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EVALUATION OF DYNAMIC CHANGE OF WATER LEVEL OF THE SMALL ARAL SEA BASED ON DATA OF OPEN SOURCES

The study of the Aral Sea water level and volume dynamics is an urgent scientific task due to the need to understand the mechanisms of natural, anthropogenic processes. In particular, the study of water balance component dynamics of Small Aral basin is the most important task in planning scenarios of water use, water protection in the region. In the proposed work, on the basis of machine learning methods, two statistical models were developed: a model that takes into account the variability of the monthly values of Syrdaria runoff and corresponding change in Small Aral water volume. In the low availability conditions of data from field observations, obtained operational estimates, which compose water balance component are the most important source of information about ongoing changes in studied basin. The proposed technique can used to obtain initial conditions in hydrodynamic modeling experiments, as well as to calculate climatic scenarios for development of the Aral hydrological system.

Key words: Small Aral Sea, sea level, machine learning, river discharge

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Кіші Арал теңізі су деңгейінің динамикалық өзгерістерін ашық дерек көздері негізінде бағалау

Арал теңізінің су деңгейі мен су көлемінің өзгеру динамикасын зерттеу өзекті мәселелердің бірі болып табылады. Соңғы алпыс жылда теңіздің су және тұз теңдестігінің түбегейлі өзгеруіне алып келген табиғи және антропогендік процестердің механизмдерін түсіну қажеттілігі үлкен маңызға ие болып отыр. Аймақтың су пайдалану және су қорғау сценарийлерін жоспарлау кезінде Кіші Арал теңізі алабының су теңдестігі құраушысының динамикасын зерттеу маңызды міндеттің бірі. Ұсынылып отырған жұмыста машиналық оқыту әдісі негізінде екі статистикалық модель әзірленген: Сырдария өзенінің айлық өзен ағындысы және Кіші Арал теңізінің су көлемі мәндерінің өзгерісін ескеретін моделдер. Үлгілеудің нәтижесінде Сырдария өзені ағындысы мен Кіші Арал теңізінің су көлемінің динамикалық өзгерістері анықталды. Далалық бақылаулар мәліметтермен аз қамтамасыз етілу жағдайында алынған су теңдестігінің негізгі құраушысын құрайтын шұғыл бағалау – зерттеліп отырған алапта өтіп жатқан өзгерістер туралы маңызды ақпараттар көзі болып табылады. Ұсынылып отырған әдістеме гидродинамикалық моделдеу эксперименттерінің бастапқы шарттарын алу және сондай-ақ, Арал теңізінің гидрологиялық жүйесі дамуының климаттық сценарийлерін есептеу үшін қолданылуы мүмкін.

Түйін сөздер: Кіші Арал, теңіз деңгейі, машиналық оқыту, өзен ағындысы.

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Оценка динамического изменения уровня воды малого Аральского моря на основе данных открытых источников

Исследование динамики уровня и объема воды Аральского моря является актуальной научной задачей в силу необходимости понимания механизмов природных и антропогенных процессов, индуцировавших радикальное изменение его водного и солевого балансов за последние шестьдесят лет. В частности, исследование динамики компонента водного баланса бассейна Малого Аральского моря является важнейшей задачей при планировании сценариев водопользования и охраны вод в регионе. В предлагаемой работе на основе методов машинного обучения были разработаны две статистические модели, учитывающие изменчивость месячных значений речного стока реки Сырдария и соответствующие изменения объема воды Малого Арала. По результатам моделирования были получены динамические изменения стока реки Сырдария и объема вод Малого Аральского моря. В условиях малой обеспеченности данными натурных наблюдений полученные оперативные оценки, которые составляют компонент водного баланса, являются важнейшим источником информации о происходящих изменениях в исследуемом бассейне. Предлагаемая методика также может быть использована для получения начальных условий в экспериментах гидродинамического моделирования, а также для расчета климатических сценариев развития гидрологической системы Арала.

Ключевые слова: Малый Арал, уровень моря, машинное обучение, речной сток.

Introduction

The research of the water level and volume dynamics of the Aral Sea is an urgent scientific task due to the required to understand the mechanisms of natural and anthropogenic processes that have induced radical changes in water and salt balances of sea over the past 60 years.

