [m^3 ha^{-1}]	*Prod* W_f	Water intake (+ groundwater, rainfall) per ha net irrigated area F_{ir_n}	-	user polygon	○○●	water intake, groundwater, rainfall
Water use efficiency indicators (RS-based *)						
Actual evapo-transpiration [mm]	ET_f	Quantity of water released to atmosphere by evaporation and transpiration	cotton, rice, wheat, and irrigated cropland	all levels	●●○	-
Water availability (ET) [-]	V_c	Index of appropriate water supply (crop-specific actual ET_f per crop-specific ET_{pot})	cotton, rice, wheat and average of them	all levels	●●○	-
Water productivity (ET) [kg m^{-3}]	E_{prod}	RS-based crop-specific harvest P_{ir_f} per m^3 of water consumed (in ET_f)	cotton, rice, wheat	all levels	●●○	
Irrigation efficiency [-]	V_{ir}	Index of efficiency in delivering water to the plants and minimizing water losses (ET_f per water intake)	-	province, district, user polygon	●●●	water intake: monthly and 10-day values also for current year (user polygons only)

Annex 4 – Administrative districts

Table 15. Names and abbreviations of administrative districts

Zone	Province	District	Shortname
Aral basin	Republic of Karakalpakstan	Karauzyak	Kar
Aral basin	Republic of Karakalpakstan	Takhtakupir	Tak
Aral basin	Republic of Karakalpakstan	Kungrad	Kun
Aral basin	Republic of Karakalpakstan	Muynak	Muy
Lower	Kashkadarya	Nishan	Nis
Lower	Samarkand	Nurabad	Nur
Lower	Samarkand	Pakhtachi	Pak
Lower	Bukhara	Gijduvan	Gij
Lower	Republic of Karakalpakstan	Turtkul	Tur
Lower	Navoi	Uchkuduk	Uch
Lower	Navoi	Kiziltepa	Kiz
Lower	Navoi	Karmana	Kar
Lower	Navoi	Kanimekh	Kan
Lower	Republic of Karakalpakstan	Beruniy	Ber
Lower	Navoi	Navoi city	Nav
Lower	Navoi	Zarafshan city	Zar
Lower	Bukhara	Jondor	Jon
Lower	Bukhara	Bukhara	Buk
Lower	Bukhara	Alat	Ala
Lower	Bukhara	Karakul	Kar
Lower	Bukhara	Karaulbazar	Kar
Lower	Bukhara	Shafirkan	Sha
Lower	Bukhara	Ramitan	Ram
Lower	Bukhara	Peshku	Pes
Lower	Bukhara	Kagan	Kag
Lower	Bukhara	Kagan city	Kag
Lower	Bukhara	Bukhara city	Buk
Lower	Bukhara	Vabkent	Vab
Lower	Kashkadarya	Kasbi	Kas
Lower	Kashkadarya	Mirishkar	Mir
Lower	Kashkadarya	Mubarek	Mub
Lower	Kashkadarya	Karshi	Kar
Lower	Kashkadarya	Kasan	Kas
Lower	Kashkadarya	Karshi city	Kar
Lower	Navoi	Tamdi	Tam
Lower	Republic of Karakalpakstan	Ellikkala	Ell
Mid	Kashkadarya	Kamashi	Kam
Mid	Samarkand	Koshrabad	Kos
Mid	Samarkand	Payarik	Pay

Mid	Samarkand	Pastdargom	Pas
Mid	Kashkadarya	Chirakchi	Chi
Mid	Samarkand	Kattakurgan	Kat
Mid	Kashkadarya	Guzar	Guz
Mid	Samarkand	Dzhambay	Dzh
Mid	Dzhizak	Farish	Far
Mid	Samarkand	Bulungur	Bul
Mid	Kashkadarya	Dehkanabad	Deh
Mid	Samarkand	Ishtikhan	Ish
Mid	Samarkand	Akdarya	Akd
Mid	Kashkadarya	Yakkabag	Yak
Mid	Dzhizak	Bakhmal	Bak
Mid	Samarkand	Narpay	Nar
Mid	Dzhizak	Gallyaaral	Gal
Mid	Navoi	Khatirchi	Kha
Mid	Samarkand	Samarkand	Sam
Mid	Samarkand	Taylak	Tay
Mid	Navoi	Navbakhor	Nav
Mid	Navoi	Nurata	Nur
Mid	Kashkadarya	Shakhrisabz city	Sha
Mid	Samarkand	Kattakurgan city	Kat
Mid	Samarkand	Samarkand city	Sam
Riverine	Khorezm	Khazarasp	Kha
Riverine	Khorezm	Khiva	Khi
Riverine	Khorezm	Shavat	Sha
Riverine	Khorezm	Koshkupir	Kos
Riverine	Khorezm	Gurlen	Gur
Riverine	Khorezm	Khanka	Kha
Riverine	Khorezm	Yangiarik	Yan
Riverine	Khorezm	Bagat	Bag
Riverine	Khorezm	Urgench	Urg
Riverine	Khorezm	Yangibazar	Yan
Riverine	Khorezm	Urgench city	Urg
Riverine	Khorezm	Khiva city	Khi
Riverine	Republic of Karakalpakstan	Amudarya	Amu
Riverine	Republic of Karakalpakstan	Chimbay	Chi
Riverine	Republic of Karakalpakstan	Kanlikul	Kan
Riverine	Republic of Karakalpakstan	Shumanay	Shu
Riverine	Republic of Karakalpakstan	Khojeyli	Kho
Riverine	Republic of Karakalpakstan	Kegeyli	Keg
Riverine	Republic of Karakalpakstan	Nukus	Nuk
Riverine	Republic of Karakalpakstan	Nukus city	Nuk
Upper	Surkhandarya	Sherabad	She

