Water salinity changes of the gauging stations along the Amu Darya River

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Abstract

The Amu Darya is the most important river in Central Asia, as the river water used for agricultural, industrial and domestic purposes. The Kelif, Kerki, Chardjow, Darganata, Kipchak, Takhiatash, and Samanbay gauging stations (g/s) are located in the Amu Darya River. The water salinity of the Amu Darya River at the Kelif, Chardjow, and Darganata g/s were decreased from 0.649-0.469, 0.823-0.614, and 0.99-0.696 g/ℓ to 1991-2010; at the Takhiatash, and Samanbay g/s has been raised from 1.218-1.562, and 1.126-1.46 g/ℓ to 1991-2000. We have predicted the seven gauging stations along the river water salinity from 2010 to 2020 used by the Holt's Linear Trend Forecasts Method, and the results are then applied in the prediction of water salinity. The forecast suggested that the Amu Darya river water salinity of the Kelif g/s will be increased to around 0.495 g/ℓ in 2020; of the Kerki, Chardjow, Darganata, Kipchak, Takhiatash, and Samanbay g/s will decreases to approximately 0.483, 0.602, 0.668, 0.484, 1.104, and 0.825 g/ℓ by 2020.

Key words: Amu darya river, Aral sea, Salinity

Introduction

The Aral Sea is a saline lake, and is located in Central Asia. The water surface area, water volume, and salinity of the Aral Sea were 68,000 km^2, 1,093 km^3, and 10 g/ℓ in 1960 [3, 13]. Over the past 50 years, 80% of the lake surface area and 88% of the lake water volume had been lost, and salinity has kept increased about 12 times [8]. The dryness of the lake was caused primarily by the diversion of the inflowing Amu Darya and Syr Darya rivers to irrigation purposes. The total irrigation area was 3.0 mln ha in 1913, and increased to 4.5 mln ha in 1960 [4], because of land area development in the Aral Sea basin initiated by the Former Soviet Union. During 1950-1990 a reservoirs, irrigation canals, pumper stations, and drainage networks has been constructed. Most rivers were diverted for irrigation to support the cultivation of cotton, wheat, fodder, fruit,

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vegetables, and rice in the arid steppe, and desert areas. During this period irrigated areas were developed by 150% in the Amu Darya basin and by 130% in the Syr Darya basin [19]. The population of the Aral Sea Region had been increased from 14 mln in 1960 to 47 mln in 2008. Therefore, the irrigation area has increased to 7 mln ha, to 7.9 mln ha, and to 8.5 mln ha in 1990, 2000 and 2007. The average irrigation area of the Amu Darya basin was in 5 mln ha in 2010. Nowadays, the economies of the Aral Sea region are still essentially agricultural, especially with regard to the predominant occupation of the labour force. Typically, the agriculture earned about 20% of GDP in Tajikistan, 25% in Turkmenistan, and 28% in Uzbekistan. Agriculture employs 67% of the labour force in Tajikistan, 45% in Uzbekistan and 48% in Turkmenistan in 2006 [4, 15, 18].

In 1960, the average water salinity of the Amu Darya River was 0.3 g/ℓ [5]. Intensive development of irrigation, and land drainage in the Aral Sea basin had two major consequences were affected the river water i.e., an increased abstraction of fresh water and discharges of polluted water return flow, with toxic salts being the main pollutants. The increasing salinity of water in river, and the intensity of drainage from irrigated land substantially affect the dynamics of salinization, and increase the need for reclamation of irrigated areas. As a result, the river water quality has deteriorated due to discharges of saline and polluted drainage water and agrochemicals which were washed out into drainage systems, and mixed with river water.

At the initial time of the development of saline land, the salinity of drainage water was 6-10 g/ℓ. Since leaching irrigation, the salinity was decreased, and currently is stabilized within 3-6 g/ℓ. In 1980, as a result of discharge of drainage water into the Amu Darya, the water salinity varies within 0.4-1.7 g/ℓ in the middle, and lower reaches; whereas, the mean annual salinity was 0.8-1.1 g/ℓ. In dry years, salinity may reach up to 2 g/ℓ in the estuary, with dominating recharge from groundwater [5].

