CHAPTER

21

Impact of agricultural development on water quality in Zarafshan River, Uzbekistan, Central Asia: Trends since 1960s

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1 Introduction

Water is the most valuable natural resource in all countries of the world, and it requires rational and efficient use. In arid Central Asia, the basins of the Amu Darya and Syr Darya rivers are the main sources of water supply in the region. Located between these main rivers, the Zarafshan River in the distant past was one of the largest tributaries of the Amu Darya. The population in the Aral Sea basin, where these rivers belong, has constantly tended to grow intensively, especially in the Republic of Uzbekistan (Akramova, 2016). This led, for example, to a decrease in the amount of water per capita in Uzbekistan from 3610 m^3/person in 1960 to 1660 m^3/person in 2018, or by approximately 54% (according to UzNKID, 2020).

The Zarafshan oasis has been a hotbed of human civilization and the development of irrigated agriculture with extensive use of water for the socioeconomic development of this densely populated region since ancient times. Here, the lands for irrigation were developed to such an extent in the 17th and 18th centuries that the flow of the Zarafshan River was used

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fully, even taking into account its natural fluctuations (Qadirov, 2007). As a result, it was separated from the Amu Darya for a long time due to the emergence of irrigated agriculture and its continued development, and the widespread use of river water for this purpose. Because of this, neither Zarafshan nor the Kashkadarya River adjacent to it can reach the Amu Darya. The water quality in the Zarafshan River basin has a great impact on human activity (Kulmatov et al., 2013).

Anthropogenic pollution of the waters of the Zarafshan River has long been ahead of that in other river basins, which is primarily due to the rapid increase in population and the associated intensification of agriculture, urbanization, and industrial growth. At the same time, in the upper reaches of the river, since Soviet times, there has been an increase in mining on the territory of Tajikistan, and an increase in the area of irrigated land, industry, and energy on the territory of neighboring Uzbekistan, located in the middle and lower reaches. However, in the period from 1992 to 2015, the area of cultivated agricultural land in Central Asia was relatively stable (Su et al., 2021) which indicates to increase of impact of other anthropogenic factors on water quality. Increasing levels of anthropogenic water pollution requires special attention to ensure a sustainable environment for future generations. Without this, achieving the UN SDG goal No. 6—“clean water and sanitation” in 2030 seems impossible.

Aquatic ecosystems always contain a certain percentage of various chemicals either dissolved or present in the form of a suspension or a colloidal form. Under the influence of natural physicochemical and biochemical processes occurring in streams, as well as under the influence of anthropogenic factors, they transubstantiated, passing from one state to another (Posokhov, 1969; Karimov et al., 2020). In the Zarafshan River basin, which has been experiencing a high anthropogenic load in recent decades, especially in its middle and lower reaches, a number of hydroecological studies on water quality changes have been carried out by various authors over the years (Kulmatov et al., 2013, 2014; Olsson et al., 2010, 2013; Groll et al., 2013, 2015). The average annual salinity of water in the runoff formation zone during the entire observation period remains virtually unchanged and in the gauging station of the Dupuli ranges from 213 from May to October to 272 mg/L from November to April (Rubinova, 1987), and according to other authors (Groll et al., 2013) ranges from 161 to 188 mg/L. Kulmatov et al. (2013) studied changes in water quality in the river basin from 2002 to 2009 and found significant changes in concentrations of heavy metals, primarily zinc and arsenic in the lower reaches and concluded that transboundary impact (from Tajik territory) was the main source of heavy metals in the lower reaches of the river. To establish trends in water quality, we need data from the entire period since the 1960s. However, we could not find any reliable information concerning the water quality in the middle stream and downstream until the 1980s of the last century.

It should be noted that, almost all previous studies were based on data prior to 2010, so they are outdated. Researchers mainly cover the riverbed up to the city of Navoi (upstream and downstream of “Navoiazot” chemical plant (Olsson et al., 2010, 2013; Kulmatov et al., 2013, 2014)). A detailed analysis of the trends of ongoing changes in the qualitative state of river waters in the Zarafshan River basin throughout its entire length over the past decade still remains unclear. The vast majority of researches are devoted to the assessment of water quality for drinking, municipal and irrigation water supply, leaving consideration of the deterioration of water quality for the inhabitants of the aquatic ecosystem and wildlife. To date, untreated wastewater is discharged into the riverbed—industrial waste and the unavailability of information on these industrial facilities complicates the control of the damage caused by them (Khaydarov, 2020). Return collector-drainage water from irrigated areas is also very often discharged back into the riverbed, which can also lead to secondary anthropogenic pollution (Yakubov et al., 2011; Karimov et al., 2014, etc.). Due to the transboundary nature of the river, the issues of water quality research and control are somewhat complicated, since the upper stream of the river—the zone of flow formation (ZFF) is completely located on the territory of Tajikistan, and the middle (up to Samarkand) and downstream—the zone of flow intensive consumption (ZFC) is located on the territory of Uzbekistan. The Zarafshan River basin is classified as a zone of special attention in terms of climate change and security, since in the period 1976–2012, a slight decrease in precipitation was observed in its flat part (Novikov and Kelly, 2018). It has the largest number of days per year with air temperatures above 40°C at present and in the future by 2050, as well as an increase in the number of tropical nights with temperatures above 22°C (TNC UNFCCC, 2016).

Therefore, the main focus of our research was aimed at studying trends in water pollution of the Zarafshan River of agricultural origin mainly in the middle stream and downstream over the past 10 years and assessing the modern ecosystem status of the river. Since the ecosystem of the Zarafshan River has practically no inflow of fresh water after the confluence of its Magiandarya tributary at Penjikent in Tajikistan, a priori it can be assumed that the level of water pollution increases cumulatively from the upper to the lower reaches, the maximum pollution levels should be observed in the lower reaches and the end section. Consequently, the assessment of the current hydroecological situation and the identification of a trend based on the analysis and synthesis of the latest data is a requirement to ensure environmental safety. In view of the above considerations, the main objectives of this work are: to reveal the impact of agriculture water quality changes along river before and after beginning of intensive irrigation development; to establish seasonal, within-year and multiyear trends in water quality changes. This study will contribute to assessment of the impact of water quality changes on heavily exploited river ecosystem, to improving the provision of high-quality water to the population, agriculture and industrial development in the oasis of the Zarafshan River, where about 20.3% (about 7 million) of the population of Uzbekistan lives today.

2 Materials and methods

2.1 Study area and sampling sites

The dendritic drainage system Zarafshan River feeds mainly by Zarafshan glacier and many other smaller glaciers and snow melt water of the high mountains. Flowing in upstream watershed through the territory of Tajikistan, it crosses the border of Uzbekistan, turns to the west-to north-west, creating a unique oasis including Samarqand, Bukhara and Navoi regions of Uzbekistan stretching from East to West (Fig. 21.1). It is formed by the confluence of the Matcha and Fandarya rivers. At 56 km below this confluence, Zarafshan receives the Kishtut River from the left, and at 94 km from the left, Magiandarya. On this point the ZFF zone ends and below this point, it does not accept large tributaries, and the drains of numerous small rivers and sayas are completely disassembled for irrigation. Thus, this point is the beginning

FIG. 21.1 Map of the Zarafshan River with gauging sites (hydroposts).

of the ZFC zone. The process of dispersion of surface and partly underground runoff is completed by irrigation-discharge lakes located on the periphery of the irrigated territory (lakes Dengizkul, Tuzkan, Karakyr, Parsankul, Ayakagitma, etc.). From the end of the last century until recently, part of the collector-drainage flow (CDF) from Lake Parsankul through the main Bukhara collector entered the Amu Darya riverbed. At the same time, the CDF of the Samarkand region were dumped into riverbeds and channels.

The lands of the Jizzakh and Qashqadarya regions are also partially fed by the water of the Zarafshan river through the Eskiangar and Tuyatortar canals. The Zarafshan river Valley, situated on the territory of the republic of Tajikistan after crossing the Uzbekistan border downstream of Pendjikant enters the lowlands of Aral Sea basin forming Zarafshan oases which ends in Qarakul plateau. The dry delta of the river is located in the Karakul district of Bukhara region.

According to some sources the current length of the river is 877 km from which about 300 km belong to Tajikistan (Prokhorov, 1972; Khujanazarov and Tsukatani, 2007). However, the actual length until Karakul Oazis in Bukhara region where it divides into branches is 803 km (Mukhamedzhanov, 1978). After this point the branches are fed mainly by Amu Darya water although in high water years, they can receive also water from Zarafshan river. The total area of the drainage basin is 41,860 km^2, of which the mountainous part forming the runoff accounts for 17,710 km^2 (39°44′–40°23′N, 64°06′–67°40′E).

