ОБЗОРНАЯ СТАТЬЯ

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SHRINKING LAKES IN CENTRAL ASIA AND ENVIRONMENT CHANGES

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Abstract. Central Asia is rich in many continental lakes. The Aral Sea belonged to the category of large water reservoirs on Earth. Due to the unscientific and uncontrolled extraction of water for irrigation in Central Asia and Kazakhstan, which began in the 50-60s of last century, the water flow has shrunk in the Aral Sea, and in the 1980s has ceased. As a result of anthropogenic impacts on the basin ecosystem has led to negative consequences: soil salinization, desertification process and environmental changes. The article describes the change in the water balance in the Aral Sea basin related to anthropogenic impact, leading to negative environmental effects.

Key words: lakes, Aral Sea, water balance, Central Asia, desertification.

INTRODUCTION

There are thousands foothill lakes in Central Asia. The largest of the lakes is the Caspian and Aral Seas, Balkhash, Alakol Ebinur, Lobnur, which are included in the list of the largest inland water reservoirs on Earth. The lakes are like a «crown of diamonds» in the steppes and deserts, surrounded by mountains and they consists of linked and interacting system, which softens the arid or dry conditions surrounding areas. The Aral Sea is located amid the great deserts of Central Asia (figure 1). Its drainage basin covers 1.8 million square kilometers within seven nations: Uzbekistan, Turkmenistan, Kazakhstan, Afghanistan, Tajikistan, and Iran. Only Kazakhstan and Uzbekistan are riparian on the sea proper, with each possessing an approximately equal length of shoreline.

Figure 1 – Aral Sea basin [1]

The entire Aral coastline within Uzbekistan lies within that nation's Karakalpakstan Republic [1]. A terminal lake, it has surface inflow but no surface outflow. Therefore, the balance between inflows from two rivers, the Amudarya and Syrdarya and net evaporation (evaporation from its surface minus precipitation on it) fundamentally determine its level. Net groundwater inflow, estimated at –1.3 to 3.4 km^3 $year^{-1}$ has been considered an inconsequential part of the water balance [2]. Although this part of the water balance has become a more important factor in the past several decades as surface inflow diminished.

At the beginning of the irrigation expansion program a number of scientists showed concern about the future of the Aral Sea basin, which was suffering a critical reduction of water inflow.

Owing to the sea's shrinkage, climate has changed in a band up to 100 km wide along the former shoreline in Kazakhstan and Uzbekistan [1, 3-4]. Maritime conditions have been replaced by more continental and desertic regimes. Summers have warmed and winters cooled, spring frosts are later and fall frosts earlier, humidity is lower, and the growing season shorter. Uzbekistani climatological experts also believe that the increase in the levels of salt and dust in the atmosphere are reducing surface radiation and thereby photosynthetic activity, as well as increasing the acidity of precipitation [5].

The population living in the so-called ecological disaster zone around the sea suffers acute health problems. Some of these are direct consequences of the sea's recession (e.g., respiratory and digestive afflictions and possibly cancer from inhalation and ingestion of blowing salt and dust and poorer diets from the loss of Aral fish as a major food source). Other serious health-related problems result from environmental pollution associated with the heavy use of toxic chemicals (e.g., pesticides and defoliants for cotton) in irrigated agriculture, mainly during the Soviet era. Nevertheless, the most serious health issues are directly related to Third World medical, health, nutrition, and hygienic conditions and practices. Bacterial contamination of drinking water is pervasive and has led to very high rates of typhoid, paratyphoid, viral hepatitis, and dysentery. Tuberculosis is prevalent as is anemia, particularly in pregnant woman. Liver and kidney ailments are widespread; the latter is probably closely related to the excessively high salt content of much of the drinking water. Surveys conducted in the mid to late 1980s showed that rates of diseases such as cancer of the esophagus, tuberculosis, and various intestinal disorders had grown significantly compared to a decade earlier [6]. The infant mortality rate, a basic indicator of general health conditions, rose from an average of 45/1000 live births in 1965 to 72/1000 in 1986, with the rate in several districts adjacent to the former seashore ranging from 80 to over 100/1000. These are 3–4 times the national level in the former Soviet Union and 7–10 times that of the United States. Although efforts have been made in the post-Soviet period to improve health conditions here, there is little evidence these rates have declined substantially [7].