The chemical composition of water in the Amu Darya basin is determined by agricultural wastewater flowing into the river from the Turkmen, and Uzbek territories. The Kerki, Darganata, Kipchak, and Samanbay representative sections (r/s) are located in the Amu Darya River. In 1960, the water salinity of the Amu Darya River was 0.56 g/ℓ in Kerki r/s, and then increased to 0.7 g/ℓ in 1990. The Samanbay r/s was 0.60 g/ℓ and 1.02 g/ℓ in 1960 and 1990 respectively; because of the Samanbay r/s is located in the downstream of the Amu Darya River delta. Consequently, the water salinity was high. In 1990, the river water salinity of 0.78 g/ℓ, of 1.1 g/ℓ at the Darganata r/s, and Kipchak r/s [5]. After the collapsed of the Soviet Union, the Central Asian countries become independent in 1991, and started to collaboration with the Amu Darya river basin countries, consequently, the representative sections has been changed to the gauging stations (g/s). Therefore, the main goals of this paper are:

- to estimate the gauging stations variations of the Amu Darya river between 1991 and 2010,
- to predict the gauging stations variations of the Amu Darya river from 2009 to 2020.

Materials and Methods

Study area

The Amu Darya is a largest river in Central Asia. It is shared by Turkmenistan, Tajikistan, Uzbekistan, and Afghanistan (Fig. 1). The main volume of water comes from high glaciers and snow fields feeding into the Amu Darya, it flows nearly 2400 km from the Pamir, Alai and Hindu Kush Mountains, across Karakum and Qyzylqum deserts, and into the Aral Sea (Fig. 1 [11]). The Amu Darya average annual flow the drainage basin is 79 km^3 (Micklin, 2000), with a catchment area of 309,000 km^2 [1].

Topography, glaciers, precipitation patterns, and climate variable are the important factors which greatly influence the water flow in the Amu Darya basin, which consists of the three main zones are (1) an upstream mountainous zone (Pamir, Alai, and Hindu Kush rising to 7,495 m generate 90% of the flow); (2) a midstream region (with several distich large irrigated oases), and (3) a downstream zone of flow depletion with a delta and discharge into the Aral Sea.

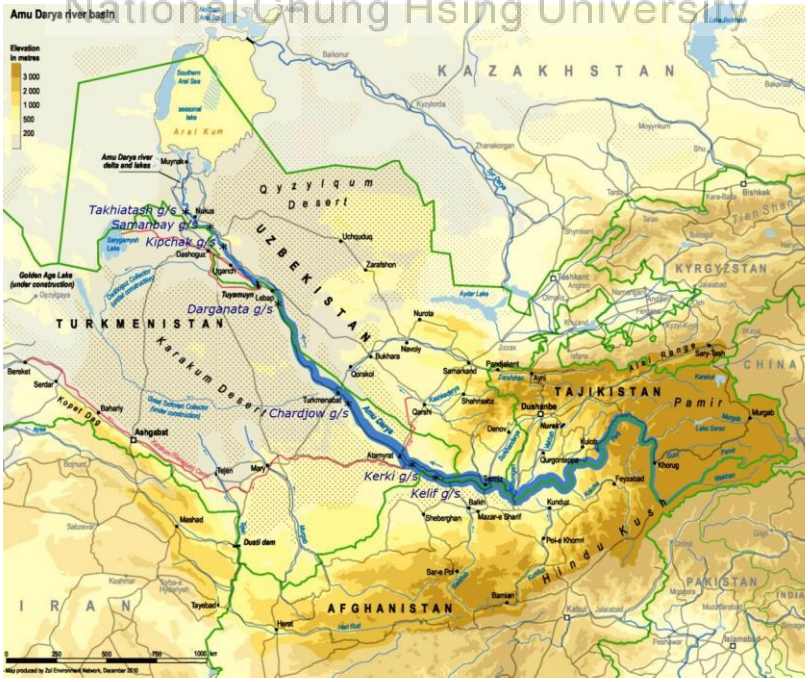

Fig. 1. Amu Darya River Basin, the location of gauging stations along the Amu Darya River

The Takhiatash (Takhiatash, Kegeyli District), Kipchak, and Samanbay (Kipchak, Amudarya District) gauging stations are located in Karakalpakstan Provence, Uzbekistan. The Kelif (Kelif, Atamurat District), Kerki (Kerki, Atamurat District), Chardjow (Chardjew, Turkmenabat District), and Darganata (Darganata, Birata District) gauging stations are located in the Lebap Province of Turkmenistan. All gauging stations are located in the mid, and downstream of the Amu Darya River Delta (Fig. 1).

The average annual precipitation is 464 mm, with a maximum of 2,000 mm (Eastern Pamir). In the lower reaches of the Amu Darya, mean annual precipitation is less than 100 mm. Rainfall is occurred from November to May, and has a typical continental climate. Summer is hot (average temperature is 35℃). Autumn is a cool and rainy (18℃), and winter is cold and snowy (average temperature is -8℃, fall to -20℃).

Data Collection

We have collected the Kelif, Kerki, Chardjow, Darganata, Kipchak, Takhiatash, and Samanbay gauging stations observation data of the Amu Darya water salinity from 1991 to 2010, respectively[1, 5, 6, 15, 17].