In the literature, we have not found a clear division of the Zarafshan River basin into upper, middle and down streams. Therefore, relying on the research of the great hydrologist of Central Asia V. Shultz (Schultz and Mashrapov, 1969), we adopted the following division: to Ravatkhodja Dam, a place below the confluence of the Magiandarya at the exit of Zarafshan from the mountains to the plain (near to the Tajik-Uzbek border)—the upper stream, from this point to the reunion of the Akdarya and Karadarya at the settlement of Yangirabad, i.e., approximately gauging station 6 is the middle stream and all the riverbed below this point is the downstream.

On the border of the upper stream and downstream at the Ravatkhodja dam near the border between Tajikistan and Uzbekistan, an average multi-year water discharge reaches the highest value 157.9 m^3/s (Groll et al., 2013). The average annual runoff is about 5 km^3. At the beginning of downstream near city Samarkand, the river splits into two branches—Akdarya (northern) and Karadarya (southern). Irrigating large arid territories through the Kattakurgan district, the river again unites into a single riverbed near the village of Yangirabad. After Navoi, the river turns slightly to the Southwest. The ZFC zones: Bukhara oases and Karakul plateau are located in the downstream of the Zarafshan. Here the river provides water to a number of irrigation systems at five hydroelectric power plants: Karmaninsky, Navoi, Shafirkan, Kharkhursky, and Duabinsky. Today it is considered that the main riverbed (main stem) of the Zarafshan River ends before the city of Bukhara, after the Dubinsky hydroelectric complex, built before the 1960s. Further, the river is called Karaul darya, but still remaining formally Zarafshan. The Shahrud Canal also begins here, providing Bukhara with water back in historical times. And then, in the Karakul plateau, Zarafshan splits into several small branches, which today have been transformed into channels fed by the water of the Amu Darya River. Of these, the main branch—the Taykyr Canal, through which Zarafshan was connected to the Amu Darya—today flows into Lake Dengizkul, draining nearby agricultural land. Zarafshan valley is densely populated, especially in such cities as Samarkand, Kattakurgan, Navoi, Bukhara, Kagan. Total land area of Samarqand, Navoi and Bukhara regions (also called as Zarafshan economic district) situated on the Zarafshan oases is 168,100 km^2 or 37.4% territory of the Republic of Uzbekistan.

According to some authors until the early 1950s, the annual flow of Zarafshan river was enough to irrigate Bukhara region and has reached Amu Darya River (Groll et al., 2015). However, other authors assume that already during 17th and 18th centuries and even early ancient times river flow was used fully for irrigation even in high water years (Schultz and Mashrapov, 1969; Qadirov, 2007). The famous hydrologist Rubinova (1987) also confirms that at the beginning of the 20th century (1916), the irrigated areas in the Zarafshan basin amounted to 547,000 ha, while in 1965 this figure was only 458,000 ha. Therefore, most probably during last two centuries, until the 1930s, the Zarafshan river had no connections with other rivers systems. However, after the start of intensive construction of extended irrigation canals network in the 1930s–1970s, the interconnected system of large rivers in Aral Sea basin was created. As a result, since a few decades the Zarafshan river has two connections with Amudarya river: through the Eskiangar canal with the Kashkadarya river, which in turn through the Karshi main canal connected with Amudarya river and through the Amu-Bukhara canal. Zarafshan River is also connected through the Iskityuyatartar canal with the Sanzar river which in turn through irrigation canals network connected with Syr Darya river. In order to effectively use the waters of Zarafshan River, the Kattakurgan, Kuyimazar, Tudakul, Shorkul, and Karaultepa reservoirs were built. The river is also connected with lakes of irrigational origin—Dengizkul and Tuzkan (Solyonoe) (Kamilov and Urchinov, 1995; Thorpe et al., 2011).

The water of the Zarafshan river is intensively used for irrigation. Since the Zarafshan River is a relatively low-water river on the right bank of the Amu Darya, today its water resources cannot fully meet the region's water demand, which, according to forecasts, is constantly growing. Therefore, since 1962, they have been replenished with Amudarya water, the supply of which through the Amu-Bukhara Canal reached 4.65 km^3/year by 1980 (Rubinova, 1987).

2.2 Data compilation and methods

The database the Center for Hydrometeorological Service under the Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet) on monitoring results containing hydrophysical and water quality parameters, has been used for in-detail analyses. This state Agency has well distributed network of hydroposts (gauging stations) along the Zarafshan river for a water quality and hydrology observations. The agency monitors and collect water samples on 8 hydroposts at least ones every month frequency (12 times per year), analyzing samples in central laboratory in Tashkent as well as in some regional laboratories. The results of the monitoring are published in "Annual databases on the surface water quality." We were kindly allowed by the Administration of Uzhydromet to use these analyses datasets for the multiyear assessment of water quality.

In order to find current trends in the water quality of the Zarafshan River throughout its entire length, we analyzed data from the Uzhydromet yearbooks from 2010 to 2019. This agency has 10 water quality monitoring posts along the main stem of the Zarafshan River in the territory of the Republic of Uzbekistan. From them eight hydroposts are located until the city of Navoi along the main stem (up to Duabinski hydrostation) and two hydroposts are located near to city Bukhara as follows (Table 21.1).

When analyzing the results of the Zarafshan River water quality study and evaluating them, it is of great importance to identify the anthropogenic component of the found changes in the values of qualitative indicators. Many researchers are mainly limited to comparing the actual salinity data with the existing maximum permissible concentrations (MPC). We believe this approach is not entirely correct, since in order to identify the scale of anthropogenic transformation of water quality, it is necessary to know the natural regime of water quality before the appearance of a significant anthropogenic impact. In principle, the corresponding indicators up to the 1960s, i.e., before the appearance of an intensive anthropogenic transformation of the salt regime of the river, can be taken as norms with which modern data can be compared. However, in the available literature sources there is no information about the salt regime of the river for that period. We managed to find only one historical document, according to which possible fluctuations in the salinity of the Zarafshan River water in the 1960s were established (for more information about this in Section 3 of this chapter). This is the report of the Uzbek Republican department of Hydrometeorology (UGMS UzSSR, 1966) and based on this document we have accepted salinity variations up to 600 mg/L as

TABLE 21.1 Description of gauging sites along Zarafshan River.

Gauging site no.	Gauging site location	Distance from Ravatkhodja Dam[a], km
Upstream		
1	Ravatkhodja Dam (on the Tajik-Uzbek border) (39°32′N, 67°24′E)	0
Midstream		
2	The city of Samarkand, 1.5 km above of the Akdarya water division (39°41′N, 67°03′E)	46
3	0.5 km below the mouth of Siab collector (39°45′N, 66°50′E)	70
4	3.7 km below the mouth of Taligulyan collector (39°92′N, 66°37′E)	85
5	0.8 km downstream of Kattakurgan city (39°96′N, 66°29′E)	135
6	Karadarya near to the settlement of Khatirchi (Yangirabad), near to confluence of the Karadarya and Akdarya rivers (40°01′N, 65°50′E)	160
Downstream		
7	The city of Navoi, 1 km above the wastewater discharge point at the Navoiazot factory (10°09′N, 65°19′E)	241
8	The city of Navoi, 0.8 km below the wastewater discharge point at the Navoiazot chemical factory (40°09′N, 65°16′E)	248
9	Above the city of Bukhara (39°98′N, 64°64′E)	350
10	Below the city Bukhara (39°78′N, 64°26′E)	360

[a] *Distance information accepted from Olsson et al., 2013.*

allowable fluctuations for the water quality evaluation. This value probably was characteristic for that period on time. This amount is still lower than Uzbek and international MPCs (1.0 g/L).

For assessing water quality, we used the values of maximum permissible concentrations (MPC) of pollutants for various types of water use (Table 21.2) generally accepted in the Republic of Uzbekistan (UzDSt950:2011, 2011; MARF, 2016). The method of classification of water according to ionic composition and salinity proposed by O. Alyokin (1970) was used to differentiate salinity metamorphism under anthropogenic impact.

To determine the degree of water pollution by the multiplicity of exceeding the MPC of pollutants, “Hygienic and anti-epidemic requirements for the protection of water bodies in the territory of the Republic of Uzbekistan” (SanPiN RUz No. 0318-15, 2015) were used (Table 21.3).

