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# HUMAN IMPACT ON WATER REGIME OF THE SHARDARA WATER RESERVOIR

**Abstract.** Under rapid population growth, food demand and other human activities, water availability is predominantly becoming a common problem worldwide. This study considers Shardara water reservoir located on the Syrdarya River within Kazakhstan and investigates changes on its water regimes under human activities. The Mann-Kendall trend test was used to explore the contributions of human activities to changes in inflow and discharge in Shardara water reservoir between 1980 and 2016. The results indicated that human activities, particularly agriculture and power generation activities are the major governing factors of changes on water regimes of the reservoir. The findings also indicated that, at significance level inflow and outflow of reservoir have positive trend. The inflow and discharge fluctuation of water often leads to serious floods in settlements at lower reaches of Syrdarya River accompanied by severe socio-economic damages and losses.

**Key words:** Shardara water reservoir, Hydrological parameters, Inflow, Outflow, Aydar-Arnasay lakes system.

**Introduction.** The construction of dams or water reservoirs is important for human beings, since reservoirs provide multipurpose uses which contribute significant value for the development of society [1]. The water reservoirs are among the most efficient tools for water resources development and management [2]. They are very complicated facilities that enable to redistribute river flow in time [3]. The main role of reservoirs is to control water resources in river basins [4], flood prevention and provision of water for different water uses such as industry, agriculture and domestic purposes [5]. Many natural, economic systems and water complexes of Kazakhstan have been operating in a stable mode under production rates, while intensification and anthropogenic impacts have become objects of environmental stress. Some of these systems have been shifted from environmental stable level to environmental crisis and degradation. The Syrdarya River Basin is one of such water management systems in Kazakhstan and Central Asia in general [6, 7].

The Syrdarya River is one of the major irrigation sources in Central Asia [8]. Its regulation permits the use for irrigation. Irrigation development in the Syrdarya River Basin has drastically changed natural conditions within this area [9]. Initially, upstream–downstream issues in the Syrdarya River Basin originated in the beginning of the 1960s [10]. Until that time, natural flow of the River met water needs of users and environmental flow to the Aral Sea. The natural flow regime had high flow in summer and low flow in winter [11]. This regime was suitable for irrigated agriculture; the main historical water user in the region [12]. However, expansion of irrigated land in the basin from the 1960s stimulated the development of large storage facilities for regulation of the River flow [13]. The Toktogul water reservoir was constructed upstream of the Naryn River; others were Andijan water reservoir at the inflow point of Karadarya River to Fergana valley, and Kayrakkum and Shardara reservoirs downstream of Syrdarya River.

By 1988 was expansion of irrigated area to 3.36 mln. hectares [14]. About half of this expansion was made possible by the development of downstream and virgin land where irrigated area increased from 456 to 977 thousand ha. Water withdrawal for irrigation amounted to 85% of the total long-term annual river flow against 40% before 1960 that significantly reduced the river inflow. This was the first manifestation of upstream–downstream conflicts in the basin [15].

In a modern geopolitical situation in Central Asia, the necessity of existing system of river flow regulation revision and safety measures provision of regions exposed to water flooding below Shardara dam have occurred. It is mainly connected with change of regional water requirements in the context of orientation on their own national interests and programs of their development. The centralized flow regulation system and accident prevention system from water flooding while controlling the stream flow using all regulating reservoirs of the basin that pre-existed until 1992 was completely changed. These changes presently are resulting from regular spring emergency conditions on the territory of Kazakhstan and winter difficulties in the context of situation of basic regulating reservoirs on territories of other countries [15, 16]. Therefore, current problems of the Syrdarya River from the Shardara water reservoir to its confluence are associated with floods and ice blocking phenomena mainly resulting from human activities [17] and in order to prevent flooding of the lower reaches of the Syrdarya River, wasteful discharges into the Aydar-Arnasay lakes system were required. Therefore, the purpose of the present study is to analyze human impact on water regime of the Shardara water reservoir.