MATERIALS AND METHODS

Lakes system are formed in the last 100 thousand years, and it has variable characteristics such as water levels and salinity, biological productivity, etc. These characteristics mainly depends on the natural climate variations: precipitation, evaporation and ice deposits.

The system began to change under the influence of human activity about 1000 years ago. Despite the man-made activities, high population and widespread agriculture in the 10-13 centuries AD, the water level of the lake and its general condition mainly dependent on natural conditions. However, over the last 50 years, the stability of the lakes was deeply disturbed by inefficient use of water for irrigation, as a result the Aral Sea were dried.

The research was conducted in lakes system of Central Asia and Kazakhstan, in particular the Aral Sea basin. According to research of [8], analyzed and reviewed a necessary materials related to water balance, ecological and human consequences, as well as environmental problems in the region.

RESULTS AND DISCUSSION

Changing of water balance and flow reduction for the Aral Sea

From the mid-eighteenth century until the 1960s, sea level variations were less than 4.5 m [9]. Instrumental observation began in 1911. From then until the early 1960s, the sea's water balance was remarkably stable with annual inflow and net evaporation never far apart. The average of each of these water balance components was near 56 km^3 during this period, with net evaporation consisting of evaporation of 66 km^3 from the sea's surface (estimated by both theoretical and empirical formulae) minus precipitation on the sea's surface (calculated from measurements at shore and island stations) of 9 km^3 (figure 2) [1-2].

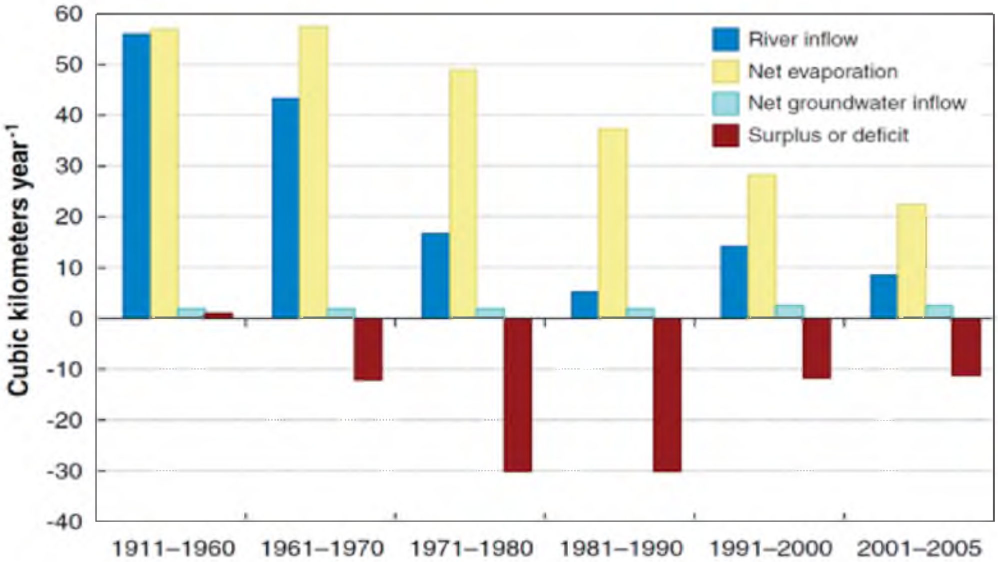

Figure 2 – Average annual water balance for the Aral Sea (1911–2005).River inflow: flow of Syrdarya and Amudarya to Aral Sea; net evaporation: evaporation from sea surface minus precipitation on it; net groundwater inflow: groundwater flow to sea minus flow from sea; surplus or deficit: (inflow to sea + net groundwater inflow) – net evaporation [1-2, 10]

Hence, the water balance was in long-term equilibrium with a maximum lake level variation of less than one meter. At slightly more than 67,000 km^2, the Aral Sea, according to area, was the world's fourth largest inland water body in 1960 [3]. As a brackish lake with salinity averaging near 10 g/l, which is one-third less than that found in the ocean, it was inhabited chiefly by fresh-water fish species [1]. The sea supported a major fishery and functioned as a key regional transportation route. The extensive deltas of the Syrdarya and Amudarya rivers sustained a diversity of flora and fauna. They also supported irrigated agriculture, animal husbandry, hunting and trapping, fishing, and harvesting of reeds, which served as fodder for livestock as well as building materials.

