Water Volume and Salinity Forecasts of the Small Aral Sea for the Years 2025

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ABSTRACT The Aral Sea is a saline endorheic basin in Central Asia. From 1960 onwards the lake started to shrink because of the utilization of rivers water for irrigation purposes. Since the irrigation began, massive amounts water has been used. Therefore, the lake divided into two parts in 1987: the Small Aral Sea in the north and the Large Aral Sea in the south. In the Small Aral Sea, the average water salinity increased from 25-130 g/l from 1987 to 2011. From 1999-2011, the water volume of the Small Aral Sea increased from 12.6 to 22.0 km^3. Holt's linear trend forecast method was used to predict the water volume and salinity of the Small Aral Sea from 2010 to 2025. The prediction results indicate that the water volume of the Small Aral Sea will increase to around 22.8 km^3, and salinity of the Small Aral Sea will rise to approximately 190 g/l by 2025.

Key Words : Aral Sea, salinity, irrigation, Holt′s linear trend.

1. Introduction

The Aral Sea is a land-locked lake is located in the semi-arid and desert areas of Central Asia (Fig. 1), and the lake water basin was filled by Amu Darya and Syr Darya Rivers. The initial reason for the lake decline was the fact that the Soviet Government decided the two rivers that fed the Aral Sea, would be diverted to irrigate the desert, in an attempt to grow rice, melons, cereals, and cotton in 1938. This was part of the Soviet plan for cotton, or "white gold", to become a major export. This eventually succeeded, and today Uzbekistan is one of the world's largest exporters of cotton (USDA-Foreign Agriculture Service, 2008).This was done through the construction of thousands of kilometers of irrigation canal sand the diversion of the waters of the Amu Darya and the Syr Darya Rivers for irrigation purposes and thus directly influencing the water discharge into the Aral Sea. The water from there rivers were used by Central Asian States over 6,000 years ago for potable water and for irrigation, during 1960–1990 water withdrawal doubled (Gulnara et al., 2003).

The initially irrigation area was 3.0 mln ha in 1938. It has increased to 4.5 mln ha in 1960, respectively (Bortnik, 1999). The Soviet Union has been profited from exporting cotton fibers. Consequently, the irrigation area has increased from 7 mln ha in 1990 to 7.9 mln ha in 2000 (UNDP, 2007; Bortnik, 1999). Lately, the irrigation area has again increased to 8.5 mln ha in 2007, due to the population in the Aral Sea region had been increased from 14.1 mln in 1960 to 47 mln in 2008 (Viktor, 2011).

The Aral Sea water surface area was 68,000 km^2 (Fig. 2), water level was 53.4 m, water volume was 1,093 km^3 and salinity was 10 g/l in 1960, respectively (CAWATER, 2012; Micklin, 2007). The water volume of the Aral Sea has reduced from 1,093 km^3 in 1960 to 502.7 km^3 in 1984

Fig.1 Aral Sea Basin (Micklin, 2007)

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(Aralgenefund, 2012). The Aral Sea water volume reduction was "formed;" the high evaporation, river runoff and precipitations were changed. As a result shown that the Aral Sea divided into two parts: the Large Aral Sea and the Small Aral Sea in 1987 (Fig. 2). The water volume of the Large Aral Sea was 323.2 km^3 and of the Small Aral Sea was 22.4 km^3 in 1987 (Aralgenefund, 2012). The water volume of the Large Aral Sea has decreased from 323.2 km^3 in 1987 to 70.0 km^3 in 2011 (Alikhanov, 2011). The water volume of the Small Aral Sea has increased from 22.4 km^3 in 1987 to 27 km^3 in 1998, and then decreased to 22 km^3 in 2011, respectively (Micklin, 2007; Alikhanov, 2011; Aralgenefund, 2012). The water salinity of the Small Aral Sea has increased from 25 g/l in 1987 to 270 g/l (maximum) in 2011 (Alikhanov, 2011).

The water surface area of the Small Aral Sea was 2,810 km^2, and of the Large Aral Sea was 37,130 km^2 in 1987 (Aralgenefund, 2012). The water surface area of the Small Aral Sea has increased to 3,240 km^2, of the Large Aral Sea has decreased to 25,750 km^2 in 1998 (Aralgenefund, 2012). Water surface area of the Small Aral Sea decreased from 3,240 km^2 in 1998 to 2,990 km^2 in 2006 (Aralgenefund, 2012), and increased to 3,300 km^3 in 2008 (Fig. 2; ENS, 2008).

