Community Environmental Health Risks in Karakalpakstan, Uzbekistan: Results of Preliminary Assessment






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Prepared for Médecins Sans Frontières (MSF) *and*

Ministry of Health of Karakalpakstan (MOHK)

8 November 2023

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Acronym List

ADB	Asian Development Bank
As	arsenic
Ba	barium
Ca	calcium
Cd	cadmium
Cr	chromium
Cu	copper
DCINA	Dichloran
DEHP	bis(2-ethylhexyl) phthalate
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
EC	electrical conductivity
EH	environmental health
HCCH or HCH	hexachlorocyclohexane (lindane)
KK	Karakalpakstan
KMI	Karakalpakstan Medical Institute
MCL	maximum contaminant level
Mg	magnesium
mg	milligram
MOHK	Ministry of Health of Karakalpakstan
MOU	memorandum of understanding
MSF	Médecins sans Frontières (Doctors Without Borders)
µg	microgram
ND	not-detected
Pb	lead
QAQC	quality analysis and quality control
RSL	regional screening level
SES	Sanitary Epidemiological Service

TB	tuberculosis
TDS	total dissolved solids
TIFO	TerraGraphics International Foundation
US	United States
USEPA	United States Environmental Protection Agency
WTP	water treatment plant
XRF	X-ray fluorescent spectrometer
Zn	zinc

Location Names

Every effort has been made to use consistent spelling within this report for the names of cities, rayons, water bodies, etc. However, due to the differences in alphabets and conversion from cyryllic, multiple spellings for these locations exist. Because other reports and authors may use different spellings, the following list is intended to help readers compare locations.

Name	Alternative Spellings	Name	Alternative Spellings
Altinkul Canal	Altinqol, Altinqul	Paxtaobod	Pakstaobad
Amudarya River	Amu Darya	Qipshadarya	Kipshadarya
Aqmangit	Akmangit	Shiminay	Shumanay
Biruni	Beruni	Sueli Canal	Suelli, Suenli, Suelle, Suwelle
Chimbay	Shimbay	Takhatapur	Taxhatapur, Takhatapor
Ellikqala	Ellikala	Taqiyatas	Takiatash
Kanlikul	Qanlikul, Qonlikol	Tortkul	Tortqul, Turtkul
Karakalpakstan	Qaraqalpakstsan	Yambasqala	Yambaskala
Khodejli	Xojeli		
Kyzylzhar	Kizilzhar		
Moynaq	Muynak		

1 EXECUTIVE SUMMARY

MSF has worked in the semi-autonomous Republic of Karakalpakstan (KK) in Uzbekistan since 1998. The initial project goal was to support the communities impacted by the effects of environmental degradation related to the Aral Sea Crisis. MSF conducted an environmental assessment, however the high burden of tuberculosis (TB) compelled MSF to refocus their efforts on TB treatment, which they have supported for the past 24 years. During this time, the Aral Sea Crisis situation has not improved. MSF and MOHK revived their ambitions to support the communities affected by environmental degradation in Karakalpakstan and engaged TerraGraphics International Foundation (TIFO) to support project development and implementation. TIFO made a preliminary visit to KK in October 2022 and completed an environmental assessment in collaboration with MOHK and MSF in March-April 2023. The sampling strategy was developed in consultation with partners, including researchers from the Karakalpakstan Medical Institute (KMI), and based on information from previous research efforts and MOHK monitoring data.

The sampling effort covered most of the populated area of Karakalpakstan by dividing the region into six "zones" along the Amudarya River. The MOHK/MSF/TIFO team visited 80 distinct sampling locations and collected 140 samples. Real time monitoring devices were also installed to collect air quality data that are publicly availabile. Soil, water, and sediment samples were analyzed at three laboratories. In total, this is the largest and most comprehensive set of environmental data to be collected and analyzed from the region in more than 20 years. The successful collaboration between MOHK, MSF, TIFO and in-country laboratories has resulted in a positive prognosis for future collaboration. The complex laboratory arrangements were necessary to assess and take full advantage of different analytical capabilities and to provide the laboratories an opportunity to compare results within and between their respective facilities. Results from the analysis of duplicate samples indicate the laboratories produced reliable and reproducible results, although some specific questions remain to better understand the environmental results and associated health risks to the local populations. The local KK laboratories are undergoing modernization and this ongoing environmental health project could be of help in building additional capacity.

The 2023 sampling results confirm that water quality concerns and historic pesticide use remain significant issues. The Soviet-era diversion of the Amudarya river to irrigate agricultural products, namely cotton, continues to have impacts on water quantity and quality today. Results from March-April 2023 indicate that drinking water salinity poses direct health risks, and is potentially interacting with other compounds in the water (nitrogen, organic material, pesticides) to effect additional health risks. The byproducts of lindane and dichlorodiphenyltrichloroethane (DDT), pesticides now widely banned and no longer used, continue to be elevated above acceptable levels in water samples, albeit at much lower concentrations than in previous decades. Chromium, arsenic, and uranium were also detected in some water samples (often below or at health-based water quality standards) and warrant additional investigation.

Soil and sediment samples contain elevated levels of pesticides that are also of human health concern. Air data are not yet available for analysis; results from real-time particulate monitors will be analyzed and presented as a supplemental chapter to this report.

The results present a temporal snapshot of environmental conditions. Given the high rates and seasonality of pesticide and fertilizer application, fluctuation in surface water flows and salinity, and use of canals to supplement drinking water supply, contamination levels likely vary over time. These results should be considered preliminary, pending additional investigations contingent on the interest and resources of MOHK, MSF, and TIFO and analysis by other researchers, agencies, and external partners.

The main body of the report expands on these findings and presents detailed recommendations and immediate steps to be taken. Recommendations for 2024 and beyond include:

Identify and intervene with vulnerable and neglected populations: Previous investigations identified a large percentage of rural residents are using unsafe shallow wells dependent on intermittent canal water. Findings from this 2023 assessment highlight that these isolated agricultural communities often lack adequate nutrition, hygiene facilities, access to health care, and are vulnerable to endemic diseases. Family members routinely engage in farm labor and direct application of agricultural chemicals. Ready access to a variety of pesticides and herbicides, some considered controlled substances in Uzbekistan and other nations, combined with the lack of information on safe handling and application, put agricultural workers (especially women) and their families at significant risk.

Develop a collaborative water quality assessment partnership: Development of a comprehensive multi-partner water quality improvement strategy for Karakalpakstan is strongly recommended. Most water quality improvement projects typically address water quantity and quality. Both are critical issues, however, Karakalpakstan faces inter-related multi-factor challenges in securing safe drinking water for the population. Both current and residual pesticide concentrations are potential hazards, salinity is increasing as freshwater river flow is diminishing, and traditional agricultural practices contribute salts to surface and groundwater and increase the demand for chemical amendments. Chemical interactions between chlorination, salts, pesticides, herbicides, and nitrogen compounds are a potential concern and are poorly understood. These factors vary seasonally, geographically among Rayons, between urban and rural populations, and are exacerbated by demographic and socio-economic conditions that have not been characterized.

Analyze trends in environmental monitoring data: Development of a more robust environmental contamination database would significantly enhance health authorities' ability to identify and respond to increasing climate-related health risks in the Republic. Historic results are currently maintained on paper in Rayon level files. These sources should be compiled into a digitized accessible database and maintained that way into the future for more precise and quantitative analysis of trends in environmental conditions and human health risks.

Support SES monitoring programs: SES is currently building laboratory capacity to monitor water and soils for contaminants by purchasing and installing new analytical equipment. Developing a strong laboratory quality control program will assist SES in becoming proficient with this equipment. In parallel, periodic sampling throughout the agricultural season should be performed to capture the types and application rates of current pesticides, and potential at-risk populations. This sampling should be integrated into SES's existing monitoring program and results included in the proposed digital database.

Engage in additional investigations: Recommendations for additional investigations and clarification of 2023 data are included in the text of the report.

Partners should review this draft, provide edits, comments, and additional text as needed, and then convene to discuss next steps.

2 PROJECT BACKGROUND

MSF has worked in the semi-autonomous Republic of Karakalpakstan (KK) in Uzbekistan since 1998. The initial project goal was to support the communities impacted by the effects of environmental degradation related to the Aral Sea Crisis. MSF conducted an environmental assessment, however the high burden of tuberculosis (TB) compelled MSF to refocus their efforts on TB treatment. For the past twenty-four (24) years MSF has been supporting the Ministry of Health in Karakalpakstan (MOHK) to better manage TB.

During this time, the Aral Sea Crisis situation has not improved appreciably. In Karakalpakstan, there have been efforts to reduce water use from the Amudarya River and some drought and salt-tolerant plants have been established in areas of the former seabed, but these appear to have had limited impact on environmental health (EH). MSF and MOHK revived their ambitions to support the communities affected by environmental degradation in KK and signed a Memorandum of Understanding (MOU) detailing the goal of collaborating to pursue an investigation and intervention.

MSF engaged TerraGraphics International Foundation (TIFO) to support EH project development and implementation. MSF and TIFO have successfully collaborated on other environmental health projects prior to engaging in the Aral Sea Crisis. TIFO is a named partner in the MOU with MOHK. After completing an in-depth review of the current information and previous environmental assessments, TIFO made a preliminary visit to KK in October 2022. Sampling results from the Nukus and Republican SES laboratories were largely inconclusive due to misunderstandings regarding standard analytical protocols. However, important foundations for collaboration with MOHK, the Sanitary Epidemiological Station (SES, under MOHK), and other local partners were established and a better understanding of regional capabilities and resources was developed. The October 2022 experience provided useful information for the March-April 2023 Environmental Assessment, which was planned in collaboration with MSF and MOHK. The sampling strategy was developed in consultation with partners and based on information from previous research efforts and MOHK monitoring data. Details can be found in the 6 March 2023 *Memorandum: Collaboration for Spring 2023 Environmental Assessment* and the Terms of Reference for the March-April TIFO trip. A Trip Report summarizing activities accomplished was shared with MSF on 4 May 2023.