**Study area.** The Shardara water reservoir is located at the altitude of 252 m in the middle reaches of the Syrdarya River in south Kazakhstan region and Syrdarya Region of Uzbekistan (figure 1). The reservoir is one of the largest reservoirs in Kazakhstan [18]. The reservoir capacity is 5.2 billion $m^3$ with a useful capacity of 4.7 billion $m^3$ and dead water horizon of 244 m [19]. The area of the reservoir's surface at the normal headwater level is 650 $km^2$ [20].

The Shardara water reservoir serves for multipurpose uses such as hydropower use, storage of irrigation water, municipal and industrial water supply and fishing. The reservoir is formed by two dams; one is in Kyzylkum canal on the Syrdarya River and the other overlaps the Arnasay-Aydarkul depression. Arnasay dam is located on the border of Kazakhstan and Uzbekistan [21]. Unlike the reservoirs of temperate zone of Europe, USA and Canada, it is filled in autumn and winter. From April/May to September/October, water from the reservoir is used for irrigation but reduces by about 12 m. At the maximum drawdown, the reservoir covers only 11,000 hectares versa 90,000 ha of entire one [16].

The climate in this region is continental highly arid. There are typical large seasonal and daily heat temperature variations. The summer is dry, cloudless and very hot. In July, the warmest month, the average monthly temperature is 25-31 °C. From June to the first half of August, the maximum temperature usually reaches 40 °C or higher. Average precipitation is 429 mm, the lowest in August is 2 mm in average. Most precipitation falls in March, 75 mm in average [22]. There are solid masses of irrigated land about 9,400 hectares along the Keles River, upstream the Syrdarya River from the reservoir at the study area. About 136,000 hectares of agricultural land are located at the southern bank of the reservoir passing the Dostyk canal at the territory of Uzbekistan. Water irrigation also occurs directly from the reservoir [22].

**Data collection and Methodology.** This study employed long-term data on the inflow and outflow of the Shardara water reservoir for the period 1980-2016. The data of the Syrdarya River runoff (1980-2016) and discharge of water from the Shardara into Aydar-Arnasay lakes system (1993-2016).

Then the statistical significance of trend in time series of water regime of the Shardara water reservoir was analyzed by using Mann Kendall (MK) test. The Mann-Kendall test is a widely used test for detecting trends in time series, and is very popular in hydrological studies [23]. The MK test is a non-parametric test for linear trend, based on the idea that a lack of trend should correspond to time series plot fluctuating randomly about a constant mean level, with no visually apparent upward or downward pattern [24].

In MK trend test, each data value is compared to all subsequent data values. Mann Kendall statistic (S) for a time series $x_1, x_2, x_3 \ldots$, and $x_n$ [25, 26] is calculated as follows:

$$S = \sum sgn(x_j - x_i) \tag{1}$$

Where $sgn$

$$(x_j - x_i) = 1, if\ (x_j - x_i) > 0$$
$$(x_j - x_i) = 0\ , if\ (x_j - x_i)\ = 0$$
$$(x_j - x_i) = \ -1, if\ (x_j - x_i) < 0$$

