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ORIGINAL ARTICLE

Quantitative and qualitative assessment of collector-drainage waters in Aral Sea Basin: trends in Jizzakh region, Republic of Uzbekistan

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Abstract
Reintroduction of highly mineralized Collector-Drainage Waters (CDW) enhances the salinity of inland waterbodies and limits water suitability for downstream users. Detailed quantitative and qualitative research based on the inter-annual and multiyear generation trends of CDW in Central Asia could help to improve the irrigation system for agriculture and furthermore in determining opportunities for reutilization and biodiversity protection. This is the first long-term research designed to study the discharge, salinity, and ionic composition of CDW in the Jizzakh region (Uzbekistan). A database of field measurements of salinity gathered during the field expeditions from 2000 to 2017 was used in the study. Spring season showed highest CDW discharge where April showed maximum while lowermost was recorded for summers, especially during August. All main collectors showed continuous increments in salinity over the last two decades. This was neither in correlation with CDW discharge nor salinity changes from the irrigation water source (Syrdarya river). A considerable increase of collectors' salinity within the range of 18%–37% was observed from upstream to downstream. The highest salinity values were observed during spring and lowest for summer with even lesser degree for the winter season. Among anions, sulfates were predominant followed by chlorides and bicarbonates; among cations, sodium was predominant followed by calcium and magnesium, which is different from the ionic composition of the water source. The study revealed that increased CDW discharge has not always resulted in low salinity and that high water years have not always caused a decline in CDW salinity showing that CDW discharge and salinity had differential dependence on each other.

Keywords Drainage water · Trends · Discharge and salinity changes · Ionic composition

Introduction

Unique in its geographic location, natural resource and biodiversity potential the Aral Sea Basin (ASB) today turned out to be at the center of a number of environmental threats. The shrinkage of the area and water volume of the Aral Sea, the salinization, degradation, and desertification of former seabed, the extensive and irrational use of the limited water resources have become one of the most sensitive problems requiring urgent solutions (Kipshakbayev et al. 2002; Dykhovny et al. 2007; Wegerich 2011; Kulmatov 2018; Karimov et al. 2020). This situation is aggravated by the climate change, transformation of hydrological regime and hydrography, habitat fragmentation and decline in biodiversity, salinization and pollution of land, surface and groundwater resources (Savitskiy et al. 2008; Thornquist et al. 2011; Karimov et al. 2014, 2019a, b; Lioubimtseva 2015; Cañedo-Argüelles et al. 2016).

Since 1950, the irrigated lands in the ASB increased from 3.5 to 8.0–8.5 million ha, which was accompanied by a sharp increase in water extraction from the two main rivers Syrdarya and Amudarya and drying up of the Aral Sea. The development and expansion of irrigated lands in the ASB have led to significant impairment of the ecohydrological

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balance of the freshwater resources (Dukhovny and Schutter 2011; Sokolov 2018).

The characteristic feature of irrigated agriculture in the arid ASB is in the formation of a huge amount of return flow from agricultural field's collector-drainage waters (CDW). In most parts of ASB, CDW network also accepts wastewater from industry and municipalities, animal husbandry and aquaculture farms (Karimov et al. 2014; Ergashev et al. 2016). The total amount accounts for about 95 percent of drainage water and about 5% of untreated wastewater (FAO 2012).

The volume of return flow on a global scale is estimated in the order of 500 km^3 or 25–30% of the total water resource used for land irrigation (Yakubov et al. 2011). In the territory of the former Soviet Union in 1993–1994, the total amount of CDW flow was 49–50 km^3 (Yakubov et al. 2011). About 32–40 km^3 from them (~ 30% of total water resources used for the irrigation needs) was formed in the ASB due to development of irrigation and drainage systems on the intensively developed irrigated lands (Yakubov et al. 2011; Groll et al. 2015; Sokolov 2018).

The volume of CDW formed in the ASB countries varies depending on the dryness of the year. Calculations of a long-term series of observations of the return water flow for the period of 1980–2009 has shown that 32.4–36.0 km^3 of CDW is formed in the region in high water years, 24.19–27.35 km^3 in the dry years and 27.35–32.4 km^3 on average (Dukhovny and Stulina 2001; Yakubov et al. 2011; Groll et al. 2015).

In the Amudarya river basin, including the Karakum Canal zone together with the Murgab and Tedzhen irrigation areas (Turkmenistan), 17–18 km^3/year of CDW is formed with the salinity from 1.8 to 14.2 g/L (Yakubov et al. 2011; Sokolov 2018). The largest amount of CDW is formed within Tuyamuyun irrigation area (downstream): up to 4.71 km^3/year with average salinity of 4.2 g/L (Yakubov et al. 2011). In terms of ionic composition, these waters are sulfate–chloride–calcium–magnesium–sodium (SC-CMS). Most of the CDW from Tuyamuyun irrigation area are taken by inter-republican collectors into the Sarykamysh depression located on the border between Uzbekistan and Turkmenistan (Yakubov et al. 2011; Kulmatov et al. 2013; Karimov et al. 2014).

In the Syrdarya river basin, 12–15 km^3/year of CDW with salinity from 1.7 to 6.0 g/L is formed (Karimov and Razakov 1989; Kulmatov et al. 2013; Sokolov 2018). The largest annual volume of CDW: up to 7.5 km^3/year is formed in the upstream (Fergana Valley) and in the Golodnaya steppe desert including the old and new irrigation zones in Syrdarya and Jizzakh regions (midstream): 2.6 km^3/year. From the territory of the Tashkent oasis (midstream), 1.2 km^3/year of CDW is generated (Yakubov et al. 2011; Groll et al. 2015).

The share of industrial and municipal wastewater varies from 1.1 to 1.4 km^3 (approximately 10%) in the Syrdarya river and from 0.9 to 1.1 km^3 (approximately 6%) in the Amudarya river basins (Yakubov et al. 2011; Kulmatov et al. 2013; Sokolov 2018). From the total volume of CDW waters (agriculture, industry and municipal), 15–16% is reused in agriculture, 33–55% is discharged into rivers, and more than 30–50% is diverted to the local depressions. The annual quantity of discharged salts by the return flow is estimated to be 143.5 million tons in ASB in 2004 including 42.5 million tons in Syrdarya river and 81 million tons in Amudarya river basins (Yakubov et al. 2011; FAO 2012; Groll et al. 2015).

In Uzbekistan, about 10% of available land resources is irrigated and water used for the needs of the agricultural sector accounts to about 90% of total water use (Dukhovny and Stulina 2001; Yakubov et al. 2011; Sokolov 2018). The demand for water resources in the country will continue to increase and climate change will most likely lead to a significant reduction in the country's water supply (Ososkova et al. 2000; Abuduwaili et al. 2019; Salokhiddinov et al. 2020).

The level of salinity increases along the rivers, especially in the downstream of the rivers mainly due to reintroduction of CDW discharges into rivers. Until the late 1960s, Amudarya and Syrdarya rivers water salinity did not exceed 1.0 g/L, even in the downstream. Currently, it varies from 0.3–0.6 g/L in the upstream and to 1.7–2.0 g/L in the downstream part of the rivers (Rubinova 1987; Yakubov et al. 2011; Karimov et al. 2019a, b). Increasing of salinity of irrigated water leads to a decrease in crop yields of agriculture. An increasing in salinity of the irrigated water for every 0.1 g/L compared to the initial value causes damage to crops productivity from 134 to 147 US dollars per ha in the Amudarya river basin, and from 70 to 150 US dollars per ha in the Syrdarya river basin (Dykhovny and Schutter 2001; Yakubov et al. 2011).