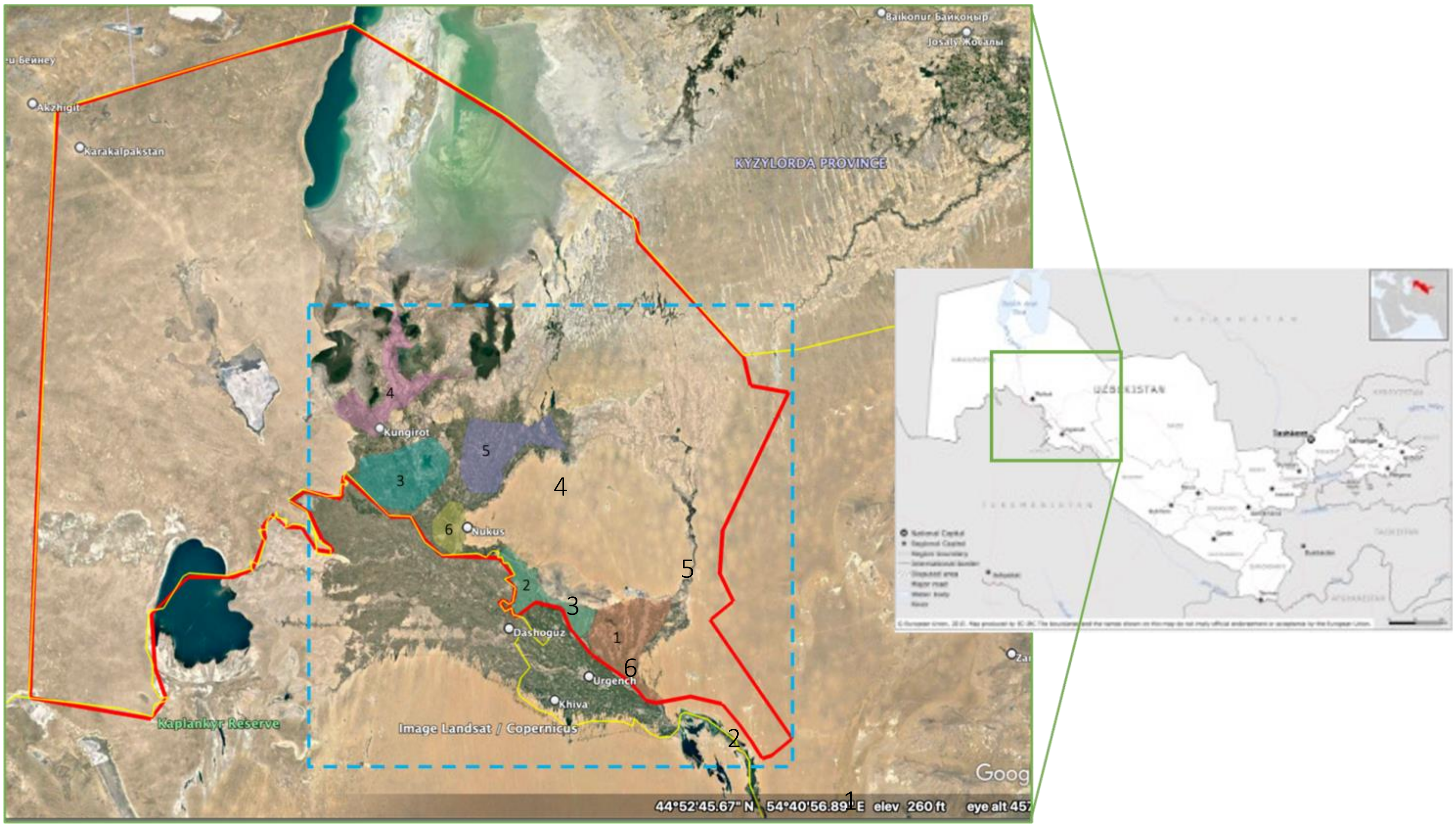
3 SPRING 2023 FIELD ACTIVITIES

3.1 Sample Locations

Air, soil, and water sampling occurred in six regions or “zones.” These zones were defined based on location of populated areas along the southern (upstream) and northern (downstream) sections of the Amudarya River and its irrigation canals (see

Figure 1). Figure 1 shows six colored polygons that approximate the intended boundaries of the zones sampled within the most populated areas of the region. The blue dashed box in Figure 1 indicates sample area detail described in greater detail in Figure 2. Most zones included more than one government administrative unit (Rayon). Sample locations covered most of the *populated areas* of the country; areas outside the 6 zones are largely desert and have few – if any – communities.

Figure 1. Sampling zones for spring 2023 sampling. The Karakalpakstan border is approximated in red.



3.2 Summary of sampling methods

The MOHK-TIFO-MSF field team visited 80 sites as summarized in Section **Error! Reference source not found.** (Appendix) and in

Figure 2 and Table 1. These included government water facilities, rural community wells, irrigation canals/collector canals, schools, playgrounds, residences, and agricultural fields/orchards. A combination of soil and/or water samples was collected at these sites. Soil and water samples were collected in sterilized glass jars and stored at 4-8 °C for the duration of the sampling period, until delivery to laboratories. Soil samples were comprised of a minimum of 5 aliquots (subsamples); these were thoroughly homogenized in stainless steel bowls before placing into sample containers. Sample splits were collected at many sites to enable intra- and interlaboratory data comparisons.

A total of 70 water samples, 54 soil samples, and 16 sediment samples were collected (see Table 1). The strategy was to use Tashkent SES as the main laboratory for analyses, with additional samples sent to MOHK SES and Nukus AgroChemical Lab.

When appropriate, *in situ* X-Ray Fluorescent Spectrometer (XRF) data was also collected to screen for heavy metals in surface soils. The October preliminary site visit did not indicate heavy metals concerns in most regions; findings from the March trip were similar. XRF screening results of interest are summarized in **Error! Reference source not found.** in the Appendix.

One weather station with direct-to-Wi-Fi capabilities was installed at the MSF office in Nukus and is currently visible on the Weather Underground website and app.

PurpleAir© particulate monitors were installed for 2-3 days in most of the zones, as were weather monitoring stations when feasible. Three PurpleAir© sensors were used during the field work and then permanently installed in three locations. They are currently reporting data to the [PurpleAir© network](). Two are located at the Rayon SES buildings in Mangit and Moynaq, and one is located at the MSF office in Nukus. Results from the PurpleAir© monitors are publicly viewable online. Data from these sensors will be analyzed over several seasons.

Figure 2. Sites visiting during field sampling. Circles with numbers in legend indicate total number of sites per zone, which aren't all visible due to image scaling. Exported from Kobo Humanitarian Survey Tool.

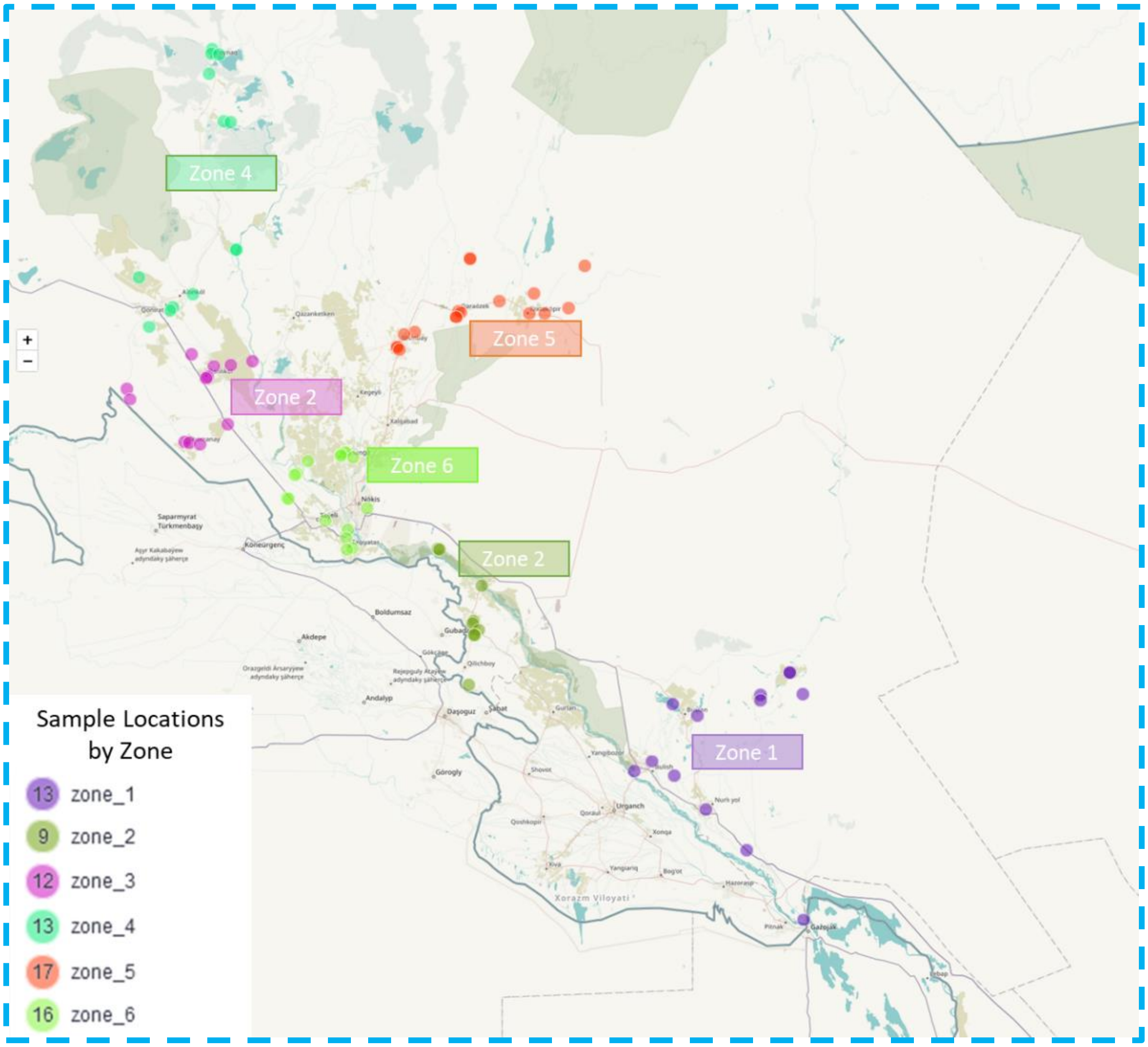


Table 1. Samples collected by Zone and sample type (media).[1]

Media	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Total
Sediment	5	2	2	4	2	1	16
Soil	6	6	12	5	13	12	54

[1]Duplicate and split samples were collected in most locations and are included in the totals as unique samples.

Water	15	10	9	12	11	13	70
Total	*26*	*18*	*23*	*21*	*26*	*26*	*140*

Table 2. Count of samples sent to laboratories.

Media	AgroChem	MOHK SES	Tashkent SES	*Total*
Sediment	5	0	11	*16*
Soil	19	0	35	*54*
Water	0	20	50	*70*
Grand Total	*24*	*20*	*96*	*140*

4 RESULTS OF ENVIRONMENTAL ASSESSMENT

Tables detailing all sample results from each laboratory are located in Sections **Error! Reference source not found.-Error! Reference source not found.** (Appendices). Summary results for quality analysis/quality control (QAQC), water, soil, and sediment samples are presented in the following subsections.

4.1 Laboratory Quality Assurance and Quality Control (QAQC)

The local and regional labs used in this effort are the Republican and Nukus City SES (collectively referred to as Nukus SES), the Karakalpak AgroChemical Lab (also located in Nukus), and the Uzbekistan National SES located in Tashkent. Each of these laboratories have varying specialties and capabilities, all expressed interest in collaboration, and all are competent in current practices. However, the Karakalpak Laboratories depend on some outdated equipment and methodologies as described below. Tashkent National SES Laboratory has state-of-the-art capabilities.

Most of the Spring 2023 samples were sent to the Tashkent SES Laboratory - 11 sediment, 35 soil, and 50 water samples for organo-chlorine, organo-phosphorous, and organo-nitrogen compounds, using internationally recognized protocols. Twenty (20) duplicate water samples were sent to the Republican SES Laboratory for Standard Drinking Water and Open Reservoir analyses, enabling comparison to their routine sampling. Five (5) sediment and 19 soil samples (all duplicates) were sent to the AgroChemical Laboratory, which provides more detailed salinity analyses and can measure more metals and chlorinated pesticides than SES. Additional information on laboratory specialties and capacity is presented in the TIFO March 2023 Trip Report.