For determining ammonium nitrogen in the water, a photometric method was used according to the qualitative reaction with Nessler’s reagent (Demutskaya and Kalinichenko, 2010). Nitrite nitrogen was determined by the Griess’ reagent method with the formation of a diazo compound with 1-naphthylamine, and nitrate nitrogen by the colorimetric method using sodium salicylate (Semenov, 1977).

TABLE 21.2 Criteria of water quality assessments—maximum permissible concentrations (MPC) for hygienic (household, drinking, cultural, general water use)—MPC_w and fishery and aquatic life—MPC_f water use from surface water resources.

Indicators and compounds	MPC in water		Hazard class
	MPC_w	MPC_f	
Biological oxygen demand (BOD)	3.0	4.0	–
Chloride	250	300	4
Sulfate	400	100	4
Sodium	120	120	4
Potassium		50	4
Calcium		180	4
Salinity	1000	–	–
$N\text{-}NH_4/NH^+_4$	2/2.6	0.39/0.5	4
$N\text{-}NO_2/NO^-_2$	1/3.3	0.02/0.08	4
$N\text{-}NO_3/NO^-_3$	10/45	8.89/40	4
Phosphorus total (P)	3.5	Eutrophic waters—0.2; mesotrophic waters—0.15; oligotrophic waters—0.05	3
Iron total (Fe)	0.30	0.10	3

TABLE 21.3 Criteria of water quality assessments for hygienic (household, drinking, cultural general water use)—MPC_w and fishery—MPC_f water use from surface water resources.

Indicators	The degree of water pollution by the multiplicity of exceeding the MPC			
	Permissible	Moderate	High	Extremely high
Pollutants with toxic properties	<1.0	1.1–3.0	3.1–10.0	>10.0
Dissolved oxygen (DO)	>4	3.9–3.0	2.9–2.0	<1
Biological oxygen demand (BOD), first category waters	<3	3.1–5.0	5.1–7.08	>7.0
Biological oxygen demand (BOD), second category waters	<6	6.1–8.0	8.1–10.0	>10.0
Salinity (TDS), mg/L	<1000	1001–1500	1501–3000	>3000

3 Results

3.1 Agricultural, industrial and municipal sources of water pollution

The Zarafshan River flows through the territory of the Samarkand, Navoi and Bukhara provinces of the republic of Uzbekistan. This is one of the main sources of water consumption by the population, including economic, cultural, domestic and drinking. The current socio-economic situation in the Zarafshan River basin region with irrational and inefficient water use requires a significant increase in water supply for municipal and household needs, the development of industry, irrigated agriculture and other spheres of the national economy. At the same time, there is a tense situation with water quality and hydroecological situation, which undoubtedly manifests itself in the sanitary and hygienic conditions in the region. During last decades the water quality of Zarafshan has deteriorated sharply due to permanently increasing anthropogenic pressure.

The Zarafshan River, being the only natural water source in the region, receives municipal, domestic, industrial and agricultural wastewater in the Khujand region of Tajikistan, Samarkand, Navoi and Bukhara provinces of Uzbekistan. The water quality in the studied part of the Zarafshan River is formed due to the discharge of industrial and domestic wastewater from the cities of Samarkand, Kattakurgan, Navoi, Penjikent and the cities of Bulungur, Jambai, as well as agricultural wastewater from rural collector-drainage network (CDN), which significantly worsens the sanitary and hygienic situation in the region. The main sources of water contamination of Zarafshan River with mineral salts on the territory of the Samarkand region are the waste waters of the Taligulyan, Chiganak and Khauzaksai collectors, as well as the wastewater of the Baynazar treatment facilities—the city of Kattakurgan. The most polluted part of the river is located in the area under the city of Navoi. Here Zarafshan receives wastewater from the chemical plant "Navoi-Azot," where the main polluting components are acids, ammonium, nitrates, cyanides, organic substances and phenols (Kulmatov et al., 2014).

The deterioration of the water quality of the Zarafshan River is influenced by a mining processing plant and mercury-antimony deposits on the territory of Tajikistan. To mine the Taror-Jilau gold deposits in the valley of the Zarafshan River, in the late 1990s, a gold mining plant was built with a design capacity of the first stage—about 2 tons. In 1994, the Tajik-British Joint Venture "Zarafshan" was organized on the basis of this plant, which includes mines for the extraction of gold-bearing ores, a plant for their processing.

3.2 Trends in water quality changes

3.2.1 Salinity and ionic composition before the intensive irrigation development

It can be assumed that the beginning of significant changes in the quality of water resources of rivers in the Aral Sea basin coincided with the intensive development of irrigation and cotton monoculture in the 1960s. At the same time, despite the intensive use of water resources of the Zarafshan River for centuries, there is practically no information on water quality until the 1980s. The oldest, but documented data on salinity, ionic composition and biogenous compounds (ammonium, nitrite and nitrate ions, phosphates and total ion) that we were able to find dates back to 1966 (UGMS UzSSR, 1966). For the general public, this valuable information is published for the first time in this paper. According to these data (Table 21.4) the salinity of water in the initial section of the middle stream (gauging site 2—the Akdarya water division) during 1966 ranged from 186.5 to 397.5 (average 284.02) mg/L. In the downstream near the city of Navoi (gauging site 7), according to summer and autumn

TABLE 21.4 Salinity and ionic composition of the water of Zarafshan river in 1966, mg/L.

Ingredients, mg/L	**Months**										**Annual average**
	1	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	
GS 2—Akdarya water division											
Chloride	5.3	5.0	5.0	4.0	1.4	2.2	1.6	2.8		4.6	3.54
Sulfate	60.9	63.8	62.0	40.4	25.0	30.8	40.3	37.0		34.3	43.83
Hydrocarbonate	228.1	217.8	232.4	137.2	123.2	115.3	100.0	123.8		218.4	166.24
Sodium +potassium	13.2	19.0	16.5	6.2	4.5	1.2	5.0	6.5		0.0	8.01
Calcium	56.5	52.7	55.9	38.1	35.9	33.7	29.2	36.9		56.1	43.89
Magnesium	23.6	21.8	22.4	13.1	7.4	10.4	10.4	9.5		22.5	15.68
Salinity	395.6	388.6	397.5	240.9	197.4	193.6	186.5	216.5		339.6	284.0
The city of Navoi, bridge, near to GS 7											
Chloride					15.6		23.8		21.6		20.33
Sulfate					268.9		137.6		119.6		175.40
Hydrocarbonate					176.3		166.5		216.6		186.50
Sodium +potassium					116.5		18.0		21.8		52.10
Calcium					52.3		57.1		62.3		57.20
Magnesium					20.2		28.5		32.5		27.1
Salinity					649.8		434.6		474.4		519.6
The city of Navoi, near to GS 8											
Chloride					19.5				28.7		24.1
Sulfate					259.1				131.1		195.1
Hydrocarbonate					158.6				218.4		188.5
Sodium +potassium					92				10		51.0
Calcium					53.8				22.0		37.9
Magnesium					11.7				68.7		40.2
Salinity					599.2				480.6		539.9

Source: *UGMS UzSSR, 1966*.

measurements, it ranged from 434.6 to 649.8 (on average 519.6 mg/L). And after Navoi city (gauging site 8), the average annual value was slightly higher—540 mg/L (Table 21.4). According to another, less accurate source Irrigation of Uzbekistan, 1979, the dry residue of Zarafshan water in the Bukhara province ranges from 0.3 to 0.8 g/L. However, it is not reported to which year these data relate. Since at that time determination of total dissolved solids (TDS) was conducted by evaporating water from a given volume of sample at 105–110° C and weighing the residue to constant mass this residue can contain not only salts but also contain considerable amount of organic matter. Therefore, TDS is not equal to salinity, and typically TDS > salinity. In case of week alkaline waters water evaporation leads to the loss of significant amounts of bicarbonate and some errors (Williams and Sherwood, 1994), which is characteristic for Zarafshan river.

It should also be noted that according to the classification of Alyokin (1970) in the 1960s, the water of the Zarafshan River in the upper stream belonged to the bicarbonate class of the calcium group type 2 ($C^{Ca}{}_{II}$). It turned out that in the midstream (gauging site 7) the waters belong to the sulfate class of the calcium group type 2 ($S^{Ca}{}_{II}$). However, immediately after the city of Navoi (gauging site 8), the following change in the salt composition was noted—namely, the calcium ion gave way to magnesium ($S^{Mg}{}_{II}$) (Fig. 21.2 and Table 21.4).