In Uzbekistan, more than 50% of the CDW waters of ASB region are diverted to local depressions forming overflowed artificial lakes of irrigational origin occupying of more than 1 million ha of marginal desert lands previously used for grazing or other needs (Thorpe et al. 2011; Sokolov 2018). The largest artificial lakes of this type are the Aydar-Arnasay lakes system (AALS) with water volume of more than 42 km^3, the Sarykamysh lake with a volume of about 100 km^3 (Turkmenistan and Uzbekistan), Dengizkul, Solenoe, Sudochye (Uzbekistan), and a number of less capacious lakes with water volume of up to several hundred million cubic meters of brackish water (Yakubov et al. 2011; Groll et al. 2016). These very shallow waterbodies raising the level of groundwater and soil salinity in the surrounding territory, and worsening the ameliorative condition of irrigated lands around these lakes (Yakubov et al. 2011; Groll et al. 2015; Karimov et al. 2019a, b).

These artificial lakes now are the source of evaporation of large water volumes that probably contributes to the irretrievable water loss in the region and probably also cause local "greenhouse effect" (Held and Soden 2000; Chembarisov et al. 2002; Yakubov et al. 2011). These terminal artificial lakes and reservoirs have low fish productivity and poorly developed fauna and flora due to the instability of the water level and hydrochemical regime especially salinization throughout the year (Karimov 1989; Pavlovskaya 1995). However, they are important lentic habitats-reservates for the conservation of remnant Aral Sea aquatic life (Thorpe et al. 2011; Gozlan et al. 2019; Karimov et al. 2020).

Thus, the generation of huge amounts of highly mineralized CDW waters became a serious environmental problem for the region. Collector-drainage canals network pollution sources include also municipal and agricultural sewage waters from rural areas; however, drainage waters from irrigated fields containing agrochemicals and especially high amounts of salts. This is why CDW is not directly used for municipal water supply. However, they are often used for other purposes as irrigation, fisheries, aquaculture, and recreation (Yakubov et al. 2011; Groll et al. 2016; Karimov et al. 2020). For these aims, water salinity (sometimes reported also as total dissolved solids—TDS) level and ionic composition is the most important quality indicators for the evaluation of suitability, especially for irrigation. The use of water containing high concentrations of sodium and chloride ions for irrigation poses greater hazards decreasing soil permeability (Grattan 2002; Zhang et al. 2019). However, if the salinization of river water in ASB and other regions of the world is more or less well studied (Brown et al. 2003; Chen et al. 2003; Isidoro and Aragues 2007; Chembarisov et al. 2013; Gaybullaev and Chen 2013; Zhang et al. 2019; Bissenbayeva et al. 2020), it is still very poorly studied concerning the CDW waters. The available rare information is either quite outdated or includes mainly the analyses of TDS within a short period (Chembarisov 1996; Letolle and Chesterikoff 1999; Elizbarashvili et al. 2016; Drovovozova et al. 2020).

Therefore, there is an urgent need to study salinity and ionic composition characteristics and development of practical recommendations for reduction and possible reutilization of agricultural return waters which would greatly alleviate the abovementioned environmental and socio-economic problems in the ASB region. One of the largest irrigated areas in the ASB, and in particular, in Uzbekistan, is the Jizzakh region where annually 800–1000 million m^3 of CDW is formed. Present work is devoted to the detailed study of multiyear trends of quantity and quality the currently generated CDW and regularities of water salinity and ionic composition formation to identify opportunities for reuse and better management of CDW in Jizzakh region.

Materials and methods

Research area

The Jizzakh region is located in the center of the Republic of Uzbekistan according to its geographic position, bordered with Syrdarya region from the east, the Republic of Kazakhstan from north, and Republic of Tajikistan from the south (Fig. 1).

In the southwestern part of the region, Molguzar, Kuytosh, Nurata mountain ranges are located, which separate Gallyaral and Forish districts, and Zomin and Bakhmal districts from the south-west. The western border of the region reaches to the lower plains of Kyzylkum sand desert, where large areas are occupied by the AALS lake system. The total area of the region is 2.05×10^4 km^2 (39°57′−41°24′N, 66°66′−68°57′E), the area of irrigated lands—3.0×10^3 km^2, population 1.250 million and 70% of the population lives in rural areas (Annual Statistics, 2017).

Climate

The climatic conditions are distinguished with sharp continentally, dry and hot summers and moderately cold winters. The lowest temperature is in January, the highest being in July, and average annual temperature is 15.6 °C. Precipitations are mainly observed in winter and spring; the average highest monthly precipitation is in March—63 mm, with an average annual rainfall of 308 mm.

Collector-drainage network

Total area of irrigated lands of the region is about 3×10^5 ha (Khamraev et al. 2017; Kulmatov et al. 2020) and most are located in the Mirzachul and Jizzakh deserts and about 2.7×10^5 ha supplied with artificial drainage. Remaining areas of irrigated lands are located on the foothills of the Bakhmal, Gallaorol, Sh. Rashidov, Forish and Yangiabad districts with no need in artificial drainage due to low level of groundwater. According to Ministry of agriculture and water resources (MAWR 2017) closed artificial horizontal drainage is constructed on 2.2×10^4 ha irrigated land and the rest supplied with open, vertical drainage.

Total length of collector-drainage networks in the region is 17,706.5 km, which consists of (Fig. 2):

– Main collector-drainage canals accepting interfarm collectors and diverting CDW to marginal lakes or rivers—281 km

Fig. 1 Research area—Jizzakh region (red colored) and irrigation zone (green colored)

- Interfarm collector-drainage canals draining the separate farms or crop-rotation sectors—1001.1 km.
- Intrafarm collector-drainage canals draining directly the fields or irrigation sectors—3187.93 km.
- Closed horizontal drainage—13,236.5 km.

Sampling and analytical methods

Unfortunately, due to the dispersion of collector-drainage canals network in hard-to-reach places, the lack of portable and automatic measuring equipment, and insufficient quantity of hydroposts, it is difficult to accurately monitor the quantity and quality of CDW flow in Uzbekistan, in particular in Jizzakh region.

Regional Hydrogeological Melioration Expedition under Ministry of Agriculture and Water Resources (HGME MAWR) is monitoring irrigated lands including measurements of water and soils quality (mainly salinization) and level of groundwaters. In present article, we use the datasets of HGME that includes the results of hydrochemical analyses of water samples gathered during the field expeditions from 2000 to 2017, kindly provided to us by the MAWR, as well as field research results obtained by the author's team within the period of 2015–2018.

The samples taken were delivered to the agrochemical laboratory under the HGME MAWR and the hydrochemistry laboratory of Hydrometeorological Scientific-Research Institute in Tashkent Uzbekistan, for hydrochemical analysis according to generally accepted guidelines (Nazarova et al. 2012). During the period from 2000 to 2017, 18,572 CDW water samples were hydrochemically analyzed.

Drainage water samples were filtered through a blue band filter paper and then analyzed for salinity (total dissolved solids) using gravimetric and calculation methods. Chloride concentration was measured using the Mohr method, i.e., argentometric titration. Sulfates, hydrocarbonates, calcium, and magnesium ions were determined using titrimetric methods, sodium and potassium by flame spectrometry. Obtained results were processed statistically using MS Excel program.