Since the late 60s the sea volume has decreased by 90 %, the salinity have increased by an order of magnitude (Zavialov, 2005). The research of the hydrological cycle processes of the Aral Sea has hampered by the almost complete absence of data from modern measurements of the water balance composing. Since the 60s, the Aral Sea has been undergoing irreversible changes in the water level and salt regimes, cardinal changes have affected not only the ecosystem of the sea itself, but also affected its entire basin. Over the past 15 years, the tendency to separate of the Aral Sea from water bodies has deepened the deep-water western and shallow eastern basins of the Greater Aral, the Small Aral Sea (Figure 1). Thus, the eastern basin of the Greater Aral Sea in recent years has virtually ceased to be a permanent reservoir, becoming an ephemeral lake, whose existence are determined by the magnitude of the seasonal water runoff of the Amudarya River. The northern basin of the Aral Sea almost lost contact with other basins - both due to natural causes of drying up of the western and eastern basins, and due to the construction of a dam designed to minimize water exchange between the basins (Izhitskiy et al. 2016a).

The Syrdarya provides an inflow of water in the Kazakhstani part of the Aral Sea. Syrdarya from source to mouth, i.e. Tien Shan zones of runoff formation to the North Aral Sea can be noted that this watercourse is a carrier of life-giving moisture, a source of energy.

Today, intensive irrigation of cotton and rice fields takes a significant part of the river runoff, which dramatically reduces the water runoff into their deltas and, accordingly, into the Aral Sea itself. Precipitation in the rain and snow form, as well as underground sources give the Aral Sea much less water than it has lost by evaporation, because of which the water volume of the lake-sea decreases and the level of salinity increases (Sambaev 2017).

In this paper, we have emphasized the research of the water volume dynamic changeability of the Small Aral Sea. In the recent years, after minimizing its water discharge with other parts of the sea, it began to establish a relatively stable water-salt regime, similar in characteristics to the “conditionally-natural” regime of the Aral Sea. Nevertheless, the significant shortage of these direct observations of the water balance component for this region is sorely. Modern field observations on all parts of the Aral Sea are episodic, lacking monitoring hydrological-meteorological stations and stations ceased to exist in the first half of the 1990 year. That is way in this work we used the database of indirect water level observations as well as climate reanalysis database.

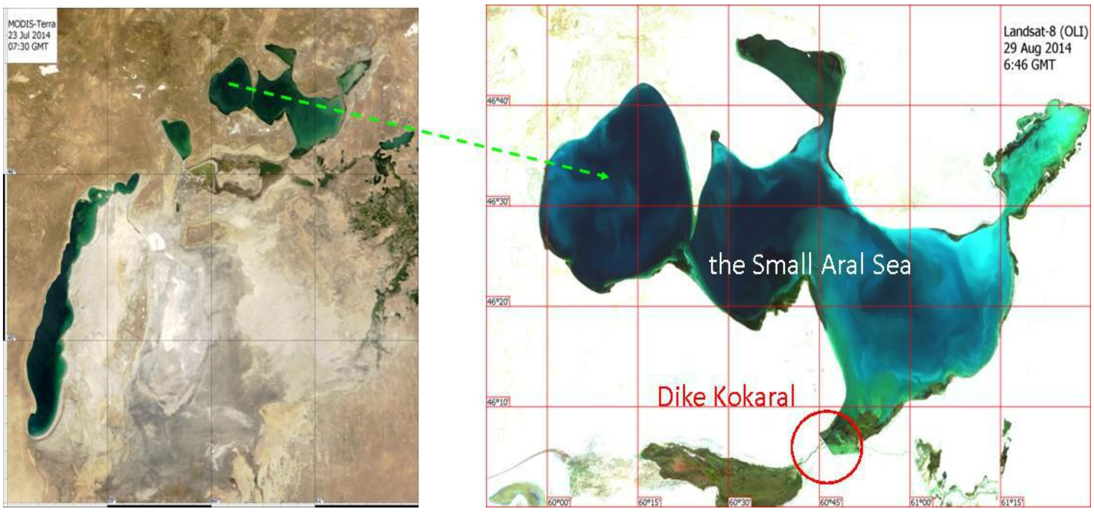

Figure 1 - Satellite image of the Aral Sea in July 2014 (left), satellite image of the Small Aral in August 2014 (right)

The main goal of this work is to research the possibility of modeling the dynamic changeabilities of the water volume of basin, which is located in arid conditions by using the data of indirect measurements of open sources (Fig. 2).