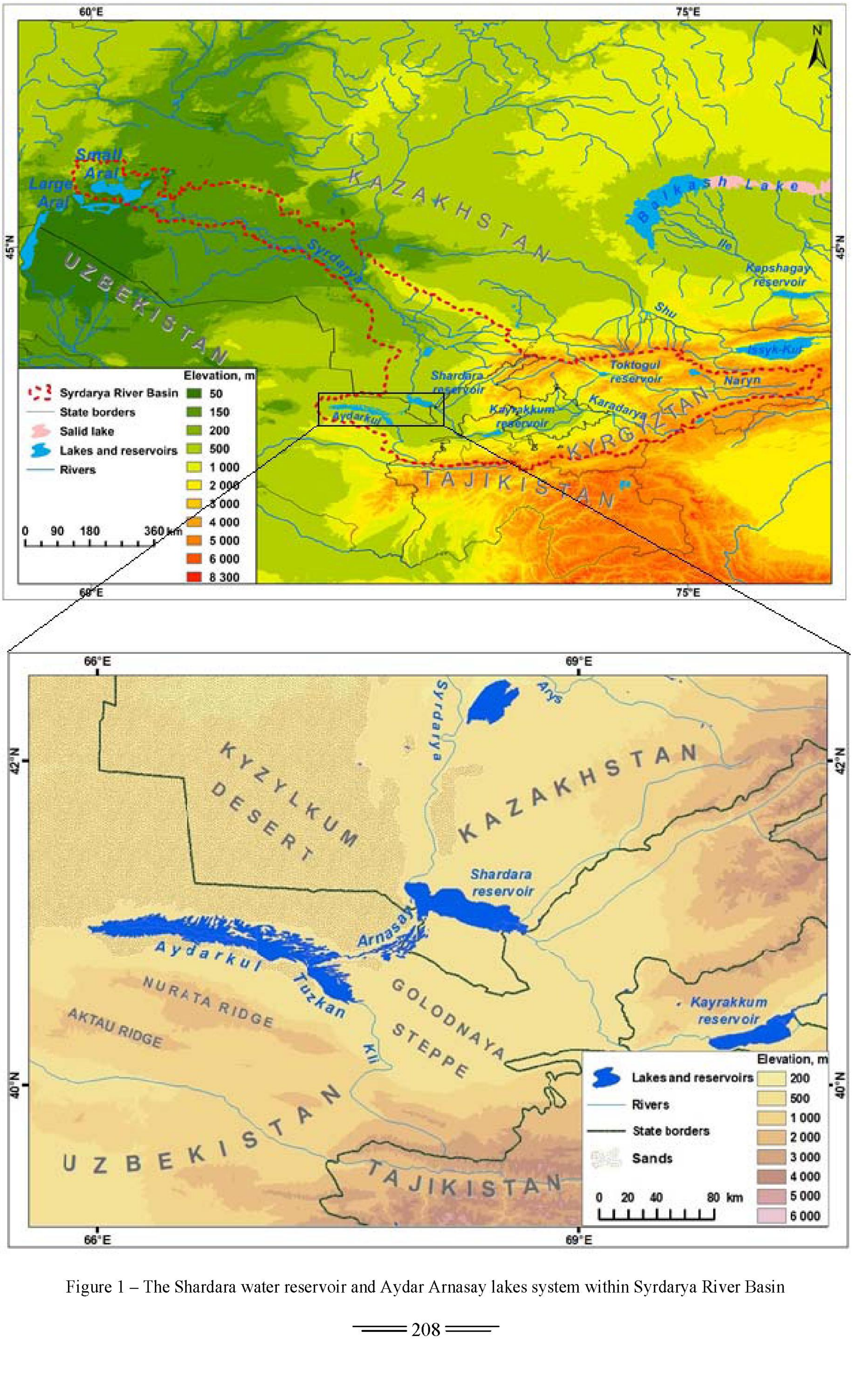


Figure 1 – The Shardara water reservoir and Aydar Arnasay lakes system within Syrdarya River Basin

The probability associated with S and the sample size, n is then computed to statistically quantify the significance of the trend using normalized test statistic, Z is formed using the equation as follows:

$$Z = \begin{cases} \frac{(|S|-1)}{SD|S|}, if\ S > 0 \\ 0, \quad if\ S = 0 \\ \frac{(|S|-1)}{SD|S|}, if\ S < 0 \end{cases}$$

While the standard deviation is computed as:

$$SD\ |S| = \sqrt{\frac{1}{18}(n(n-1)(2n+5)} \quad (2)$$

Where $n$ is the number of data points.

**Remote sensing.** Generated using Normalized Difference Water Index (NDWI) we calculated changes on water area of the Shardara water reservoir. Surface water mapping with multi-spectral remote-sensing images is based on the difference of the absorption and reflection of light between water and other features in different frequency bands. As reflections from water of the visible to infrared bands are gradually weakened, the surface water on an image can be delineated with the (NDWI) by the contrast of the visible wavelength with the near-infrared and short-wave infrared wave lengths [27]. The NDWI was first suggested by to detect surface waters in wetland environments and measure surface water dimensions [28].The NDWI index was calculated with the following equations