Characteristic of the sampling points

To limit the number of samples within affordable analytical capacity, all sampling points were located along main collector-drainage canals network. Their hydrological

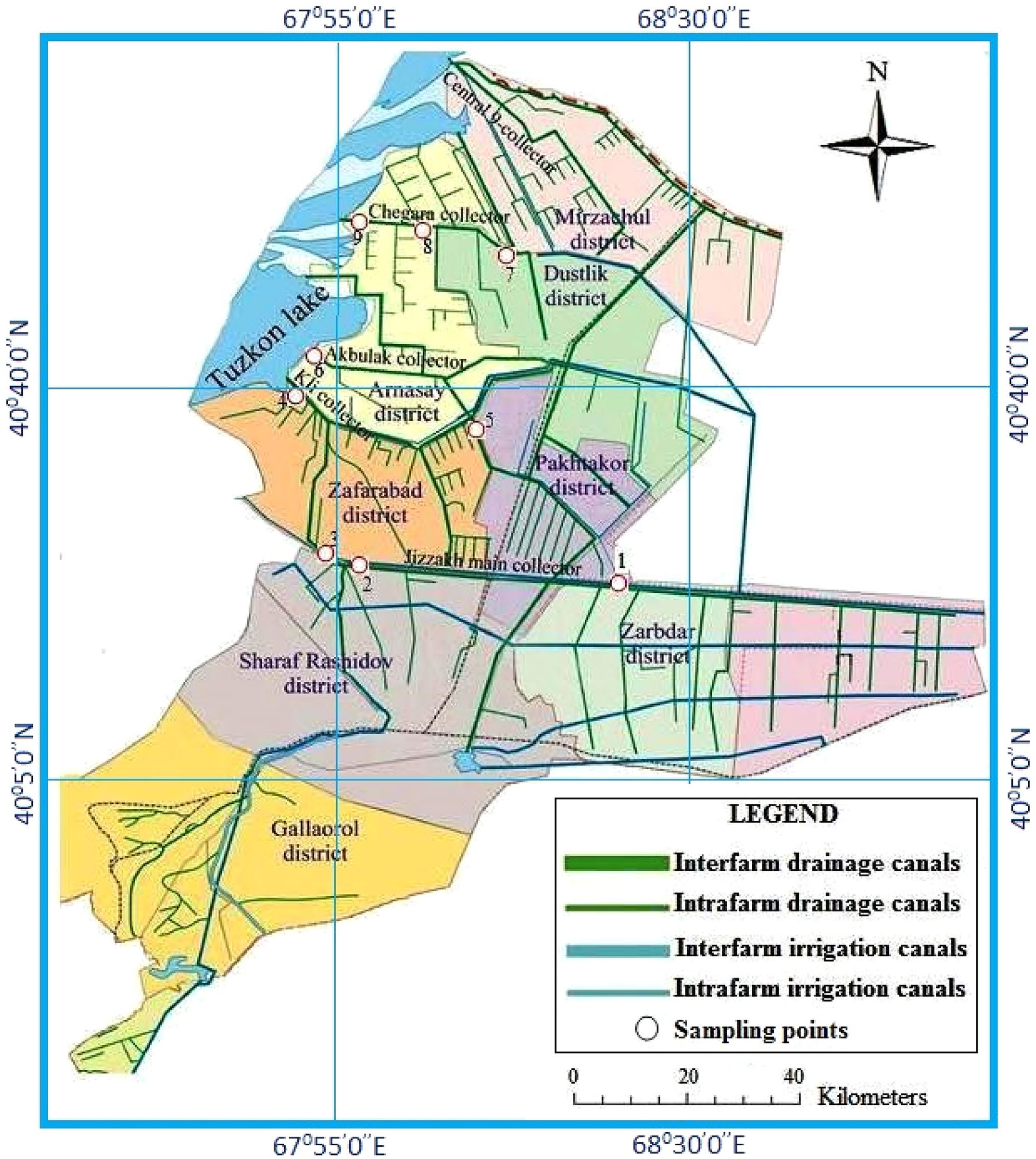

Fig. 2 General scheme of the main collector-drainage network into the Lake Tuzkon and sampling points (magnified green area on Fig. 1 including part of Lake Tuzkon): 1, 2—the sampling points on the mid- and downstream parts of JMC; 3, 4—the sampling points on the mid- and downstream parts of Kli collector; 5, 6—the sampling points on the mid- and downstream parts of Akbulak collector; 7, 8, 9—the sampling points on the up-, mid-, and downstream parts of Chegara collector

Table 1 The hydrological characteristics of main collector-drainage canals network of Jizzakh region

Main collector-drainage canals	Total length, km	Drainage area, ha	Annual average Discharge, Min.-Max., m^3/s	Annual average runoff, million m^3	Flowing into:
Jizzakh Main collector (JMC)	78	80,002	6.7–13.6	315.24	Kli collector
Kli	100	11,350	7.8–16.6	384.38	Lake Tuzkon
Akbulak	51.8	6700	3.5–4.8	98.74	Lake Tuzkon
Chegara	22.9	49,673	1.4–3.4	84.78	Lake Tuzkon
Central 9	28.7	20,140	0.3–2.5	52.8	Lake Tuzkon
Total:	281.4	167,865		936.36	

characteristics and schematic map are given in Table 1 and Fig. 2.

The JMC collector is located in the Yangi hayot farm of Zamin district where it accepts CDW water flow from 7 small drainage canals. The sampling point on the middle part of JMC is located near the Bostan village in Zarbdor district. The main inter farm collector-drainage canals confluencing to JMC here are Jayilma and Tukursoy with 8700 ha and 12,933 ha of irrigated lands, respectively. Afterwards water from 17 inner- and inter collector-drainage canals are flowing into JMC from Zafarobod district, which has the irrigated area of 12,008 ha. From the downstream part of the JMC, samples were taken 500 m above its confluence to Kli collector in the Zafarobod district before the entrance to Kojaxmed village.

The upstream part of the Kli collector is located until its entrance to village Arvatin of the Sh. Rashidov district. On this part, Kli collector accepts discharges of various collectors from Yangi hayot and H.Nasirov farms of Sh.Rashidov district, draining 2305 ha and 3011 ha irrigated lands, respectively. In the midstream, the sampling point were located in the village of Kojaxmed in Zafarabad district. The sampling point on the downstream is located in F.Khodjaev farm of the Zafarobod district.

The Akbulak collector accepts CDW water discharges mainly from irrigated lands of Pakhtakor and Arnasay districts of Jizzakh region. The upstream part of the Akbulak collector is located on the A.Ikromov farm of Pakhtakor district with an irrigated area of 3700 ha. The midstream of Akbulak collector is located on Samarkand farm of the Pakhtakor district with an irrigated area of 26,400 ha and the lower part is located on B.Fayziyev farm of Arnasay district with an irrigated area of 36,780 ha, respectively.

Sampling points on the Chegara collector. The Chegara collector accepts CDW water discharges from irrigated lands of the Dustlik and Arnasay districts. The sampling points are located upstream in Dustlik district, midstream in Fergana farm of Arnasay district, and downstream in the Turkiston farm in Mirzachul district. Total irrigated area of the Chegara collector is 49,673 ha.

Results and discussion

Development of multiyear (2000–2017) water discharge and salinity changes

JMC collector. During the period of 2000–2017, the mean annual drainage water discharge in the JMC has been changed from 13.6 m^3/s in 2005 to 7.2 m^3/s in 2010 (Fig. 3). In the spring season of 2005, there was heavy rainfall (524.5 mm), which led to increased mean annual discharge of CDW up to 13.6 m^3/s, not only in JMC but also in Kli, Akbulak and Chegara collectors. However, due to the low rainfall in the spring season of 2010, the volume of CDW decreased considerably to 7.2 m^3/s and during last years has slightly increased and stabilized at around 10 m^3/s. The mean annual salinity of JMC water has continuously increased during the last years from 1.4 g/L in 2000 to 3.8 g/L in 2017 (Fig. 3).

Kli collector During the period of 2000–2017 in Kli collector, the maximum water discharge was observed in 2005, and the lowest—in the spring season of 2010 (16.3 and 8.8 m^3/s, respectively) due to the low rainfall in the spring 2010 similarly to JMC collector (Fig. 3). During the last years, it has been slightly increased and stabilized at the level of about 12 m^3/s. In general, as in JMC, water salinity has been increased gradually from 1.8 g/L in 2000 to 3.75 g/L in 2017.