4.1.1 Uzbekistan National SES Laboratory, Tashkent

Results from split samples sent to the same laboratory, referred to as double blinds, are presented in

Table 3 and Table 4.

Double blind water results for alpha and beta hexachlorocyclohexane (HCCH, lindane byproducts) results were moderately different, but may be within the error values for the reporting laboratory; this needs to be confirmed as Tashkent SES did not provide detection or reproducibility criteria. Lindane (gamma HCCH) results were comparable between water samples, as were dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), and DDT results.

Double blind soil results for alpha HCCH results were 2 orders of magnitude different from each other, which is a significant difference that should be reviewed with the Tashkent lab. Beta HCCH and lindane (gamma HCCH) were comparable. Heptachlor results were comparable, but Aldrin results were orders of magnitude different (3.7 versus 0.16 mg/kg) and should also be reviewed to better understand potential sources of the variability.

Table 3. Double blind water sample results from Tashkent SES.(ND=not detected).

Sample ID	Media	Lab Index	α,-HCCH	β-HCCH	γ HCCH	DDE	DDD	DDT
KK23-Z2-W44, KK23-Z2-W45	Water	13	0.00031	0.00014	0.00002	0.00001	0.00001	0.00001
		14	0.00005	0.00006	0.00001	0.00001	ND	ND

Table 4. Double blind soil sample results from Tashkent SES.

Sample ID	Media	Lab Index	α,-HCCH	β-HCCH	γ HCCH	Heptachlor	Aldrin	DDE	DDD	DDT
KK23-Z1-S18, KK23-Z1-S19	Soil	12	0.0231	0.0001	ND	0.2016	3.752800	ND	ND	ND
		13	0.0002	0.0001	ND	0.2197	0.1557	ND	ND	ND

4.1.2 Karakalpakstan SES Laboratory, Nukus

The results from the double blind water samples (Table 5) were all comparable.

Table 5a and b. Double blind soil sample results from Nukus SES.

Sample ID	Media	Lab Index	Smell	Color level	Turbidity mg/L	PH	Oxidability mg/L	Total hardness mg/eq L	Dry residue mg/L	Total iron mg/L	chlorides mg/L	sulfates mg/L	fluorine mg/L
KK23-Z5-W49, KK23-Z5-W51	Water	12	ND	33	2.3	8	1.6	20.5	2508	0.1	533	345	0.08
		13	ND	29	2.4	8	1.6	20	2534	0.1	552	331	0.09

Sample ID	Media	Lab Index	Nitrate mg/L	Nitrite mg/L	Cadmium mg/L	Copper mg/L	Lead mg/L	Zinc mg/L	Chromium^{6+} mg/L	Exceeds UZ standard Y/N
KK23-Z5-W49, KK23-Z5-W51	Water	12	0.4	0.007	ND	0.3	ND	ND	0.02	Y
		13	0.7	0.013	ND	0.25	ND	ND	0.02	Y

4.1.3 AgroChemical Laboratory, Nukus

Double blind soil sample results (

Table 6) were all comparable. However, the results for metals in soil (Cu, Mn, Ba, Mo, Co, Fe) and mobile compounds (Cu, Co, Zn, Cd, As, pesticide residues) were all non-detect ("ND"), which is unlikely given that several of these metals were detected with the XRF screening. Results from *in situ* XRF analyses indicate that the metal results from AgroChem are not comparable. Additionally, Tashkent SES identified pesticide residues in some of the split samples that were not detected by AgroChemical lab. Discussions with the AgroChemical lab should be undertaken to confirm analytical protocols, reporting and detection limit criteria.

Table 6 a-d. Double blind soil sample results from Nukus AgroChemical Lab (ND=non detect).

Sample ID	Media	Lab Index	Dry residue (%)	pH	Amount of salt (%)	P_2O_5 (mg/kg)	K_2O (mg/kg)	Humus (%)	Sieve Size
KK23-Z1-S21,	Soil	6	0.41	6.6	0.38	53.8	290	0.14	0.25
KK23-Z1-S22		7	0.34	6.5	0.32	42.0	312	0.46	0.25

Sample ID	Media	Lab Index	Bicarbonate HCO_3		Chlorine		Sulphate SO_4		Calcium		Magnesium		Anions – cations
			%	mg/eq	%	mg/eq	%	mg/eq	%	mg/eq	%	mg/eq	
KK23-Z1-S21,	Soil	6	0.03	0.6	0.071	2	0.168	3.5	0.025	1.25	0.018	1.5	6.1
KK23-Z1-S22		7	0.022	0.36	0.064	1.8	0.144	3	0.02	1	0.023	1.9	5.16

Sample ID	Media	Lab Index	Na+K separately		Sum of components	Salting type	Salting level	Humidity (%)	Copper (mg/kg)	Manganese (mg/kg)	Barium (mg/kg)
			mg/eq	%							
KK23-Z1-S21,	Soil	6	3.35	0.07	0.38	X-C	Strong	4,2	ND	ND	ND
KK23-Z1-S22		7	2.26	0.052	0.32	X-C	Strong	5,02	ND	ND	ND

Sample ID	Media	Lab Index	Molybdenum (mg/kg)	Cobalt (mg/kg)	Iron (mg/kg)	Mass fraction of mobile Cu & Co (mg/kg)	Mass fraction of Zn (mg/kg)	Mass fraction of Cd (mg/kg)	Mass fraction of As (mg/kg)	Pesticide residues (mg/kg)	Organochlorine & biphenyl residues (mg/kg)
KK23-Z1-S21,	Soil	6	ND	ND	ND	ND	ND	ND	ND	ND	ND
KK23-Z1-S22		7	ND	ND	ND	ND	ND	ND	ND	ND	ND

4.1.4 QAQC Findings

Overall, results of the QAQC analyses are encouraging, although some inconsistencies warrant follow-up with respective labs. Double blind results should be reviewed with respective laboratories to identify possible explanations for the discrepancies in the data.

4.2 Water Results

Irrigation diversions from the Amudarya River have resulted in a complex water management infrastructure that interconnects both drinking and irrigation supplies throughout the Republic. The original concept was to capture clean water in the Tuyamoyan Reservoir near the Turkmenistan border and provide drinking water through a 350 km pipeline to the population centers as far north as Moynaq. Several downstream diversions then routed the river to thousands of kilometers of irrigation canals. Irrigation return flows were to be diverted into "collector" canals paralleling the river and diverted to the Aral Sea, preserving both drinking and river water quality. However, diminishing water levels made this plan impracticable; all Amudarya River fresh water is diverted, and irrigation runoff waters are returned to the river to replenish surface flow and groundwater levels. Many rural areas use these waters for domestic purposes either through canal water or shallow wells that draw from "perched" aquifers created by irrigation. Urban areas now routinely divert river or canal water to treatment plants to be disinfected and supplement the drinking water supply. During low-water periods, collector canal water is re-used for irrigation or other purposes.

The declining water quality is exacerbated by irrigation practices to support commodity crops, particularly cotton. Increasing soil salinity threatens yields. The Aral Sea area is reportedly the northern-most major cotton producing region in the world, and one of few relying on annual cropping. Repeated planting and tilling cycles greatly increase the need for amendments, fertilizers, and agrochemicals. To maintain productivity, the fields are flooded in the off-season to wash away salt. This results in increased salinization of groundwater and surface waters, particularly as the overall water supply decreases. The practice also requires extraordinary levels of soil amendments and chemical fertilizers to replace nutrients and humic materials lost in flushing. Residual pesticides and nutrients flushed with the salts contribute to water contamination.

During the Soviet era, cotton production in Karakalpakstan was notorious for the magnitude of herbicide and insecticide use, most notably using highly persistent DDT and HCH. Investigations in the early 2000s indicate as much as 90% of cropland was contaminated with these chemicals. The Aral Sea was identified as a sink for these persistent pollutants and windblown dust from the contaminated dry seabed has become a concern. Additional details on the history of water diversion, pesticide use, and environmental health research conducted by Karakalpak researchers can be found in the March 2023 TIFO Trip Report.

Four primary factors seem to interact to adversely affect water quality in the Karakalpak domestic water supply system:

i) Water quality in the Amudarya River as it enters the Republic
ii) Salinization as the water system progresses north
iii) Agricultural-related chemical contaminants
iv) Inconsistent and inadequate water supply and disinfection

These factors vary by season and water year, and are exacerbated by an aging infrastructure, and climate-related and regional water conflicts that threaten supplies. As a result, the quality of drinking water delivered at any point in the system can vary considerably.

As a result, it is important to develop a critical understanding of the Karakalpakstan drinking water infrastructure and salinization effects within the system. This report relies on a comprehensive description of this system from the *West Uzbekistan Water Supply Improvement Project Report* by the Asian Development Bank (ADB) from 2016. The ADB project was designed to upgrade water supply infrastructure and services and provides a comprehensive description of drinking water supply systems and salinity, including system-wide data on water quality for the 2016 water year. The following section provides a summary of the 2016 ADB system-wide salinity results and Section 6 (Appendix) compares salinity parameters measured in March 2023 to the ADB 2016 levels. *Partners should identify the extent to which the ADB Project and any additional improvements to drinking water infrastructure have been implemented.*

4.2.1 Water Salinity

Seventy (70) samples were collected for water quality and salinity evaluations. Twenty samples were analyzed at the Republic SES Laboratory in Nukus using the standard methodologies applied in the SES drinking water quality monitoring program. SES water results have been compared to the 2016 ADB Report, which evaluated drinking water in Karkalpakstan. Fifty (50) samples were analyzed at the Tashkent SES lab.

Table 7 summarizes the primary water quality salinity parameters from the March 2023 Survey. Many, but not all, water samples were taken at water treatment plants (WTPs). Surface waters used for drinking and domestic applications are highlighted in blue, groundwater sources obtained from wells are in green, and collector canals are highlighted in brown.