$$NDWI = \frac{band_{GREEN} - band_{NIR}}{band_{GREEN} + band_{NIR}}$$

Where GREEN is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation

**Results and discussion.** *Water regimes of the Shardara water reservoir*. The problems of the Syrdarya water flow release are associated with flood and subsequent material damage and human losses. While the construction of Shardara reservoir enabled to avoid floods in the lower reaches of Syrdarya River almost completely during the seventies and eighties of the last century. But at present, the flow volume entering Shardara reservoir and lower reaches of Syrdarya River is determined by operation regime of higher reservoirs cascade and, mainly the largest ones, designed for long-term and seasonal regulation [29]. The highest inflow rate in Shardara reservoir and outflow from reservoir to river can be observed in the first decade (1980-1989). In this period, inflow is equal to11 892, 3 mln $m^3$ per year (figure 2), the outflow is equal to 10211, 4 mln.$m^3$ per year (figure 3).

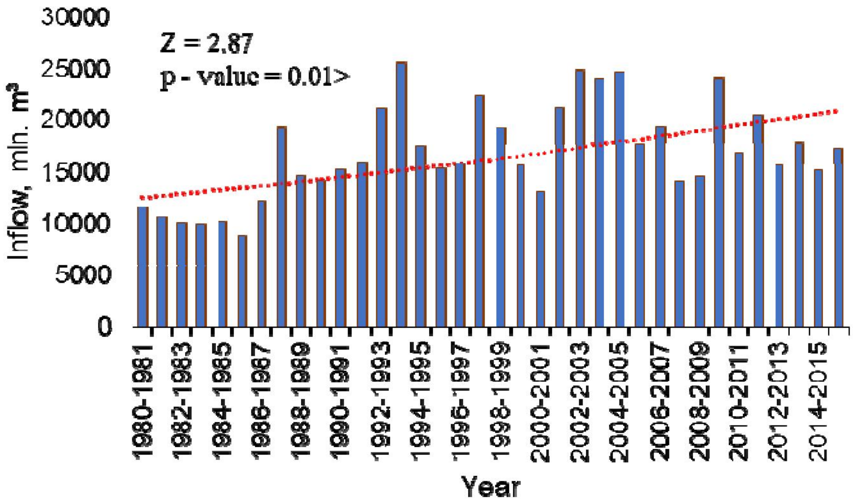


Figure 2 – Dynamics of the inflow to the Shardara water reservoir

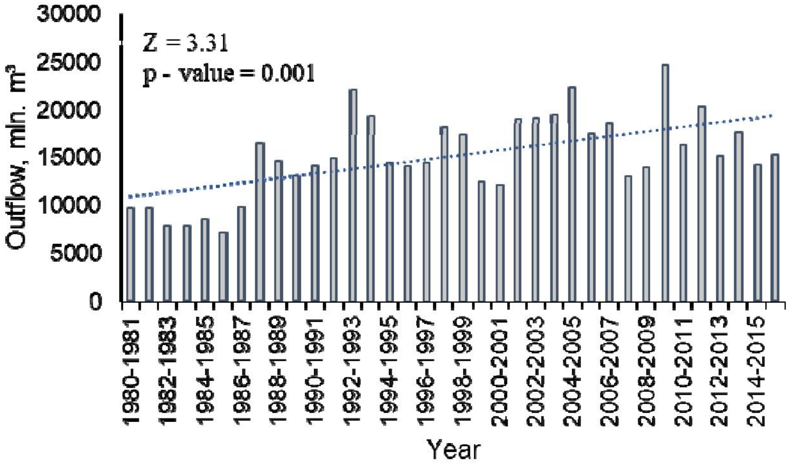


Figure 3 – Outflow dynamics from the Shardara water reservoir

These indicators decreased in the period of 1982-1986. The lowest inflow and release rate was between 1985 and 1986 with inflow equal to 8745, 9 mln.m$^3$ (figure 2) and outflow of about 7156, 5 mln.m$^3$ (figure 3).

The indicators worsened within this period (1982-1986) likely due to the facts that, there was shortage of water in the region and that, specific water consumption decreased to 35.1 thousand m$^3$/ha, then after irrigated land expanded to 199 thousand hectares. While the volume of discharge required for irrigation has reached 7 km$^3$/year [30]. Accordingly, the runoff of Syrdarya River decreased between 1982 and 1986 (figure 4).