A comparison of the average annual values of the salt composition data for the period 2010–19 for the studied gauging sites clearly shows that up to the sixth gauging sites, the salinity of water ranges from 284.8 to 434.3, which does not exceed the historical norm we have adopted—600 mg/L (Table 21.5, Fig. 21.3). At the same time, isolated cases of achieving intra-annual values up to 800 mg/L are observed only in some years. Such cases are noted below the third gauging sites, but mainly in the month of February (50% of cases). Although such cases were also noted at the sixth gauging sites in April 2011, 2012 and 2015. It is noteworthy that there were no such cases in 2017–19. Thus, the dynamics of average annual and long-term changes in the salinity of water in the upper and middle reaches shows that here it remains within the limits of MPC norms.

However, in the downstream, starting from the seventh gauging site, a sharp increase in water salinity is observed throughout the period 2010–19. Both average annual and long-term averages exceed not only the 600 mg/L limit, but also the MPC (Table 21.5, Fig. 21.3). At the same time, if the salinity of water near the city of Navoi (gauging sites 7 and 8) ranges from 1.28 to 1.45 g/L, then near the city of Bukhara it is already about 2.43 g/L. That is, there is an almost twofold increase. These data clearly show the presence of powerful sources of discharge of highly mineralized return and groundwater into the riverbed.

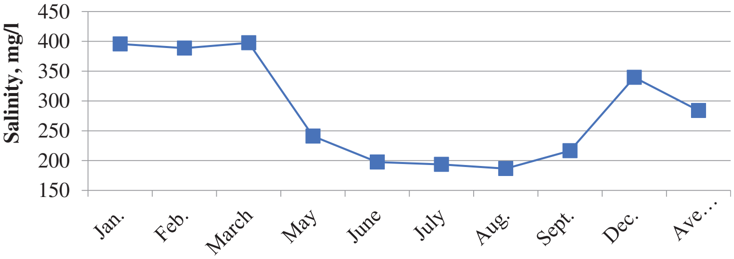

FIG. 21.2 Within-year seasonal dynamics of water salinity in the upper midstream of Zarafshan river (GS 2) in 1966.

TABLE 21.5 Average annual and long-term multiyear values of salinity fluctuations and classification of Zarafshan River water for 2010–19, mg/L.

Gauging station	Annual average, min.–max.	Multiyear average	Classification
1	252.7–294.8	284.8	$C^{Ca}{}_{II}$
2	266–389.8	314.6	$C^{Ca}{}_{II}$
3	356.8–453.5	424.5	$C^{Ca}{}_{II}$
4	318.5–410.2	360.4	$C^{Ca}{}_{II}$
5	343–486.2	413.7	$C^{Ca}{}_{II}$
6	347.8–537.7	434.3	$C^{Mg}{}_{II}$
7	1085–1437.7	1278.5	$S^{Mg}{}_{II}$
8	1152.9–1623.2	1451.1	$S^{Mg}{}_{II}$
9	2319.1–2575.3	2428.8	$S^{Mg}{}_{II}$
10	2260.1–2652.2	2427.0	$S^{Mg}{}_{II}$

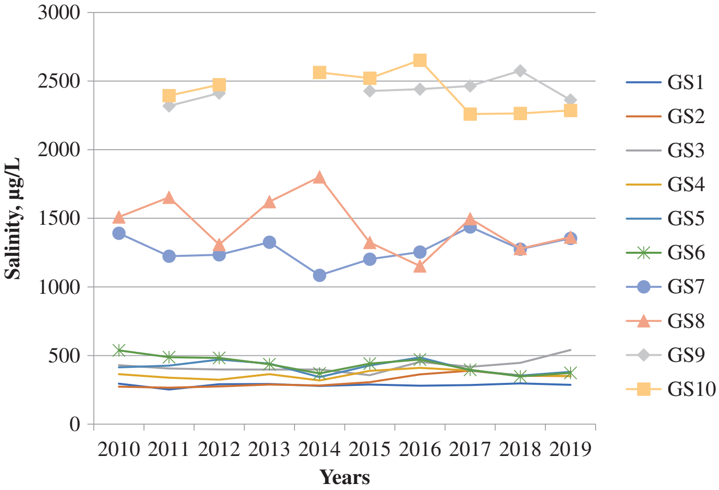

FIG. 21.3 Average annual changes in water salinity of Zarafshan river in 2010–19 (*GS*—gauging sites numbered as indicated in methods; the breaks of the curves for GS9 and GS10 are due to the lack of primary data).

Analysis of the ionic composition of water along the riverbed in different years also shows the presence of significant metamorphosis of the qualitative and quantitative state of river waters (Fig. 21.4). On the upper stream and middle stream, including the gauging site 5, bicarbonates remain the dominant anions, and calcium is clearly the leader among the cations, the waters belong to the second type ($C^{Ca}{}_{II}$). However, starting from the sixth gauging site, i.e., after about 25 km (middle stream), the ionic composition of the water changes dramatically. Water still belongs to the bicarbonate class, the second type, but instead of

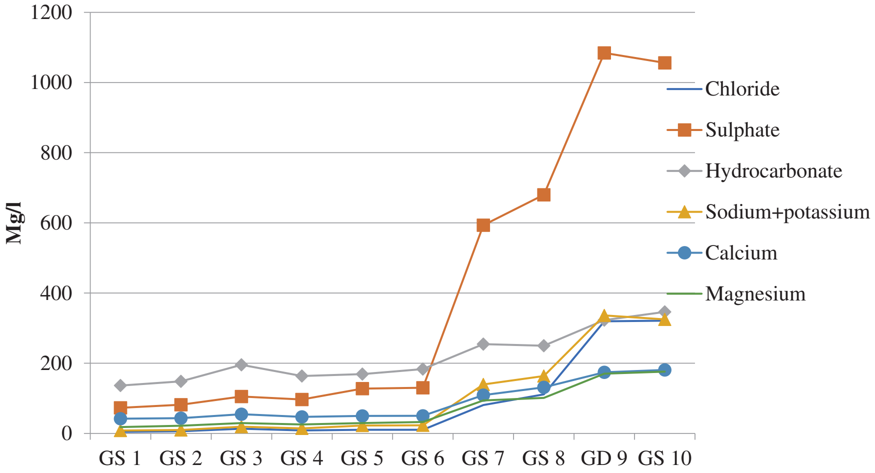

FIG. 21.4 Multiyear (2010–19) average values of ionic composition of Zarafshan river water, mg/L.

calcium, magnesium cations begin to dominate ($C^{Mg}{}_{II}$). But starting from the gauging site 7 (downstream), bicarbonate ions give way to sulfate ions. Magnesium cations continue to dominate ($S^{Mg}{}_{II}$). And after the Zarafshan River enters the Bukhara oasis, the ionic composition of the water does not change, but sodium cations are contained in almost the same amounts with magnesium, slightly inferior to it.

The intra-annual indicators of chlorides at the eighth gauging site relative to the first gauging site increased by 19 to 36 times, sulfates by 9 to 10 times, bicarbonates by 1.7 to 1.9 times, sodium by 21 to 22 times, potassium by 2 to 9 times, calcium by 2 to 4 times, magnesium by 5.5 times, mineralization by 4 to 6 times, and electrical conductivity by 4.5 to 6 times. And judging by the average annual values, in the segment of the riverbed near the city of Bukhara, the content of sulfate ions relative to the upper stream of the river increases by 15 times, chlorides—72 times, hydrocarbonates 2.5 times, sodium and potassium 39 times, calcium 4.3 times, sodium 9.7 times.

Thus, the ionic composition of the waters metamorphosed from the bicarbonate-calcium of the second group from the upper to the end of the middle stream, and in the last gauging site of the middle stream (GS 6) passed to the bicarbonate-magnesium type 2. Starting from the gauging site 7 to the end of the riverbed, the water of the Zarafshan River began to belong to the sulfate-magnesium type 2 in the lower reaches.

Regarding seasonal changes in water salinity, we have analyzed data for 2010 and 2019 for GS 2 in the upper midstream and in downstream at city Navoi (GS 8). In general, the tendency in GS 2 in both years was identical, however, in 2019, we observed more abrupt (hopping) changes during the year. Similar to case of 1966, the highest salinity levels were observed during winter months and the lowest during the summer period. In GS 8 the highest salinity levels were observed in February–March–April period and in August month. For both years the lowest salinity levels were characteristic for July. During the September–December period the changes in salinity level were insignificant (Fig. 21.5).