The descriptive statistical analyzes were the maximum, minimum, mean, standard deviation, and 2-tailed p-values of the seven gauging stations in Amu Darya river from 1991 to 2010 as a results shown in Table 1.

Table 1 demonstrates that the mean water salinity of the Amu Darya River in the Kelif g/s was 0.477 g/ℓ, and maximum-minimum were 0.65-0.44 g/ℓ. The river water salinity at the Kelif g/s has diminished from 0.649 g/ℓ in 1991 to 0.448 g/ℓ in 2006. The river water salinity in the Kerki g/s has silently reduced from 1991 to 2007 as 0.694-0.458 g/ℓ (the mean was 0.498 g/ℓ).

Table 1. A descriptive statistical data of the seven gauging stations in the Amu Darya River water salinity (g/ℓ) from 1991 to 2010

Gauging Stations (g/s)	Time (year)	Minimum	Maximum	Mean	Std. Deviation	*p*-Value
Kelif	20	0.44	0.65	0.477	.04585	.000
Kergi	20	0.45	0.69	0.498	.05028	.000
Chardjow	20	0.57	0.82	0.643	.04998	.000
Darganata	20	0.66	0.99	0.734	.08529	.083
Kipchak	20	0.75	1.57	1.096	.23501	.001
Takhiatash	20	0.88	1.56	1.167	.18316	.004
Samanbay	20	0.78	1.66	1.146	.20034	.004

The mean, maximum, minimum, and standard deviation of the river water salinity in the Chardjow g/s were 0.643, 0.82, 0.57 (g/ℓ), and 0.04998. The water salinity of the Amu Darya at the Chardjow g/s was 0.823 g/ℓ in 1991, it has decreased to 0.646 g/ℓ in 2010. The river water salinity of the Darganata g/s has dropped from 0.990 g/ℓ in 1990 to 0.655 g/ℓ in 1998. It has rose to 0.850 g/ℓ in 2000, and then fallen to 0.658 g/ℓ in 2010. The mean river water salinity in the Darganata g/s was 0.734 g/ℓ as a result shown in Table 1. The mean water salinity of the Amu Darya in the Kipchak g/s was 1.096 g/ℓ, and p-value was 0.001, and it is water salinity has declined from 1.572-0.750 g/ℓ to 2001-2010. The Amu Darya water salinity of the Takhiatash g/s was 1.2 g/ℓ in 1991, and it has increased to 1.562 g/ℓ in 2000 (the mean, and p-value were 1.167, and 0.004). In Table 1, the mean water salinity of the river at the Samanbay g/s was 1.146 g/ℓ (max-min as 1.66-0.78 g/ℓ). The river water salinity in the Samanbay g/s were 1.1, 1.662, and 0.783 g/ℓ in 1991, 2001, and 2005.

Forecasting Method

Holt's Linear Trend computes a developing trend equation through the data using a special weighting function that places the greatest emphasis on the most recent time periods. Both the trend and forecasting equations change from period to period, was defined as:

$$\alpha = \alpha X_t + (1+\alpha)(\alpha_{t-1} + b_{t-1}) \dots\dots\dots\dots ①$$

$$b_t = \beta(\alpha_{t-}\alpha_{t-1}) + (1-\beta)b_{t-1} \dots\dots\dots\dots ②$$

where α and β are smoothing constants that are each between zero and one. We have used the value between 0.3 and 0.5. Also, α_t gives the y-intercept at time t, while b_t is the slope at time t. X_t is the value of the series at the current period. The forecast from time T for the value at time $T+K$ is $\alpha_T + b_T K$. We have used the Holt's Linear Trend to assess the predictive power of the seven gauging stations in the Amu Darya. The software NCSS 8 for Windows XP [10] was used for Exponential Smoothing forecasting time series.

Results and Discussion

Kelif Gauging Station

The water salinity of the Amu Darya River in the Kelif g/s was 0.649 g/ℓ in 1991. It had been reduced to 0.488 g/ℓ in 1997, after that it was raised to 0.469 g/ℓ in 2010 [6]. As the large-scale development in the industry, agriculture, and urban areas had been increased pollution of natural water recourses throughout the river basin such as light, food, textile, coal, iron, nonferrous, and chemical. In addition, other industries were focused in the Amu Darya basin. Industrial effluents, the parameters of which exceed the water quality targets to a factor, are finally the sewage water discharged into Amu Darya river delta. The water pollution in the Amu Darya basin is the collector drainage water discharged both into tributaries and the river itself. In general, currently the total water withdrawal from the river is 61 km^3, which is about 41 km^3 are used for irrigation. By 15-18% of the withdrawn water is returned back into the river i.e. 9-11 km^3/year [(6)]. The mean water salinity of the Amu Darya River at the Kelif g/s was 0.477 g/ℓ in Table. The mean of 10 years (from 2011 to 2020) estimated water salinity was 0.485 g/ℓ, which is higher than the observed result in Table 1. Therefore, our prediction of the Kelif g/s in the Amu Darya water salinity will be linearly (R^2 = 0.986) increased to around 0.495 g/ℓ in 2020 (Fig. 2).