Akbulak and Chegara collectors In Akbulak and Chegara collectors, maximum mean annual water discharge has been also highest in 2005, however, in contrary to JMC and Kli collectors, the water discharge in 2010 was higher than in 2015–2017. During the last years water discharge in Akbulak collector has stabilized at a level of about 4.1 m^3/s; however, in Chegara collector, it was not stable and changed between 1.6 and 2.7 m^3/s. In these collectors, in analogy to JMC and Kli, the trend of permanent increasing of mean annual water salinity was observed: from 1.0 to 4.5 m^3/s for the Akbulak and from 1.6 to 4.6 m^3/s for the Chegara collectors (Fig. 3). Remarkably, there was no

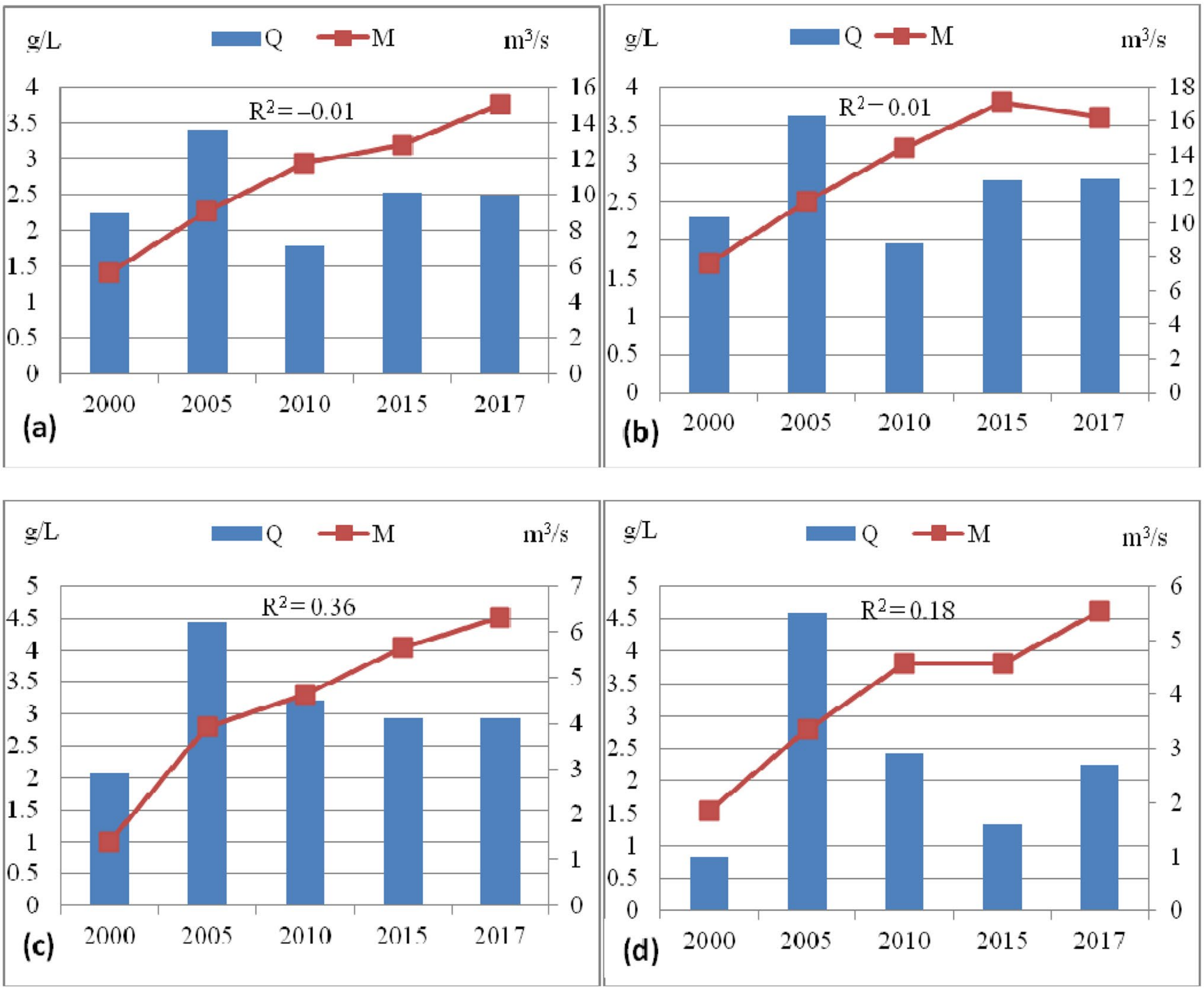

Fig. 3 Development of mean annual water discharge (Q) and salinity (M), and correlation (R^2) between them in JMC (**a**), Kli (**b**), Akbulak (**c**) and Chegara (**d**) collectors during 2000–2017

correlation found between the water discharge and salinity in all investigated collectors. Thus, increasing CDW water salinity in the Jizzakh region during 2000–2017 was not related to changes in CDW discharges.

Dynamics of within-year seasonal variability in water discharge and salinity

JMC collector During whole study period, the maximum water discharge of JMC collector has been observed during the spring months, especially in April and the minimum at the end of summer period mostly in August. The minimum level of water salinity was characteristic for winter months except 2010 when October, January and February indicators were maximal, whereas annual average was 2.9 g/L (Fig. 4). The sharp decline in water discharge usually starting from early summer has resulted in some slow increase in salinity which did not correspond to expected sharp increase of salinity. Exception was 2010 when this was clearly observed which probably explained with the transition to more saline groundwater feeding. However, results for other years did not confirm this explanation. In most years, the maximum water salinity was observed in March, April, and May which can be explained by increase of CDW flow in early spring due to salt leaching irrigation. However, in controversy, 2010 minimal values of salinity was observed in March. The dependence between the seasonal changes in water discharge and salinity was inversely proportional; however; no significant correlation has been found (R^2=—0.04–0.30).

Kli collector During the all years, the highest discharges in collector Kli were observed in the spring season, especially with maximum in April month (14.5–27 m^3/s).