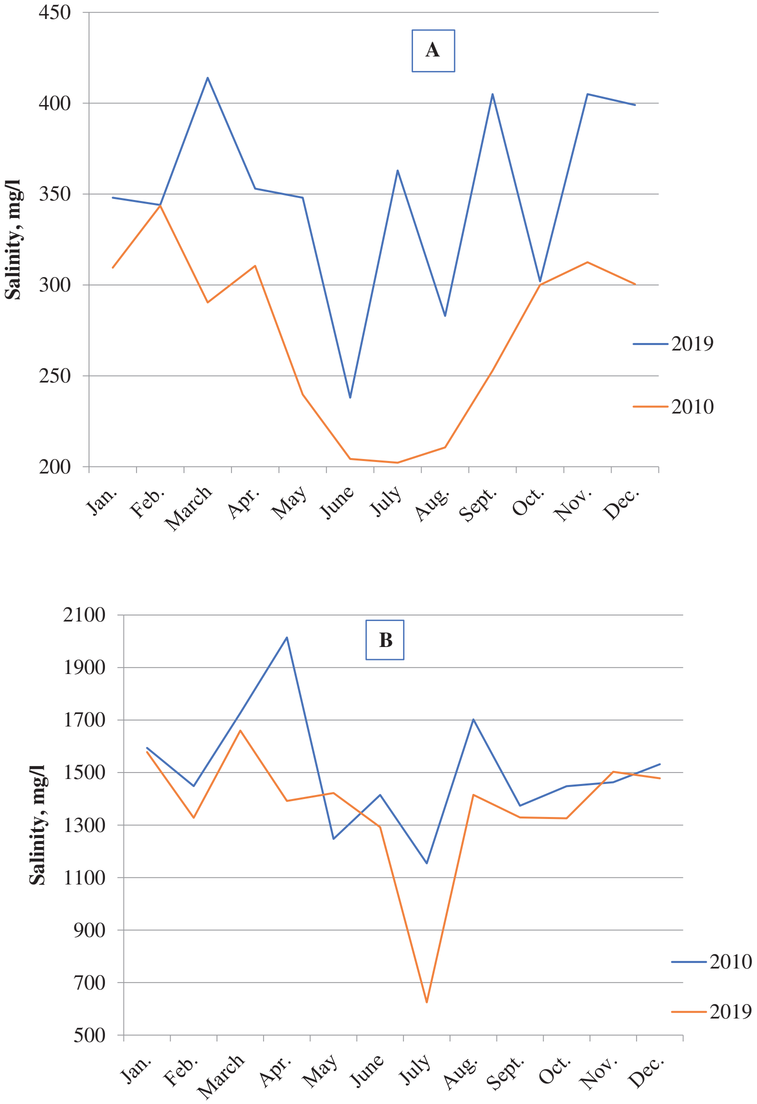

FIG. 21.5 Within-year seasonal dynamics of water salinity in GS 2 in 2010–19 (A) and in GS 8 in 2010–19 (B) of Zarafshan river.

3.2.2 Electric conductivity

The average annual values of the electrical conductivity (EC) of the Zarafshan River water for the period 2010–19 in the upper and middle streams of the Zarafshan River were quite close and varied between 370 and 705 μS/cm. As expected, in the lower reaches, starting from the gauging site 7, there was a sharp threefold or more increase in the EC. The maximum

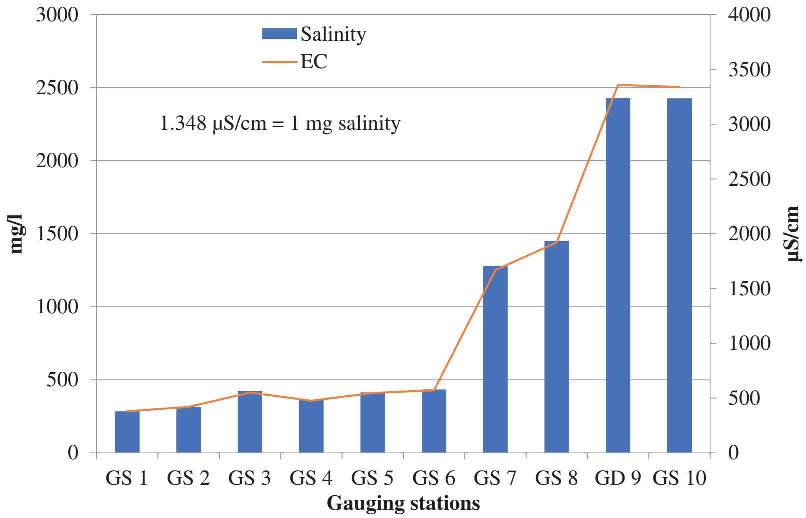

FIG. 21.6 Relationship between the dynamics of average multiyear values (2010–19) of water electric conductivity (EC) and salinity of the river Zarafshan.

annual average value of the EC in the gauging site 8 was observed in 2014—2437 μS/cm (Fig. 21.6). However, the EC values reach maximum in the downstream. Near the city of Bukhara, the EC value was 3358.6 μS/cm. At the same time, the average multiannual value of the EC for all studied gauging sites was 1323 μS/cm. There was a high degree of correlation between the EC and the salinity of water, for every 1 mg of salinity, the EC corresponded to 1.348 μs/cm.

3.2.3 *Biogenous compounds*

RETROSPECTIVE DATA

Literature information on content of biogenous compounds in Zarafshan river before starting the impact of intensive irrigated agriculture in the 1960s absent until today. According to the only source of such information we could find (UGMS UzSSR, 1966) in upper midstream (GS 2), as well as in upper downstream (GS, 8) concentrations of biogenous compounds (except nitrite nitrogen and total iron) have never exceeded MPS for all types of water use. Concentrations about 2 to 3 times above MPS_f for nitrite nitrogen was observed only February and March in GS 2. Concentration of total iron exceeding MPCw and MPC_f 16 and 49 times respectively was observed only in June near to GS 8 (Table 21.6).

CURRENT STATUS

AMMONIUM NITROGEN According to the average long-term indicators, the most dynamic concentrations of ammonium nitrogen were distinguished by gauging sites 3 and 8. At the third gauging site, there was a gradual increase in its concentration with distinct peaks in 2014, 2017 and 2019. Only in 2014 and 2019, its concentration exceeded the MPC_f and was equal to 0.82 and 0.59 mg/L per nitrogen, respectively. However, even more pronounced

TABLE 21.6 Biogenous compounds in the water of Zarafshan river in 1966, mg/L (Source: UGMS UzSSR, 1966).

	Months									
Ingredients, mg/L	**1**	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**12**
GS 2—Akdarya water division										
Ammonium nitrogen				0.10	0.29	0.02	0.24	0.14		0.03
Nitrite nitrogen	0.004	0.057	0.050	0.003				0.003		0.003
Nitrate nitrogen	8.00	8.44	3.28	1.93				0.00		3.66
Phosphate (as "P")	0.008	0.008						0.039		0.003
Iron total	0.03	0.02	0.02	0.02				0.04		0.02
The city of Navoi, bridge, near to GS 7										
Ammonium nitrogen					0.50		0.05		0.26	
Nitrite nitrogen							0.001			
Nitrate nitrogen							3.07			
Phosphate ("P")							0.038		0.012	
Iron total							0.04		0.02	
The city of Navoi, near to GS 8										
Ammonium nitrogen					0.04				0.07	
Nitrite nitrogen									0.001	
Nitrate nitrogen									1.68	
Phosphate ("P")									0.007	
Iron total					4.87				0.05	

dynamics with extremely high concentrations of ammonium nitrogen is observed at the gauging site 8. The highest concentrations were observed here in 2011, 2014, 2017 and 2019. The excess of the MPC_f by 1.6 times was observed in 2014. In these two gauging sites, the peak concentrations coincided in 2011 and 2014. However, the peak for gauging site 3 in 2017 did not coincide with that of gauging site 8, where the lowest concentrations were observed that year (Fig. 21.7).

If we consider the average annual concentrations, the highest indicators of ammonium nitrogen were observed in the gauging site 3 (2010, 2012, 2016–19) and the gauging site 8 (2011, 2013, 2014, 2015). The maximum indicator was noted in 2014 in the gauging site 8—0.82 mg/L and in 2017 in the gauging site 3—also 0.82 mg/L. Relatively the lowest values were observed during 2016, where the average annual concentration of ammonium nitrogen varied from 0.01 to 0.06 mg/L.