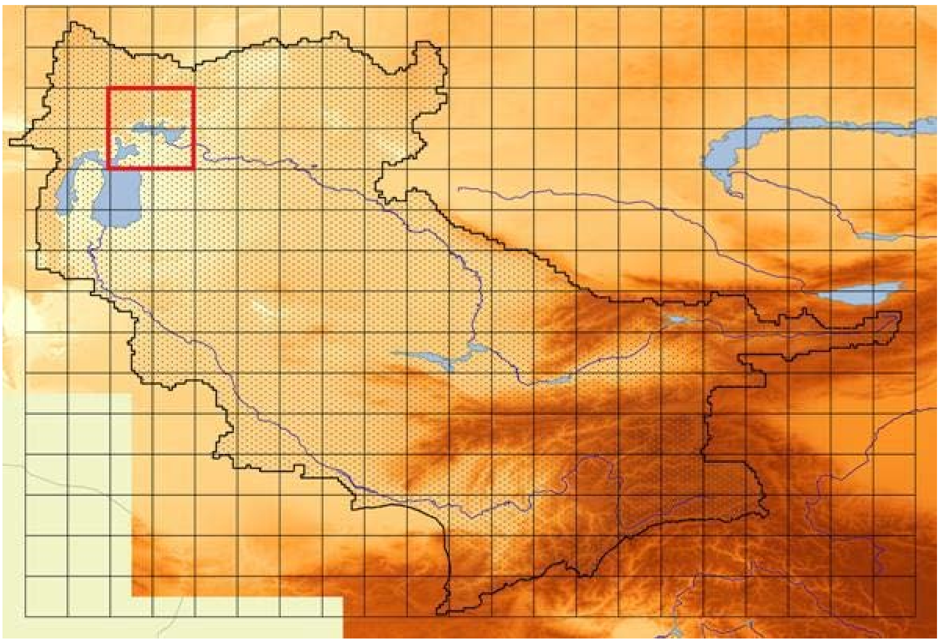

Figure 2 – Study area: the Small Aral Sea and the Aral Sea basin

Key modeling concept has based on implementation of a simple Decision Tree model in case of regression task (Ayzel, 2017; Breiman et al., 1984). Typical Decision Tree model is a «white box» consists of the range of boolean classifiers which split our samples to tiny «leaf» nodes where all samples constantly refers to the one target value (Hastie et al., 2005). Single tree-based implementation of Decision Tree is algorithm faced with the case of overfitting and robustness lack that lead to limited using in real world examples (Freund, Schapire, 1997). In our work, we used three cutting-edge machine-learning techniques based on ensemble approach to predictions: Random Forest, Extra Trees and Gradient Boosting (Ayzel, 2017; Mason et al., 2000; Zhang, Hsieh, 2017). All of them are based on group of simple Decision Tree models and provide useful trick such bagging, bootstraping, prunning etc. that totally reduce overfitting and make our models suitable to provide robust dynamics (Friedman, 2001; Kohavi, 1995; Schapire, Freund, 2012).

Materials and methods

The research material has selected as the analysis period from 2002 to 2014, all daily (reanalysis) and decadal (water level) measurements have taken to monthly values. Below is given more specific description of used the data:

1. Sea level variability based on satellite altimetry data from 1992 to 2014 (decadal values), DAHITI project (Schwatke et al., 2015);
2. River runoff of Syrdarya river (gauging station Kazaly), historical monthly values from 1979-1986, Global Runoff Data Center (GRDC) (www.bafg.de);
3. Atmospheric forcing: reanalysis Era-Interim, resolution 1x1 degree, daily values (Deeetal., 2011).

A hypsometric relationship between the sea surface layer and the water volume was obtained for the entire range of sea level variability according to the DAHITI data for the period under research based on a detailed bathymetric map of the Small Aral (Izhitskiy et al., 2016b).

As a model linking the average monthly rates of fluctuations in climatic characteristics with the dynamics changeability of river runoff values (Ayzel and Izhitsky, 2016), a regression model of solving trees was chosen, which in general is a nonparametric model of machine learning - a simple model of the “white box” solutions, which can be described by a set of simple Boolean functions. Advantages of the regression model of decision trees are: interpretability, quick learning, high tolerance for incomplete data. As shortcomings, usually distinguished: high ability to retrain, instability with the dominance of one decisive class, the difficulty of finding the exact structure of the tree.