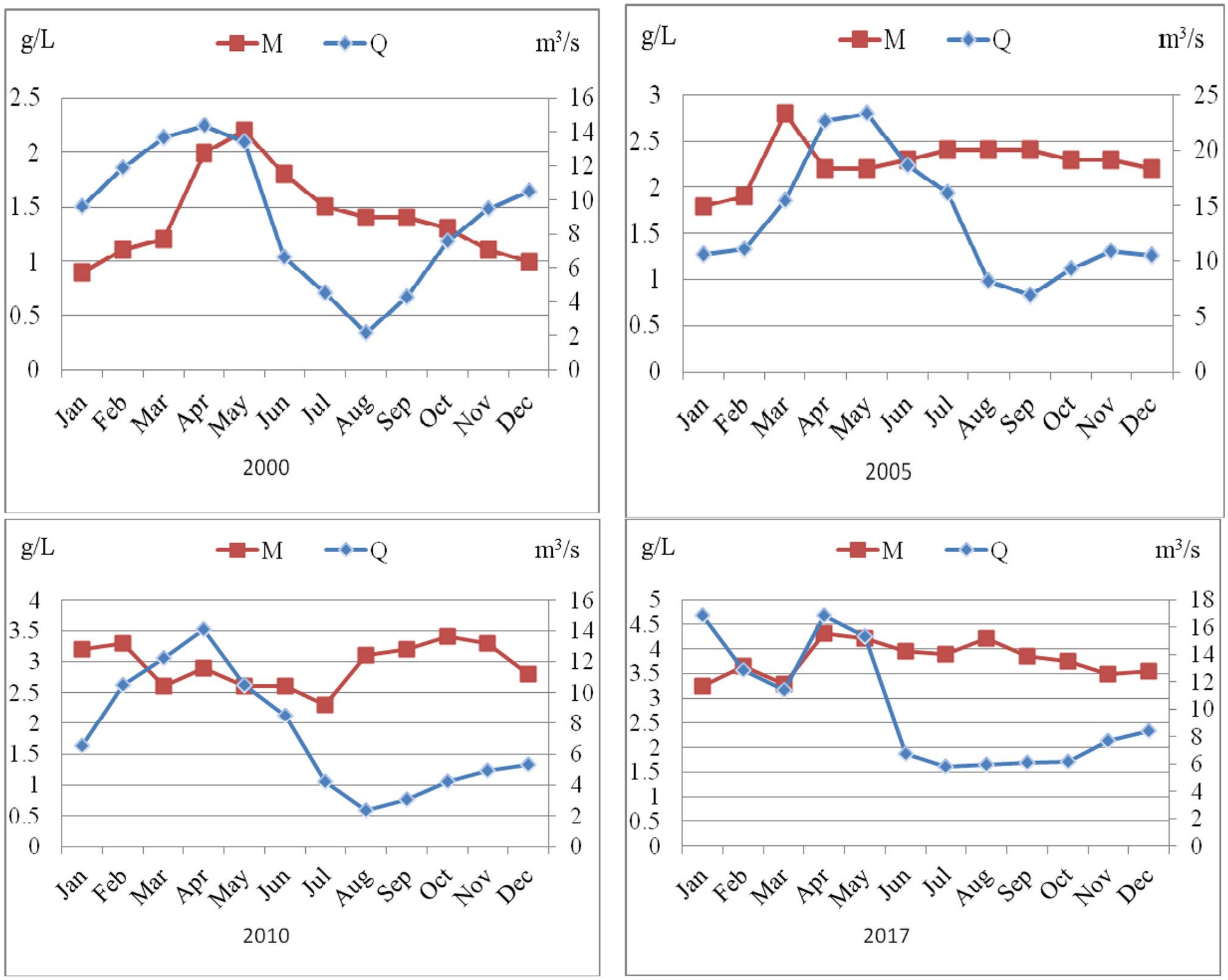

Fig. 4 Dynamics of the within-year variability in water discharge and salinity of JMC in 2000, 2005, 2010, and 2017

Discharge values have declined always sharply starting from June month until August–September (4.0–10 m^3/s) and during Autumn in general increased again reaching about half of its maximum values in spring season (7.0–14.0 m^3/s; Fig. 5). Changes in water salinity was clearly dependent on discharge dynamics; the minimum values were observed during high discharges (spring) season (1.3–3.2 g/L) and the maximum values were characteristic for the periods of low discharge—winter and summer seasons, especially in July and August months (2.1–4.3 g/L). Correlation analyses have revealed inversely proportional dependence between the water discharge and salinity as confirmed above; however, this dependence was significant only in the case of 2017 (-0.45). It should be noted that the "Kli" collector is the branch of a small mountain river "Sanzor", and for that reason, the salinity of the collector has been lower comparing to other collectors.

Akbulak collector In Akbulak collector similarly to Kli collector during the all years, the highest discharges was observed in the spring season, especially with maximum in April month (4.5–8.0 m^3/s). Starting from the summer, it declines, reaching minimum values in August (1.5–5 m^3/s) and starting to increase again during autumn season until the December reaching almost spring season values (Fig. 6). Much complicated picture of water salinity dynamics has been observed; departing from two previous collectors in the spring season of 2000, 2010, and 2017 salinity values were in direct proportionality to water discharge values. Only in 2005 spring season, the increase of discharge has lead to decline of salinity. The decline in discharge from the beginning of summer has lead to increase of salinity as usual; however, this was not clearly seen in 2010 and 2017. The results of correlation analyses have confirmed above stated. In general, during the whole 2000 and 2005 seasons insignificant inversely proportional ($R^2 = -0.20, -0.25$) and in

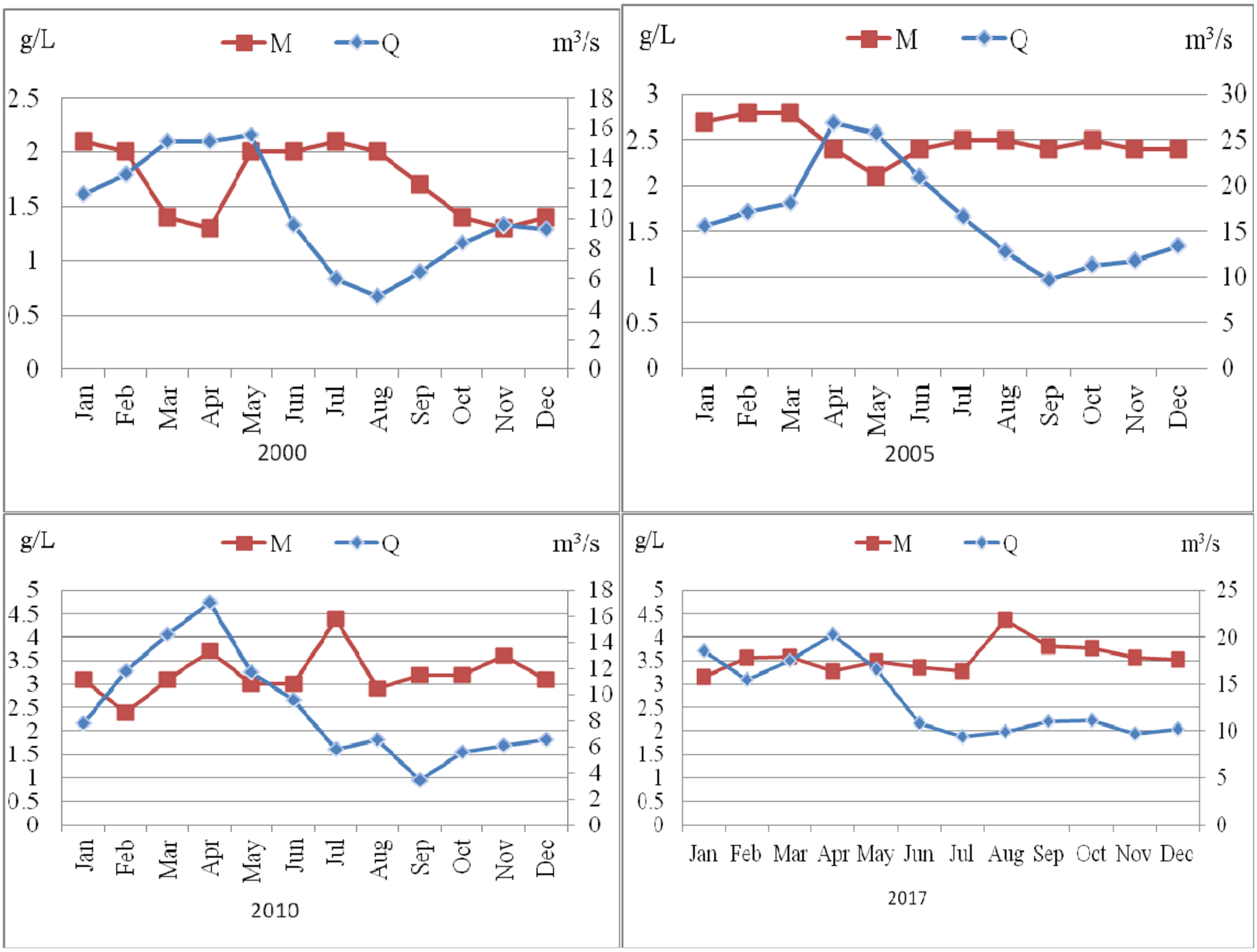

Fig. 5 Dynamics of within-year variability in water discharge and salinity of the “Kli” collector in 2000, 2005, 2010, and 2017

insignificant direct proportional in 2010 and in significant direct proportional in 2017 (0.24, 0.80, respectively), correlation values have been found. Thus, the increase of water discharges must not always lead to decline in salinity.