Upper	Surkhandarya	Kumkurgan	Kum
Upper	Surkhandarya	Baysun	Bay
Upper	Kashkadarya	Shakhrisabz	Sha
Upper	Kashkadarya	Kitab	Kit
Upper	Surkhandarya	Dzharkurgan	Dzh
Upper	Surkhandarya	Kizirik	Kiz
Upper	Surkhandarya	Uzun	Uzu
Upper	Surkhandarya	Muzrabad	Muz
Upper	Surkhandarya	Denau	Den
Upper	Samarkand	Urgut	Urg
Upper	Surkhandarya	Sariasiya	Sar
Upper	Surkhandarya	Shurchi	Shu
Upper	Surkhandarya	Angor	Ang
Upper	Surkhandarya	Altinsay	Alt
Upper	Dzhizak	Zaamin	Zaa
Upper	Surkhandarya	Termez	Ter
Upper	Surkhandarya	Termez city	Ter

Annex 5 – Water availability data per district

Table 16. Water availability of the regions in the Amu Darya River basin during the off-irrigation season

Regions	Year	Actual irrigated area, ' 000 ha	Total actual intake from sources, Mm^3	Actual water supply at district boundaries, Mm^3	Water supply at farms boundary, Mm^3		Water Availability, %	Efficiency
					Plan	Fact		
Republic of Karakalpakstan	2017-18	284,30	1291,71	1199,80	1107,60	1007,83	91,0	0,78
	2018-19	288,34	1345,53	1250,02	1292,00	1050,02	81,3	0,78
	2019-20	216	886,33	836,37	1142,27	702,55	61,5	0,79
	2020-21	216,00	886,33	836,37	1142,27	702,55	61,5	0,79
Khorezm region	2017-18	226,17	1187,86	1099,22	1199,35	917,10	76,5	0,77
	2018-19	225,34	1094,22	1011,70	1103,73	842,73	76,4	0,77
	2019-20	225,06	1217,84	1129,03	1077,70	942,62	87,5	0,77
	2020-21	223,96	933,44	866,14	1129,89	730,25	64,6	0,78
Bukhara region	2017-18	275,11	1479,44	1355,10	1089,19	1074,98	98,7	0,73
	2018-19	274,65	1245,40	1140,25	911,88	894,88	98,1	0,72
	2019-20	274,60	1391,50	1345,50	1075,44	1067,00	99,2	0,77
	2020-21	274,56	1213,10	1181,37	1075,35	928,93	86,4	0,77
Kashkadarya region	2017-18	460,37	1315,51	1121,50	1329,54	984,47	74,0	0,75
	2018-19	460,37	1486,35	1404,02	1280,22	1182,45	92,4	0,80
	2019-20	439,59	1504,69	1347,97	1309,84	1216,03	92,8	0,81
	2020-21	455,55	1532,37	1407,66	1335,90	1271,53	95,2	0,83
Surkhandarya region	2017-18	326,00	1045,72	941,15	826,90	840,61	101,66	0,80
	2018-19	326,00	1012,88	911,59	826,90	814,01	98,44	0,80
	2019-20	326,00						
	2020-21	326,00	1012,86	911,58	974,43	759,07	77,90	0,75

Source: BISA data, ICG

Table 17. Water availability of the regions in the Amu Darya River basin during the irrigation season

Regions	Year	Actual irrigated area, ' 000 ha	Total actual intake from sources, Mm^3	Actual water supply at district boundaries, Mm^3	Water supply at farms boundary, Mm^3		Water Availability, %	Efficiency
					Plan	Fact		
Republic of Karakalpakstan	2018	509,56	4903,00	4265,59	4693,55	3583,1	76,3	0,73
	2019	510,39	6248,48	5599,03	4225,04	4703,19	111,3	0,75
	2020	375,28	4528,47	3888,54	3776,84	3266,37	86,5	0,72
	2021	332,72	4316,13	3533,32	3781,21	2967,99	78,5	0,69
Khorezm region	2018	222,96	2576,46	2392,50	2361,58	1998,57	84,6	0,78
	2019	236,93	3294,22	3054,46	2359,40	2555,40	108,3	0,78
	2020	243,99	2636,75	2458,58	3023,88	2068,05	68,4	0,78
	2021	235,94	2305,39	2147,99	2912,96	1827,16	62,7	0,79
Bukhara region	2018	274,65	2808,89	2575,90	2730,78	2098,80	76,9	0,75
	2019	274,60	2995,04	2747,16	2677,98	2242,50	83,7	0,75
	2020	274,60	2680,86	2534,51	2717,79	2064,57	76,0	0,77
	2021	274,60	2099,16	1999,34	2955,03	1615,35	54,7	0,77
Kashkadarya region	2018	515,08	3097,88	2677,23	4443,84	2374,48	53,4	0,77
	2019	514,57	3600,79	3406,88	4861,83	3101,63	63,8	0,86
	2020	514,11	3895,31	3461,99	4634,73	3074,13	66,3	0,79
	2021	514,11	2828,96	2513,38	4827,91	2191,68	45,4	0,77
Surkhandarya region	2018	326,00	2516,00	2378,44	2301,21	2140,60	93,02	0,85
	2019	326,00	2516,00	2378,44	2301,21	2140,60	93,02	0,85
	2020	326,00						
	2021	326,00	2239,96	1856,51	3008,54	1670,85	55,54	0,75

Source: BISA data, ICG