The water balance, morphology, and ecology of the Aral Sea have changed dramatically since the early 1960s. The sea has steadily shrunk and salinized (table 1) [1]. The dramatic drop in river inflow for the period after 1960 is clearly shown on figure 2. For the 1960s, discharge to the sea averaged 43 km^3 $year^{-1}$ and net groundwater inflow averaged perhaps 2.5 km^3 $year^{-1}$, whereas net evaporation was 57 km^3 $year^{-1}$, giving a deficit of

12 km^3 year^{-1}. The difference between river inflow and net evaporation was particularly pronounced during the 1970s and 1980s, with water balance deficits for both periods above 30 km^3 year^{-1}. Consequently, the sea dropped especially rapidly over these two decades. Reportedly, the Syrdarya provided no flow to the Aral from 1974 –86 and the Amudarya provided minimal or no flow for 1982–83, 1985–86, and in 1989 [1, 11].

In 1960 the water flow from the Amudarya and Syrdarya Rivers, which represented the major input for the Aral Sea, was about 55-60 km^3 [12]. Five decades later during 2006-2010 the water volume discharged had almost ceased and was only 4.1 km^3 [8].

The water balance for Aral Sea substantially improved during the 1990s owing to more precipitation in the flow generating mountains of the Aral Sea Basin and some reduction in water withdrawals for irrigation (12 % between 1980 and 1995). River discharge to the sea, averaging approximately 14 km^3 year^{-1}, and a significant reduction in net evaporation reduced the water balance deficit to approximately 12 km^3 year^{-1} [1]. Average annual inflow to the Aral Sea for 1999 through 2001 was near 5 km^3, with nearly 90 % provided by the Syrdarya river. For the period 2001–2005, inflow to the sea averaged approximately 9 km^3 and net groundwater inflow averaged perhaps 2.5 km^3, with net evaporation of approximately 22 km^3, giving a deficit around 11 km^3 [1].

According to [13] since 1960 the sea level declined substantially with a 53 % decrease in surface area and 70 % decrease in volume. In 1960 the water volume of the Aral Sea was 1093.0 km^3, in 1986 it decreased more than half 448.00 km^3, continuing decreasing to 105 km^3 in 2009. In 1960 the Aral Sea area was 67,500 km^2 [8], while in 2009 the water surface occupied the area of 13,500 km^2. In 1987 the fourth biggest inland water body in the world was divided into two parts: northern Small Aral, and southern Big Aral (the latter in 2009 had separated into deep Western and shallow Eastern parts). The Syrdarya flows into the former and the Amudarya into the latter. Between 1960 and January 2006, the level of the Small Aral fell by 13 m and the Large Aral fell by 23 m (table 1).

During most of the year, the flow is much less and it often entirely ceases. The area of both seas taken together diminished by 74 % and the volume by 90 % [1].

Efforts to partially restore/preserve the Small Aral Sea are underway. Thereby, in 2005, thirteen km length dike was constructed blocking inflow of Syrdarya River water into the Big Aral Sea in order to preserve at least the Small Aral. Already, the dike discharge gates have been opened and flow again allowed to the Large Aral. The level of the Small Aral will be maintained at 42–m, freshening the water body and improving its ecological condition as well as fishery prospects [1].

Ecological and human consequences

The mainly human-induced desiccation of the Aral Sea and flow reduction, salinization, and pollution of its influent rivers has had severe negative effects [14-15]. Besides the consequences for the sea proper, a zone around the water body of several hundred thousand square kilometers with a population of several million has also been damaged [16]. The Republic of Karakalpakstan in Uzbekistan and portions of Kyzylorda region in Kazakhstan has suffered the most harm. Turkmenistan, although not abutting on the sea, has one Oblast, Dashauz, that has been substantially impacted [1].

The rich and diverse ecosystems of the extensive Amudarya delta, primarily located in the Karakalpak Republic of Uzbekistan, have suffered considerable harm [3, 15].