Chegara collector Very complicated picture of dynamics of water discharge and salinity in dependence from each other has been observed in Chegara collector. Although in this case also, as usual, the maximum values of discharge was found for the spring season (1.7–7.0 m^3/s), the sharp decline of discharge starting from summer has been observed only in 2000. In 2010, there was even some increase in water discharge up to the spring levels (Fig. 7). Besides that, in autumn of 2010 and 2017 in opposite to other years and collectors some decline or lower values of discharge comparing to summer time has been observed. Controversial data showing dependence between the discharge and salinity have been found for different study years. Increase of water discharge during spring season has lead to slightly declining in salinity only in 2000 and 2005 which was not characteristic for 2010 and 2017. Remarkably, the decline in discharge starting from early summer did not lead to a clear increase of salinity, especially in 2017.

The dependence between the water discharge and salinity was in inversely proportional in 2000 (-0.24) and especially in 2005 (-0.87), whereas in insignificant direct correlation was observed in 2010 and 2017 (0.24, 0.01, respectively).

Dynamics of upstream–downstream CDW flow and ionic composition changes

During the investigated years (2000–2017), Tuzkon lake has received 732 to 1322 million m^3/year of water from collector-drainage networks with an average of 802 million m^3/year of drainage water (Table 2). Among the collectors, most CDW water inflow comes from the Kli collector and less from the Chegara collector. The total flow of collector-drainage water varied from 25.4 to 45.3% in relation to the total water volume used for irrigation. The average salinity of CDW in main collectors of the region discharged to the lakes Tuzkon and Arnasay in downstream rose constantly

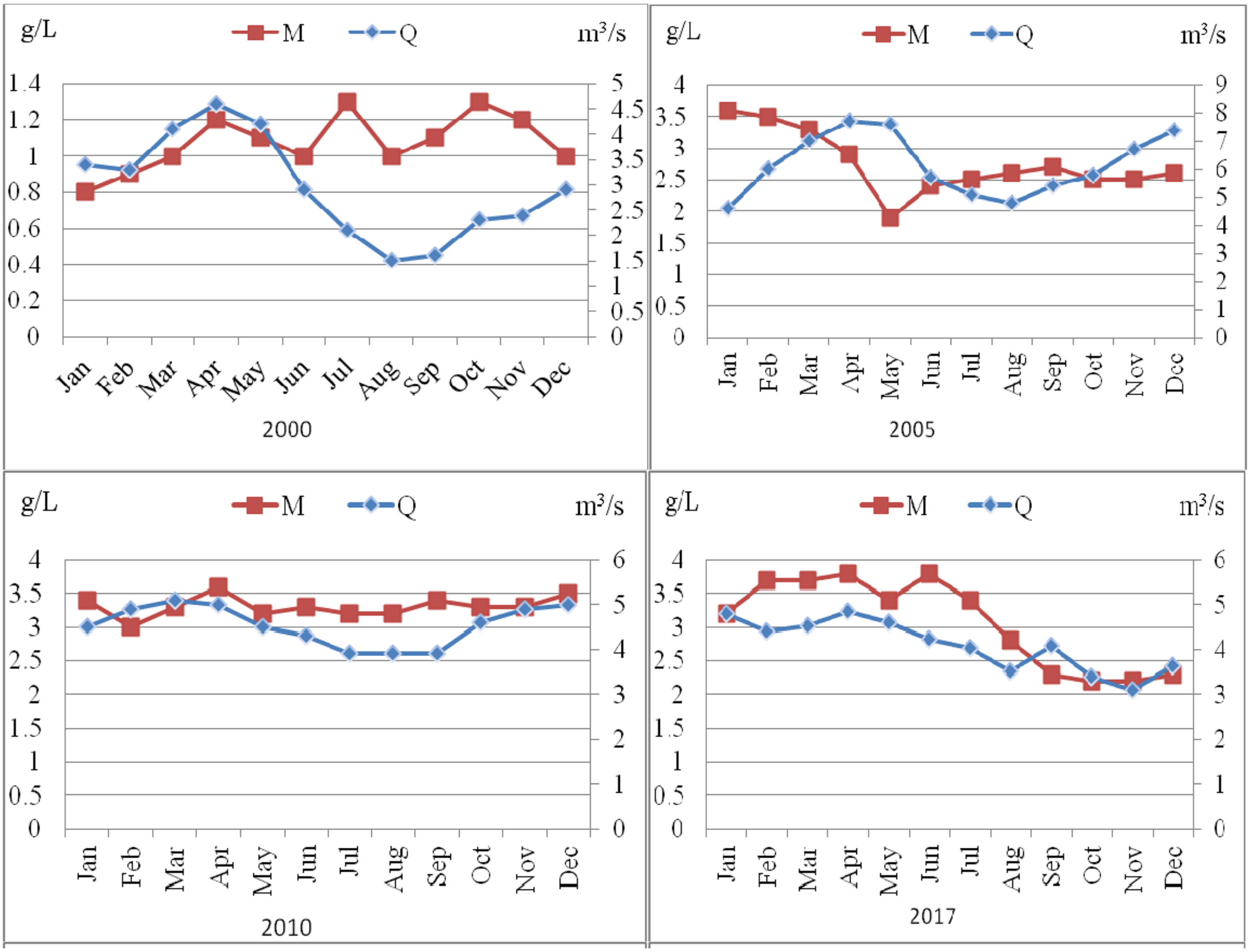

Fig. 6 Dynamics of within-year variability in water discharge and salinity of "Akbulak" collector in 2000, 2005, 2010, and 2017

year by year (Table 3). The average total salinity of the CDW water in investigated collectors increased from 1.4 to 3.9 g/L. The results of hydrochemical analyses of water samples collected in November and December 2018 from the upstream, midstream, and downstream parts of the main collectors have revealed that water salinity in all collectors has been increasing along upstream–midstream–downstream direction. The most increase has been observed in JMC and Kli collectors (37% and 35%, respectively) followed by Akbulak (25%) and Chegara (18%) collectors (Table 4).

Regarding the ionic composition among anions sulfates were dominating followed by chlorides and bicarbonates. Among cations sodium was dominant followed by the calcium and magnesium (Table 5).

Discussion

Total ion concentration or salinity is the most important chemical indicator in hydrochemical–physical and hydrobiological studies of aquatic habitats (Karimov and Keyser 1998; Karimov et al. 2019a, b). During the different years: 2000, 2005, 2010, 2017, we have studied multiyear water discharge and salinity seasonal dynamics in all collectors to obtain reliable conclusions on seasonal dynamics of investigated parameters. The results on collector-drainage canals network in Jizzakh region have revealed that the permanent high concentrations of mineral salts and continuously changing discharges are main characteristics of

