The impact of climate change on surface water quality in the Amu Darya basin Project

Analysis of the water quality parameters in the Amudarya River

Analytical Report

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1 Introduction

The Amu Darya River basin (Figure 1), with approximately 310 000 km^2 (excluding Zeravshan - which practically does not reach the Amu Darya stream anymore) is one of the main water sources of Central Asia. The Amu Darya River takes its beginning at the conjunction of Vahsh and Pianj rivers on the territory of Tajikistan, which, in turn, originate in the Tien Shan and Pamir mountains. The total length of the river is 1,415 km (2620 km including Pianj River) and mean annual discharge is around 2000 m^3/s. The main tributaries are Vahsh River, Surkhandarya, Sherabad River, Zeravshan River – right; Pianj River and Kunduz – left. The major part of water resources of the Amu Darya is formed on the territory of Tajikistan; in the middle part of the river it receives water from the Kafirnigan and Surkhandarya Rivers, while in the downstream reach the river has no further tributaries. The average rainfall in the downstream part, in the steppe is approximately 200-300 mm a year. Main water user in the Amu Darya River basin is agriculture, which relies nearly to a full extent only on the irrigation.

Figure 1 The Amu Darya River basin

The Amudarya system highly dependent on the changes in the glacier mass balances and snowmelt processes as nearly all of the water resources of the Amu Darya River are originating from the high-ranges of the Tian Shan and Pamir mountains. The river flow is therefore characterized by strong seasonality, with peak flows occurring in summer, reaching their maximum in July when glacier melt reaches its maximum, as presented in Figure 2. The minimum river discharge occurs in January – February. Only the Kafirnigan River tributary has slightly different discharge dynamics, with peak flow occurring in May, as this river is driven to a larger extent by snowmelt and not by glacier melt.

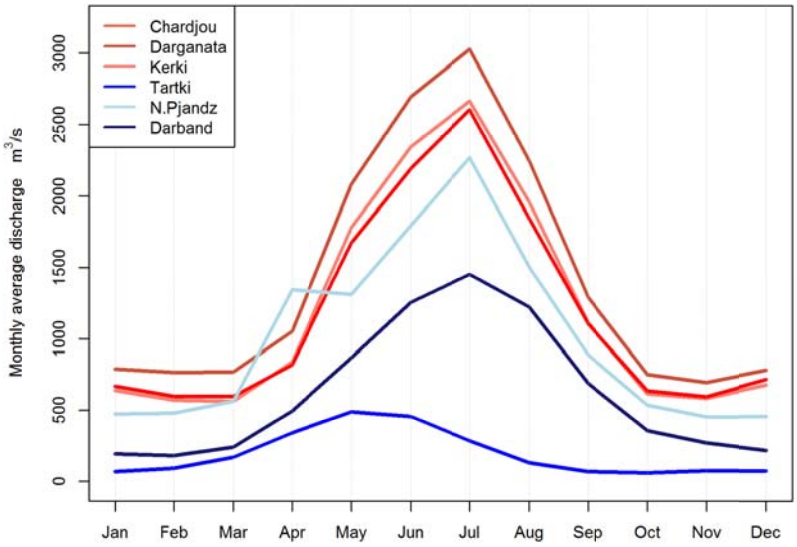

Figure 2 Long-term mean annual discharge, averaged over 1990-2015, at the gauging stations in the Amu Darya River Basins

In general, the water resources of the Amu Darya River are abundant. However, the rapid development of irrigational farming activities from 1960ies, large withdrawals (e.g. in the middle part nearly half of the river flow is diverted via the Karakum channel), construction of dams and reservoirs have led to significant depletion of water resources availability in the river and deterioration of water quality. The projected changes in climate will likely act as an additional stressor and will impose further challenges to water managers of the region. In fact, the current warming trends in the region show faster temperature increase than average global values, what also allows to suggest that the consequences of the climate change may have more pronounced effects in the region. E.g. Figure 3 and 4 present projections of temperature and precipitation for the Dashouz region, under RCP4.5 and RCP8.5. As one can observe from the figures, the projected changes in temperature show a strong increase, reaching up to plus six degrees until the end of the century under the high-end climate change scenario, while for the precipitation no clear trend can be observed. A strong increase in temperatures will likely affect the glacier mass balances and therefore also the Amu Darya River flow, which in turn may affect the chemical composition of the water altering the dilution processes.

In the view of projected changes, current state of the water resources of the Amu Darya River, as well as necessity for economic and social development in the region, the task of assessment of projected impacts of climate change on the water resources availability and water quality becomes to be essential.

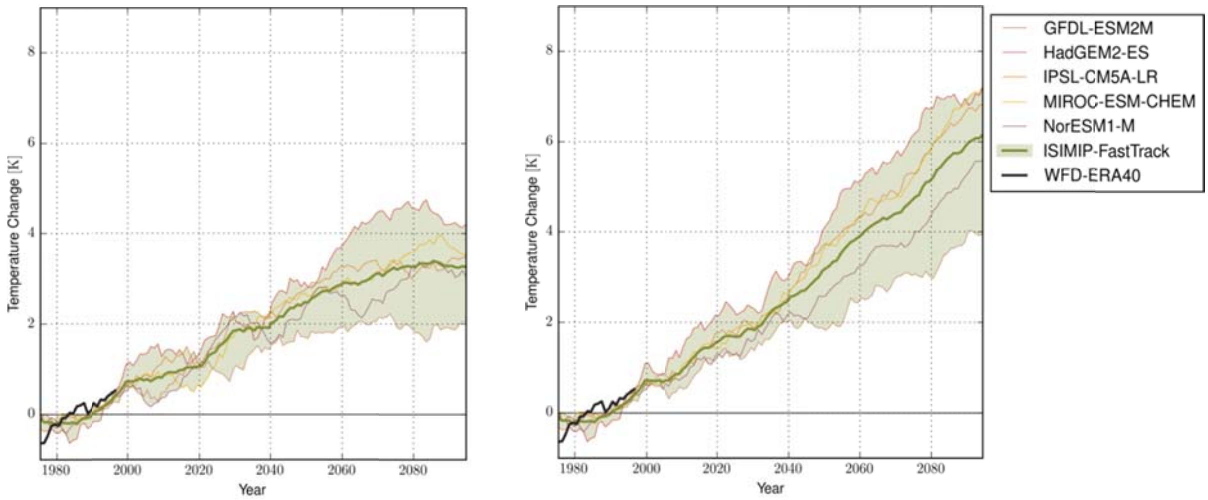

Figure 3. Anomalies in the average daily temperature in degrees K obtained as running means (10 years) with respect to 1971-2000 for Dashouz district under RCP4.5 and RCP8.5 scenarios; and anomalies for the WATCH ERA40 data until 2000 (Lobanova et al. 2017)

The aim of this consultancy task is to investigate, how the water quality parameters in Amu Darya River are changing along the course of the river, estimate the links between the discharge and water quality parameters, and provide an assessment, qualitative and, where possible, quantitative of how the projected changes in discharge under climate change scenarios RCP4.5 and RCP8.5 may influence the water quality parameters in the river basin. This report provides an overview of the water quality parameters dynamics in the Amu Darya River at the present moment and investigates the links between the discharge and selected water quality parameters.

For this analysis the datasets of the water quality parameters at seven observational stations, in Tajikistan, Turkmenistan, and Uzbekistan were received: Tartki (Kafirnigan River), Darband (Vahsh River), Kizyl Kala (Vahsh River), Karatag (tributary of Surkhandarya River), Kerki, Chardjou, Dargan-Ata (Amu Darya River). The measurements contained observations of mineralization, suspended matter, pH, NO_2, O_2, NH_4, NO_3, P, Ka from 1990 to 2015. The number of observations was varying significantly, depending on the station and parameter selected. An overview of number of observations per year for selected parameters at selected gauging stations is provided in Annex 1. The discharge and mineralization of main drainage channels in the lower part of the Amu Darya River and the mineralization of the effluent water were also provided with the monthly time step, covering a period of 1992 to 2015.