Table 7. Summary salinity parameters for water samples collected during March 2023 survey.[2]

								Cations						
Zone	Sample ID	Description	Color Level	Turbidity mg/dm³	pH	Oxidability mg/dm³	Total Hardness mg/eq dm³	TDS mg/l	Na mg/l	Ca mg/l	Mg mg/l	K mg/l	Mn mg/l	Cu mg/l
1	KK23-W17	Inlet Canal to WTP	301	24	8.0	0.7	10.3	1331						0.26
1	KK23-W20	WTP Post-treatment	20	0	8.0	1.1	9.6	1356						0.1
1	KK23-W25	Water distribution facility	2	0	8.0	0.3	0.3	563						0.02
1	KK23-W23	Community well 13m deep	8	0	8.1	0.5	5.2	793						0.06
1	KK23-W28	Collector canal from fields	7	0	8.1	1.2	29.8	3852						0.3
2	KK23-W36	Water distribution post-chlorination	77	5	8.0	1.6	10.8	1433						0.25
2	KK23-W39	Residential Well	4	0	7.7	0.6	13.1	1548						0.05
3	KK23-W60	Well at Bazaar	12	1	7.8	0.4	13.0	1574						0.17
3	KK23-W63	Irrigation Canal	15	1	7.4	1.1	33.7	3558						0.4
3	KK23-W68	Community Well 10 meters deep	8	0	7.6	0.5	14.6	1638						0.28
4	KK23-W71	Reservoir inlet to WTP	9	0	7.8	0.3	8.6	1766						0.17
4	KK23-W82	Amudarya River	31	4	7.8	0.7	11.9	1625						0.28
4	KK23-W74	Community Well 7m deep	6	0	8.0	0.8	10.8	1254						0.26
5	KK23-W57	Irrigation Canal	35	3	8.0	2.2	9.8	1420						0.08
5	KK23-W48	Community Well 10-20 m deep	22	0	7.9	0.4	12.9	1241						0.055
5	KK23-W51	Collector canal	29	2	8.0	1.6	20.0	2534						0.25
5	KK23-W49	Collector canal	33	2	8.0	1.6	20.5	2508						0.3
6	KK23-W10	Community Well 40-50 m	8	0	8.1	0.4	11.3	1612						0.1
6	KK23-W12	Community well 10m deep	4	0	7.7	0.9	17.0	1932						0.15
6	KK23-W8	Settling Pond Intake Canal	65	2	7.0	1.2	10.0	1190						0.2

March 2023 surface water sources TDS levels ranged from 563 mg/l to 1766 mg/l with most observations in the 1200 mg/l to 1400 mg/l concentration range. Similar TDS levels are observed in the southern and central reaches of the Amudarya River. Well water sources in most southern Zone 1 near Tortqul were notably lower with TDS concentrations near 800 mg/l. One of these wells was reportedly known for good tasting water and many people travel considerable distances to exploit the supply. Well water sources farther north, however, showed higher

[2] TDS is either dry residue or calculated as the sum of salt ions using the following equation: TDS (est) = Sum(Na,K, Ca, Mg, HCO3, Cl, SO4)/.95, HCO3=.66CaCO3

salinity ranging from 1600 mg/l to 1932 mg/l TDS. Collector canals highlighted in brown show the highest TDS concentrations, typically exceeding 2500 mg/l to >3500 mg/l, as expected.

4.2.2 Comparisons of 2023 and 2016 Water Quality Results

The 2016 ADB report summarized surface water quality at the inlets to the main WTPs providing drinking water to the population centers. Monitoring results were obtained from gauging stations at Pakhta Canal intake (feeding Tuyamuyun WTP), Sueli Canal intake (feeding Takhiatash WTP), Mangit Canal intake (feeding Mangit WTP), Altinkul Canal intake (feeding Kungrad District Altinkul headworks), and Tallyk Canal intake (feeding Muynak District headworks). Water quality in each of these inlet canals reflects both contamination levels for both the Amudarya River at the diversion point, and the supply to the WTPs and the respective settling basins.

Figure 3 and Figure 4 below are reproduced from the ADB to illustrate the seasonal pattern in Total Dissolved Solids (TDS) and turbidity, respectively, for 2016. TDS readings reflect salinity and turbidity is a general indicator of suspended solids. Turbidity is reduced at the WTPs by settling basins prior to chlorination and distribution from the WTPs. TDS levels will generally remain constant through the WTPs, unless specific efforts to de-salinize are applied.

Reportedly, there were some desalination plants at specific locations in the past, that have been abandoned due to disrepair or budgetary constraints. *Partners should consider determining the status of any operational or abandoned desalination or other treatment facilities.*

Figure 3. TDS of raw water at canal intakes for water supplies (ADB 2016 Report, Figure 3.1).

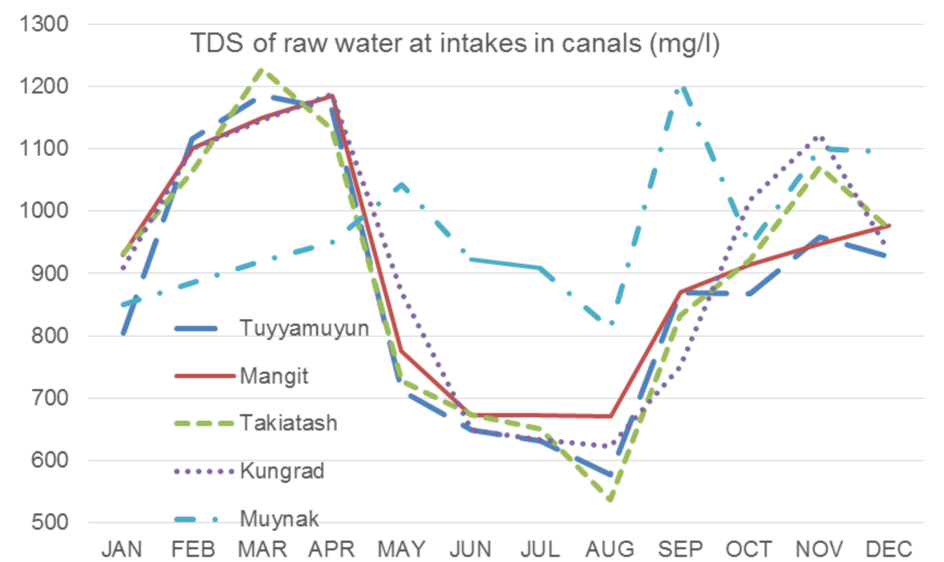
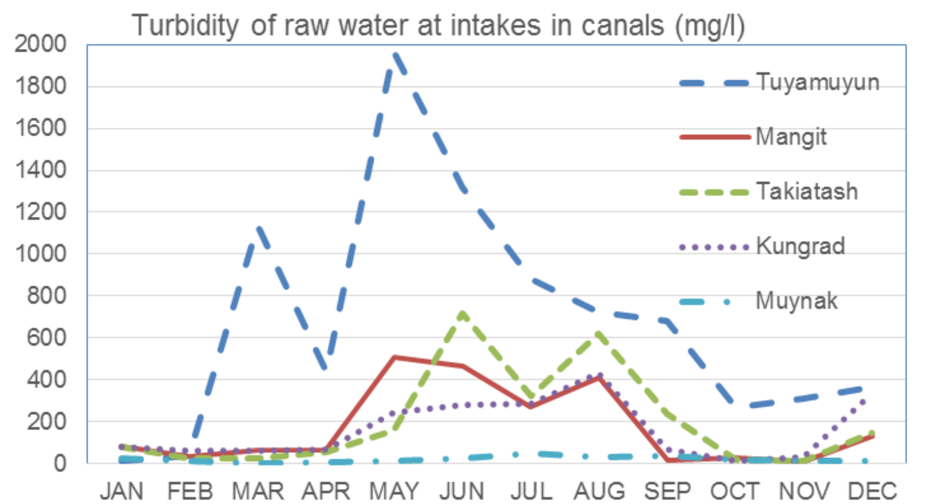


Figure 4. Turbidity of raw water at canal intakes (ADB 2016 Report, Figure 3.2).



The 2016 data show a clear seasonal pattern in salinity and turbidity levels at the treatment plant inlets. In 2016, maximum TDS levels near 1200 mg/l were observed in March-April and decreased by 50% to near 600 mg/l by August, then gradually increased to a second peak in November and returned to intermediate levels in December-January. The ADB report attributes these peaks to heavy solids loading in the Amudarya River during rainfall and snowmelt events in the upper catchment basin. TDS levels at Muynak did not show such a regular pattern with intermediate concentrations evident throughout the year. Turbidity readings were highest in the summer (May through August) and were low the remainder of the year. Muynak and Tuyamuyun were an exception. Muynak showed low turbidity throughout the year, possibly due to the sample being collected after the large settling ponds upstream of the Muynak chlorination and distribution facility. The Tuyamuyun turbidity measurements likely reflect Amudarya River levels at the diversion point from the reservoir.

Comparison of the March 2023 salinity results to the 2016 ADB findings is summarized below and detailed for each monitoring location in Section 6. Table 11 compares the 2016 ADB and 2023 MOHK/MSF/ TIFO/ water quality findings at the Pakhta or Sueli Canal intake feeding the Tuyamuyun WTP. The ADB Report summarized the annual average and range (minimum and maximum) values. Monthly results were available only from Figures 3 and 4 for TDS and turbidity. As a result, the March 2023 levels are compared to the annual range of values observed in 2016.

Table 8. Pakhta Canal Intake (feeding Tuyamoyan WTP). ADB results from table 3.1 in their 2016 report.

	Number	Turbidity (mg/l)	pH	Oxidability (mg/l)	NO3 (mg/l)	Alkalinity (meq/l)	Total Hardness (meq/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	TDS (mg/l)	SO4 (mg/l)	Fe (mg/l)	Cu (mg/l)	F (mg/l)
ADB 2016	Min	12	6.9	1.5	3	2.2	4.7	54.1	24.3	117.3	577	205	0.02	0.04	0.02
	Max	1970	7.2	2.7	4.25	2.9	10.8	132.3	58.3	290.7	1185	377.3	0.12	0.18	0.14
	Avg	678.2	7	2.1	3.5	2.5	7.7	97.4	34.5	190.6	871.5	287.1	0.06	0.11	0.07
2023 Results		24	8	0.70	4.8	ND	10.3	123	46	245	1331	278	0.16	0.26	<1.00

Seasonal patterns identified by the ADB indicate the March 2023 survey was conducted at peak TDS and lowest turbidity in the Spring season. Overall comparison of the 2016 and 2023 data indicates that the initial diversion from the Tuyamuyum reservoir showed dissolved oxygen levels less the half the 2016 minimum. TDS, pH, nitrate, iron and copper ion levels were higher than 2016 maximum values. These same degraded water quality effects were notable throughout the water conveyance systems and were evident at the downstream WTP and distribution and disinfection facility intakes. These trends suggest the declining water quality between 2016 and 2023 largely reflects differing conditions in the Amudarya River as it entered the Republic in 2016 and 2023 water years. Salinity levels, however, not only increase to the north, but were 30% to nearly 50% higher in 2023 compared to 2016.

The 2016 ADB report noted the downstream increase in salinity levels in the Amudarya and noted maximum concentrations in excess of 3 mg/l between March and May. TDS levels in the inlet canals were higher in 2023 than 2016 and generally increased downstream. However, the concentration in the Amudarya River in March 2023 was 1638 mg/l and did not show the 3 mg/l high noted in 2016. Higher salinity levels in the river, however, may manifest in the river as the irrigation season progresses.

Partners should consider investigating multiple years of data to better understand trends and variability in water quality in the Amudarya across water years.