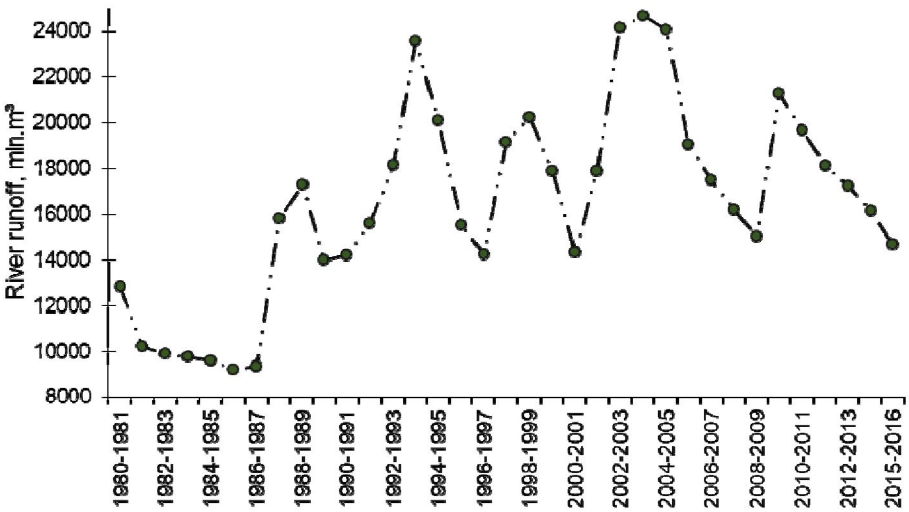


Figure 4 – The runoff of the Syrdarya River (Source:[20]).

The increasing indicators are observed in the period between 1987 and 1989 with higher trends between 1980 and 1989. The inflow to Shardara reservoir in 1987-1989 amounted to 16 917,9 mln.m$^3$/year (figure 2), and the outflow from reservoir is also high, amounting to 15555 mln.m$^3$/year (figure 3). In this period, the runoff of Syrdarya River is increasing (figure 4). In the first decade (1980-1989), discharge water from Shardara reservoir was no more than 10508, 6 mln.m$^3$ per year (figure 3) and the inflow was 12119, 6 mln.m$^3$/year (figure 2). Then during the second decade of 1990-1999, there are slightly fluctuating inflow to the reservoir (figure 2) and the release from reservoir (figure 3). The highest rates of inflow and discharge are particularly observed within the period 1992-1994 in particular.

The inflow rate within this period is 23411, 4 mln.m$^3$ (figure 2) and discharge rate is 20744,4 mln.m$^3$ per/year (figure 3).

Since 1992, for economic reasons, Kyrgyzstan has changed the purpose and mode of the Toktogul reservoir into energy regime. As a result of the transition to the energy regime, winter and summer changed places and this led to floods in winter and, in summer, artificial water scarcity [31]. As electricity needs increase in winter, inflow rate to the reservoir from higher reservoirs increases as well [32]. Intensive use of water resources for power generation, along with changes in the Toktogul operating regime created serious problems in the Syrdarya River in both summer and winter periods. That regime differs significantly from the irrigation regime, although until 1993 its regime was underlined to the irrigation schedule, according to which the reservoir was filled from October to March and discharged from April to September. The simultaneous inflow and discharge is supposed depending on the flow rate in winter regime of Shardara reservoir operating in the energy regime of the upper reservoirs. Water was supplied from January to March. Slightly higher consumption is observed at the beginning and end of the freeze-up, and decreased during vegetation period [33]. We observed that since of changing purpose of Toktogul reservoir the inflow of Shardara reservoir decreased in vegetation period and raised in non-vegetation periods, but outflow raised in the vegetation, non-vegetation periods (figure 5).