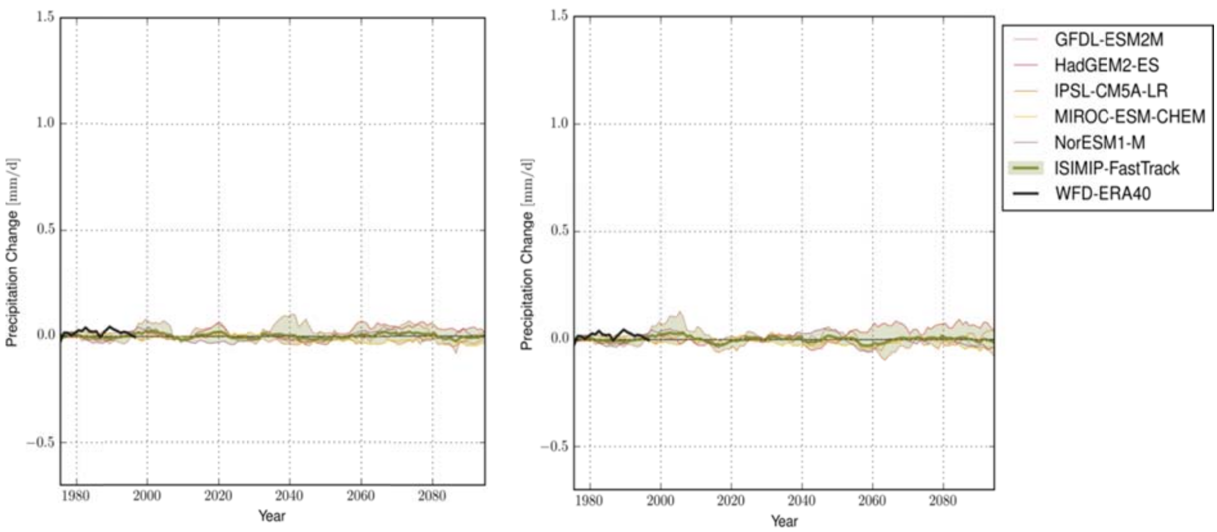

Figure 4 Anomalies in the average daily precipitation in mm K obtained as running means (10 years) with respect to 1971-2000 for Dashouz district under RCP4.5 and RCP8.5 scenarios; and anomalies for the WATCH ERA40 data until 2000 (Lobanova et al. 2017)

The discharge and water quality parameters were measured simultaneously only at five of the provided stations: Tartki, Darband, Kerki, Chardjou, Darganata, therefore the current analysis is focused on these five gauging stations.

Firstly, in order to perform this study, it was intended to set-up an eco-hydrological model SWIM (Krysanova, Müller-Wohlfeil, and Becker 1998) for the entire Amu Darya River basin to conduct a process-based analysis of the water quality parameters. However, such modelling exercise, apart from the data needed for a hydrological model set up, requires a lot of additional input data, of high quality, in order to reach adequate model performance for the water quality parameters. To perform a thorough calibration of the model, bi-weekly measurements of the water quality parameters are needed, with exact dates when each specific measurement was conducted. Further, daily discharge is needed in order to link the measurements of water quality with river discharge. Third, all information of the diffuse (e.g. effluent from agricultural fields) and point (untreated domestic, industrial or animal farms waste water etc.) pollution sources have to be provided, in order to be included in the model set-up. The received datasets contained observations, performed once per month (in the best case) with missing date of observation, the information on the point and diffuse sources of pollution was also not available, as well as information on the type and amount of fertilizers used at the agricultural fields.

Therefore, it was decided to investigate the statistical link between the selected water quality parameters – mineralization, nitrates and phosphorous. The mineralization of the water is one of the main issues, associated with water quality in the Amu Darya and therefore it was selected for the analysis. The phosphorous and nitrates (originating, e.g. from sewage and agricultural fields) are two other common parameters, suitable for general estimation of the quality state of a water source.

As was mentioned before, the observations of the discharge in the five gauging stations were provided as mean monthly values, whereas the observations of the water quality parameters were performed on several days per year, without the specification of the calendar date of the measurement. It should be therefore, noted, that in some cases it may be challenging, it at all possible, to find direct statistical links between the measured with daily time step values of water quality parameters and river discharge, provided with monthly timestep, even if they exist.

2 Water quality of Amu Darya River

It should be noted that information and data regarding the state of the water quality of the Amu Darya River is poorly covered in the international literature.

In Amu Darya and in general in Central Asia there is a growing abstraction of water resources for industrial and household needs and, sequentially, increased discharges of polluted return flows into water bodies. In general the water quality in the Amu Darya River is influenced by, in the first place, agricultural activities, followed by discharges of the untreated return flows from industry, domestic wastewater, mining and animal farms (SIC ICWC 2011).

As was mentioned before, one of the major challenges is the increase of mineralization of the water in the downstream part of the river basin. The current levels of mineralization at some stations limit the use of water for water supply and agriculture (Crosa et al. 2006). The major salt contributors to the river flow are the effluents from the drainage collectors, which collect water after irrigation and washing of saline soils. Currently the total water withdrawal from the Amudarya river is 61 km^3, of which about 41 km^3 are used for irrigation. Besides, 15-18% of this withdrawn water is returned back into the river, i.e. 9-11 km^3/year. Figure 5 presents the increase in the mean monthly mineralization levels at selected gauging stations. One can observe that while in the Kafirnigan River basin the mineralization is not exceeding 400 mg/l, at the downstream parts, at Kerki, Chardjou and Darganata stations mineralization exceeds the 1000 mg/l level in the spring months. The highest mineralization levels are recorded at the Kerki and Chardjou stations.

From Figure 5 one can also observe that the relationship of mineralization levels and discharge is inverse, hence for all analysed locations, the minimum values for mineralization occurring during summer (July and August) when the discharge of the river reaches its maximum, and maximum mineralization values occur in March and April, during the low flow period (see Figure 2).

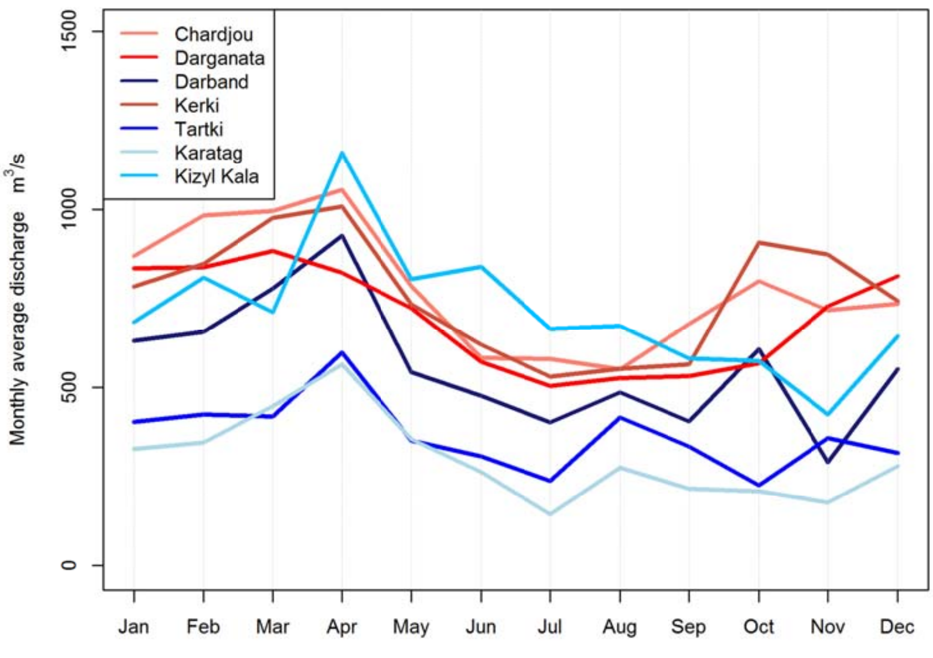

Figure 5 Mean monthly mineralization levels at the selected gauging stations over 1990-2015

The scheme of diverting and returning water back to the river has emerged in 1960ies as a measure to save water resources, however the natural limits of water availability for dilution of saline effluents were not considered. Between 1960 and 1989 the average mineralization of the Amu Darya River has increased from 540 mg/l to more than 1000 mg/l (Crosa et al. 2006). Nowadays, more than 50% of the observations between 1996-2001 exceed the value of 1000 mg/l, which is considered as the limit of palatability (Crosa et al. 2006). Figure 6 presents yearly mean mineralization levels at the selected gauges. It is clear from the figure that before the 1998 the observations for all stations are characterized by scarce data availability. The years 2000 and 2001 are characterized by peaks in the mineralization levels, especially at the downstream gauges. This period there were drought conditions and the dilution processes were hampered. From the graph one can see that in recent years there is a slight upward trend in the mineralization levels in the downstream gauges and strong in the Kizyl Kala station and Darband stations (Vahsh River basin) as well as downward in Tartki and Karatag stations (Kafirnigan and Surkhandarya Rivers).