The drying of the Aral Sea has caused more extreme air temperatures (e.g., hotter summers and colder winters), which have reduced the amount of precipitation. The precipitation was 9.4 km^3 in 1960 (Micklin, 2007). As a result, the precipitation has reduced to 3.5 km^3 in 1984 (Aralgenefund, 2012). After separation of the lake, during 1986 to 2000 the precipitation of the Small Aral Sea was almost null (CAWATER, 2012). The water height of the Aral Sea has dropped to 49 m in 1975. The water level has dropped by 40.8 m of the Small Aral Sea and by 40.1 m of the Large Aral Sea in 1987 (Aralgenefund, 2012).

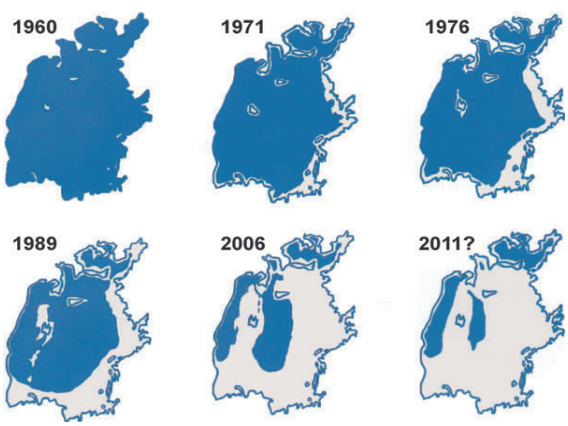

Fig.2 Dry-out dynamics of the Aral Sea (Micklin, 2007). The total water surface area was 68,000 km² in 1960, and then declined to 11,600 km² in 2010 (83% lost)

The dry seabed of the sea has reached from 4.5 mln ha in 1960 to 8.7 mln ha in 2010 (Viktor, 2011). Desiccation of the Aral Sea water level was losing fish resources (20 fish species in 1960, reduced from11 fish species in 1970 to 1 species in 1990) and local climate change, respectively (Alikhanov, 2011; Forkutsa, 2006).

The main objective of this study are (i) to analyze the residual value of the Small Aral Sea water volume and salinity between 1987 and 2011; (ii) to predict future the Small Aral Sea water volume and salinity increases from 2010 to 2025.

2. Materials and Methods

1. Study area

The Aral Sea is located in the heart of Central Asia. The Aral Sea basin is covered by Uzbekistan, Tajikistan, Kazakhstan, Turkmenistan, Kyrgyzstan, Afghanistan, Iran, and near the Caspian Sea (Fig. 1), and has a 1,549,000 km^2 closed basin with catchment mostly covered by Kara Kum and Kyzyl Kum deserts, and has virtually no forests. Previously one of the four largest lakes in the world, the Aral Sea has been decreasing since the 1960s after the Amu Darya and Syr Darya Rivers that fed it were diverted by Soviet Union irrigation projects for cotton and rice. The rivers water runoff from the Tien Shan and the Pamir Mountains. The average inflows from the Amu Darya and the Syr Darya Rivers once were 72 km^3 and 37 km^3 per year, but now decreased to a mere trickle because of large-scale irrigation water withdrawals, high water consumption during water distribution, conveyance and field applications. The Amu Darya River water flow into the Large Aral Sea, and has a mean annual flow of about 70-80 km^3/year, is 2,540 km long, with a basin area of more than 300,000 km^2. The Syr Darya River runs in the north of the sea basin. The annual flow is half of the Amu Darya, is 2,790 km long, with a basin area of almost 300,000 km^2.

The average annual precipitation is 100 mm, and has a typical continental climate. Summer is long, arid, hot and average temperature is approximately 35℃. Autumn is a cool and rainy (18℃), and winter is cold and snowy, and average temperature around -8℃, and winter temperatures fall to -20℃.

2. Data Collection

We have collected the observation data of the Small Aral Sea evaporation, precipitation, water surface area, water level, water volume, Syr Darya River runoff (including surface water and groundwater), and salinity from 1987 to 2011 given by Micklin (2007), Aralgenefund (2012), Bjorklund (1999), Zavialov et al. (2003), Oroud (1999), UNDP (2007 and 2008), CAWATER (2012), Viktor (2011), Alikhanov (2011), and UNESCO (2000).

The statistical analyzes were the maximum, minimum, mean, coefficient of determination (R^2) and standard deviation of the Small Aral Sea water volume, Syr Darya, precipitation, evaporation, water surface area, salinity and water level from 1987 to 2011 as a result shown in Table 1.