During the 1980-2016 period, the discharge rate is equal to 9129, 8 mln.m$^3$ and inflow rate is 6338 mln.m$^3$ annually in average in vegetation period (figure 5). But outflow rate is 6060, 7 mln. m$^3$ and inflow 10 478.9 mln.m$^3$ annually in average in non- vegetation period (figure 5). The inflow rate higher in non-vegetation period than vegetation period, which explain because for economic reasons, Kyrgyzstan has changed the purpose and mode of the Toktogul reservoir into energy regime. The Toktogul reservoir began intensive use of water in non-vegetation period. The Toktogul reservoir saved water in vegetation period, accordingly the inflow of the Shardara reservoir is low. But outflow of the reservoir lower in non-vegetation period than in vegetation period. Because during vegetative period, demand for irrigation water grows in the lower reaches of the river and discharge rate is quite high accordingly. As well as we can see changes on water area of the Shardara reservoir in vegetation, non-vegetation periods in figure 6.

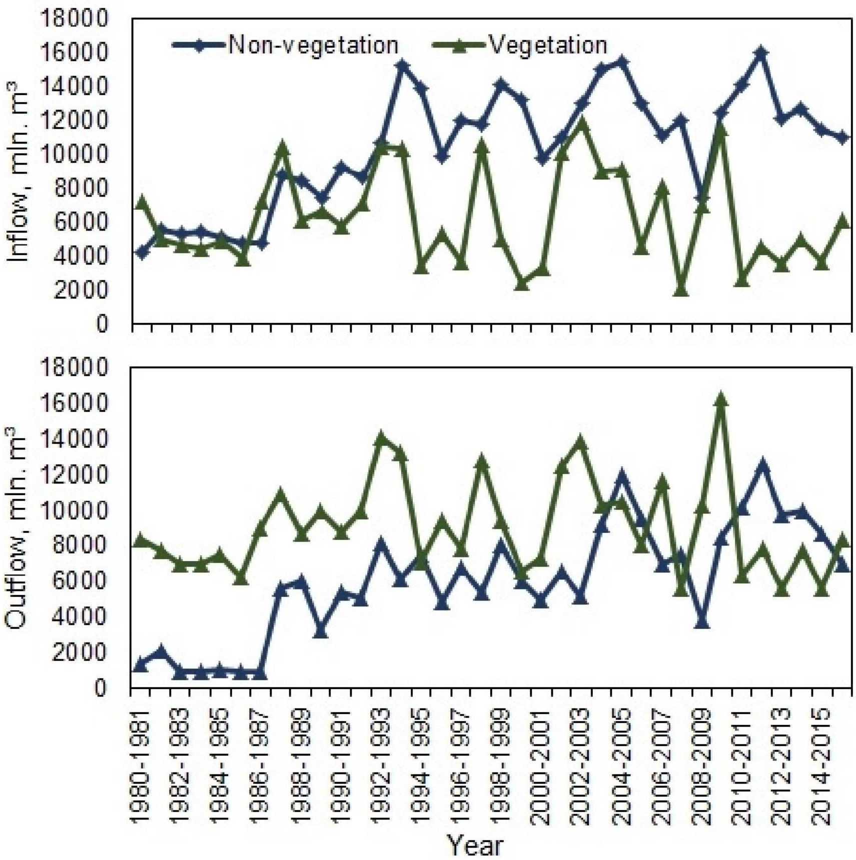


Figure 5 – Dynamics of inflow to the reservoir Shardara outflow from the reservoir in vegetation and non-vegetation periods