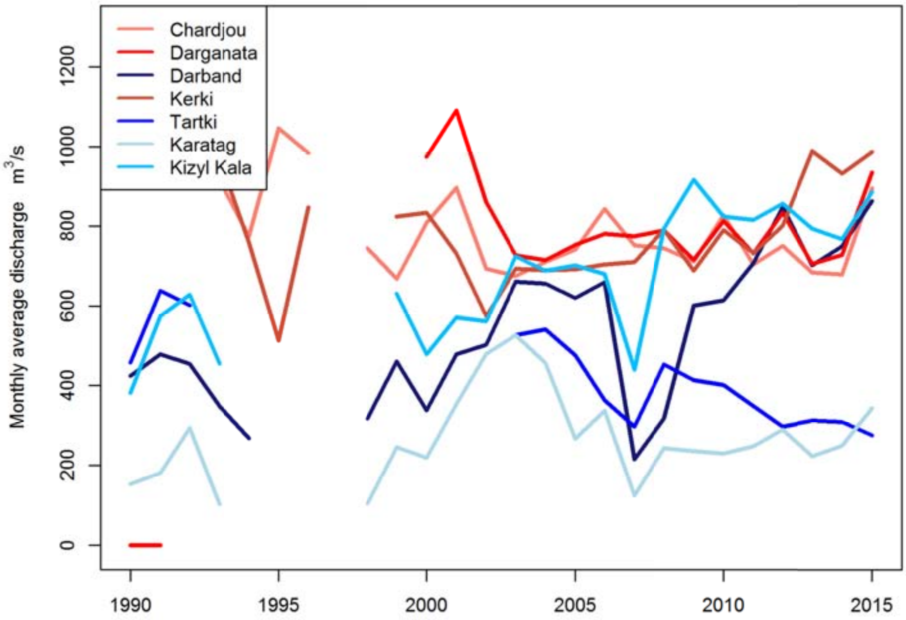

Figure 6 Mean annual mineralization levels at the selected gauges

Though naturally the soils in the Amu Darya catchment are saline, the natural runoff processes are the minor contributor to salt effluents, due to low precipitation intensity in the catchment. The water quality at one of the downstream sections of Amu Darya at the Samanbay gauging station exhibit exceedance of maximum levels nearly for all important parameters, including mineralization, nitrates and phosphates (Crosa et al. 2006).

The main tributaries of the Amu Darya River are rivers Vahsh, Surkhandarya, Kafirnigan and Pianj. The former tributaries Zeravshan and Kaskadarya are not reaching the main stream of the Amu Darya, as all water resources of both rivers are diverted to the agricultural fields (SIC ICWC 2011).

The lowest water quality is observed in the **Surkhandarya River**, due to untreated effluents of the industrial and municipal waste water, as well as agricultural chemicals along its entire length. The water quality of the **Zeravshan River** is mainly impacted by the mining and polluted by heavy metals. In the **Kafirnigan River** basin, as well as in **Pianj River** Basins there are agricultural collector drains, but the soils are in general low saline and the mean annual mineralization of water discharged into the reach is 350 to 700 mg/**l** for Kafirnigan and up to 1000 mg/l for Pianj River. The soils in the Vahsh River catchment are more saline than in the Kafirnigan and Pianj River catchments and there are about 20 collector drains, serving irrigated area (SIC ICWC 2011).

Apart from Surkhandarya the contribution of the untreated urban and industrial wastewaters to the overall level of pollution can be considered minor, as compared to the pollution with agrochemicals.

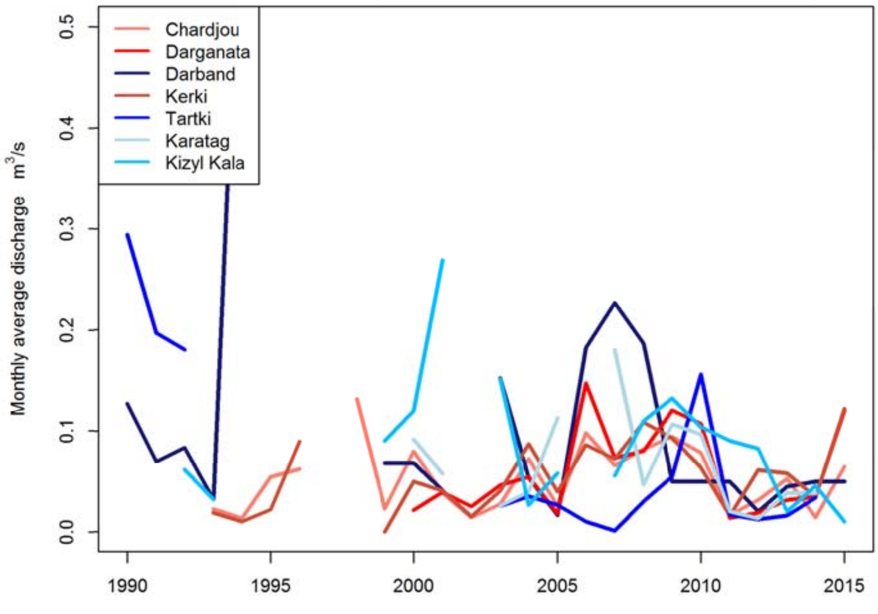

Figure 7 Mean annual phosphorous levels at the selected gauges

Figure 7 depicts mean annual levels of phosphorous at the selected gauges. One can observe the scarcity of observations before the year 2003 in al gauging stations. The levels of phosphorous show no growing trend in the longitudinal profile and seem to depend rather on the point source pollution in each particular case.

Figure 8 presents the nitrates levels at the selected gauges with yearly time step. The nitrates levels are lowering when moving from upstream to downstream, possibly due to the dilution processes, showing the maximum values in the upstream parts of the Amu Darya River Basin, until the year 2010, after that the measurements are indicating growing trend in nitrates levels.

Chardjou, Dashouz, and Khorezm oases are located further downstream of the Amudarya river. Collector drains located in the first two oases have water mineralization varying from 1300 to 3500 mg/l, while their discharge is from 1.3 to 45 m^3/s. Between the Kerki and Darganata gauges the Amu Darya River receives approximately 40% of all return water.

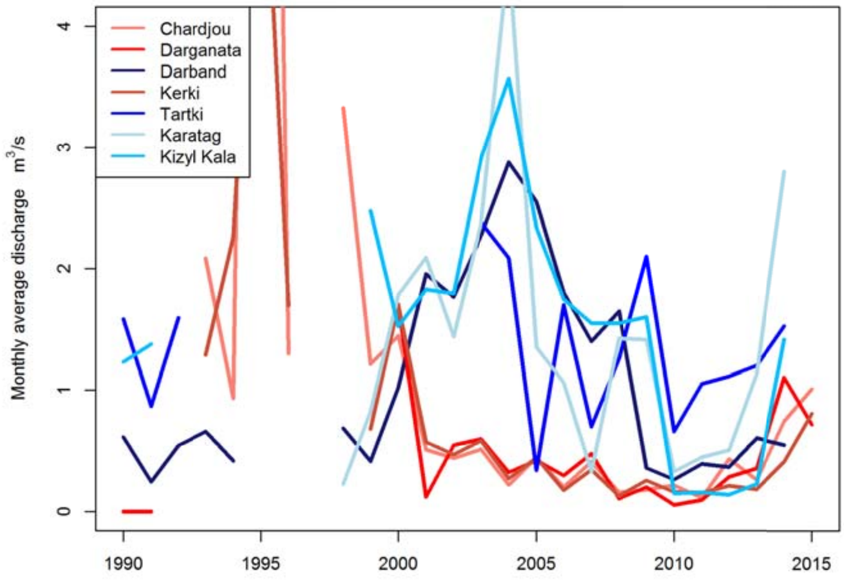

Figure 9 Mean annual nitrates levels at the selected gauges

The estimated mean discharge from main drainage outlets to the Amu Darya River between the Termez and Samanbay gauges is approximately 140 m3/s (based on the received datasets with records of drainage discharge over 1992 -2015).

Figure 10 presents the mean monthly discharge, averaged over 20 selected drainage channels, over the period of 1992-2015 and their average mineralization based on the received datasets with observations. One can observed that, there are growing trends trend in terms of water volumes, discharged back into the Amu Darya, as well as in their average mineralization.

Figure 11 depicts the mean monthly discharge of the drainage effluents into the Amu Darya River, based on the received data, as well as average mineralization of those. One can observe that the drainage discharge reaches its maximum from March until August and the mineralization of flows is slightly higher in the spring months – March April.