4.2.3 Water Fertilizer and Pesticide Analyses

Pesticide results were provided by all laboratories. However, only Tashkent SES has the most appropriate equipment for producing reliable results for health assessment purposes. Local laboratory capacity in the Republic is, at present, dependent on outdated techniques that are only useful to detect the presence or absence of a limited number of organochlorine pesticides no longer in use. The Republic SES is currently attempting to significantly enhance the Rayon office and central laboratory capacity to monitor several classes of herbicides and pesticides. *Partners should support QAQC efforts to assist the SES in developing a rigorous and informative program of data collection and processing to better understand trends and variability in water quality in the domestic water supplies.*

Tashkent SES is world class laboratory and achieved much lower detection limits. Most of the elevated results for pesticides highlighted below are results from the Tashkent SES lab. Preliminary screening for organic pollutants involves a tradeoff between a broad screen to identify any compounds that might be present versus more precise measurement of suspect contaminants. The broad screen for the March 2023 samples did not indicate a large variety of contaminants. This may be due to the sampling occurring in the Spring prior to significant application of farm chemicals. *Partners should collaborate with the laboratories to better identify target compounds for analysis. This should be accomplished by i) developing a better understanding of chemicals being used or likely to be encountered in the field and ii) soliciting more detailed advice from the laboratories and in-country researchers and experts familiar with agricultural practices. Some confusion remains among the participating institutions as to whether the purpose of the sampling effort is to compare results to existing regulations, or a forensic investigation to better understand potential health and environmental implications.*

Hexavalent chromium: Some water samples analyzed by Nukus SES identified elevated chromium^{6+} (see **Error! Reference source not found.** in Appendix). Three of these values were above the USEPA screening level for Cr^{6+}(0.035 µg/L), but none were above the USEPA maximum contaminant limit (MCL, 100 µg/L)).

Nitrate and Nitrite: Nitrate/nitrite results from Nukus SES were all below USEPA MCLs, which is unexpected given the high application rates of fertilizers in the region (**Error! Reference source not found.** in Appendix). The lack of nitrates/nitrites could be due to sample preservation methods. Normally, the samples should be preserved with acid. Acidification of the March 2023 samples was not done to not interfere with detection of potential pesticides and herbicide contaminants or salinity levels. However, reducing the pH to <2 would potentially improve nitrate/nitrite recovery by laboratories. Collection of separate samples should be considered in future surveys.

The lack of elevated results could also be due to the timing of the sampling relative to the season when nitrate/nitrite compounds are being applied and then mobilizing in surface waters.

Lindane: Lindane (gamma HCCH or γ-HCCH) was historically used as a pesticide throughout the former Soviet Union. It is no longer in use, but byproducts from environmental degradation (alpha (α) and beta (β) HCCH) were identified during screening. Lindane (γ-HCCH) was not found above USEPA MCL values (0.0012 µg/L) in any of the samples analyzed. However, the lindane isomers α and β HCCH were above US drinking water regional screening levels (RSLs, non-enforceable screening values: 0.0072 µg/L and 0.025 µg/L for α and β HCCH, respectively) in *most* samples (**Error! Reference source not found.** in Appendix).

The highest value of α-HCCH was in a 10m deep well in Zone 2. The locations in order from highest to lower values α-HCCH levels are as follows: 10m deep well in Zone 2, collector canal in zone 2, a 380 m deep well at distribution facility in Zone 6 (post filtration), collector canal in zone 5, a 7 m hand pump well in Zone 4, irrigation canal in Zone 5, water facility (treated canal water from radial settling pond) in Zone 6, and an apartment complex well 10-20 m deep in Zone 5. There is no apparent spatial or vertical profile patterns to α-HCCH results as some shallow wells show results were an order of magnitude higher than deeper wells. The concentration likely varies with season. There seems to be fewer exceedances in Zones 1 and 3 than farther north. The elevated result in the 380 m deep well at distribution facility in Zone 6 (post filtration) is particularly unusual given the depth of the well and should be confirmed in future sampling efforts and discussed with local partners to understand possible causes.

The highest value of β-HCCH was at an apartment complex well 10-20 m deep in Zone 5. In order from high to low β-HCCH values, the remaining sites are as follows: 330 m deep well in Zone 5, Sueli intake canal in Zone 6, collector canal in Zone 5, irrigation canal in Zone 5, and a 10 m deep community well in Zone 6. Similar to α-HCCH, there are no apparent spatial or vertical profile patterns to β-HCCH.

DDT and its derivatives: DDT was historically used as a pesticide throughout the world and application rates in Central Asia were known to be particularly high, especially on cotton crops. DDT is banned and no longer in use, but the degradation byproducts of this compound (DDD and DDE) are known to exist in the environment for decades. DDT results were all below USEPA screening levels (for DDD, DDE, and DDT respectively: 0.032, 0.046, and 0.23 µg/L). One sample (from the Sueli canal near a treatment plant intake in Zone 3) had DDD levels above USEPA screening level. Eight (8) samples were found to have DDE values exceeding USEPA screening values (**Error! Reference source not found.** in Appendix). From highest to lowest, those are: the Amudarya channel in Zone 6, a well in Zone 4 that is too salty for drinking, the Amudarya River in Zone 4 (near to the salty well result), a well in Zone 1 (post chlorination), a 13 m community handpump well in Zone 2, the Sueli Canal in Zone 3, a 10 m deep handpump well in Zone 2, and a well at an apartment complex (10-20 m deep) in Zone 5.

4.2.4 Interactions between salinity and other water contaminants

Several Karakalpak health researchers have identified adverse health effects associated with the frequency of SES reported exceedances of drinking water hygienic requirements. It is likely that a substantial portion of the water samples that SES has historically identified as "exceeding hygienic requirements" were related to water salinity concentrations. Excess disease could be associated with salinity directly, or possibly to increased concentrations of other contaminants due "salinity cocktail" exposures. The "cocktail effect" refers to higher salt levels in water causing increased leaching of other contaminants, or promotion of chemical reactions that produce more toxic compounds. This is a particular concern with waters that contain organic materials, nitrogen compounds, herbicides, or pesticides. An additional concern is systems that are subject to excess chlorination in disinfection systems. As a result, it is plausible that the percentage of samples exceeding salinity hygienic requirements variable is not only an indicator of high salt content but is also a surrogate for other toxic chemicals resulting from the salt-related reactions. Currently, SES does not digitize or report summaries of pollutant concentrations. The reports available to investigators and health researchers only identify the percentage of samples exceeding hygienic criteria. *Partners should support SES to digitize the sample results and make these accessible to in-country investigators to identify potential links between increasing disease incidence and contamination of the water supply and other environmental pathways.*

Partners might consider sampling for disinfection by-products and additional organic nitrogen decomposition compounds. However, protocols for collection and analyses of these contaminants are more challenging. Also, corrective actions to retard the formation of these compounds would be difficult in the current state of the water delivery infrastructure. As such, sampling for these compounds might best be approached as an independent effort, as opposed to integrating it into the ongoing routine sampling.

4.3 Soil and Sediment Results

4.3.1 Soil and sediment salinity

The quality of both raw surface and ground water throughout Karakalpakstan is impacted by the high salinization of soils. Soil and sediment are the primary sources of salts in surface and groundwaters and ultimately domestic drinking water. Saline soils are also the primary source of windblown dusts and particulate air pollution in the country. The situation is exacerbated by agricultural practices that require frequent “flushing” (inundation with water) of the soils to reduce salt levels to facilitate crop production. Dissolved salts are either discharged to collection canals (often returning to the river) or this water percolates to the groundwater. This results in ever increasing salinization of water sources. The practice of flooding farm fields also flushes nutrients, agricultural chemicals, nitrates, and other contaminants to drinking water, potentially increasing human exposures. There are numerous reports, studies and evaluations regarding salinity impacts and mitigation efforts regarding agriculture and soils. Investigations regarding human health assessments are less common in the available literature.

Soil salinity has been extensively studied in Karakalpakstan and other Central Asian Republics. Most international organizations characterize soil salinity by measuring the Electrical Conductivity (EC) of a soil/water paste. Many former Soviet Union Republics continue to use some variation of the Russian Academy of Science methodology developed in the Soviet era. The methodology for analyzing and interpreting soil salinity results can significantly affect the reliability of information when compared to EC or other countries’ data. For the March 2023 survey, it was determined to apply the Nukus AgroChemical Laboratory methodology for comparison to 2016 ADB data, because this methodology was most familiar to local agencies. The AgroChemical Laboratory has produced comprehensive and valuable results. However, some questions remain as to how to interpret the units and the indices used. The Agrochemical methodology has the advantage of identifying specific ions in the soil salts, while the EC methodology is less expensive and time consuming and can be performed in the field to provide timely results.

The March 2023 survey soil and sediment results are summarized by Zone in Table 12. More detailed soil salinity results are in **Error! Reference source not found.**-**Error! Reference source not found.** in the Appendix. Results show that the lowest salinity results are observed in recently flushed agricultural fields or the more productive home gardens. The highest results are from canal sediments, and from a garden that is watered by hand from tap water because no canal water is available. School and playground soils also indicate higher salinity, perhaps because these non-agricultural soils are not routinely flushed. All the soils and sediments tested are classified as high or very high salinity, and three salinity types are indicated. The parameters of the classification categories are not clearly understood and may vary from those used in the former USSR. *Partners should obtain a description of the saline severity classification procedure employed at the laboratory, to develop a better understanding of the salinization classification methodology and determine the relevance to health considerations. The*

MOHK/MSF/TIFO effort might consider further investigating other methodologies that could be employed to monitor salinity levels for the purpose of assessing potential health effects, as opposed to the agriculturally-oriented techniques.

Table 9. Nukus SES soil salinity results from March 2023 survey.

Sample ID	Type	Zone	Rayon	Site Category	pH	Dry residue %	Mass fraction dry residue %	Anions - cations, mg/eq	Salting type	Salting level	Mass fraction salt %
KK23-Z1-D8	Sediment	1	Elikqala	River resort	6.5	0.45	0.45	6.75	X-C	Strong	0.431
KK23-Z1-S20	Soil	1	Tortqul	Residence garden	6.6	0.41	0.41	6.1	X-C	Strong	0.388
KK23-Z1-S20	Soil	1	Tortqul	Residence garden	6.5	0.34	0.34	5.16	X-C	Strong	0.325
KK23-Z2-D13	Sediment	2	Amudarya	Riverbank	6.7	1.49	1.49	20.5	X-C	Very strong	1.2563
KK23-Z2-S23	Soil	2	Amudarya	Residence garden	6.3	1.35	1.35	19.6	X-C	Very strong	1.288
KK23-Z2-S25	Soil	2	Amudarya	Residence garden	6.6	0.31	0.31	5.05	X	Very strong	0.296
KK23-Z3-D16	Sediment	3	Shiminay	Canal	6.6	17.5	17.5	256	X-C	Very strong	16.66
KK23-Z3-S48	Soil	3	Shumanay	School playground	7.4	2.18	2.18	30.3	C	Very strong	2.078
KK23-Z3-S51	Soil	3	Shiminay	Agricultural field	7.1	1.89	1.89	27.7	X-C	Very strong	1.804
KK23-Z3-S55	Soil	3	Qanlikul	Well site	6.8	9.4	9.4	133.5	C	Very strong	8.979
KK23-Z3-S57	Soil	3	Qanlikul	Agricultural field	7.7	2.65	2.65	36.5	C	Strong	2.524
KK23-Z3-S59	Soil	3	Qanlikul	Residence garden	7.4	2.37	2.37	33	C	Strong	2.254
KK23-Z4-D18	Sediment	4	Kungirot	Canal	7.6	2.93	2.93	40.8	X-C	Very strong	2.792
KK23-Z4-S61	Soil	4	Qanlikul	Agricultural field	7.3	5.81	5.81	79.2	C	Strong	5.528
KK23-Z5-D14	Sediment	5	Takhtatopur	Canal	7.1	2.64	2.64	35.8	C	Very strong	2.515
KK23-Z5-S32	Soil	5	Takhtatopur	Agricultural field	6.3	1.63	1.63	23.1	X-C	Very strong	1.549
KK23-Z5-S33	Soil	5	Takhtatopur	School playground	6.6	9.17	9.17	128.25	X-C	Very strong	8.717
KK23-Z5-S39	Soil	5	Karauzyak	School playground	6.7	2.48	2.48	40.75	X	Very strong	2.282
KK23-Z5-S41	Soil	5	Karauzyak	Residence garden	6.7	7.54	7.54	108.75	X-C	Very strong	7.168

KK23-Z6-S10	Soil	6	Nukus	Agricultural field	6.5	0.34 0.34	5.44	C-X	Very strong	0.329
KK23-Z6-S14	Soil	6	Nukus	Residence garden	6.4	1.23 1.23	17.55	X-C	Very strong	1.17
KK23-Z6-S5	Soil	6	Xojeli	Agricultural field	6.1	0.65 0.65	9.5	X	Very strong	0.622
KK23-Z6-S6	Soil	6	Taqiyatas	School playground	6	6.14 6.14	95	X	Very strong	5.833
KK23-Z6-S8	Soil	6	Nukus	Agricultural field	6.8	0.24 0.24	3.84	X-C	Strong	0.227

4.3.2 Soil and Sediment Pesticide Analyses

There was a limited number of persistent pesticides detected in soil and sediments. Results for pesticides, fertilizers, and other organic compounds are presented in **Error! Reference source not found.** in the Appendix. It is important to remember that, as opposed to salinity, the March survey was undertaken when contaminant concentrations were likely at low levels.