The Syrdarya delta in Kazakhstan has endured lesser, but still substantial, damage. Greatly reduced river flows

Table 1 – Hydrological and salinity characteristics of the Aral Sea, 1960–2011 (Micklin, 2007)

Year	Level m asl	Area km²	% 1960	Volume km³	% 1960	Average salinity g/l	% 1960
1960 (Whole Aral Sea)[a]	53.4	67,499	100	1089	100	10	100
Large Aral Sea	53.4	61,381	100	1007	100	10	100
Small Aral Sea	53.4	6118	100	82	100	10	100
1971 (Whole Aral Sea)[a]	51.1	60,200	89	925	85	12	120
1976 (Whole Aral Sea)[a]	48.3	55,700	83	763	70	14	140
1989 (Whole Aral Sea)[b]		39,734	59	364	33		
Large Aral Sea	39.1	36,930	60	341	34	30	300
Small Aral Sea	40.2	2804	46	23	28	30	300
2006 (Whole Aral Sea)[b]		17,382	26	108	10		
Large Aral Sea	30.0	14,325	23	81	8	East Sea >100 West Sea 70-80	100 700-800
Small Aral Sea [d]	40.5	3057	50	21	26	12	120
2011 (whole Aral Sea)		12.130	18	90	8		
Large Aral Sea [c]	28.3	8550	14	62	6	> 100	> 1000
Small Aral Sea [d]	42.0	3258	53	27	33	~10	100

Notice: [a] Annual average

[b] On January 1.

[c] The Sea will have divided into a western and eastern part

[d] After implementation of north Aral project in 2005 [2, 13]

through the deltas, the virtual elimination of spring floods in them (owing both to reduced river flow and construction of upstream storage reservoirs), and declining groundwater levels caused by the falling level of the Aral Sea have led to spreading and intensifying desertification. Halophytes and xerophytes are rapidly replacing endemic vegetation communities [17]. In some places, salts have accumulated on the surface forming solonchak (salt pans) where practically nothing will grow. Expanses of unique tugay vegetation complexes that formerly stretched along all the main rivers and distributary channels have been particularly hard hit. According to [17] tugay covered 100,000 hectares in the Amudarya delta in 1950, but shrank to only 20,000 to 30,000 hectares by 1999 [18].

Desiccation of River deltas and irrigation in the basin

Desiccation of the deltas has significantly diminished the area of lakes, wetlands, and their associated reed communities. Between 1960 and 1980, the area of lakes in the Amudarya delta is estimated to have decreased from 49,000 to 8000 km² [19]. The area of reeds in the delta (as much as 500,000 hectares in 1965) also declined dramatically by the mid-1980s [20]. This has resulted in serious ecological consequences as these zones provide prime habitat for a variety of permanent and migratory waterfowl, a number of which are endangered [3]. Diminution of the aggregate water surface area coupled with increasing pollution of the remaining water bodies (primarily from irrigation runoff containing salts, fertilizers, pesticides, herbicides, and cotton defoliants) adversely affected aquatic bird populations. Since the late 1980s, significant efforts have been made to restore wetlands, improve habitat conditions, and reduce pollution [19].

Irrigated agriculture in the deltas of the Amudarya and Syrdarya rivers has suffered from an inadequacy of water as inflow to the deltas has decreased owing to heavy upstream consumptive use for irrigation. Additionally, water that does reach the deltas has elevated salinity from the leaching of salts caused by repeated usage in the middle and upper courses of the rivers [1, 21]. At times over 2 g/l, these saline flows have lowered crop yields and, in conjunction with inadequate drainage of irrigated fields, promoted secondary soil salinization. Animal husbandry, both in the deltas and desert regions adjacent to the Aral Sea, has been damaged by reduction of area and declining productivity of pastures resulting from desertification, dropping groundwater levels, and replacement of natural vegetation suitable for grazing by inedible species [1].