Results and discussion

Based on the described method, two statistical models were developed: a model which shows dynamic changeability of water level corresponding changes of water volume of Aral Sea and the variability forecast of the water volume of the Small Aral. In the first model, the predictors used air and precipitation values for the current and previous six months averaged over the entire Aral Sea basin. The model was trained on the period from July 1979 to December 1985 according to the monthly values of the river runoff at the gauging station Kazaly (Figure 3). As a result, it was used to simulate river runoff values for the period from January 1986 to September 2015 - for this period, the actual measurements of the river runoff were not available (Fig. 4).

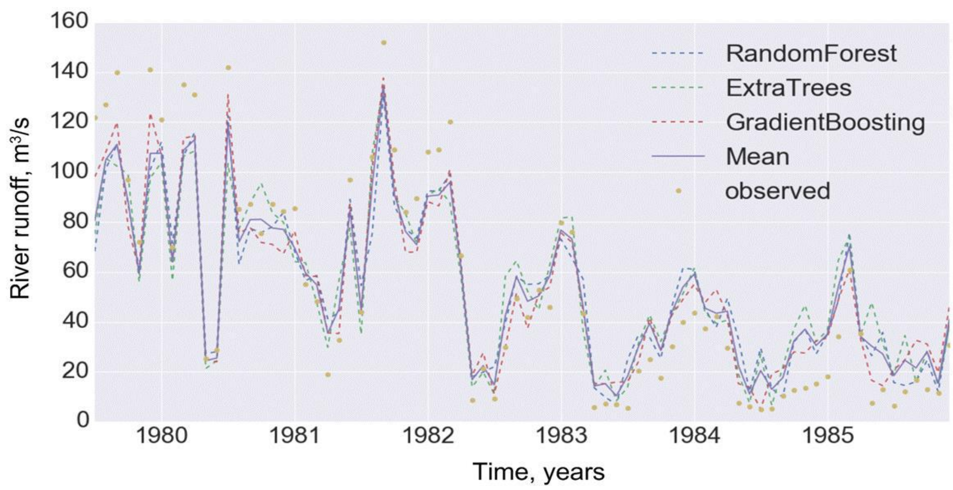

Figure 3- Training of the model of river runoff formation for the period from July 1979 to December 1985

These data, together with reanalysis data (air temperature, wind speed, precipitation) were used to train the second statistical model for predicting Small Aral volume fluctuations on satellite altimetry data for the period from October 1992 to November 2014 (Fig. 5).

In conclusion, a modelling was made for the monthly values of the Small Aral Sea water volume for 2015 (Figure 6). Analysis of the significance of the signs showed that the parameters of mean temperature, precipitation amount and total evaporation are most significant for the results of constructing the model of decision trees, so only they were chosen as changeability of the final model - this made the model less susceptible to noise (robust), and also minimized the risk of retraining.

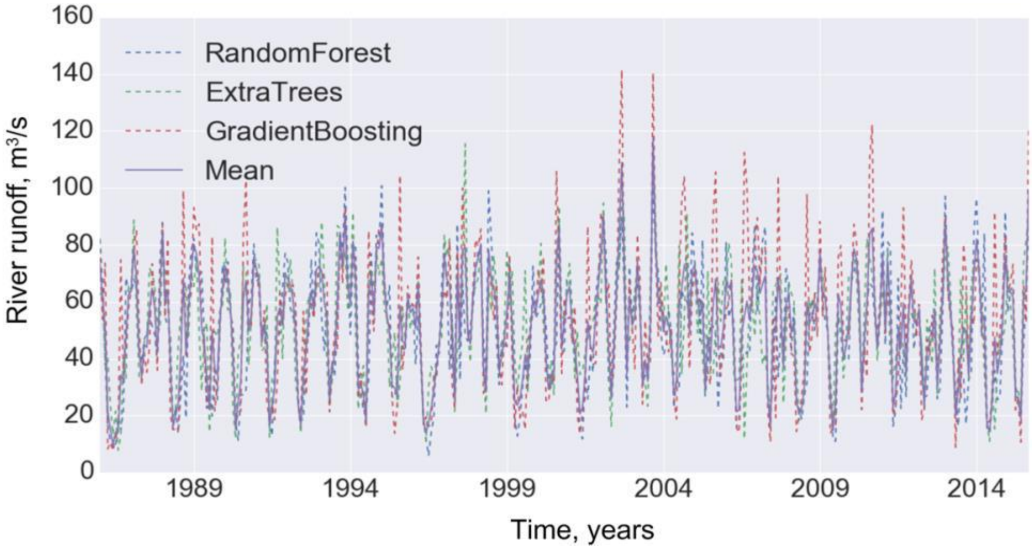

Figure 4 - Simulation of monthly river runoff values for the period from January 1986 to September 2015