Kerki Gauging Station

The Amu Darya water salinity in the Kergi g/s was 0.56 g/ℓ in 1960, and it was increased to 0.7 g/ℓ in 1990 [(5)]. In Fig. 3, the water salinity was 0.694 g/ℓ in 1991, and then dropped to 0.486 g/ℓ in 2010. Because the river water regime is characterized by significant variations in the intra-annual flow distribution. Normally, the highest value of water discharge has recorded at the Kerki g/s was 9060 m^2 s-1 (20 July 1958), however, the maximum water discharge was mainly not more than 8000 m^2 s-1, and 65% of the maximum values were within 5000-7000 m^2 s-1, respectively [(17)].

The Vakhsh oasis of Tajikistan is located the upper irrigation areas in the Amu Darya Basin, the mean annual salinity of the collector drainage water values from 1.0 to 2.0 g/ℓ. The mean collector drainage water salinity in the Amu Darya river tributaries of the Pyandj river basin were less saline (within 0.5-1.0 g/ℓ), of the Kafirnigan river basin were less saline (0.35-0.7 g/ℓ). The Surkhandarya and Sherabad river basins irrigation areas were varied in term of water salinization. Consequently, the collector drainage water

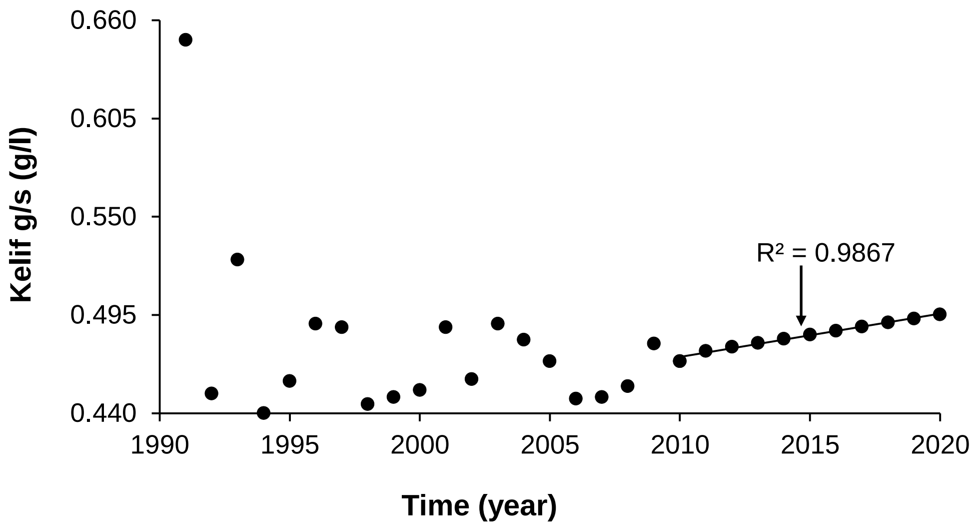

Fig. 2. The Amu Darya river water salinity at Kelif g/s

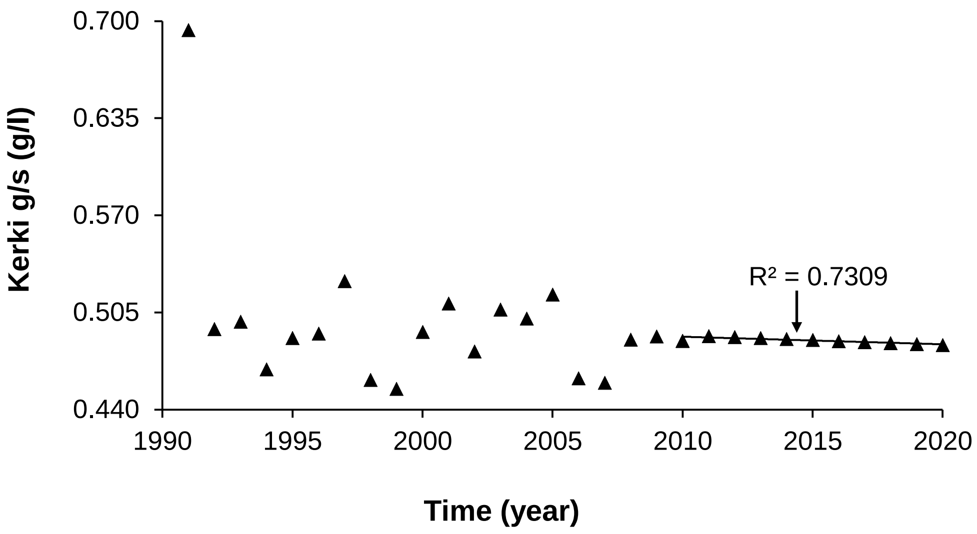

Fig. 3. The water salinity of the Amu Darya river in Kerki g/s

salinity values from 0.2 to 0.7 g/ℓ (lowest) in the sub-mountain zones, then the values between 0.7-2.3 g/ℓ in the middle reaches, and the ranges from 2.3 to 8.7 g/ℓ in the lower reaches of the rivers [(6)]. The other raisons were the location of the gauging station (see Fig. 1), and precipitation has been occurred. In this situation, Fig. 