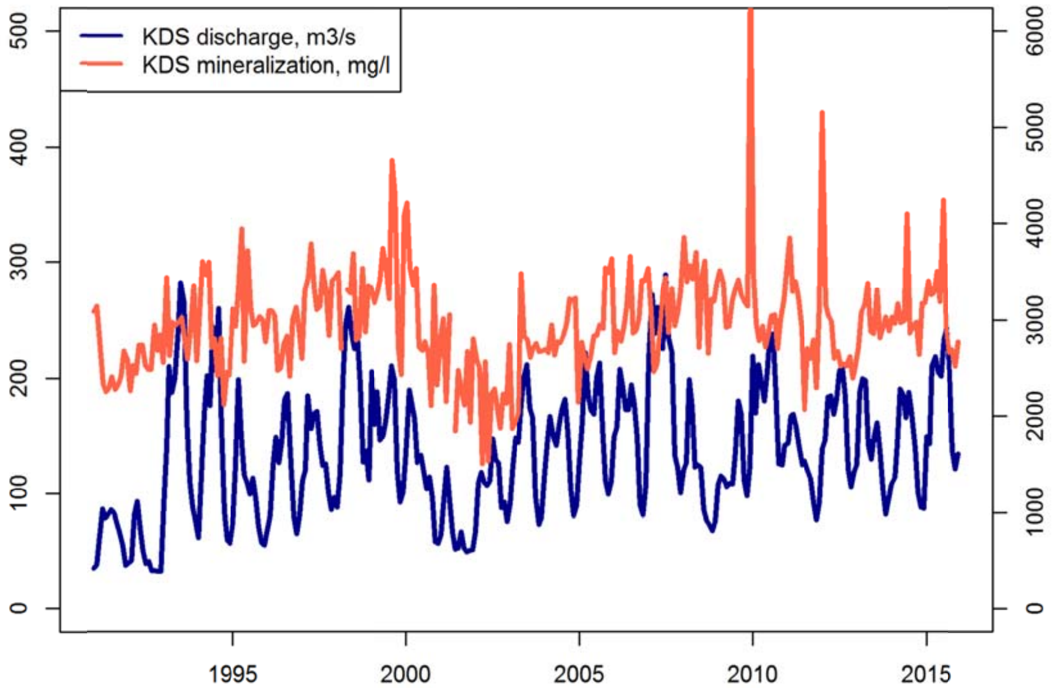

Figure 10 Sum of monthly discharge of drainage water into Amu Darya River and its average mineralization based on selected drainage channels over 1992-2015

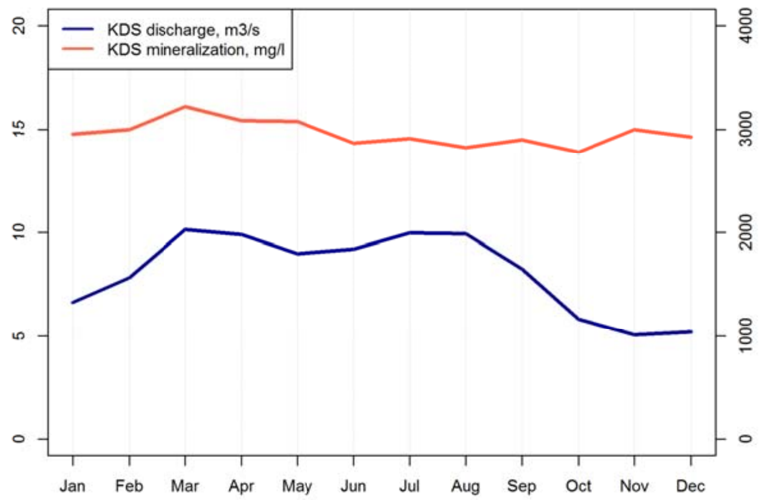

Figure 11 Mean monthly discharge and mean mineralization of return flows into the Amu Darya River over 1992-2015

3 Water quality parameters – flow relationships

3.1 Mineralization-discharge relationship found in the literature

Crosa et al. (2006) conducted an analysis of the relationship between mineralization and river discharge for the Kerki and Darganata gauging stations. The data were supplied with the monthly timestep and covered the period of 1996 to 2001.

They conducted, that the Amu Darya is a system where mineralization responds strongly to the variations of discharge. Further, there are two major factors influencing the mineralization levels in the river reach, firstly the high flows that are diluting the drainage effluents and decreasing the mineralization of water and second, the influence of low flows which are occurring in spring months – March –April, when also the leaching from the drainage system is slightly higher due to soil washing.

Based on their analysis of observed data, both discharge and mineralization recorded with monthly timestep, they suggest the following model to describe the mineralization-discharge relationship for the Kerki and Darganata gauging stations (graphical representation on Figure 12):

$$C_i = a \cdot Q_i^b$$

Where c – concentration of dissolved compound, Q_i – discharge, a – dilution effect, b – basal flow

The estimated values of the coefficients for the Kerki station are: a = 6664.08, b = 0.34, and for the Darganata station are: a = 11032.91, b = -0.34.

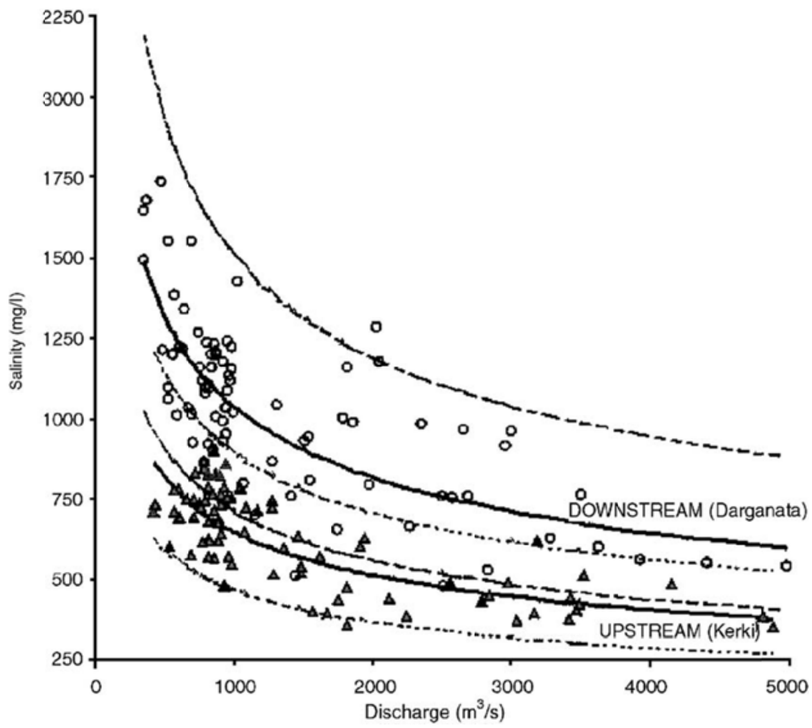

Figure 12 Mineralization and discharge relationship at Kerki and Darganata gauging stations. (Crosa et al. 2006)

3.2 Estimated from the observed data received

Based on the received observed data, described in Chapter 1 the following graphs, representing the mean annual discharge values against the three selected water quality parameters: mineralization, phosphorous and nitrates are presented for each selected gauge – see Figures 13 to 17.

3.2.1 Tartki

For the Tartki station, located at the Kafirnigan River basin from the Figure 9 it can be seen that there is a positive correlation between the levels of nitrates that are growing together with the increasing of the flows in spring, levelling off during the summer months and then decreasing in winter and autumn. For the mineralization the picture is slightly different than for the other gauges – the increased level of mineralization in spring months – April, when possibly the washing of the soils is happening is diluted by the peak flow in May, reducing the levels dramatically, then in summer the mineralization levels are levelling off. No direct correlation between the discharge and mineralization levels can be observed, although the visual inspection of the graphs suggests an inverse relationship between those. For the phosphorous no clear correlation can be found with the discharge. From Figure 9 one can observe increase in the phosphorous levels during the low flows and decrease during the high flows.