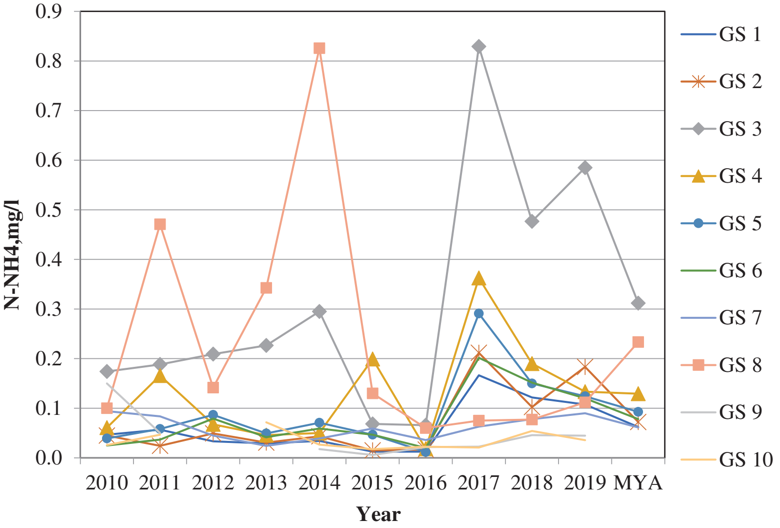

FIG. 21.7 Dynamics of changes in the average annual value of ammonium nitrogen in the Zarafshan river, 2010–19. *MYA*—multiyear average value.

NITRITE NITROGEN Unlike ammonium, the content of nitrite nitrogen in most cases exceeded the MPC_f, but remained within the limits of sanitary and hygienic standards (MPC_h). The highest average annual concentrations of nitrite nitrogen in the third gauging site were observed in 2010, and the second peak was also noted in 2014. In almost all years, the concentrations of nitrite nitrogen in the gauging site 3 exceeded MPC_f. being in the range of 0.04 to 0.14 mg/L. At the same time, as in the case of ammonium, the maximum concentrations exceeding the MPC_f by 11 times were noted in 2014. In other cases, the allowable MPC was not exceeded. According to the long-term average data, the maximum concentrations were characteristic of the gauging site 8, followed by the gauging site 3. At the gauging sites located below the gauging site 8, the concentrations of nitrite nitrogen remained permanently lower than the both types of MPC.

The maximum annual average values of nitrite nitrogen in the water of the Zarafshan River during the studied period were observed in 2010, 2011 and 2014. In 2010, the maximum annual average value was recorded in the gauging site 3—0.135 mg/L, in 2011 in the gauging site 8—0.147 mg/L, in 2014 in the gauging site 8—0.216 mg/L. In 2019, the average annual values in the gauging sites 3 and 8 were almost the same—0.051 mg/L and 0.056 mg/L, respectively. At the same time, in gauging sites 1 and 2, over a 10-year period, there has never been an excess of the MPC level for nitrite nitrogen. This means that there are sources of pollution with nitrogenous compounds throughout the entire riverbed below the gauging site 2 (Fig. 21.8).

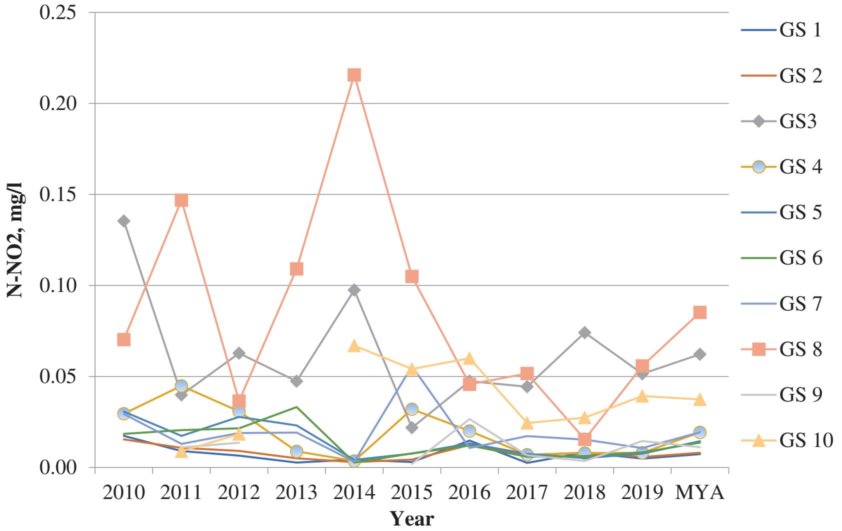

FIG. 21.8 Dynamics of changes in the average annual value of nitrite nitrogen in the Zarafshan river, 2010–19.

NITRATE NITROGEN With regard to nitrate nitrogen, one should immediately note such an important point—that during the 10-year period studied, there was never an excess of both types of MPC. As in the case of ammonium and nitrite nitrogen, the first peak of the average annual concentrations of nitrate nitrogen was observed in gauging site 8 in 2011. However, here this peak significantly exceeds the next typical maximum for the same gauging site in 2014 (6.4 mg/L versus 5.1 mg/L). And in the case of ammonium and nitrite nitrogen, it was the opposite. Whereas the following gauging sites in terms of average annual concentrations include gauging sites 10 and 9 (4.5 and 3.7 mg/L) (Fig. 21.9). It should be particularly noted that only in the gauging site 1 during the studied 10-year period, an excess of the concentration of nitrate nitrogen of 1 mg/L was never observed. And this probably indicates the absence of nitrate pollution on the upper reaches of the Zarafshan River over the past 10 years.

In the middle course of the river (gauging sites 2–6), the highest average annual concentrations of nitrate nitrogen were observed in gauging site 3 in 2010, 2011, and 2016, which was located 0.5 km below the sites in the area of Samarkand. The probable sources of this are the discharge of industrial and agricultural wastewater from Samarkand city and the Samarkand province. Fluctuations in the nitrate nitrogen concentration during the studied period amounted to 1.11–2.32 mg/L. Also, the maximum annual average values were observed in the gauging site 8, after the wastewater discharges of the Navoi-Azot plant. The average annual concentration of nitrate nitrogen in this gauging site reached 6.4 mg/L (2011), 4.9 mg/L (2013), 5.1 mg/L (2014). The figures for 2018 and 2019 have relatively decreased compared to previous years.

PHOSPHORUS TOTAL The dynamics of concentrations according to the average annual and long-term average data for 2010–19 for another important biogenic element, total

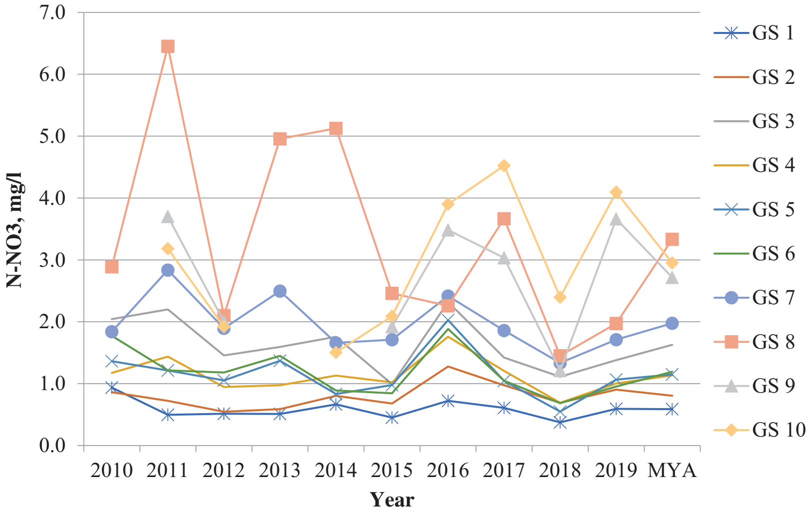

FIG. 21.9 Dynamics of changes in the average annual value of nitrate nitrogen in the Zarafshan river, 2010–19.

phosphorus, turned out to be somewhat peculiar. It should be emphasized that Uzhydromet determines phosphates by total phosphorus ("P"). During the entire period 2010–19, the highest concentrations were observed in gauging site 3. For mesotrophic waters, to which the Zarafshan River belongs, the MPC_f for this element is set at an amount of 0.15 mg/L P. Only at this gauging site was there an excess of quality standards, in 2012 at the level of MPC_f, and especially in 2019 (1.85 MPC_f). Slightly increased long-term average concentrations were also observed in four gauging sites, but in moderate ranges—up to 0.08 mg/L. At the same time, until 2012 there was a gradual increase in concentration, and then from this year to 2016 there was a gradual decrease in concentration. And then, until 2019, there was a sharp increase in this indicator, reaching a maximum of 0.277 mg/L. In all other gauging sites, the concentration of total phosphorus in the period 2010–19 was in the range of up to 0.04 mg/L (Fig. 21.10). Concentrations of total phosphorus did not exceed of MPC for household drinking and cultural water use.