Table 1 demonstrates that the mean water volume of the Small Aral Sea was 21.2 km^3. The coefficient of determination of the water volume was 0.118. The Syr Darya River flow into the Aral Sea was 21.3 km^3 in 1960 (Aralgenefund, 2012). During 1961-1987 the river runoff into Aral Sea is approximately null, which caused the Aral Sea separated into two parts through the heavy usage of river water for irrigation areas. In 1991, after the collapse of the Soviet Union, the Central Asian countries become independent, it has been consideration to the Aral Sea seriously, and then during 1991-1998, the river runoff into the Small Lake has increased from 3.2 km^3 in 1992 to 7.6 km^3 in 1998, which causes the water volume of the lake has increased from 20.3 km^3 in 1992 to 27.0 km^3 in 1998. However, river runoff into the Small Aral Sea has decreased to 2.0 km^3 in 2011 (R^2 = 0.107). The precipitation is less about 0.2 – 0.7 km^3 (min-max). The evaporation has silently fallen from 2.6 km^3 in 1987 to 2.0 km^3 in 2011 (the mean is 2.6 km^3). The Small Aral Sea water surface area was 2,870 km^2 in 1987, it has fell from 3,240 km^2 in 1998 to 2,700 km^2 in 2011. The mean water level of the lake was 40.0 m. The lake average water salinity was 25 g/l in 1987, and increased to 130 g/l (R^2 = 0.959) by 2011.

3. Forecasting Method

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

$$a_t=\alpha X_t+(1-\alpha)(a_{t-1}+b_{t-1}) \quad (1)$$

$$b_t=\beta(a_t-a_{t-1})+(1-\beta)\,b_{t-1} \quad (2)$$

Here α and β are smoothing constants that are each between zero and one, a value between 0.3 and 0.5 was used. Again, a_t gives the y-intercept (or level) 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 $X_{t+k}=a_t+kb_t$. Holt's Linear Trend was used to assess the predictive power of the water volume and salinity of the Small Aral Sea. The software NCSS 8 for Windows XP (Version 8.0.12, NCSS LLC., Utah, USA; Hintze, 2012) was used for forecasting time series.

3. Results and Discussion

1. Water Volume

We have forecasted of the Small Aral Sea water volume used by Holt's Linear Trend Forecast Method. The value of the smoothing constant Alpha and Beta were used to generate the forecasts. The forecast summary of the suggested mean water volume was 21.176, the numbers of rows were 25 years (from 1987 to 2011), Mean Square Error (MSE) was 7.674543, Mean Error was 1.972288, Mean Percent Error was 10.34477, Alpha was 0.1095899, Beta was 0.09547862, Intercept (a_t) was 19.92944, Slope (b_t) was 0.07324994, and specify the number of forecasts to be generated 14 years of the Small Aral Sea. Consequently, the actual, forecasts and residuals values were shown in Figs. 3 and 4, and Table 2.

Table 1 Descriptive Statistics of the Small Aral Sea from 1987 to 2011

	Syr Darya (km^3)	Evaporation (km^3)	Volume (km^3)	Precipitation (km^3)	Salinity (g/l)	Level (m)	Surface area (1000 km^2)
Time (Year)	17	17	25	17	17	25	17
Minimum	1.0	1.9	12.6	0.2	25.0	36.8	2.5
Maximum	9.9	4.8	27.0	0.7	130.0	42.5	3.2
Mean	4.1	2.6	21.2	0.5	78.7	40.0	2.8
Std. Deviation	2.6	0.86795	2.6676	0.15733	37.59573	1.26205	0.18026
R^2	0.107	0.048	0.118	0.125	0.959	0.417	0.051

Fig. 3 showed that the actual water volume of the Small Aral Sea was 22.4 km^3 in 1987. The Berg Bay dam was constructed very fast and provisionally in the eastern coast of the Small Aral Sea, it has purposed to stop that deleterious dynamics in 1992. Unfortunately, the dam was destroyed the next spring by high tides and storms in 1993, because the Berg Bay was made by soil, and around 1 m high, therefore, the water volume has been decreased to18.4 km^3 in 1993. The large dam was constructed again

Table 2 Holt's Linear Trend reports of water volume and salinity in the Small Aral Sea