Aldrin: Aldrin exceeds the US RSL in 19 samples analyzed by Tashkent SES, with another 2 samples just at the RSL. Aldrin is unstable in the environment and typically degrades rapidly to dieldrin. Because dieldrin was not reported in any samples, it is unlikely that aldrin results are accurate. This may be due to a false positive on aldrin results, that dieldrin results were "masked" by the DDT byproducts, or due to the translation of results from Uzbek to English. The first two issues are common occurrences at any laboratory.

From highest to lower aldrin results were as follows: a kindergarten in Zone 1 (two samples with high aldrin results in different areas of the school), a school playground in Zone 2, a remote school near Turkmenistan in Zone 3, rice fields in Zone 6, an agricultural warehouse in Zone 3, a home garden in Zone 3, and a home garden that sells crops to Nukus in Zone 2.

Heptachlor: Two samples exceeded the USEPA RSL for Heptachlor, both from the kindergarten in Zone 1 that also had high aldrin levels.

Lindane and DDT: No soil exceedances for Lindane and its byproducts, or DDT and its byproducts were found in soil or sediment samples.

4.4 Health Risks of Contaminants Identified

Health risks associated with the contaminants identified will depend greatly upon the frequency, duration, and severity of exposure. In general, any contaminant exposure is of greatest concern for the fetus and young children, who are at critical developmental stages and experience a greater dose per body weight than adults. Workers often have higher exposures than the general public and are thus considered an additional high-risk group. Any individuals with other risk factors, such as malnutrition (including anemia, which is known to be high in Karakalpakstan), suppressed immune function, or other co-morbidities (i.e., TB) would also be at higher risk of health effects. Brief summaries of the health risks associated with contaminants identified follows.

DDT, DDE, DDD: In studies where animals were fed DDT, DDE, or DDD, harmful effects were seen on their nervous system, liver, and reproductive system (including decreased fertility). These compounds are linked to cancer (International Agency for Research on Cancer (IARC) Group 2B classification[3]).

Lindane is a neurotoxin, impacts liver and kidneys, and is carcinogenic (IARC Group 1 classification). Prenatal exposures may impact thyroid and brain development.

Heptachlor is a developmental and reproductive toxicant, and is possibly carcinogenic (IARC Group 2b).

Aldrin and dieldrin are neurotoxins, in addition to impacting the liver, kidneys, and reproductive system.

Chromium^{6+} (Cr, hexavalent chromium): Not to be confused with Cr^{3+}, a micronutrient, Cr^{6+} is a known human carcinogen (IARC Group 1) with multiple target organ toxicities.

Salinity: chronic consumption of water with excess saline content has been associated with cardiovascular disease, gastro-intestinal issues, and increased risk for kidney disease. The salinity of water can also increase the mobilization of other contaminants (metals, pesticides, etc.) potentially creating a synergistic toxic effect.

5 Conclusions, Recommendations, and Action Items

The March 2023 Survey represents the first comprehensive analysis of water, soil, and air contamination levels in Karakalpakstan in more than 20 years. The successful completion of the study was possible due to the cooperation and collaboration among all partners, and from lessons learned during the October 2022 assessment. The investigation successfully implemented field protocols, sample handling and logistics, and utilized in-country laboratories to analyze for a variety of contaminants in several media.

Preliminary evaluations indicate that while potential environmental risks from pesticides and herbicides have decreased from levels observed twenty years ago, residual contamination from persistent pesticides used in the historical eras (DDT byproducts and Lindane isomers) remain in some soils and sediments at levels presenting significant health risks. It should also be emphasized that the March survey was conducted prior to the peak periods of agricultural chemical application. Farm chemicals in use today are less persistent compared to twenty years ago and are less likely to be detected from the previous season's applications. However, these chemicals are toxic and there are potential occupational and para-occupational exposures and environmental pathways that could contaminate drinking water supplies. Future sampling to assess potential drinking water contamination from herbicides and pesticides should be timed to coincide with seasonal farm chemical and irrigation/flushing cycles. There are also para-occupational exposures, environmental, and socio-economic issues that clearly pose significant risks to human health that should be carefully considered by all partners to determine the next steps in the investigations.

Potential health risks from drinking water are likely increasing due to a combination of diminished flows and higher salinization levels in the Amudarya River and irrigation diversions, and deterioration of the water supply infrastructure. Salinization should be further investigated to evaluate both potential direct, and indirect, health risks associated with increasing salt levels. Because saline levels vary significantly with season and water year, sampling should be performed at intervals over the course of the agricultural season.

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[3] The IARC Classification System is: Group 1: sufficient evidence of carcinogenicity in humans; Group 2A: limited evidence of carcinogenicity in humans but sufficient evidence in animals or mechanistic models; Group 2B: limited evidence of carcinogenicity in humans and animals but sufficient evidence in mechanistic models; Group 3: Not classifiable due to inadequate or limited information (*not* determined to be "safe", but needing further research).

There are several drinking water exposure scenarios in the Republic. According to the ADB, in 2016 about 37% of the population was served by the existing centralized water supply system either by in-house connections or street standpipes (65% in urban areas, 23% in villages, and 13% in the rural settlements). Some rural settlements have developed independent water infrastructure, much of which seems to be abandoned or dysfunctional. About 9% of people living in rural settlements and 40% in rural Muynak district were served by trucked-in water. About 10% of the rural population use unsafe water from shallow wells with handpumps due to the unavailability of water supply service. Many of the areas with inconsistent and poor water quality have higher poverty levels, are remote from public services, and experience other risk co-factors that put them at higher risk of disease and adverse health effects. Future investigations should take care to ensure that these more vulnerable populations are appropriately considered in future assessments.

5.1 Health Risks Identified

Similar to findings from Karakalpakstan government monitoring and academic researchers, MOHK/MSF/TIFO identified the diminishing water supply and increasing salinity as a likely factor contributing to excess disease burden noted in the region. Overall disease and morbidity continue to increase in the Republic and adverse health effects are diverse, including: disease in blood and blood forming organs and incidence of malignant neoplasms associated with water quality; incidence of respiratory diseases and the level of air pollution; and astigmatism, impaired immune system function, increased heterochronism of morpho-functional development, and allergic diseases associated with general environmental conditions in the Aral Sea region.

There are numerous poverty and stress-related risk-cofactors, and the etiology of the observed health effects are poorly understood. The potentially adverse drinking water chemical exposures could be due to the direct effects of salt ingestion, or to secondary chemical and physical effects caused by interactions of salt with other compounds in waters, soils, and sediments. Agricultural practices developed to mitigate the high salt concentrations combined with high rates of fertilizer, pesticide, and herbicide application could produce a seasonally variable “cocktail” of contamination. Although, health researchers have identified an association between adverse health outcomes and increasing contaminant concentrations, the characteristics of the potential saline cocktail have not been studied. Airborne contaminants and occupational and para-occupational exposure to farm chemicals and dusts are also likely contributing to overall disease burdens.

Contamination of soils, sediments and surface waters (including canals) with persistent lindane and DDT byproducts remains an issue. Increasing reliance on canals could impact the drinking water supplies throughout the country. Aldrin was also identified in soils and sediments and could be a potential drinking water contaminant. Aldrin has been banned in many countries for several years and drinking water was not analyzed for this persistent organochlorine pesticide.

Few analyses of trends in drinking water quality are available. Overall, the results suggest that salinity levels are about 30% higher than observed in 2016 by the ADB. Oxygen and pH levels seem to be lower, and nitrates and some metals concentrations are higher. There was little indication of lingering contamination from less-persistent herbicides and pesticides reported in-use today. However, this survey was conducted at a time when few agricultural chemicals were being applied. As such, the survey represents samples collected at peak-salinity but in a period of low agricultural chemical input.

Occupational and para-occupational exposures to pesticides and herbicides are a concern for agricultural workers and families of workers. Reportedly, at the present time most cotton planting and picking is done by women as many men migrate for work in Kazakhstan and Russia. The heavy use of pesticides and cotton defoliants can result in significant risk for women, fetus and breast-fed infants during critical developmental periods. Para-occupational (‘take home’) exposures are commonly seen in farm workers globally, putting family members at risk of exposure when chemicals released in the home environment from work clothes, equipment, dust, and skin, and contaminate food supplies during production and preparation. Windblown dusts from bare soils in these arid conditions remain a concern due to elevated suspended particulate levels and chemical contamination in fine dusts from the dry Aral seabed, Amudarya River channel, disturbed desert soils, and urban traffic. Three particulate air monitors were installed in the March 2023 survey and the incoming data will be analyzed and reported in the future.

5.2 Recommendations

The following recommendations should be reviewed and commented on by all partners. Several of the strategies are likely outside of the mission and budget of MSF to implement. We propose that TIFO and MOHK lead this effort with funding from outside sources, with limited logistical support from MSF.