IRON TOTAL The maximum concentrations of the next important biogenic element—total iron, according to the average annual and long-term data, for the study period ranged from 0.06 to 0.08 mg/L, which did not exceed the sanitary and hygienic (0.3 mg/L) and fishery (0.1 mg/L) norms. The maximum average annual concentrations were observed at the gauging sites 1—0.08 mg/L, followed by the gauging sites 3 and 5—0.06 mg/L and the gauging sites 6 and 8—0.05 mg/L. The highest concentrations were observed in the period 2011–12, and in the period 2013–19 the values of total iron remained low, not exceeding 0.03 mg/L (Fig. 21.11).

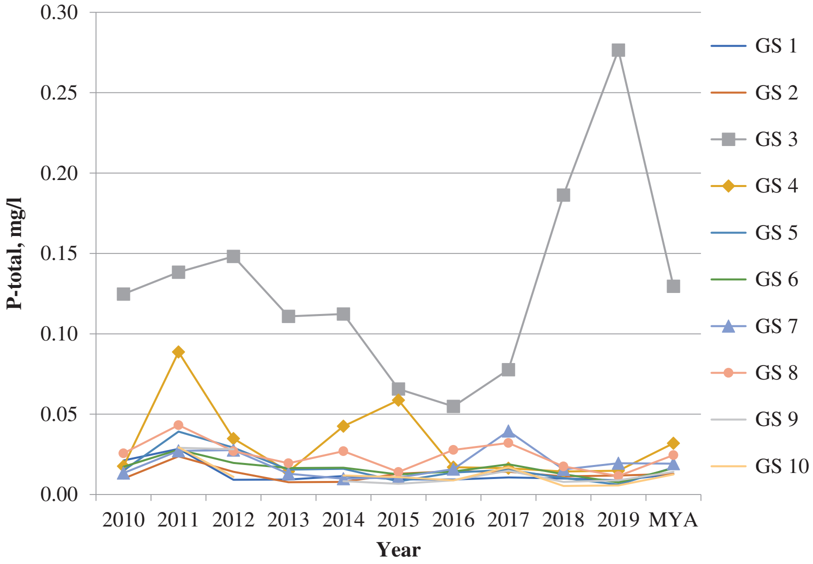

FIG. 21.10 Dynamics of changes in the average annual concentrations of total phosphorus in the Zarafshan river, 2010–19.

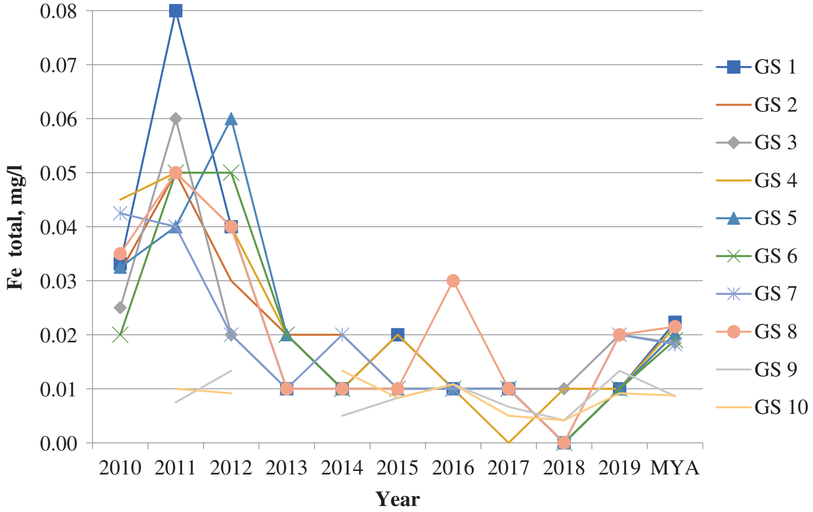

FIG. 21.11 Average annual and multiyear fluctuations of total iron (Fe) concentrations in the Zarafshan River in 2010–19.

4 Discussion

Before proceeding to the analysis of the data obtained on changes in water quality in the Zarafshan River over the past 10 years, it is important to note that the waters of the Zarafshan River obviously stopped flowing into the Amu Darya River long before the intensive development of irrigation in the 1960s. According to the leading hydrologists of Central Asia (Schultz and Mashrapov, 1969; Rubinova, 1987; Qadirov, 2007), it can be confidently stated that from about the 17th and 18th centuries until the 1930s, the Zarafshan River had no connection with other river systems. However, since the 1930s, due to the beginning of intensive construction of irrigation canals Eskiangar, Amu-Bukhara, etc. the river again became connected not only with other river systems, with which it historically formed a single water system (Amu Darya, Kashkadarya), but also with the Syr Darya River through the Sanzar River. But with one significant difference: after the construction of the Amu-Bukhara Machine Canal in 1962, the water resources of the Zarafshan River in its lower reaches are replenished with the water of the Amu Darya River, at the same time it gives part of its water through channels to the Kashka Darya and Syr Darya river basins. Thus, for several decades now, the water quality of the Zarafshan River in its lower reaches, after the Duaba dam, has been formed under the significant influence of the Amu Darya River.

The second important aspect of the study and assessment of the water quality of the Zarafshan River is the need to establish water quality indicators before the start of intensive impact on its water resources in order to establish the anthropogenic component of the metamorphosis of the chemical composition, both in terms of drinking, cultural and household, and for the purposes of fisheries and other uses of water resources of the Zarafshan River basin. Compliance with the latter criteria also guarantees the fulfillment of environmental objectives. Since the development of fishery MPCs during the former Soviet Union and after it covers the study of the impact of pollution on all components of the hydroecosystem, including abiotic and biotic components (Moiseenko, 2005). The river flow observations carried out since 1913 on gauging station Dupuli in Tajikistan, however, water quality measurements were conducted very rare and no information is available in literature until the 1980s. Based on the unpublished data on the water quality of the Zarafshan River in 1966 (UGMS UzSSR, 1966), it can be concluded that water salinity levels up to 600 mg/L in the upper part of the lower course (GS 7, 8) can be taken as a boundary, an increase in salinity above which already occurs due to anthropogenic salinization. This value refers to the upper section of the downstream. The Akdarya water reservoir, built in the late 1970s, could also contribute to a certain increase in salinity due to evaporative concentration (Rubinova and Kuropatka, 1998). Therefore, in the lower sections of the downstream (below the Duabinsk hydroelectric complex), the salinity could be slightly higher, for example, presumably about 800 mg/L. Thus, the salinity of water in the range from 600 to 800 mg/L can be taken as normal when comparing data before 1966 and in the modern period. This approach makes it possible to assess the change in the water quality of the river not only by comparing it with existing water quality criteria, but also from the standpoint of determining the anthropogenic component of these changes.

High evaporation rate in the conditions of the Zarafshan River basin during the growing season is due to high air and water temperatures. As a result, bicarbonate waters metamorphose first into sulfate, and then into sulfate-chloride and even chloride (Posokhov, 1969). The direction of metamorphization of the Zarafshan River water first from calcium-bicarbonate to magnesium-bicarbonate from ZFF to the end of the midstream, and then in the downstream (ZFC) to magnesium-sulfate confirms the correctness of the above. But with one exception—chloride anions do not dominate in the Zarafshan River basin.

Discharge of collector-drainage waters into rivers leads to an increase in mineralization and subsequently the water quality of the river deteriorates (Tilman et al., 2002; Longley et al., 2019; Mirkhasilova et al., 2020). Collectors such as Taligulyan, Khauzaksay, Boynazar, Cheganak, Sanitarniy, and others discharge collector-drainage water into the Zarafshan River (Kulmatov et al., 2013). As a result, the long-term salinity in the drainage of the lower Zarafshan is high enough to exceed the Uzbek threshold of 1000 mg/L. In terms of monitoring the level of anthropogenic salinization, the fact that we have established a strong correlation between EC and salinity of water in various sections of the Zarafshan River is of great interest. As expected, the maximum EC value was typical for the lower part of the river near the city of Bukhara (3358.6 μs/cm). According to the results of statistical analyses for the entire Zarafshan River, for each mg/L of salts corresponds to 1.348 μs/cm, which is close to the values we have established for the waters of the Amu Darya and Syr Darya rivers (Karimov et al., 2019) and other researchers for other regions (Cañedo-Argüelles et al., 2013).