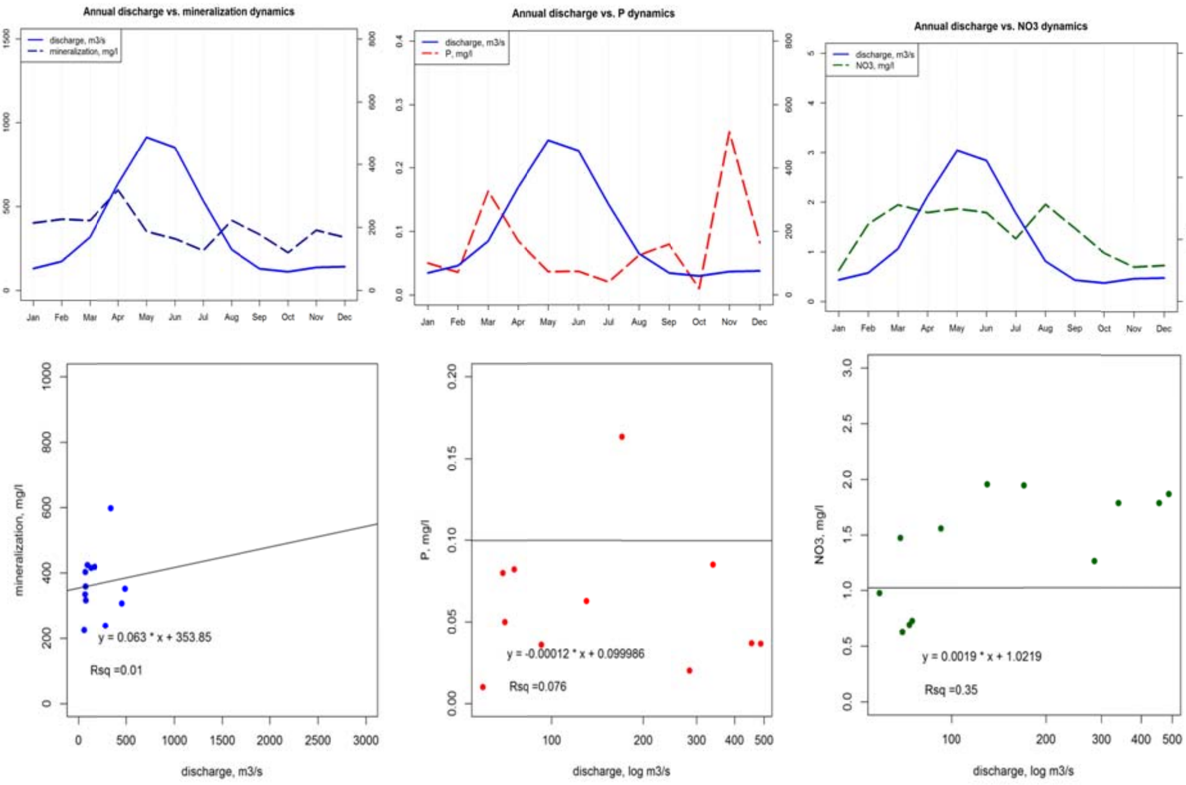

Figure 13 Average annual discharge vs mineralization, phosphorous and nitrates dynamics and their correlations for the Tartki gauging station

The levels of the phosphorous are also relatively high in November, which allow to suggest some point pollution source, e.g. outlet of untreated waste water or similar.

3.2.2 Darband

The relationship between the discharge and water quality parameters for the Darband station is similar to the one described for the Tartki, in particular, inverse relationship between the levels of mineralization and phosphorous with the discharge rates and direct between nitrates levels and discharge. Also for Darband station there are peak in the phosphorous levels in November, indicating probable point source pollution, as for Tartki station.

Similarly, little inverse correlation between the mineralization and discharge was found, but from the graph with mean annual discharge and mineralization levels it is clear that there should be a stronger inverse relationship.

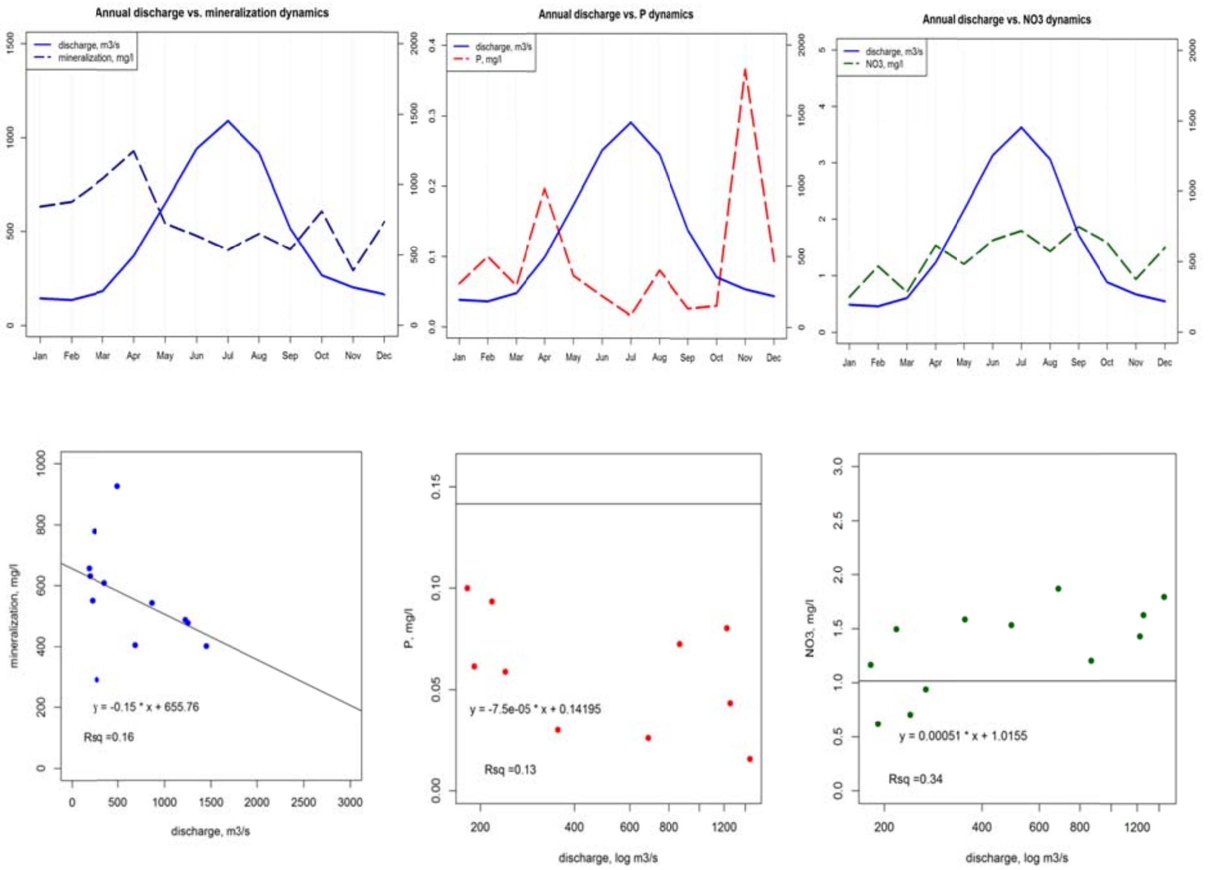

Figure 14 Average annual discharge vs mineralization, phosphorous and nitrates dynamics and their correlations for the Darband gauging station

3.2.3 Kerki

For the Kerki station, the correlation between the mineralization levels and the discharge becomes to be stronger, resulting in R^2=0.57. At the same time there is no clear correlation between the phosphorous and nitrogen levels as for the upstream gauges. The phosphorous levels at this station also show relatively stable levels throughout the year and are lower, than in the upstream gauges, possibly also due to dilution processes and less pollution load.

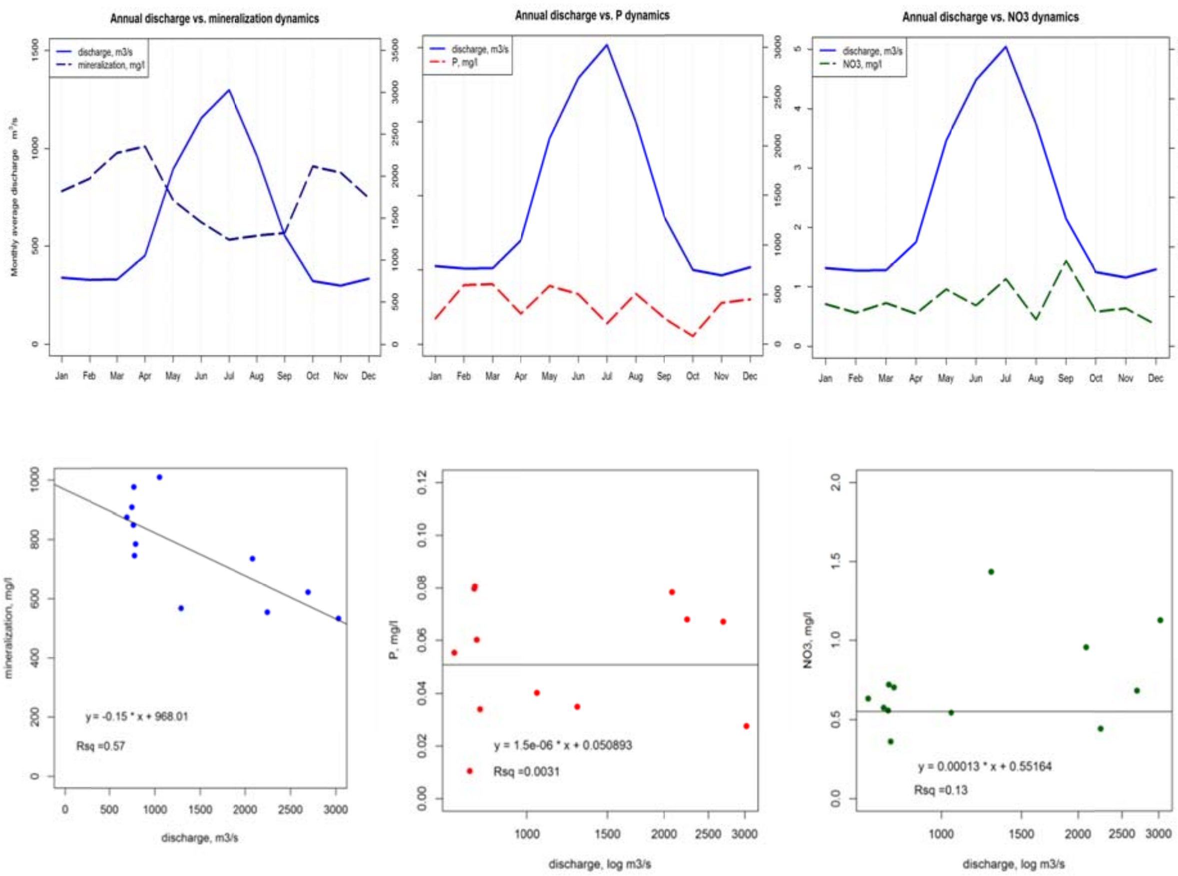

Figure 15 Average annual discharge vs mineralization, phosphorous and nitrates dynamics and their correlations for the Kerki gauging station