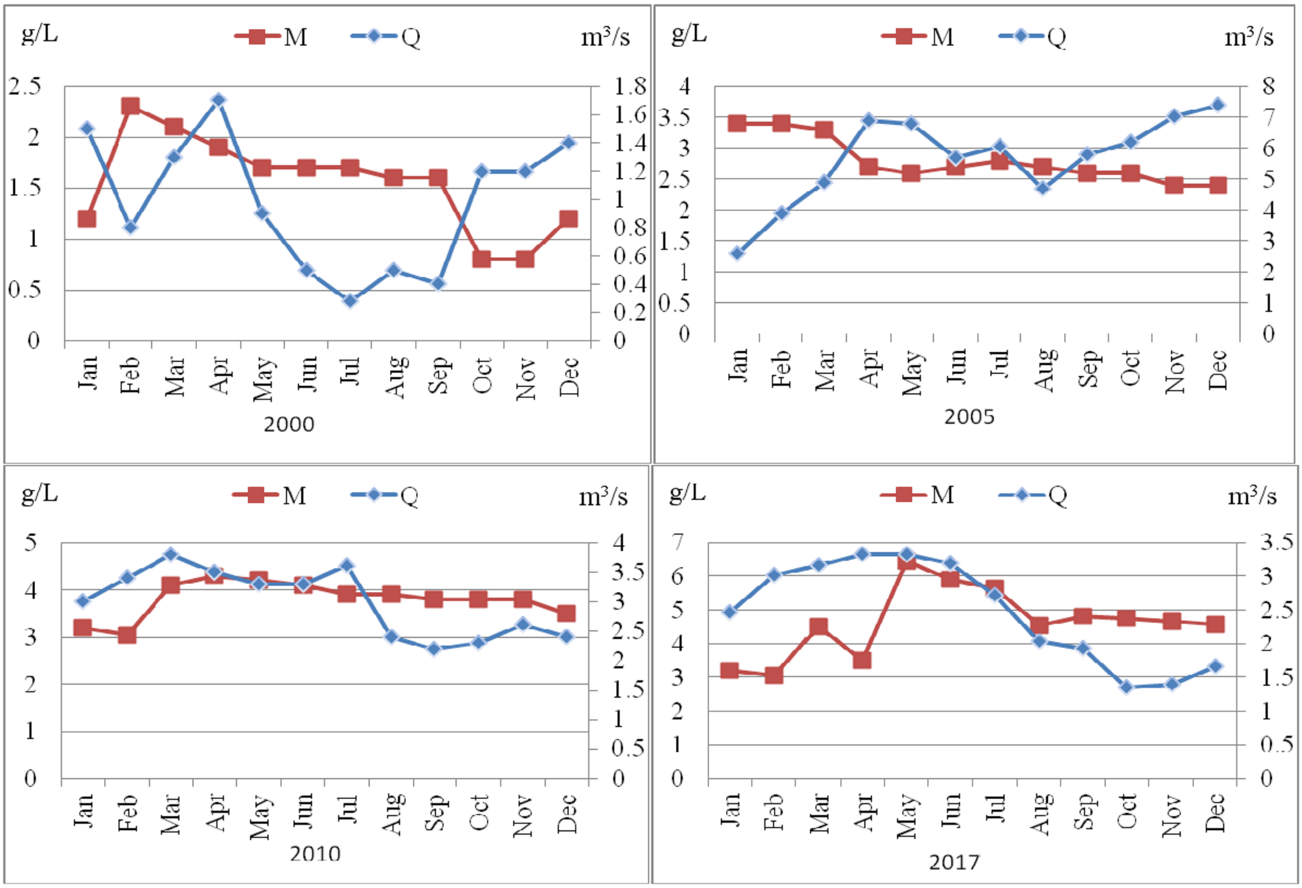

Fig. 7 Dynamics of the within-year variability in water discharge and salinity of "Chegara" collector in 2000, 2005, 2010, and 2017

Table 2 Annual water flow of main collectors into Tuzkon, $\times 10^6$ m^3

Main collectors	Years				
	2000	2005	2010	2015	2017
JMC	284.4	430.1	227	319.4	315.3
Kli	326.7	524.7	280	394.5	396
Akbulak	92.7	193.9	143.2	128.6	129.2
Chegara	28.3	173.4	93.9	50.5	77.8
Total	732.1	1322.1	744.1	893	918.3

Table 3 The mean annual water salinity of the main collectors discharged into the Tuzkon Lake, g/L

Collectors	Years				
	2000	2005	2010	2015	2017
JMC	1.4	2.3	2.9	3.2	3.8
Kli	1.7	2.5	3.2	3.8	3.5
Akbulak	1.1	2.7	3.3	4.1	3.6
Chegara	1.5	2.8	3.8	3.9	4.6
Average	1.4	2.6	3.3	3.7	3.9

CDW. In combination with the frequently increased levels of pollution with residues of agricultural chemicals (mineral fertilizers, various pesticides) as well as domestic and industrial sewage waters from rural areas and intensive animal husbandry, salinization is a main constraint for reuse of CDW waters in the region for irrigation and other purposes (Rubinova 1987; Kulmatov et al. 2018; Karimov and Razakov 1990; Karimov et al. 2014, 2019a, b; FAO 2012). Arnasay depression, in particular Tuzkon lake, is a natural drain and receiver of collector-drainage water from the irrigated lands of the Jizzakh region (Fig. 1). Almost all CDW runoff from the region (97.8%) is being collecting in main collectors JMC, "Kli", "Akbulak" and "Chegara" and discharged to the lake Tuzkon which belong to Aydar-Arnasay lakes system.

For the period of 1980–2000 annual salt diversion from irrigated lands of Jizzakh region to this lake system was estimated between 7.6 and 12 t/ha, respectively, which is much higher than for other irrigated areas within Syrdarya river basin (Yakubov et al. 2011). Previous investigations (Karimov, Razakov, 1989) have revealed that in Syrdarya River midstream, the CDW waters from old irrigation zone

Table 4 The mean values of salinity of water samples collected in November and December 2018 from the upstream, midstream and downstream parts of the main collectors, g/L

Main collectors	Upstream	Midstream	Downstream	Average	Upstream/downstream, %
JMC	2.91	3.76	4.26	3.64	37
Kli	2.57	3.24	3.98	3.26	35
Akbulak	2.97	3.52	3.94	3.48	25
Chegara	4.33	4.81	5.26	4.80	18
Mean values	3.19	3.56	4.36	3.79	27

Table 5 Ionic composition of the main collector's water in 2018, g/L

Main collectors	Salinity	Cl^-	SO_4^{2-}	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
Kli	3.63	0.242	1.970	0.277	0.578	0.016	0.261	0.226
Akbulak	4.06	0.396	1.992	0.207	0.712	0.018	0.297	0.212
Arnasay	5.38	1.058	2.182	0.211	1.041	0.016	0.261	0.270
Chegara	4.93	0.967	1.716	0.192	0.810	0.017	0.313	0.207
JMC	4.44	0.642	1.758	0.172	1.429	0.016	0.257	0.209

(Syrdarya and Tashkent regions) have much lower salinity than in new irrigation zone (Jizzakh region), which confirms above findings. For the study period of 2000–2016, the total volume of the collector-drainage water varied from 27 to 49% in relation to the total irrigation water used, which was estimated to be an average of 2691×10^3 m^3 (Kulmatov et al. 2020). The outflow of salts from 300,333 ha of irrigated land varied from 1549×10^3 to 4319×10^3 t/year or from 5.2 to 14.4 t/year ha with an average value of 9.6 t/year ha (Kulmatov et al. 2020). At the same time, CDW contains not only salts and toxic pollutants, but also nutrients like nitrogen and phosphorus and many other organic compounds (Karimov et al. 2014; Sokolov 2018; Kulmatov et al. 2020), which makes all main drainage collectors and the Aydar-Arnasay lakes system high productive suitable aquatic habitats for wildlife. The aquatic biodiversity of Tuzkon lake includes many different species 171 phytoplankton species, 59 invertebrates, 25 vertebrates (fish, 3 amphibian, 29 reptilian, 39 terrestrial vertebrate mammals more than 200 natatorial migrating, wintering and hydrophilic with 75 nestings (nidification) species, including 24 species included in IUCN Redlist (Filatova 2012). Collector-drainage canals network including terminal lakes are also important grasslands for the local animal husbandry. Large water surfaces of lakes are providing opportunities for fishery and aquaculture; therefore, it is important to provide agriculture with CDW water quality information (Thorpe et al. 2011; Gozlan et al. 2019).