Dust, sand and salt storms in the region

Strong winds blow sand, salt, and dust from the dried bottom of the Aral Sea, large portions of which are a barren desert, onto surrounding lands. Since the mid -1970s, satellite images have revealed major salt/dust plumes extending as far as 500 km downwind that drop dust and salt over a considerable area adjacent to the sea in Uzbekistan, Kazakhstan, and to a lesser degree Turkmenistan [3-4, 15, 22]. Although dust/salt storms affect the entire zone surrounding the Aral, most of the major storms occur with north and northeast winds, which most seriously impact the Usturt Plateau to the sea's west and the Amudarya delta at the south end of the water body [2]. The latter is the most densely settled as well as economically and ecologically important region around the sea [4], after analyzing estimates of the total deflated material (ranging from 13 million to as high as 231 million metric tons per year) that were made in the 1980s, concluded that the most probable figure was from 40 to 150 million tons. Salts in dry and aerosol forms, the most harmful of which include sodium bicarbonate, sodium chloride, and sodium sulfate, settle on natural vegetation and crops, particularly in the Amudarya delta [23]. In some cases, plants are killed outright, but more commonly, their growth (and for crops, yields) is substantially reduced. The salt and dust also have ill effects on wild and domestic animals by directly harming them and reducing their food supply [20].

Local health experts also consider airborne salt and dust a factor contributing to high levels of respiratory illnesses and impairments, eye problems, and throat and esophageal cancer in the near-Aral region [24-25]. A field work by a British-led group indicates that salt and dust blowing from the dried bottom (and likely from irrigated farmland in regions adjacent to the Aral Sea) is laced with pesticides and heavy metals, which would enhance the negative impacts on humans and other animals.

CONCLUSIONS

The entire lake system is threatened by catastrophic destruction, the use of water resources of all water reservoirs in Central Asia and Kazakhstan increased.

Human activities have changed the level and volume of the Aral Sea. Syrdarya and Amudarya rivers regulation provoke soil degradation and contributed to the development of intensive deflation and desertification processes. The anthropogenic causes are playing major role in environmental changes of the region.

Dried bottom of the Aral Sea became active and main powerful sources for aeolian dust/sand/salt storms. The powerful source of aerosols have a great effect on the climate and environmental changes in Central Asia and Kazakhstan.

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ТҮЙІН

Исанова Г.Т., Солтанаева А.М., Устемирова А.М.

ОРТА АЗИЯДАҒЫ КӨЛДЕРДІҢ ТАРТЫЛУЫ ЖӘНЕ ҚОРШАҒАН ОРТАНЫҢ ӨЗГЕРУІ

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Орта Азия көптеген континенттік көлдерге бай. Арал теңізі Жер шарындағы ірі су қорларының бірі болып табылған. Өткен ғасырдың 50-60 жылдары басталған Орта Азия мен Қазақстанның жерлерін суару кезінде суды ғылыми негізсіз және бақылаусыз қолдануынан Арал теңізіне келетін су ағысы күрт азайып, 1980 жылдары мүлдем тоқтап қалды. Алаптың экожүйесіне антропогендік әсерлерідің нәтижесінде топырақтың тұздануы, аймақтың шөлге айналуы және қоршаған ортаның өзгеруі сияқты жағымсыз жағдайлар орын алды. Мақалада антропогендік әсерлердің нәтижесінде Арал теңізі алабы су балансының өзгеруі және олардың жағымсыз экологиялық салдары қарастырылған.

Түйінді сөздер: көлдер, Арал теңізі, су балансы, Орталық Азия, шөлейттену.

РЕЗЮМЕ

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ВЫСЫХАНИЕ ОЗЕР В ЦЕНТРАЛЬНОЙ АЗИИ И ИЗМЕНЕНИЕ ОКРУЖАЮЩЕЙ СРЕДЫ

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Средняя Азия богата многочисленными континентальными озерами. Аральское море относилось к разряду крупных резервуаров воды на Земле. Из-за научно необоснованного и неконтролируемого забора воды на орошение земель в Средней Азии и Казахстане, начавшегося в 50-60-е годы прошлого века, сток воды в Арал резко уменьшился, а в 1980-е годы и прекратился вовсе. В результате антропогенное воздействие на экосистему бассейна привело к негативным последствиям: произошло засоление почвы, опустынивание территории и изменение окружающей среды. В статье рассмотрены изменения водного баланса в бассейне Аральского моря, связанные с антропогенным воздействием, приведшим к негативным экологическим последствиям.

Ключевые слова: озеро, Аральское море, водный баланс, Центральная Азия, опустынивание.