3.2.4 Chardjou

The relationship between the mineralization and discharge is also strong for this gauging station. The levels of phosphorous are also relatively stable throughout the year. However, there were two observations in the time series of phosphorous of 6.68 and 13 mg per litre, which probably indicate single untreated waste water discharges or an erroneous observation. Those were excluded from the analysis as outliers.

The nitrates show some peaks in spring months, what probably can indicate the agrochemical pollution, coming from the fertilizers applied in the agricultural fields and washed out during the soil washing in spring months.

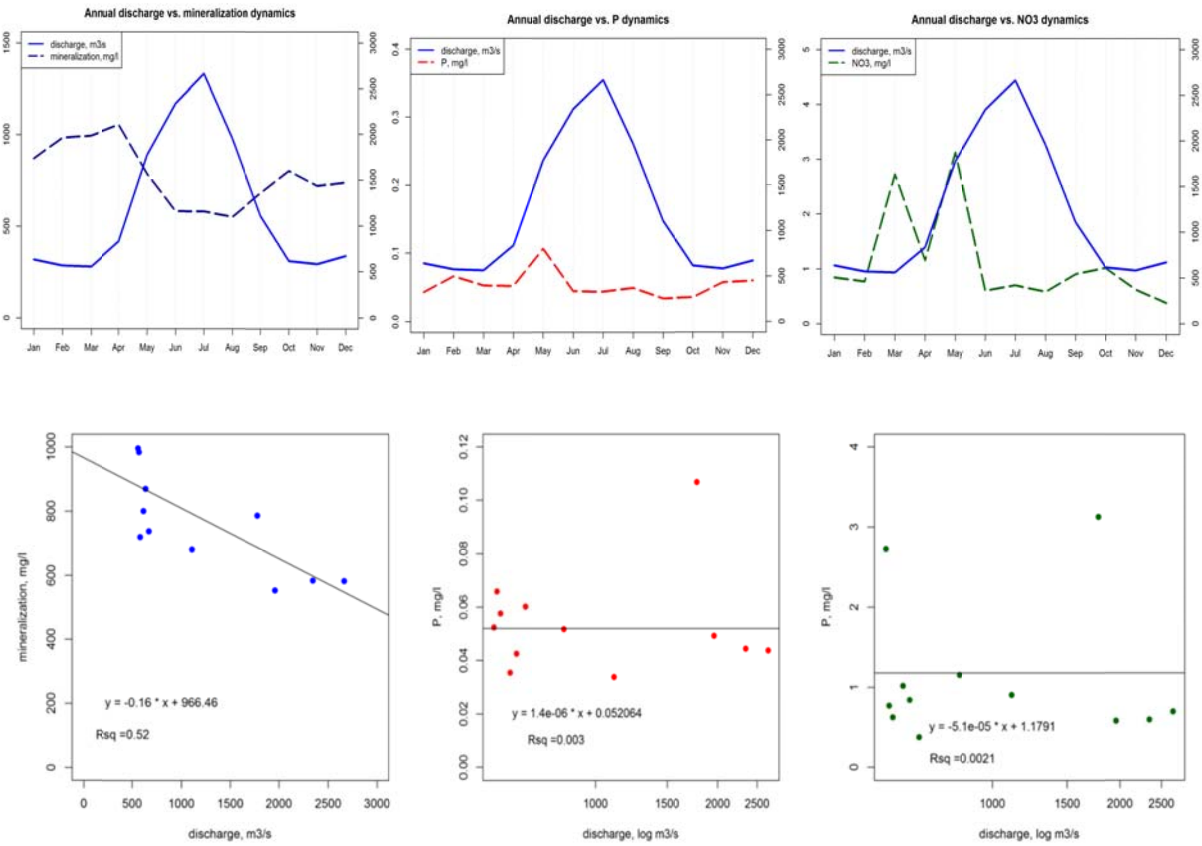

Figure 16 Average annual discharge vs mineralization, phosphorous and nitrates dynamics and their correlations for the Chardjou gauging station

3.2.5 Darganata

For the Darganata the picture is similar as for the Kerki and Chardjou gauges – strong correlation of mineralization to discharge levels, relatively stable levels of nitrates and phosphorous throughout the year.

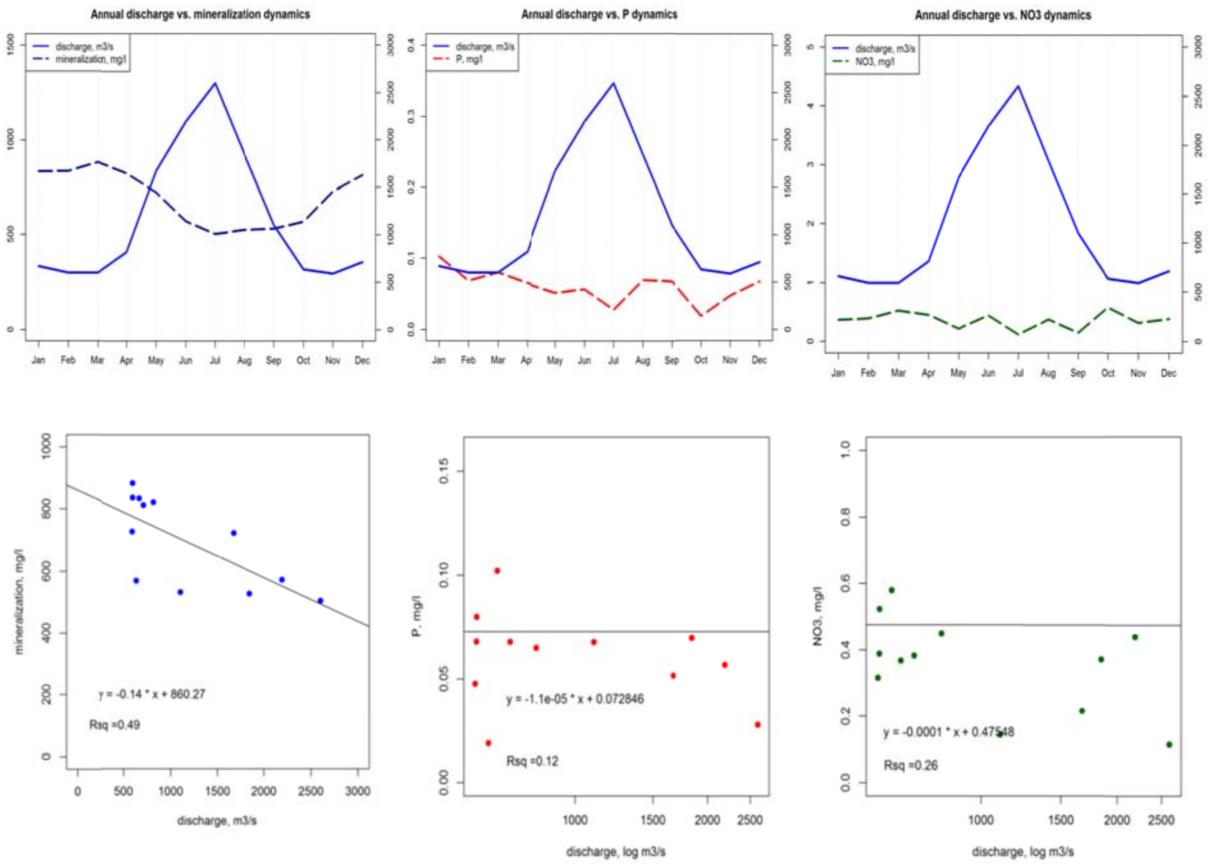

Figure 17 Average annual discharge vs mineralization, phosphorous and nitrates dynamics and their correlations for the Darganata gauging station

4 Conclusions

Firstly, the observed data availability and quality were relatively low and further endeavours in the region should be aimed at increasing the number of sampling stations, regularity of the observations and recording of dates when the samples were made. Such information is essential even for such simple statistical analysis as correlation estimation, what can explain that not for all stations a strong correlation was found for the water quality parameters, which is associated with data scarcity and missing information of dates of sampling, as well as discharge values on that day.