Comparison of seasonal dynamics in water salinity in 1966 and 2010 in upper midstream (GS 2) demonstrated the high similarity; the highest concentrations in both cases were registered in late autumn and winter months and in March. The lowest amounts were registered in summer period. Comparing Figs. 21.2 and 21.5A, it is not difficult to notice a gradual decrease in salinity from May to August and again a gradual increase until November. For the midstream (GS 7–8), it was impossible to make such a comparison with certainty due to the sketchy factual data in 1966. It can be assumed that the picture here was somewhat different with a trend with high salt concentrations in the month of June exceeding the salinity of the water for August and October. However, in GS 2 in 2019, the situation is changing significantly, salinity fluctuations become abrupt, with peaks in March, July, September and November. In contrast to 1966 and 2010, in July there is a jump in the increase in salinity by almost 50%, which is significantly higher than the level of January 1966 and 2010. One can guess that there is clearly an impact of such an anthropogenic factor as the discharge of highly mineralized collector-drainage waters. Even more differences are revealed when compared with the data for GS 8 (Fig. 21.5). Here, both in 2010 and in 2019, consistently high salinity levels are observed in the range of approximately 1300 to 1500 mg/L. In addition, in both years there is a sharp increase in salinity in March–April up to the maximum annual values (up to 2000 mg/L). However, a sharp jump down occurs in July, especially in 2019 (up to 600 mg/L), which can only be explained by salvo discharges from the overlying reservoirs. Thus, the analysis shows an obvious violation of the natural regime of seasonal fluctuations in water salinity along the Zarafshan riverbed from the upper and middle reaches to the lower reaches. At the same time, smooth fluctuations of the natural salinity level in 1966 are changed by abrupt and complex changes in the final section of the midstream and in the downstream. This may present certain difficulties in water quality management and should be taken into account in the development of water management plans.

Various fertilizers rich in nitrogen, phosphorus and potassium are used for the development of agriculture. The introduction of nutrients contained in organic (manure) and artificial fertilizers often remains in the soil or is washed out into drainage water (Zia et al., 2013). Proportions of nutrients (e.g., ratios of N/P) and forms (e.g., ammonium, nitrate or urea) are important factors causing the spread of harmful algal blooms that pollute drinking water and harm aquatic organisms (Glibert, 2017; Wang et al., 2019). Indeed, distribution analysis of variables, pollution indices (SLA—Sládeˇcek index of saprobity), and toxicity indices (WESI—Water Ecosystem State Index) demonstrated increases in salinity, turbidity, and decreases in organic pollution downstream (Barinova and Mamanazarova, 2021). This confirms the need for a mechanism for monitoring and evaluating the intake of nutrients into crops, their uptake by crops and losses through runoff and leaching from farms. The increase in water pollution of the Zarafshan River to the lower reaches causes environmental instability in the Samarkand and Navoi regions (Groll et al., 2013, 2015; Kulmatov et al., 2014). According to other researchers (Zhan et al., 2021) principal component analysis indicated that the toxic elements of Pb and Cd in surface waters of the ADBU had industrial origins; local agricultural activities were considered to have contributed much of the NO_3, Zn, Ni, Hg, and Mn through pesticides and fertilizers; and Cu, Cr, As, and Co were controlled by mixed anthropogenic and natural sources.

According to unique data for 1966 concentrations of biogenous compounds in Zarafshan river water did not exceed MPC before large agricultural development (Table 21.6) except some cases with nitrite nitrogen. However, they were very variable in all gauging sites and seasons of the year and various years which made difficult to follow general dynamics of pollution levels. But nevertheless, some regularities can be found if we operate with mean annual and multiannual concentrations However, during the investigated decade (2010–19) the maximum concentrations of ammonium, nitrite and nitrate nitrogen ions exceeding MPC_f was observed below the gauging site 3—Siab collector and gauging site 8—below the wastewater discharge point at the Navoiazot chemical factory. The extreme high concentrations of nitrite nitrogen were characteristic for gauging sites 3 and 8—0.135 and 0.216 mg/L respectively. This indicates existence of both agricultural (CDW) and industrial sources of water pollution with biogenous compounds downstream of gauging site No.2. The content of nitrate nitrogen in water has never exceeded permissible levels with maximum values after gauging site No.8—after release of sewage waters of large chemical enterprise "Navoiazot." In upstream site never have been observed exceeding concentrations of all nitrogen compounds which indicated absence of pollution sources during the last decade. The concentrations of other two biogenous elements: phosphorus and total ion generally not exceeded MPC levels.

The ratio $[NO_3^-]:[NO_2^-]:[NH_4^+]$ is serving as an excellent indicator of water pollution with organic contaminants containing nitrogen. The higher the proportion of nitrate nitrogen, the better the ecosystem copes with the biochemical oxidation of organic pollutants entering it. The close to uniform ratio of these three forms of nitrogen indicates the natural state of the organic oxidation process. According to the calculations based on results of GS 1, 4, 7, and 8, in 2019, the share of ammonium and nitrite nitrogen was always much lower than the same for the nitrate nitrogen (Table 21.7). Maximum values of this ration in our investigations were

TABLE 21.7 Concentrations of ammonium, nitrite and nitrate nitrogen and their ratio in the Zarafshan river, 2019.

Gauging sites	**1**	**4**	**7**	**8**
Indicators (mg/L)	**Min.–max. average**			
$N\text{-}NH_4$	0.04–0.310.12	0.02–0.350.13	0.02–0.310.09	0.01–0.250.11
$N\text{-}NO_2$	0.001–0.0150.005	0.002–0.0220.008	0.001–0.0560.01	0.004–0260.05
$N\text{-}NO_3$	0.07–1.490.59	0.04–2.671.0	0.12–4.251.71	0.24–4.61.97
$[NO^-{}_3]:[NO^-{}_2]:[NH^+{}_4]$	1.0:0.009:0.2	1.0:0.008:0.13	1.0:0.005:0.05	1.0:0.02:0.05

about 1.0:0.02:0.20, which indicates that the assimilation capacity of the river ecosystem, despite permanent contamination with nitrogen-containing compounds, successfully copes with their transformation to a relatively harmless form of nitrogen compound—nitrates.

5 Conclusions

From the 17th and 18th centuries until the 1930s, water resources of Zarafshan River were fully used for irrigation and did not reach the Amu Darya River long before the intensive development of irrigation in the 1960s. Based on the unpublished data on the water quality of the Zarafshan River in 1966 water quality indicators for the Zarafshan River before the start of intensive impact of agricultural and industrial development was identified to distinguish the anthropogenic component of the metamorphosis of the chemical composition. Thus, the main indicator of agricultural impact on water quality—salinity between the range of 600 and 800 mg/L can be taken as natural fluctuations and the values above as anthropogenic disturbance when comparing data before 1966 with the present period. This approach makes it possible to assess the change in the water quality of the river not only by comparing it with existing water quality criteria, but also from the standpoint of identifying the anthropogenic component of these changes.

The analysis shows an obvious disturbance of the natural regime of seasonal fluctuations in water salinity along the Zarafshan riverbed from the upper and middle reaches to the lower reaches. Controlled fluctuations of the natural salinity level in 1966 changed by abrupt and complex changes in the final section of the midstream and in the downstream basin. This may present certain difficulties in water quality management and should be taken into account in the development of water management plans and policies.

In terms of monitoring the level of anthropogenic salinization, the fact that we have established a strong correlation between EC and salinity of water in various sections of the Zarafshan River is of great interest. As expected, the maximum EC value was typical for the lower part of the river near the city of Bukhara (3358.6 μs/cm). According to the results of statistical analyses for the entire Zarafshan River, for each mg/L of salts corresponds to 1.348 μs/cm.

Until 1966, before large agricultural development, concentrations of biogenic compounds in Zarafshan river water did not exceed MPC. In 2010–19, the extreme high concentrations of nitrites were characteristic for gauging sites 3 and 8—0.135 and 0.216 mg/L respectively. This indicates existence of both agricultural (CDW) and industrial sources of water pollution downstream at gauging site No.2. Maximum values of $[NO_3^-]:[NO_2^-]:[NH_4^+]$ ratio in our investigations were about 1.0:0.02:0.20, which indicates that the assimilation capacity of the river ecosystem, despite permanent contamination with nitrogen-containing compounds, successfully copes with their transformation to a relatively harmless form of nitrogen compound—nitrates.

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