3 demonstrated that the forecast of the Amu Darya River water salinity in the Kerki g/s will be silently decreased exponentially (R^2 = 0.730) from 0.486 g/ℓ in 2010 to 0.483 g/ℓ in 2020. Observation data of the Amu Darya mean water salinity at the Kerki g/s was 0.498 g/ℓ in Table 1. Our prediction of the mean water salinity within 10 years (2011-2020) was 0.486 g/ℓ, comparison with the observed data, which is less than the mean water salinity result from Table 1.

Chardjow Gauging Station

The Chardjow g/s is located in the midstream of the Amu Dar River. The water discharged at the Chardjow g/s after the Kerki and Kelif g/s from the Amu Darya River (Fig. 1). The drainage water of the Qarshi and Qorakol oases has been affect to increase the water salinity of river basin. Therefore, the Amu Darya river water salinity at the Chardjow g/s was 0.823 g/ℓ in 1991, comparing the Kerki g/s data, which is higher than the result for 1991 shown in Fig. 3. However, the water salinity was exponentially (R^2 = 0.324, Fig. 4) decreased to 0.614 g/ℓ in 2010. In Table 1, the mean water salinity was 0.643 g/ℓ. From 2011 to 2020, our prediction of the mean water salinity was 0.609 g/ℓ; consequently, which is less than the observed resulted in Table 1. In Fig. 4, the

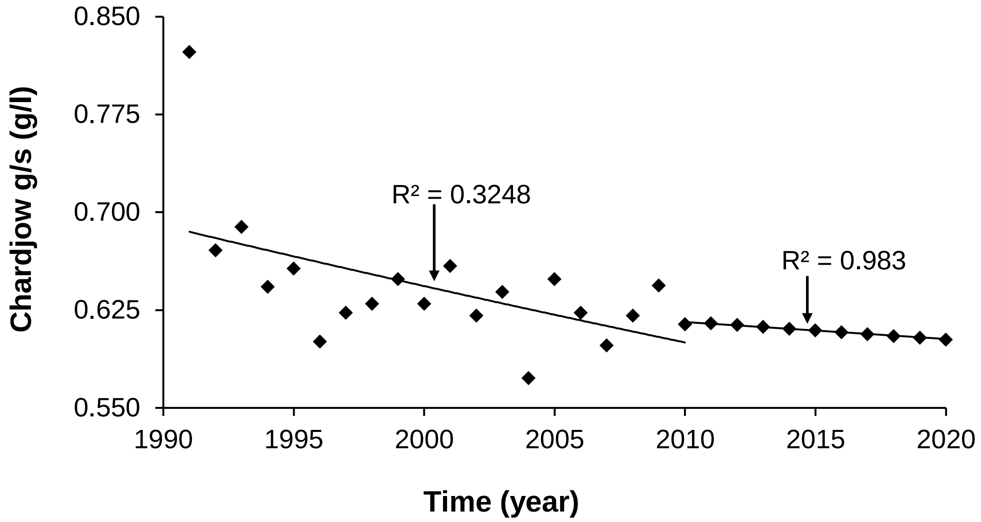

Fig. 4. The Amu Darya water salinity in Chardjow g/s

prediction of the Amu Darya River water salinity at the Chardjow g/s will be linearly diminished to approximately 0.602 g/ℓ in 2020. The coefficient of determination value of water volume was 0.983, and it's almost 99%, because, Table 1 shows that the test result was p = .000 accepted, and it's shows highly connected.