The phosphorous levels are relatively high at all sampling stations and do not exhibit increasing trend in the longitudinal profile of the river, on the other hand, the phosphorous values are higher in the upstream gauges, indicating possible point source pollution, e.g. with untreated domestic waste water. The measured levels of nitrates are highest in the upstream gauges and at the Chardjou gauge.

There is a strong correlation between the mineralization and the discharge: the maximum levels of mineralization are occurring during the spring months during the low flow period and when the leaching of the drainage water is slightly higher. The relationship between the mineralization and discharge shows stronger correlation for the downstream gauges, allowing the suggestion that the dilution processes have stronger influence on the downstream water quality than the upstream. The lowest values of mineralization are observed during summer months, when the discharge levels are reaching its maximum. There was also found an inverse relationship between the phosphorous levels and discharge and direct relationship between the nitrogen and discharge, especially for the upstream stations. Such relationships are also described in the theoretical literature, therefore current conclusions can be considered as robust.

At the later stage, when analysing the changes, triggered by projected climate change, in the discharge special attention will be paid to the changes in the seasonality of the discharge, which is likely to occur due to projected strong increase in the temperature, which in turn will affect the mineralization and nitrates levels though dilution. Additionally, it will be important to analyse how the frequency of low (Q90, Q95) and high flows (Q5, Q10) will be changing in the future, as they will also have a direct impact on the mineralization levels.

At the further stage the model, proposed by Crosa et al. (2006) will be tested in order to estimate the mineralization levels at the Kerki and Darganata levels, in addition to estimated relationships, provided in this report.

While climate change may have a significant impact on the hydrological patterns of the system and therefore the important dilution processes, the Amu Darya River is a system strongly affected by anthropogenic activities, which in the future may also outweigh the impact of climate change.

5 References

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ANNEX 1

Total number of observations per month at five stations

Month	Discharge	Mineralization	Suspended matter	pH	NO2	NO3	Total N	P
Tartki								
Jan	14	9	6	9	8	7	9	5
Feb	14	6	3	6	5	5	6	4
Mar	14	4	2	4	3	3	3	1
Apr	14	7	4	7	7	6	7	4
May	14	8	6	8	8	7	8	5
Jun	14	8	6	8	7	7	8	5
Jul	14	9	7	9	7	6	7	8
Aug	14	4	1	4	4	4	4	3
Sep	14	4	3	5	4	4	5	3
Oct	14	4	3	5	4	3	4	2
Nov	13	6	4	7	7	4	7	3
Dec	14	8	6	9	9	7	9	5
Darband								
Jan	21	12	11	14	15	12	15	7
Feb	21	6	5	8	8	6	8	3
Mar	21	13	8	14	14	12	14	8
Apr	21	12	9	12	13	11	14	6
May	21	19	15	21	21	20	20	14
Jun	21	11	9	13	11	11	11	8
Jul	21	10	7	11	10	9	10	6
Aug	21	13	9	14	13	14	15	10
Sep	21	5	3	6	7	7	7	5
Oct	21	5	5	9	6	6	9	3
Nov	21	11	9	17	16	14	15	9
Dec	21	10	6	13	13	9	13	6
Kerki								
Jan	26	14	2	14	14	14	17	14
Feb	26	12	2	12	12	12	17	12
Mar	26	13	1	13	13	13	16	13

Apr	26	14	2	14	14	14	16	14
May	26	10	3	10	10	10	16	10
Jun	26	14	2	14	14	14	16	14
Jul	26	13	2	13	13	13	16	13
Aug	26	14	3	15	14	14	16	15
Sep	26	8	2	8	8	8	16	8
Oct	26	2	1	2	2	2	16	2
Nov	26	11	2	11	10	11	16	10
Dec	26	12	1	12	12	12	16	12
Chordjou								
Jan	25	18	4	18	18	18	16	18
Feb	25	16	4	16	16	15	16	16
Mar	26	16	3	16	16	16	16	16
Apr	26	16	2	16	16	16	16	16
May	26	16	3	16	16	16	16	16
Jun	26	16	2	16	15	16	16	15
Jul	26	15	1	15	15	15	16	15
Aug	26	18	1	18	18	18	16	18
Sep	26	10	2	10	10	10	16	10
Oct	26	4	1	4	4	4	16	4
Nov	26	9		9	9	9	16	9
Dec	26	13	1	13	13	13	16	13
Darganata								
Jan	26	15	19	14	15	15	16	14
Feb	26	9	1	8	9	9	16	8
Mar	26	12	1	11	12	12	16	11
Apr	26	12	1	11	12	12	16	11
May	26	13	2	11	13	13	17	11
Jun	26	12	1	11	12	12	16	11
Jul	26	11	1	10	11	11	16	10
Aug	26	12	1	11	12	12	16	11
Sep	26	8	1	7	8	8	16	7
Oct	26	3	1	2	3	3	16	2
Nov	26	9	1	8	9	9	16	8
Dec	26	12	1	11	12	12	16	11

Schematic Representation of drainage channel network of the Amu Darya River (source BWO "Amudarya")

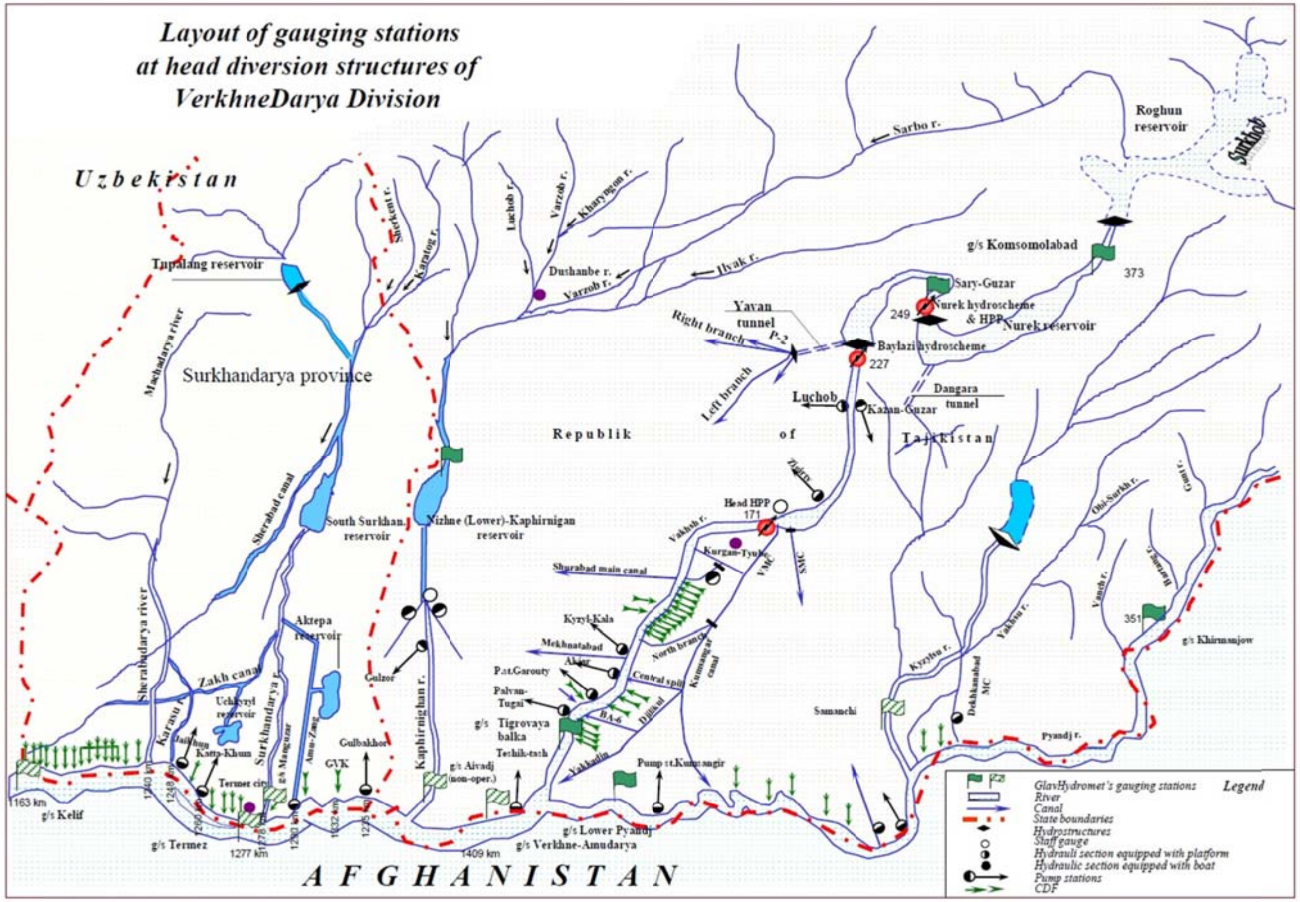

Figure A1 Schematic representation of gauging stations, drainage channel networks and hydraulic structures in the upstream part of the Amu Darya River Basin