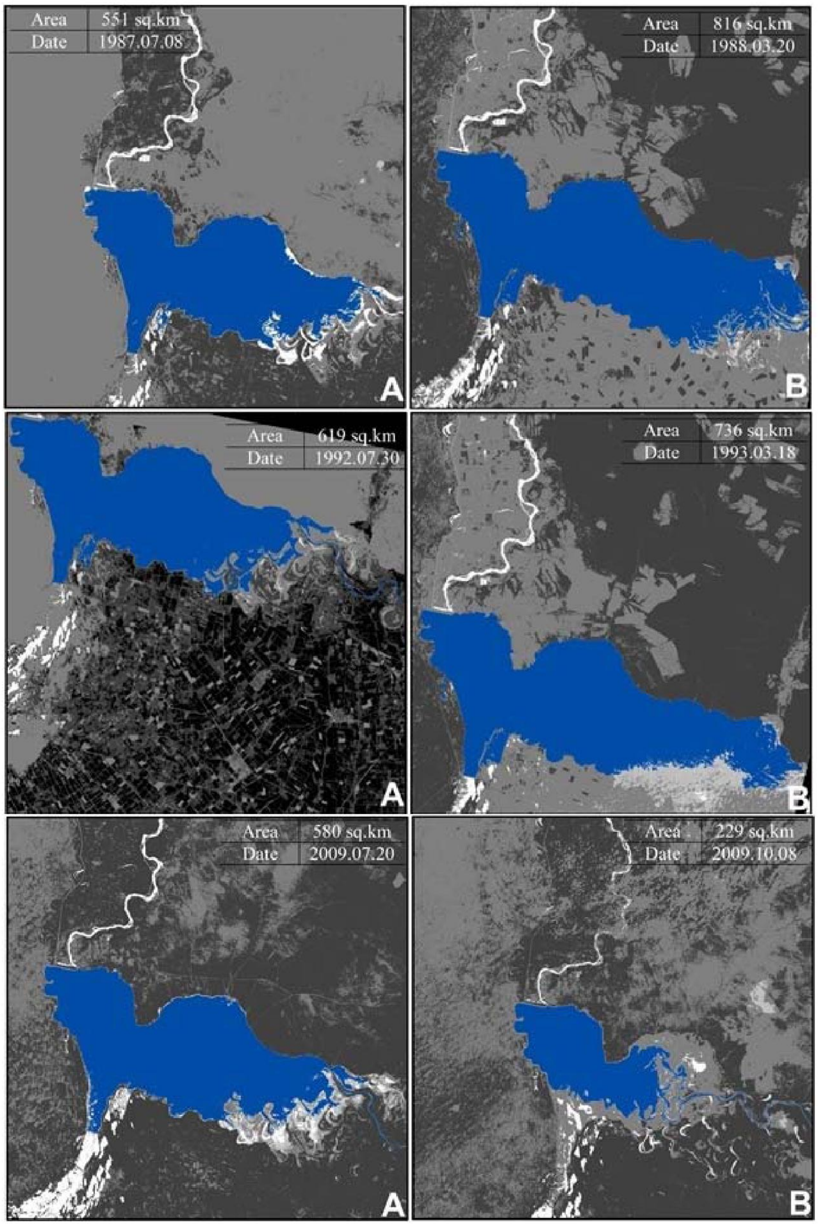


Figure 6 – Changes in the water area of the Shardara reservoir 1987-1988, 1992-1993, 2009 within in vegetation (A) and non-vegetation (B) periods generated using NDWI

In the third decade period 2000-2009, there are slightly fluctuating inflow to the reservoir and the release from the reservoir (figures 2, 3). The largest inflow and release rate was in the period of 2002-2005 where inflow rate to the reservoir is 24540 mln.$m^3$ (figure 2) and discharge rate from the reservoir is 20330 mln.$m^3$ per year (figure 3). As a result, Shardara reservoir began to fill up at critical level, and water was discharged to the Syrdarya. That caused flooding in this region [34, 35].

Accordingly, the river flow rose (figure 4). Stable inflow and discharge rates in the reservoir are observed in fourth decade (2010-2016). Only from 2010 to 2014, inflow and outflow parameters showed high level (figures 2, 3).

This can be due to the compensating reservoir constructed in Kazakhstan in early 2011, which took the first 2 bln.$m^3$ of water. Since flood occurred in South Kazakhstan region in spring of 2008 [36], the compensating reservoir enabled to reduce the forced discharge rate to Aydar-Arnasay lakes system [30]. After that, there is stable decrease of the inflow and outflow (figures 2, 3) and river runoff of the Syrdarya (figure 4). Using statistical tests for estimating Mann-Kendall slope, such a fluctuation in the indices showed that at significance level the inflow and outflow of reservoir have positive trend (figures 2, 3).