Darganata Gauging Station

The water salinity of the Amu Darya River at the Darganata g/s was 0.88 g/ℓ in 1971. It was decreased to 0.78 g/ℓ in 1990 (5). After collapse the Former Soviet Union, the river water flow into the Aral Sea has been increased, it has caused the water salinity of the river in the Darganata g/s was decreased from 0.99 g/ℓ in 1991 to 0.668 g/ℓ in 1999 (Fig. 5). The average river water salinity was exponentially decreased from 0.85 g/ℓ in 2000 to 0.696 g/ℓ in 2010, and a coefficient of determination was 0.651. The estimate suggests the river water at the Darganata g/s will be declined to approximately 0.668 g/ℓ in 2020 as a result shown in Fig. 5. The mean water salinity was 0.734 g/ℓ in Table 1. Raises of the Amu Darya water flow, as a result indicated the prediction (as 2011-2020) of the mean water salinity will be decreased to approximately 0.680 g/ℓ.

Kipchak Gauging Station

The Dashoguz, Khorezm oases, and Karakalpakstan region are located in the downstream of the Amu Darya River (Fig. 1). The average collector drainage water salinity of the river in the Dashoguz oasis was 2.5 g/ℓ, and the water discharge was from 1.3 to 45 m^3/s. The Khorezm oasis irrigated lands are mainly highly,

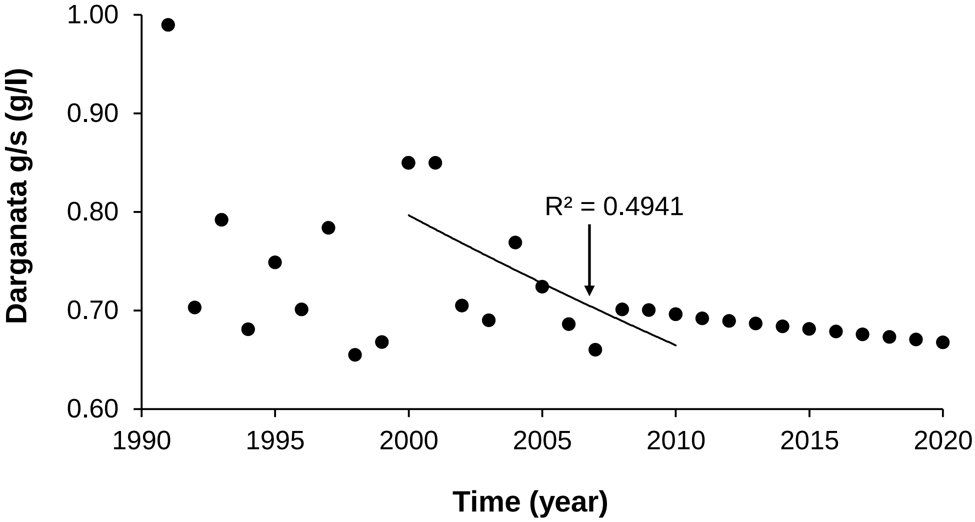

Fig. 5. The river water salinity at Darganata g/s

and medium salinized (the collector drainage water salinity ranges from 2.9 to 18 g/ℓ). Typically, 2 km^3 of the collector drainage water was formed in the lower reaches of the Amu Darya River at the Karakalpakstan region, Uzbekistan. The mean water salinity values between 2.8-5.7 g/ℓ in the main collector drain [(6)]. Consequently, the collector drainage water discharged into the Amu Darya River has caused considerable changes in the river's water-salt regime, especially in the middle and lower reaches.

The river water salinity in the Kipchak g/s was 1.1 g/ℓ in 1971 [(5)]. Fig. 6 demonstrates that the river average water salinity was increased linearly ($R^2 = 0.762$) from 1991 to 2001 as 1.008-1.572 g/ℓ. However, it has fallen to 0.75 g/ℓ in 2010. From 2002 onwards the water salinity started to reduce because of the increases of river water for irrigation areas. Because of this situation, the river water flow at the Kipchak g/s was reduced, as a result indicated our estimation of the mean water salinity will reduces to approximately 0.603 g/ℓ. Therefore, our forecast of the river water salinity at the Kipchak g/s will be exponentially ($R^2 = 0.996$) reduced to around 0.484 g/ℓ (Fig. 6) in 2020.