5.2.1 Identification of vulnerable and neglected populations

Previous investigations have identified that a large percentage of rural residents are using unsafe shallow wells dependent on intermittent canal water. These isolated agricultural communities often lack adequate nutrition, hygiene facilities, access to health care, and are vulnerable to endemic diseases. Family members routinely engage in farm labor and direct application of agricultural chemicals. Ready access to a variety of pesticides and herbicides, some considered controlled substances in Uzbekistan and other nations, combined with the lack of information on safe handling and application, put agricultural workers (especially women) and their families at significant risk. Recommendations are as follows:

- MSF and MOHK, with technical support from TIFO, could conduct additional surveys to characterize potential environmental, occupational, and para-occupational exposures and health risks for these vulnerable populations
- Develop occupational health and safety programs, with special attention to women of childbearing age and families of agricultural workers
- Position the project for MSF transition to MOHK, TIFO, and other partners to continue these efforts

5.2.2 Develop a collaborative water quality assessment partnership

Development of a comprehensive multi-partner water quality improvement strategy for Karakalpakstan is strongly recommended. Most water quality improvement projects typically address water quantity and quality. Both are critical issues; however, the Republic faces inter-related multi-factor challenges in securing safe drinking water for the population. Both current and residual pesticide concentrations are potential hazards, salinity is increasing as freshwater river flow is diminishing and traditional agricultural practices contribute salts to surface and groundwater and increase the demand for chemical amendments. Chemical interactions between chlorination, salts, pesticides, herbicides, and nitrogen compounds are a potential concern and are poorly understood. These factors vary seasonally, geographically among Rayons, between urban and rural populations, and are exacerbated by demographic and socio-economic conditions that have not been characterized. Related recommendations are as follows:

- Develop and finalize a consensus report among project partners
- Share the study results with pertinent agencies and potential additional partner institutions
- Present summary findings at October 2023 International Network for Children's Health, Environment and Safety (INCHES) Conference
- Solicit partners for continuing characterization and assessment efforts, including KK health, agricultural, and University and health research institutions
- Develop a "white paper" to facilitate identification and pursuit of project funding opportunities

5.2.3 Analyzing trends in environmental monitoring data

Karakalpak researchers and health authorities have substantial expertise and experience regarding disease incidence and related environmental contamination. Development of a more robust environmental contamination database would significantly enhance health authorities' ability to identify and respond to increasing climate-related health risks in the Republic.

Historic MOHK/SES soil and water monitoring results are currently maintained on paper in Rayon level files. These sources should be compiled into a digitized accessible database for more precise and quantitative analysis of trends in environmental conditions and human health risks. Data should include actual geo-located concentrations for each parameter. The database could be compiled as a collaboration between TIFO, MOHK, and KMI by using both US and Karakalpak student researchers to support the effort. The database protocols and methodologies could then be used as the foundation for developing the improved, digitized public health and environmental monitoring database recommended above. Recommendations for analyzing data trends are as follows:

- Support university researchers in assessing relationships between environmental exposures and disease
- Concatenate Historic SES sampling results in an accessible digitized database
- Compare seasonal fluctuations in salinity and chemical pollutants in surface, groundwater and WTP intakes
- Consult with health authorities and in-country researchers regarding selection of sampling analytes
- Assist in the development of an accessible SES monitoring digital database

5.2.4 Support SES monitoring programs

SES is currently building laboratory capacity to monitor water and soils for organic contaminants by purchasing and installing GCMS analyzers. This capability would enable SES to detect and respond to contamination incidents. Implementing an effective monitoring and response program will require:

- Upgrading sample collection, laboratory, and database management protocols
- Integrating sample collection protocols and scheduling into SES monitoring programs
- Assisting in the development of SES GCMS analytical capability
- Soliciting funding for continuing monitoring assessment and upgrade of drinking water supplies

Periodic sampling throughout the agricultural season should be performed to:

- Capture the types and application rates of herbicides and pesticides more commonly in use today
- Understand any fluctuations in DDT and lindane byproducts, aldrin/dieldrin concentrations in environmental media
- Capture the fluctuation in salinity and drinking water parameters
- Assure sampling locations reflect the various drinking water scenarios active in the Republic

This sampling effort should be built into SES's existing monitoring program. A comprehensive monitoring program will include drinking water samples analyzed for salinity parameters, organo-chlorine, organo-phosphate, organo-nitrogen compounds, and nitrogen parameters. An efficient design should provide the laboratories with a list of targeted analytes. Determining those analytes should be accomplished in consultation with:

- In-country agricultural experts to identify current agricultural chemical use and soil flushing patterns
- In-country health authorities and researchers to identify chemical compounds of health concern
- Tashkent and Republic SES laboratories regarding appropriate sample collection, analytical methods, and analytes

5.2.5 Future investigations

Recommendations for additional investigation and clarification are included in the text of the report. These are summarized below as topics that partners should consider for future work:

Water Infrastructure

- Identify the extent to which the ADB project and other improvements to drinking water infrastructure have been implemented
- Determine status of desalination or other treatment facilities (operational, temporarily not working, or abandoned)
- Clarify the canal names and establish sampling locations consistent with the SES monitoring program
- Develop a better understanding of potential threats to the overall freshwater supply to KK
- Develop a stronger understanding of the water supply in rural areas remote from the main water supply system
- Investigate multiple years of data to better understand trends and variability in water quality

Republic SES Operations

- Coordinate with SES to identify the public health implications of the water system deficiencies noted in the 2016 ADB assessment
- Support SES plans to upgrade sample collection and laboratory capacity; consider supporting QAQC efforts to assist the SES in developing a rigorous and informative program of data collection and processing to better understand trends and variability in water quality in the domestic water supplies
- Support SES to digitize sample results and make these accessible to in-country investigators to identify potential links between increasing disease incidence and contamination of the water supply and other environmental pathways; Dr. Amet (KMI) and health authorities conducting pertinent research should be consulted to coordinate with SES in such an effort

Laboratories

- Collaborate with the laboratories to better identify target compounds for analysis by i) developing a better understanding of chemicals being used or likely to be encountered in the field and ii) soliciting more detailed advice from the laboratories and in-country researchers and experts familiar with agricultural practices; some confusion remains among the participating institutions as to whether the purpose of the sampling effort is to compare results to existing regulations, or a forensic investigation to better understand potential health and environmental implications
- Consider sampling for disinfection by-products and additional organic nitrogen decomposition compounds, with the caveat that protocols for collection and analyses of these contaminants are more challenging and corrective actions to reduce the formation of these compounds would be difficult in the current state of the water delivery infrastructure
- Obtain description of the saline severity classification procedure employed at the AgroChemical laboratory, develop a better understanding of the salinization classification methodology, and determine the relevance to health considerations
- Further investigate other soil and water salinity measurement methodologies that could be employed to monitor salt content levels for the purpose of assessing potential health effects, as opposed to the agriculturally-oriented techniques

5.3 Next Steps

1. MSF and MOHK should review this draft report and provide critical feedback and comments before it is considered to be final.
2. MOHK should determine how, when, and to what extent the results can be made public in order to advocate for additional funding and partner engagement.
3. With permission from MOHK, the report should be shared with Tashkent SES and Karakalpakstan Medical Institute (Dr. Amet) for their feedback.
4. Comments and changes to this report can be incorporated into a final version with a summary document for public release and circulation for advocacy purposes.
5. Partners should develop a proposed plan for 2024, along with budgetary needs, based on the recommendations agreed to by project stakeholders and potential funding sources.
6. Laboratory results should be reviewed by respective laboratory experts. Anomalies should be reviewed to determine possible explanations, need for follow-up investigations, or protocol amendments.

6 APPENDIX A: SUMMARY OF ADB 2016 INVESTIGATION

The following text summarizes findings from the 2016 Western Uzbekistan Water Supply System Development Project (RRP UZB 50259) by the Asian Development Bank (ADB). Most of the information summarized was from the Supplementary Appendix to that report.

6.1 Drinking Water Infrastructure

The ADB project was designed to upgrade water supply infrastructure and services and provides a comprehensive description of drinking water supply systems and salinity concentrations in 2016. The project area covers six of the Republic's fourteen major districts, representing 75.4 % of the total area of Karakalpakstan. When completed the project will significantly improve local living standards, environment, health, and local economies. The following summary excerpted from that report provides useful context for the March 2023 MOHK/MSF/TIFO sampling program. It is unclear how much of the project has been implemented. *The MOHK/MSF/TIFO effort should identify the extent to which the ADB program and any additional improvements to drinking water infrastructure has been implemented.*

The Amudarya River is the main source of fresh water in the region and directly supplies both drinking and irrigation water to Karakalpakstan by surface diversions, or indirectly through recharge of groundwaters. The Amudarya is regulated by four reservoirs (Tuyamuyun, Kaparas, Sutansanjar and Koshbulak). A large portion of the river is diverted at the Tuyamuyun reservoir to a massive canal system for irrigating the semi-arid desert lands of Karakalpakstan, Uzbekistan, and Turkmenistan. Water diversions from the river are over-allocated and no water from the Amudarya has reached the Aral Sea for decades. About 98% of river flow is diverted for irrigation and 2% for domestic and industrial uses. Currently, the Amudarya is impounded about 40 km southeast of Muynak City and diverted into a lagoon near the village of Porlitau. Climate change associated droughts, other users, and upstream diversions threaten to further diminish both Amudarya water quantity and quality. The entire Republic is almost exclusively reliant on the Amudarya River. *The MOHK/MSF/TIFO effort should develop a better understanding of potential threats to the overall freshwater supply to the Republic.*

The water supply infrastructure includes three main water treatment plants (WTP), interregional transmission and distribution pipeline mains, smaller WTPs and distribution headworks, local service mains, and is integrated with the Republic's massive irrigation canal network. The largest WTPs are:

i) Tuyamuyun 1 WTP, supplying districts on the right bank of the Amudarya downstream of the Tuyamuyun reservoir;
ii) Tuyamuyun 2 WTP, originally supplying Khorezm province and the Amudarya district of Karakalpakstan on the left bank of the River; and
iii) Takhiatash WTP, located on the left bank of the Amudarya, for the supply of the Takhiatash and other districts North of Takhiatash.

The water supply from the Tuyamuyun 2 WTP to the Amudarya district was interrupted several years ago and the pipeline from this facility no longer supplies water to Karakalpakstan. Each of the WTPs are fed by inlet canals from the Amudarya River. The Tuymuyan WTP is fed from the reservoir by the Pakhta Canal. The Takiatash WTP inlet is from the Sueli Canal. The capital Nukus is now supplied with drinking water from the smaller Nukus WTP constructed a decade ago withdrawing raw water from the Kizketken Canal. There are smaller WTPs and distribution headworks providing settling and chlorination at Mangit using the Mangit Canal, Kungrad from the Altinkul Canal, and Muynak from the Tallyk Canal. During the March 2023 MOHK/MSF/TIFO some discrepancies in Canal names were noted. *The MOHK/MSF/TIFO effort should clarify the Canal names and establish sampling locations consistent with the SES monitoring program.*

There are also developed water supply systems utilizing groundwater wells despite generally high salinity levels. Well water is used for drinking purposes either due to lack of access to other sources, or to augment insufficient surface water supplies. There are four recognized groundwater aquifers providing water to community distribution systems:

i) the lower Amudarya aquifer, extending in both right and left bank of the Amudarya
ii) the Karakalpak aquifer in the left bank of the River
iii) the Khorezm aquifer
iv) the Turtkul aquifer.

In addition, several limited capacity groundwater lenses are exploited using small discharge wells to supply communities remote from existing water distribution networks. These small aquifers are recharged by seepage of fresh surface water from irrigation canals crossing the permeable areas of the shallow groundwater bearing sediments. The exploitable reserves of these aquifers are not extensive due to the limited freshwater recharge and salinity intrusion of groundwater. Groundwater sources are generally highly saline due to the salt content of water bearing sediments and infiltration from irrigation and collection canals. There are also numerous small shallow wells serving small communities or individual neighborhoods. It is unclear the extent to which drinking water is drawn from irrigation canals in the rural areas.