Analysis of the multiyear trends of average water flow of the main collectors of the region and its seasonal dynamics have revealed that these changes were in close relation to the amount of precipitations in different months of winter, spring and autumn seasons which is clearly seen on the example of 2005 when in spring season, unusual heavy rainfall has been observed. However, the dynamics in CDW flow volumes in the region did not follow dynamics of water flow in Syrdarya River (main water source for irrigation). Since in 2010 and 2017, high water years in Syrdarya River has been observed, however, CDW flow was roughly 32% less than in 2005, although in the last case low water years has been observed (Table 2).

During our studies in most collectors, the highest values of water discharges have been observed in spring season with maximum in April and lowest values were characteristic for summer time especially in August. Starting from September–October, it has increased again reaching in most cases about half of the spring values. Increased CDW water discharges were also determined by the vegetation period that mostly matches to crop irrigation period as well as the irrigation of the autumn crops in September and December resulting in an increase of the CDW flow. Salt leaching activities, which are taking place in the irrigated lands mainly in the winter season (December, January), have lead to sharp increase of CDW discharges.

There was a clear trend that the mean annual salinity of all main collectors has constantly increased during the last two decades and this was not in correlation with water discharge changes although there has been insignificant inversely dependence tendency observed. Considerable increase of salinity within the range of 18–37% especially in largest collectors JMC and Kli was observed from upstream to downstream direction in all collectors. Without 2005 CDW discharge from drainage area was rather stable, but salinity has been continuously increasing. The reason for this increase is not yet clear; probably it can be explained by the high summer temperatures and well-developed plant cover leading to intensive evapotranspiration. The same increase

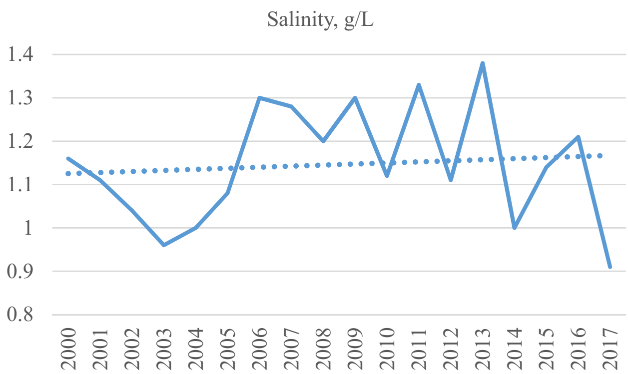

Fig. 8 Dynamics of the multi-year variability in water salinity of Syrdarya River near city Bekabad in 2000–2017 (based on Uzhydromet data)

in salinity of Syrdarya river water used for irrigation could be also the reason. However, the salinity of river water since 2006 was rather stable and in 2014–2017 even has decreased considerably (Fig. 8). Thus, there must be a source for the additional salt in the region, i.e., increasing salinization due to irrigation.

The highest values of the salinity of CDW water in all collectors were observed in spring season and lowest in summer and in less degree in winter. The reason for this is not yet fully clear and probably is explained by leaching salts from the saline lands in the irrigated areas. In other words, this can be explained by the greater dilution of salts in spring and lower in summer and winter. The high summer temperatures and well-developed plant cover in most collector-drainage canals leading to intensive evapotranspiration should be taken also into account. We anticipated dependence inverse proportionality between the seasonal changes in water discharge and salinity levels, but found an insignificant correlation, however. The sharp decline in water discharge, usually starting from early summer, has resulted in a slow increase in salinity, which did not correspond to expected sharp increase of salinity. However, it should be noted that the increase of water discharge not always led to decline in salinity, e.g., in 2017, strong direct proportionality was found in Akbulak collector between these two indicators ($R^2 = 0.80$). These results are contradicting to conclusions made by other researchers earlier confirming that "drainage water is highly saline: 2–3 g/L from April to September and 5–12 g/L during autumn and winter" (FAO 2012). Thus, the regime of water discharge and salinity of CDW may be very different to other irrigation areas depending on many natural and anthropogenic factors. For example, salinity was found to increase strongly (median increase of 21%) and statistically significantly ($p \leq 0.05$) during drought conditions for 59/66 stations in the USA compared to non-drought conditions (Jones and van Vliet 2018.

The anionic composition was dominated by sulfates followed by chlorides and bicarbonates. Among cations, sodium was dominant followed by calcium and magnesium. This is different from multiyear trend of Syrdarya River water for which sulfates and bicarbonates are leading anions and calcium followed by sodium are dominating cations (Karimov et al. 2019a, b).

Since 2000, during the years when there was a shortage of river water for irrigation, the flow of the main collectors of the region was blocked, which probably has contributed to an increase of salinity in the CDW water already starting from August. However, the comparison of the dynamics of water discharge in the Syrdarya River during the whole investigated period with Jizzakh region CDW water salinity changes clearly confirms that this conclusion is not always true. In our study, the significant increase in salinity starting from August was characteristic for JMC only in 2010 in spite of the fact that this year was high water year for Syrdarya River (Sokolov 2018; Vereshagina et al. 2018). Similarly, the salinity level of CDW in JMC collector during summer period in 2000 and 2005 was around 1.5 and 2.3 g/L, respectively, although 2000 was very low water year comparing to 2005. In Kli collector, the salinity even has increased during summer period of 2010 and 2017 although they were high water years.

Water average salinity of the "Kli" collector is substantially lower than in other main collectors in the region (2.8 g/L in the period 2000–2017) and could therefore be recommended for use as an additional source of water in water shortage periods for the needs of agriculture and other sectors of the economy of the region. However, during vegetation period of 2010 and 2017, much higher concentrations of salts (between 3.5–4.5 g/L) has been observed, therefore decisions have to be made based on current measurements of salinity.

Conclusions

For the first time, the multiyear trends in quantitative, i.e., water flow, and qualitative characteristics, i.e., salinity formation, of the collector-drainage waters generated in irrigated areas in Jizzakh province of Syrdarya River basin, Uzbekistan, have been assessed in detail. During 2000–2017 in the region, each year on average 802 million m^3 of collector-drainage waters were generated. The highest values of water discharges have been observed in spring season with maximum in April and lowest values in summer, particularly in August (27–0.4 m^3/s, respectively). Increased seasonal CDW water discharges were determined also by crop irrigation during their vegetation period and, in particular, salt leaching activities.

The salinity of all main collectors has continuously increased during the last two decades and this was not in correlation with CDW water discharge changes although there has been tendency of insignificant inversely dependency observed. This increase was not related to salinity changes in water source for irrigation (Syrdarya river) as well. In all collectors, especially in largest ones JMC and Kli, considerable increase of salinity within the range of 18–37% was observed from upstream to the downstream direction.

Concerning the ionic composition of CDW among anions sulfates were dominating followed by chlorides and bicarbonates; among cations sodium was dominant followed by the calcium and magnesium which is different from the ionic composition of the water used for irrigation. The highest values of the salinity of CDW water in all collectors were observed in spring season and lowest in summer and in less degree in winter (4.5–0.9 g/L respectively). Dependence between the seasonal changes in water discharge and salinity levels was inversely proportional; however, as a rule, this correlation was insignificant. Contrary to expectations, the sharp decline in water discharge usually starting from early summer has not resulted in sharp increase of salinity.

However, the regime of water discharge and salinity of CDW may be very different depending on many natural and anthropogenic factors, e.g., the increase of water discharge not always led to decline in salinity. In Akbulak collector in 2017, dependence between these two indicators was strongly direct proportional ($R^2 = 0.80$) as well as high water years not necessarily led to decline in CDW salinity.

Multiyear trends in quantity and quality of generated CDW and dependencies of water salinity formation of CDW in other river basins in the ASB should be studied in the future, due to the possibility of accelerated salinization and pollution of land and water resources, biodiversity decline, as well as to determine opportunities for reutilization of CDW for irrigation of agricultural crops in years of water shortage and raising of salt tolerant plants.

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