**Conclusion.** The changes on water regimes of Shardara reservoir was investigated in this study, with use of statistical tests of the Mann-Kendall slope estimation. Results revealed that between 1980 and 2016, the trend of inflow to reservoir Shardara and outflow from reservoir to Syrdarya River at significance level have positive trend. The results also indicated strong fluctuation of indicators (inflow and outflow or discharge) for the period (1980-2016). These indicators increased significantly only in the period 1992-1994 and amounted to 23 411, 4 mln.m$^3$ of inflow and 20 744, 4 mln.m$^3$ of discharge per year. Accordingly, the river runoff of Syrdarya river, and that occurred because in 1992, the Toktogul reservoir, which located in the upper part of the Syrdarya River was switched to the energy regime. As electricity needs increase in winter, the inflow to the reservoir from the upper reservoirs increases as well. As a result, the ice is formed in the lower reaches of the river in the non-vegetation period that brings the floods in the region. The analysis of Mann-Kendall trends long-term data for the period of 1992-2016 showed that at significance level overall trend release from Shardara to Arnasay lake system is decreasing. During this period, 1899, 5 mln.m$^3$ of water was discharged from the reservoir to the lakes system. The highest rates (9193, 3 mln.m$^3$) are noticed between 1993 and 1994 while the lowest rates (0 mln.m$^3$) are observed in the period 2012-2013.

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## ШАРДАРА СУ ҚОЙМАСЫНЫҢ СУ РЕЖИМІНЕ АДАМ ҚЫЗМЕТІНІҢ ӘСЕРІ

**Аннотация.** Халық санының тез өсуі, азық-түлікке деген сұраныс пен басқа да адами қызмет түрлері әсерінен судың қолжетімділігі бүкіл әлемде кеңінен тараған проблемаға айналуда. Бұл мақала Қазақстандағы Сырдария өзенінде орналасқан Шардара су қоймасындағы адам қызметінің белсенділігінің әсері мен су режимінің өзгеруін қарастырады. Манн-Кендалл трендінің сынағы 1980 жылдан 2016 жылға дейін Шардара су қоймасындағы ағынның өзгеруіне адам қызметінің белсенділігін зерттеу үшін пайдаланылды. Алынған зерттеу нәтижелері, адамның қызметі, әсіресе, ауыл шаруашылығы және электр энергиясын өндіру су қоймасының су режиміндегі өзгерістердің басты факторы болып табылатынын көрсетті. Нәтижелер маңыздылық деңгейінде су қоймаса судың келуі мен шығысы оң үрдіске ие екендігін көрсетті. Жиі су ағынының ауытқуы Сырдария өзенінің төменгі ағысындағы елді мекендерді елеулі әлеуметтік және экономикалық шығындарға әкеп соғуы мүмкін.

**Түйін сөздер:** Шардара су қоймасы, гидрологиялық параметрлер, ағын, ағыс, Айдар -Арнасай көлдер жүйесі.

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## ВЛИЯНИЕ ЧЕЛОВЕЧЕСКОГО ФАКТОРА НА ВОДНЫЙ РЕЖИМ ШАРДАРИНСКОГО ВОДОХРАНИЛИЩА

**Аннотация.** В условиях быстрого роста населения, спроса на продовольствие и других видов деятельности человека доступность воды становится все более распространенной проблемой во всем мире. В статье рассматриваются изменения водного режима Шардаринского водохранилища в результате деятельности человека, который расположен на реке Сырдария в Республике Казахстан. Тест тренда Манна-Кендалла использовался для изучения влияние человеческой деятельности в изменении притока и оттока в Шардаринское водохранилище в период с 1980 по 2016 год. Результаты исследования показали, что человеческая деятельность, особенно сельское хозяйство и производство электроэнергии, являются основными определяющими факторами изменений в водным режиме водохранилища. Результаты также показали, что на уровне значимости приток и отток водохранилища имеют положительную тенденцию. Колебание воды в притоке и сбросе воды часто приводит к серьезным наводнениям в населенных пунктах в низовьях реки Сырдария, сопровождающимся серьезными социально-экономическими потерями.

**Ключевые слова:** Шардаринское водохранилище, гидрологические параметры, приток, отток, система озер Айдар-Арнасай.

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