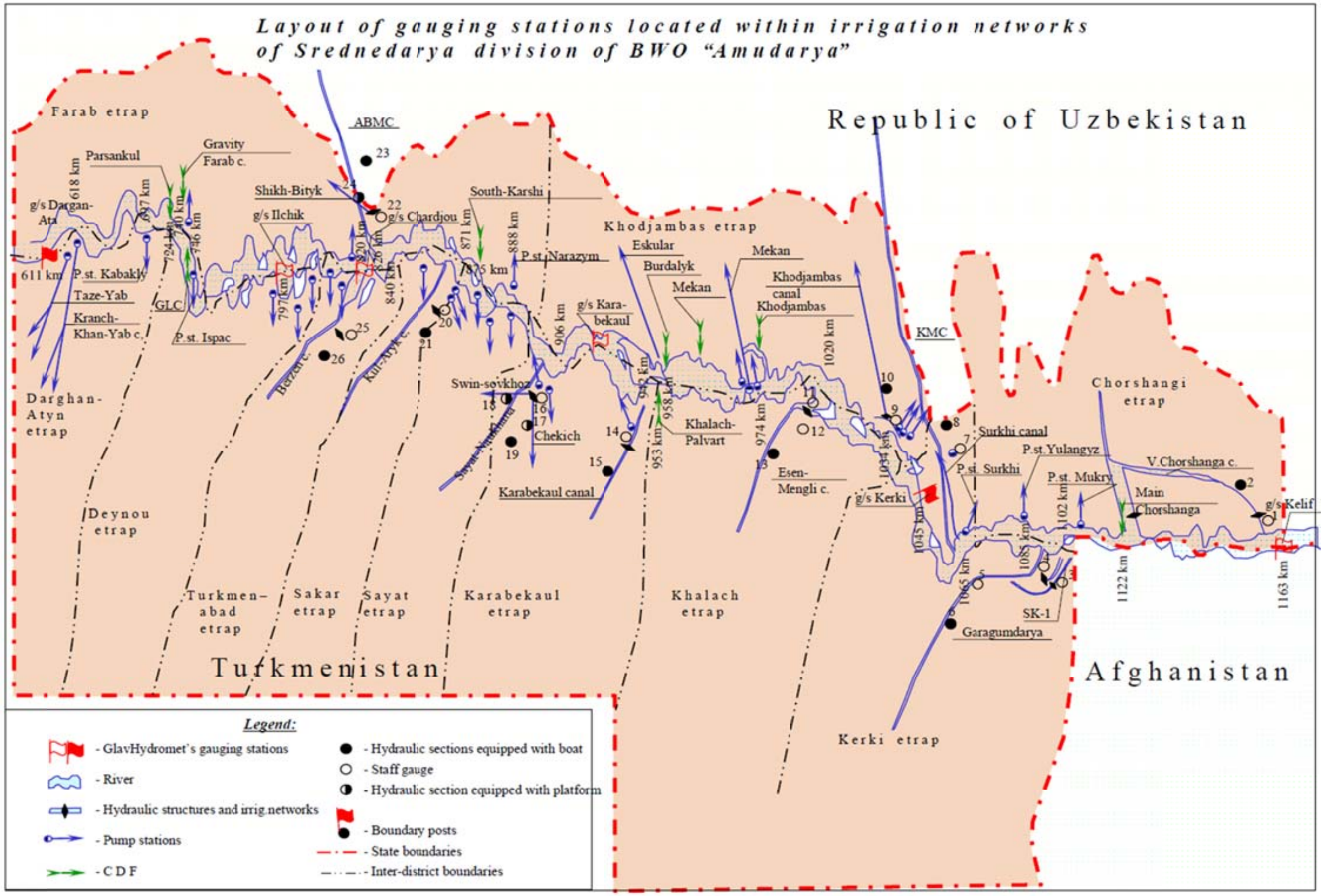

Figure A2 Schematic representation of gauging stations, drainage channel networks and hydraulic structures in the middle part of the Amu Darya River Basin

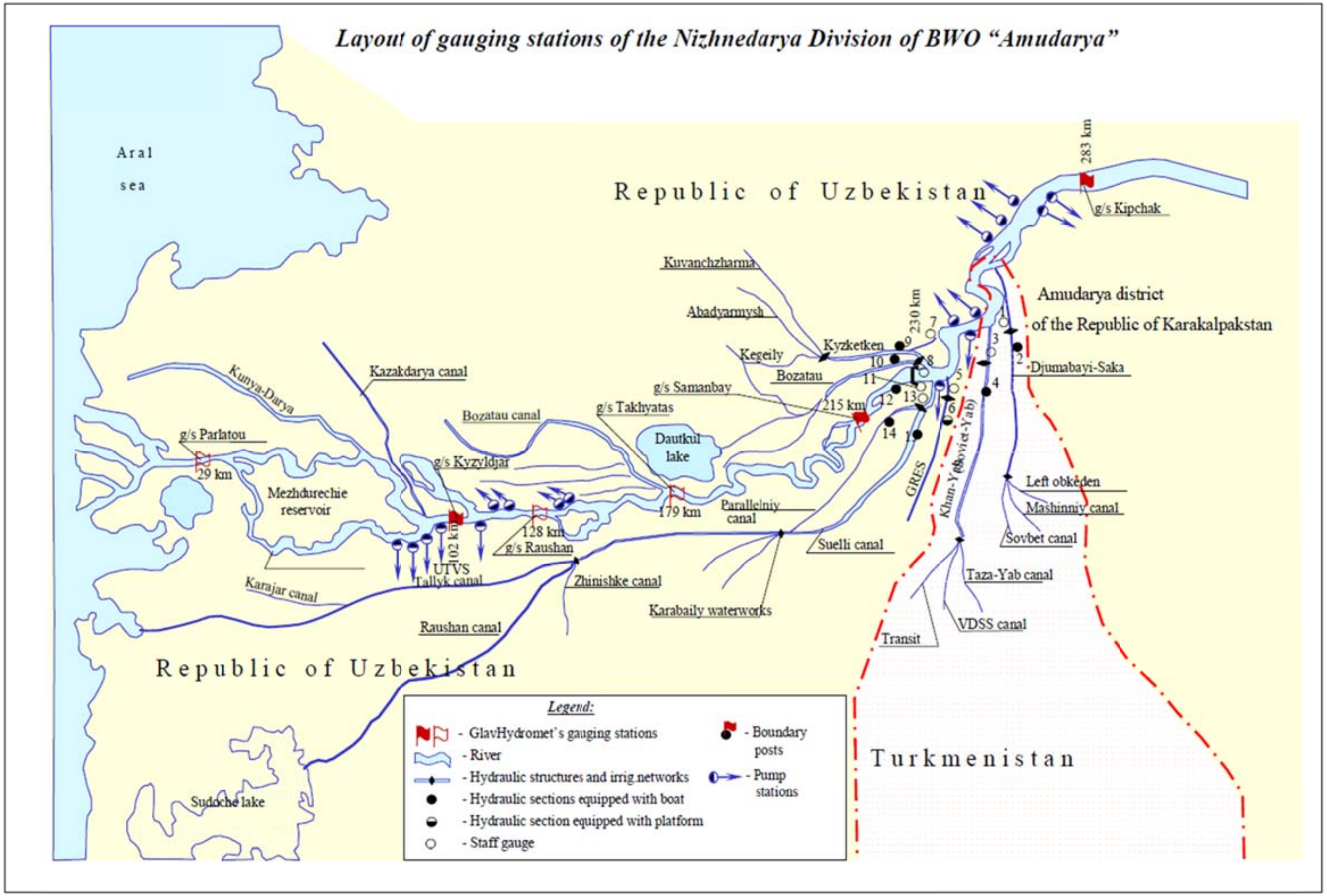

Figure A3 Schematic representation of gauging stations, drainage channel networks and hydraulic structures in the lower part of the Amu Darya River Basin