Takhiatash Gauging Station

The river water salinity and drainage amount increases from irrigated lands were affected the salt regime and status of irrigation areas, which is dependent on water-salt balance of the river and irrigated areas. On average, 50 mln tons of salt annually ending up in the river stem from a natural runoff, and drainage return flow [(5)]. Due to the salt balance in rivers and irrigated areas makes it

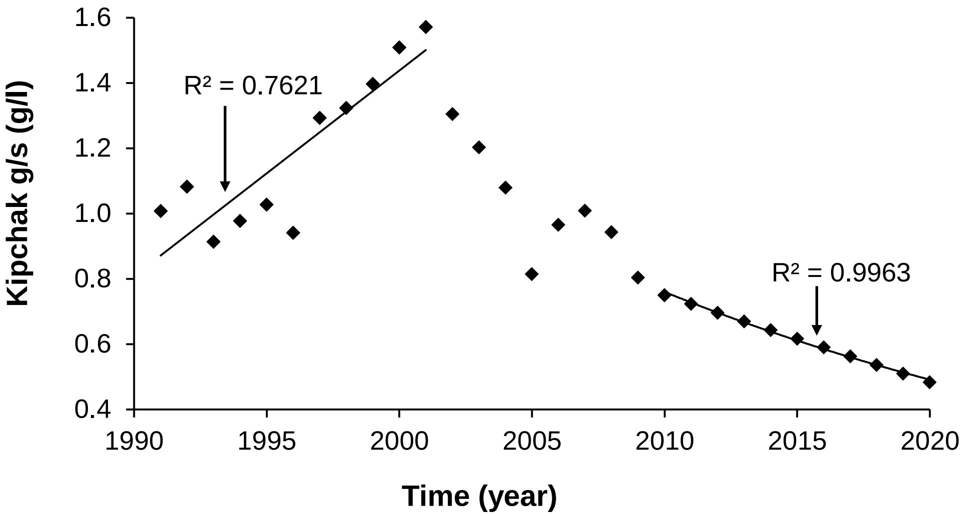

Fig. 6. The Amu Darya river water salinity in Kipchak g/s

possible to pinpoint salt accumulation areas is a need to reclamation of irrigated lands, such as the Dashoguz, Karakalpakstan and Turkmenistan coastal areas. In Fig. 7, the river water salinity was raised linearly (R2 = 0.460) from 1.218 to 1.562 g/ℓ as 1991-2000, and then linearly (R2 = 0.943) reduced from 2001 to 2005 as 1.521-0.879 g/ℓ. Because of these conditions, the estimated mean water salinity will be declined to around 1.106 g/ℓ (e.g., the observed mean water salinity was 1.167 g/ℓ in Table 1). Our prediction shown in Fig. 7, the Amu Darya river water salinity at the Takhiatash g/s will slightly lessen around to 1.104 g/ℓ in 2020.

Samanbay Gauging Station

Reduction of the Aral Sea is one of the world's largest environmental disasters [9, 12]. The Aral Sea exposed dry seabed has been reached from 27,961 to 54,059 miles as 1960-2010 [7]. Consequently, each year the wind spreads around 45 mln metric tons of salty and contaminated dust into the atmosphere; dust plumes can be 400 km long and 40 km wide, while the range of dust storms can reach 300 km, respectively [2]. Because the altered atmosphere was salty and dust spoiled, and was polluted, as resulted in serious public health problems at the Aral Sea region [16].

In 1960, the Amu Darya river water salinity at the Samanbay g/s was 0.5 g/ℓ, and then reached to 1.02 g/ℓ in 1990 [5]. The average water salinity of the river in the Samanbay g/s had linearly (R^2 = 0.679) raised from 1.126 g/ℓ in 1991 to 1.46 g/ℓ in 2000, and then fallen from 2001-2010 to 1.662-1.002 g/ℓ (Fig. 8). The Amu Darya river water inflow and outflow at the Samanbay g/s was nonstandard, it has been caused the water salinity variable. Therefore, our estimated mean water salinity is 0.905 g/ℓ, which is less than the mean

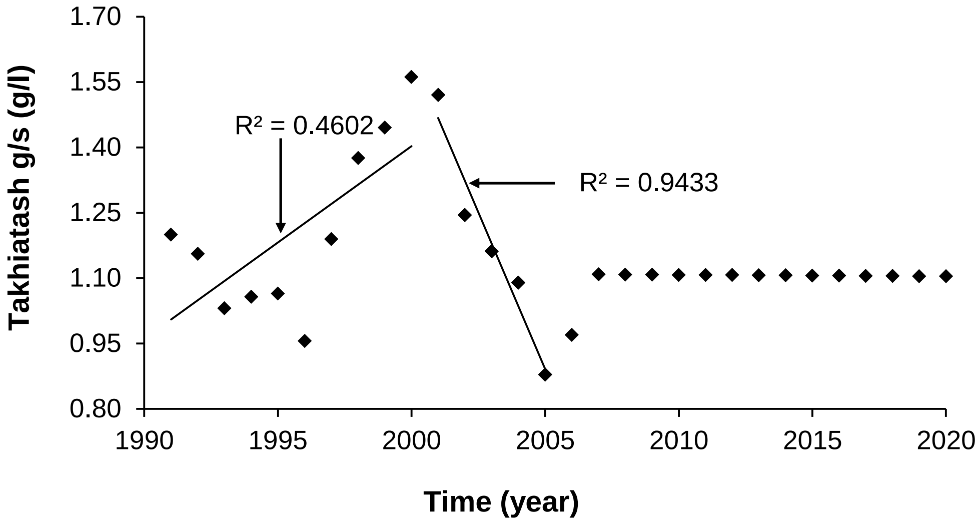

Fig. 7. The water salinity of the Amu Darya in Takhiatash g/s

water salinity result shown in Table 1. However, Fig. 8 verified that the forecast of the river water salinity at the Samanbay g/s will be decreased to around 0.825 g/ℓ by 2020.