Year	Water volume (km^3)			Water salinity (g/l)		
	Forecasts	Actual	Residuals	Forecasts	Actual	Residuals
1987	21.12	22.4	1.27	25.59	25.0	-0.59
1988	21.37	21.8	0.43	27.95	28.0	0.049
1989	21.48	20.3	-1.18	29.33	31.0	1.669
1990	21.41	21.8	0.39	32.39	33.0	0.61
1991	21.51	20.9	-0.61	35.15	34.0	-1.15
1992	21.51	20.3	-1.19	36.39	35.0	-1.39
1993	21.41	18.4	-3.01	36.84	36.5	-0.34
1994	21.08	20.1	-0.98	37.71	37.2	-0.46
1995	20.97	21.8	0.82	38.29	38.0	-0.29
1996	21.07	21.8	0.72	38.83	39.0	0.16
1997	21.17	22.7	1.53	39.71	40.5	0.79
1998	21.36	27.0	5.63	41.29	42.0	0.71
1999	22.07	12.6	-9.47	43.17	50.3	7.12
2000	21.02	19.2	-1.82	51.96	54.4	2.49
2001	20.81	17.9	-2.89	59.35	58.6	-0.75
2002	20.41	18.4	-2.01	64.59	82.0	17.41
2003	20.12	19.8	-0.31	88.08	86.0	-2.08
2004	19.99	22.4	2.41	99.81	91.0	-8.81
2005	20.21	22.5	2.29	103.66	98.0	-5.66
2006	20.42	24.0	3.57	106.58	109.0	2.41
2007	20.82	23.2	2.38	115.12	112.0	-3.11
2008	21.12	23.0	1.89	119.12	117.0	-2.12
2009	21.36	22.8	1.43	122.67	120.0	-2.67
2010	21.58	22.3	0.71	124.66	125.0	0.33
2011	21.73	22.0	0.26	128.47	130.0	1.52
2012	21.83			133.66		
2013	21.91			138.01		
2014	21.98			142.35		
2015	22.05			146.69		
2016	22.13			151.04		
2017	22.21			155.38		
2018	22.27			159.73		
2019	22.35			164.07		
2020	22.42			168.42		
2021	22.49			172.76		
2022	22.56			177.11		
2023	22.63			181.45		
2024	22.71			185.81		
2025	22.78			190.14		

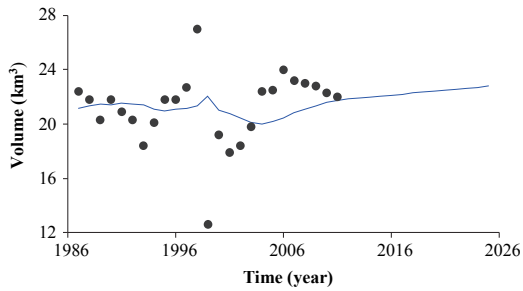

Fig.3 Plot of water volume in the Small Aral Sea

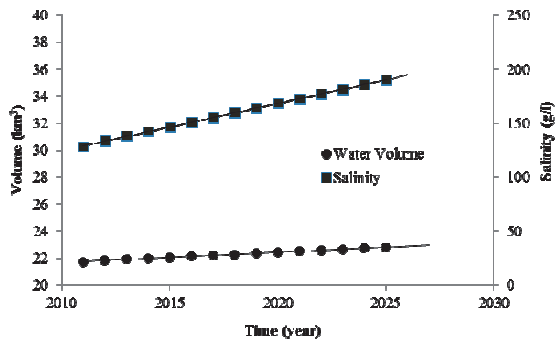

Fig.4 Forecasted of water volume and salinity in the Small Aral Sea

Fig.5 The Kok-Aral Dam: a). The Kok-Aral Dam was allowing the North Aral Sea to fill with water from the Syr Darya River (JAXA, 2007); b). A portion of the Kok-Aral Dam (ENS, 2008)