As of 2016, 36.6% of the population was connected to the existing centralized water supply system, either by in-house connections or street standpipes. Connectivity is highest in urban areas at 65.2%, in smaller settlements 22.5%, and only 12.9% in the rural settlements. Some rural settlements have developed independent water infrastructure, much of which seems to be abandoned or dysfunctional. About 8.4% of people living in rural settlements were served by trucked-in water in 2016. In 2016, 40.9% of the population in Muynak district rural settlements relied on trucked water. About 10% of the rural population use unsafe water from shallow wells with handpumps due to the unavailability of water supply service. *The MOHK/MSF/TIFO effort should develop a better understanding of the water supply in rural areas and small villages remote from the main water supply system.*

6.2 Drinking Water Quality Assessment

The 2016 ADB report indicated several challenging issues have resulted in deterioration of the entire water supply infrastructure, poor water quality, and frequent system outage. Water delivery through the existing centralized distribution network is unreliable and water supply is only available on a scheduled basis, in some areas only for less than one hour each day. Both water quality and quality in rural area wells and surface water supplies depend on canal flow and irrigation water delivery schedules. As irrigation supplies become more stressed, drinking water concerns are becoming more serious. The MOHK/MSF/TIFO survey noted significant deficiencies associated with deteriorating infrastructure and operations. *The MOHK/MSF/TIFO effort should coordinate with the SES in identifying and assessing the public health implications of these deficiencies.*

The 2016 ADB report summarize annual fluctuations in Total Dissolved Solids (TDS) and Turbidity at the five main intakes for WTPS and distribution headworks. The Figures showing annual TDS and turbidity and Table 7. Below were reproduced in the Section 4.2.2 in this report for illustrative purposes. Table 10 through Table 13 compare the 2016 and March 2023 salinity parameters for five main canal fed drinking water treatment plants and headworks.

6.2.1 Pakhta Canal intake (feeding Tuyamuyun WTP)

Table 10**Error! Reference source not found.** presents the 2016 ADB water quality findings and 2023 TIFO/MOHK/MSF water quality findings. In 2016, turbidity increased significantly during the Spring and early Summer months when the discharge of the Amudarya reached seasonal high levels with heavy solid loading runoff from rainfall and snow melting in the upper catchment area. Precipitation during Spring and Autumn generates the spreading of highly mineralized content inflows that were contaminated by the erosion of salinized soils into the Amudarya causing a typical bi-seasonal increase of TDS content.

Table 10. Pakhta Canal Intake (feeding Tuyamoyan WTP). ADB results from table 3.1 in their 2016 report.

	Number	Turbidity (mg/l)	pH	Oxidability (mg/l)	NO3 (mg/l)	Alkalinity (meq/l)	Total Hardness (meq/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	TDS (mg/l)	SO4 (mg/l)	Fe (mg/l)	Cu (mg/l)	F (mg/l)
ADB 2016	Min	12	6.9	1.5	3	2.2	4.7	54.1	24.3	117.3	577	205	0.02	0.04	0.02
	Max	1970	7.2	2.7	4.25	2.9	10.8	132.3	58.3	290.7	1185	377.3	0.12	0.18	0.14
	Avg	678.2	7	2.1	3.5	2.5	7.7	97.4	34.5	190.6	871.5	287.1	0.06	0.11	0.07
2023 Results		24	8	0.70	4.8	ND	10.3	123	46	245	1331	278	0.16	0.26	<1.00

Seasonal patterns identified by the ADB indicate the March 2023 survey was conducted at peak TDS and lowest turbidity in the Spring season. Overall comparison of the 2016 and 2023 data indicates that the initial diversion from the Tuyamuyum reservoir showed dissolved oxygen levels less the half the 2016 minimum. TDS, pH, nitrate, iron, and copper ion levels were higher than 2016 maximum values.

6.2.2 Sueli Canal intake (feeding Takhiatash WTP)

Table 11 summarizes the fluctuation in surface water quality at Sueli Canal intake in 2016. Turbidity and TDS decreased during the summer, mainly due to dilution with relatively high flow in the Amudarya. The peaks of dissolved solids content in the Spring and Autumn may be related to seasonal dilution from rainfall runoff.

Table 11. Sueli Canal intake to Takhiatash TWP results. ADB results from table 3.2 in their 2016 report.

	Parameter	Turbidity (mg/l)	pH	Oxidability (mg/l)	NO3 (mg/l)	Alkalinity (meq/l)	Total Hardness (meq/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	TDS (mg/l)	SO4 (mg/l)	Fe (mg/l)	Cu (mg/l)	F (mg/l)
ADB 2016	Min	13	6.9	1.8	2.2	2.1	4.5	50.1	23.1	127.5	537	210	0.02	0.02	0
	Max	720	7.2	2.6	4.5	3	11.3	136.3	60.8	296.8	1227	394	0.1	0.12	0.06
	Avg	202.1	7.05	2.2	3.3	2.4	7.967	96.2	38.1	206.7	895	297	0.05	0.06	0.03
2023 Results		2	7.0	1.2	5.7	ND	10.0	119	44	245	1190	216	0.08	0.20	<1.00

Most of the salinity parameters at the Takhiatash WTP inlet in March 2023 were in the same range of values noted in 2016. Oxygen was notably lower. Nitrates and copper levels were higher than 2016. These results are consistent with those at the Tuyamuyun WTP inlet. It is believed that both these WTPs are serviced by the same Sueli Canal that parallels the Amudayra River from the Tuyamuyun Reservoir through the Republic to the north. There seems to be a slight increase in oxygen and nitrate levels, and a decrease in pH between these sampling points.

6.2.3 Mangit Canal intake (feeding Mangit WTP)

Table 12 summarizes the fluctuation in surface water quality at Mangit Canal intake. During 2016 the TDS in Mangit canal had exceeded the concentration of 1,000 mg/l in February, March, and April with a maximum measured value of 1,185 mg/l in April. The pH values were relatively neutral, which in turn indicates that no correction of pH is required for the water treatment process. Seasonal trends of the two water quality indicators are typical of surface waters in the region, with TDS decreased during the high flows season and peaking of salinity and solids in the Spring and Autumn due to rainfall runoff.

Table 12. Mangit Canal intake results (feeding Mangit WTP). ADB results from table 3.3 in their 2016 report.

	Parameter	Turbidity (mg/l)	pH	Oxidability (mg/l)	NO3 (mg/l)	Alkalinity (meq/l)	Total Hardness	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	Dry residue (mg/l)	SO4 (mg/l)	Fe (mg/l)	Cu (mg/l)	F (mg/l)
ADB 2016	Min	12	6.9	1.8	2	2	5	64.12	21.8	128	671	218	0.02	0.03	0.02
	Max	510	7.2	2.6	3.75	2.9	10.6	130.3	54.7	306	1185	404	0.12	0.13	0.08
	Avg	172.8	7.0	2.2	2.9	2.4	8.0	99.4	36.5	202	905	300	0.06	0.07	0.06
2023 Results		4.9	8.0	1.60	2.4	ND	10.8	104	44	250	1433	273	0.40	0.25	<1.00

Results from the March 2023 MOHK/MSF/TIFO turbidity and oxygen levels are lower, and pH, iron and copper levels are higher than the ranges noted in 2016. Salinity expressed as TDS is 20% higher than the maximum 2016 concentration. The increase in TDS does not seem to be attributable to the toxic ions summarized in the 2016 report and may be due to other ions considered toxic in former Soviet Union and Uzbek salinity analyses as discussed below.

6.2.4 Altinkul Canal intake (feeding Kungrad District Altinkul headworks)

Table 13 summarizes the fluctuation in surface water quality at Altinkul Canal intake in 2016.The TDS in the water of Altinkul canal intake had slightly exceeded 1,000 mg/l in February, March and April and again in October and November 2016, with a maximum recorded concentration of 1,187 mg/l in April. TDS levels were lower from May to September as is typical for surface water in Karakalpakstan. The peak turbidity level was recorded at 434 mg/l in 2016.

Table 13. Altinkul Canal intake results (feeding Kungrad District Altinkul headworks). ADB results from table 3.4 in their 2016 report.

	Parameter	Turbidity (mg/l)	pH	Oxidability (mg/l)	NO3 (mg/l)	Alkalinity (meq/l)	Total Hardness (meq/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	Dry residue (mg/l)	SO4 (mg/l)	Fe (mg/l)	Cu (mg/l)	F (mg/l)
ADB 2016	Min	11	6.9	1.9	1.8	2	5	60.12	24.3	137.7	622	228	0.02	0.02	0.02
	Avg	163.0	7.0	2.1	2.5	2.4	8.1	100.9	37.6	210.6	911.8	300.1	0.06	0.05	0.05
	Max	434	7.1	2.3	3.75	2.9	10.7	168.3	54.7	311	1187	396	0.11	0.1	0.08
2023 Results		0.2	7.8	0.30	4.4	ND	8.6	ND	ND	221	1766	268	0.09	0.17	0.04

Results from the March 2023 MOHK/MSF/TIFO turbidity and oxygen levels are considerably lower. pH, nitrates and copper levels are higher than the ranges noted in 2016. The March 2023 TDS concentration is nearly 50% higher than the maximum observed in 2016. Unfortunately, no analyses of cation species content were accomplished for samples from this facility and the characteristics of the salinity are difficult to evaluate.

6.2.5 Soil Salinity

Soil and sediments are the primary source of salts in surface and groundwaters and ultimately domestic drinking water. Several soil and sediment samples were analyzed for salt content by the Nukus AgroChemical Laboratory. The FAO and USDA utilize a methodology that classifies salinity by Electro-Conductivity (EC) measurement of a water-soil paste in terms of plant sensitivity. This Nukus AgroChemical Laboratory utilizes a variation of USSR soil salinity classifications common in Central Asia. The system is based on total dissolved solids and the sum of soluble (toxic) salts or the chloride ion concentration in the soil water extracts (soil:water = 1:5). Since the breakup of the USSR, soil classification systems have evolved independently among the Central Asian Republics because of different levels of acceptance of international literature and available resources. The adaptations can significantly affect the reliability of information when comparing to EC or other countries data. For the March 2023 survey, it was determined to apply the Nukus Agricultural Laboratory methodology for comparison to 2016 ADB data because it was most familiar to local agencies.

The former USSR methodologies classify the degree of soil salinity by taking into account the sum of toxic soluble salts in the root zone. The salinity index is based on the Cation Exchange Capacity (CEC) expressed in cmol/kg soil, (centimoles per kilogram) according to the USSR soil scientist (Pankova et al.). This concentration can also be expressed as meq/100g or milliequivalents per 100 grams of soil. Because 1 meq/100 = 1 cmol(+)/kg it seems reasonable to assume that Nukus Agricultural Laboratory is using this index for measuring salinity. However, the original Laboratory results Tables express the solute concentration as мг/экв, that is translated as mg/eq. These units have a different definition in solute concentration expressions and there is some confusion as to how to interpret the Nukus AgroChemical Laboratory results, that may be due to translation. *The MOHK/MSF/TIFO effort should clarify these discrepancies and obtain a description of the saline severity classification procedure employed at the laboratory. The MOHK/MSF/TIFO effort might consider further investigating other methodologies that could be employed to monitor salinity levels for the purpose of assessing potential health effects, as opposed to the agricultural oriented techniques.*