Conclusions

The Amu Darya is the largest river in the Aral Sea Basin, is located in Central Asia, and is the water used for agricultural irrigation. The Holt's Linear Trend Forecasts Method was used to predict the Kelif, Kerki, Chardjow, Darganata, Kipchak, Takhiatash, and Samanbay gauging stations among the Amu Darya river water salinity from 2010 to 2020. Consequently, our forecasts method is then applied in the estimation of water salinity.

The Amu Darya River water salinity at the Kelif g/s has been raised from 0.448 g/ℓ in 1997 to 0.469 g/ℓ in 2010. The observed mean water salinity at the Kelif g/s was 0.477 g/ℓ, our 10 years (from 2011 to 2020) assumes suggests that the mean water salinity will increases to around 0.485 g/ℓ. Therefore, our prediction of the river water salinity at the Kelif g/s will be linearly (R^2 = 0.986) increased to around 0.495 in 2020.

The river water salinity at the Kerki g/s was 0.56 g/ℓ in 1960, was 0.7 g/ℓ in 1990, and then fallen to 0.486 g/ℓ in 2010. The water salinity of the river in the Chardjow g/s was exponentially (R^2 = 0.324) decreased from 1991-2010 to 0.823-0.614 g/ℓ. Consequently, our forecast proposes that the river water salinity in Kerki, Chardjow, and Darganata g/s will be declined to approximately 0.483 g/ℓ (the mean was 0.486 g/ℓ), 0.602 g/ℓ (the mean was 0.609 g/ℓ), and 0.668 g/ℓ (the mean was 0.680 g/ℓ) in 2020.

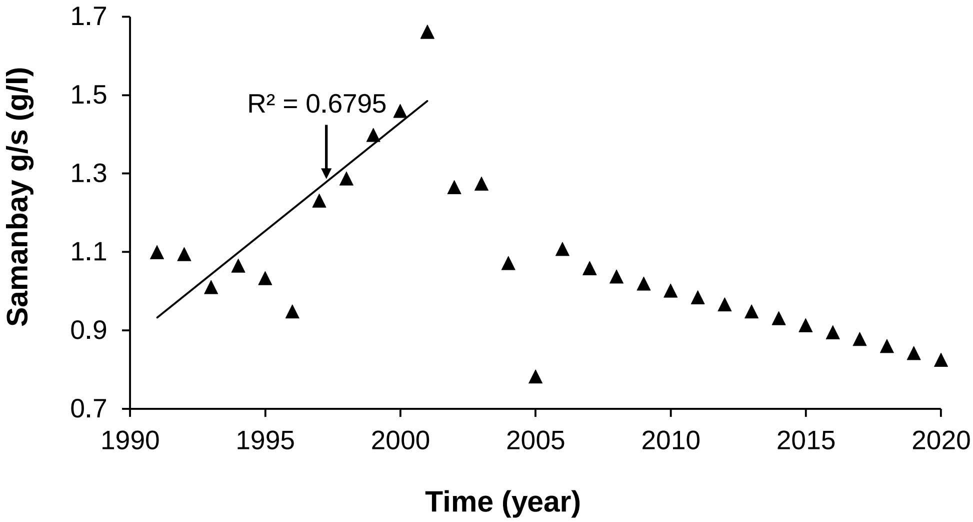

Fig. 8. The Amu Darya water salinity in Samanbay g/s

The river water salinity at the Kipchak g/s was fallen from 1991 to 2010 as 1.008-0.75 g/ℓ. The water salinity of the Amu Darya in the Takhiatash, and Samanbay g/s has been decreased from 1.218, and 1.126 g/ℓ in 1991 to 1.108, and 1.002 g/ℓ in 2010. The estimates suggests that the river water salinity at the Kipchak, Takhiatash, and Samanbay g/s will decreases to approximately 0.484 (the mean was 0.603), 1.104 (the mean was 1.106), and 0.825 g/ℓ (the mean was 0.905) in 2020. Our estimation results were clearly described important issues such as river water salinity will be reduced, suitability useful for irrigation, and water purification technologies in the future.

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