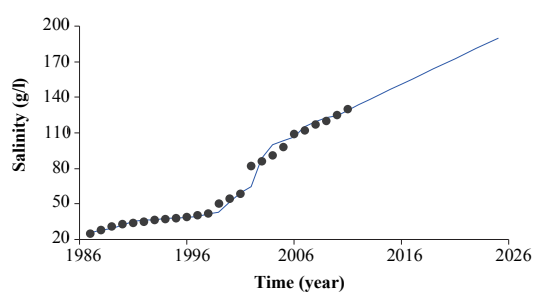

Fig.6 Water salinity plot of the Small Aral Sea

in 1997. It forced the Syr Darya River runoff into the Small Aral Sea. The hydrological budget turned very positive, which led to an increase in the water level to about 42 m and water surface area of 3,240 km^2 in 2008. Consequently, the water volume of the lake increased to 27 km^3 in 1998, since the water volume changes were precipitation (increased from 0.2 km^3 in 1995 to 0.7 km^3 in 1998), and runoff (increased from 1.6 km^3 in 1995 to 7.6 km^3 in 1998) has been increased, respectively (Aralgenefund, 2012). Subsequently on 21 April 1999, after a strong storm and high waves, the dam broke and the water level reduced to 38.8 m, water volume fell to 12.6 km^3 in 1999 (ENS, 2008). Since 2000-2005, several new canal systems have been constructed to improve the efficiency of the water budget and management in the irrigation areas and to construct a new and better dam. The Kok-Aral Dam was constructed in 2005 (Fig. 5a.b; ENS, 2008). Accordingly, this new dam keeps the water level of the Small Aral Sea more stable. The Aral Sea Region has a new basis for efficient and sound reliable water use, and distribution for the agricultural systems as well as for fish ponds. This can improved the living standards of the inhabitants in the Aral Sea region. As a result, the water volume of the Small Aral Sea has increased from 19.8 km^3 in 2003 to 22.0 km^3 in 2011 (Alikhanov, 2011).

Table 2 shows the residual value of the Small Aral Sea water volume. The forecasted water volumes were 21.4 km^3 in 1993, and 22.07 km^3 in 1999, which were higher than the results for 1993 and 1999 actual values of the Small Aral Sea from Table 2.

The y-intercept value was the time period. Hence, to forecast for time period 26 (the next period after the current period, or after 2011) we have used 19.92944 + 26(0.07324994) = 21.83393. Fig. 4 and Table 2 presented that the Small Aral Sea water volume was 21.83393 in 2012. The prediction of the Small Aral Sea water volume will increases to approximately 22.8 km^3 by 2025.

2. Salinity

Holt's Linear Trend Forecasts Method was used to predict the water salinity of the Small Aral Sea. The result proposes the mean water salinity was 66.104, the numbers of rows were 25 years (from 1987 to 2011), Mean Square Error (MSE) was 20.49586, Mean Error was 2.589878, Mean Percent Error was 3.750818, Alpha was 0.5533565, Beta was 0.8513417, Intercept (a_t) was 20.70151, Slope (b_t) was 4.344717, and specify the number of forecasts to be generated 14 years of the Small Aral Sea. As a result, the actual, forecasts and residuals values were shown in Table 2, and Figs. 4, and 6.

The Aral Sea water salinity was 10 g/l in 1960 (Aralgenefund, 2012), and it was increased to 25 g/l in 1987 (Alikhanov, 2011). After separation of the lake, the Small Aral Sea water salinity increased from 25 g/l in 1987 to 130 g/l in 2011 (Fig. 6). Subsequently, the reasons of increase in water salinity include the changes of the water volume, water surface area, precipitation and river runoff, and evaporation can produce corresponding salinity which shows that they are consistent with resulting data established in Fig. 6.

Fig. 6 shows that the estimated value of Small Aral Sea water salinity was 25.6 g/l in 1987, and it has been increased to 128.5 g/l in 2011, which is higher than the result for 1987, and is less than the result for 2011 presented in Table 2. This study results, our forecasts of the Small Aral Sea water salinity will be increased to 190 g/l in 2025 exhibited in Figs. 4 and 6.

4. Conclusions

The Aral Sea is a saline closed basin in Central Asia. The initial reason for the Aral's decline was the fact that the Soviet Union undertook a major water diversion project on the arid plains of Kazakhstan, Uzbekistan, and Turkmenistan in 1960. The region's two major rivers, fed by snowmelt and precipitation in faraway mountains, were used to transform the desert into farms for cotton and other crops. Before the project, the Syr Darya and the Amu Darya rivers flowed down from the mountains, cut northwest through the Kyzyl Kum Desert, and finally pooled together in the lowest part of the basin. The lake they made, the Aral Sea was once the fourth largest in the world. Consequently, the Aral Sea separated into two parts: the Small Aral Sea and the Large Aral Sea in 1987. The Small Sea water volume increased from 12.6 km^3 in 1999 to 22.0 km^3 in 2011 and salinity rose from 25 g/l in 1987 to 130 g/l in 2011. We have used the Holt's Linear Trend Forecasts Method to predict the water volume and salinity of the Small Aral Sea from 2010 to 2025. Our prediction was suggested that the Small Aral Sea salinity will be increased to around 190 g/l and water volume will rise to approximately 22.8 km^3 by 2025.

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