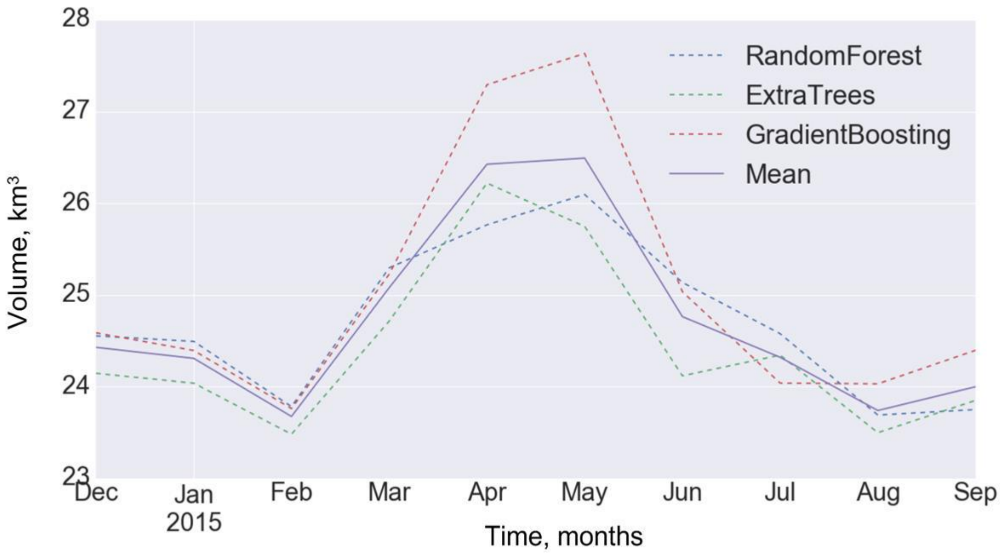

Figure 5 - Training model for forecasting the water volume of the Small Aral Sea, the period from October 1992 to November 2014

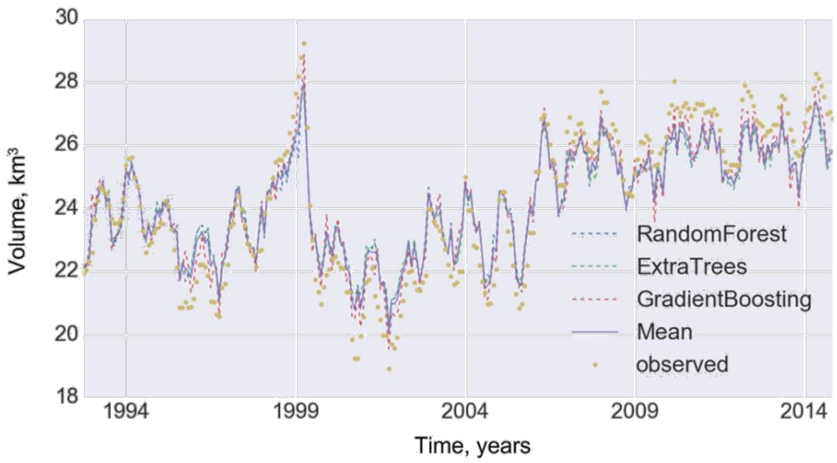

Figure 6 - Modeling of monthly values of the water volume of the Small Aral Sea in 2015.

Annual river runoff of Syrdaria River in the lower reaches over a long period of time is characterized by instability, which is due to both natural and anthropogenic factors. At present, the influence of the anthropogenic factor on the natural ecological system is very large. One of the main negative factors is the irrational use of water infrastructure.

The Syrdarya River in the first half of the last century was significantly regulated. Since then, the largest monthly water discharge has been characteristic of the beginning of spring, the minimum - for the entire summer period.

This distribution of river runoff is due to large volumes of water for irrigation of agricultural fields in the upper and middle reaches. Spring floods in the lower reaches of the river. The Syrdarya usually begins in late March - early April. Then, in connection with the filling of overlying reservoirs and water intakes, a recession begins in April.

The lowest monthly water discharges (in some years - 6-10 m^3/s) at the mouth of the river (Kazaly gauging station) has observed in the summer months, when irrigation of agricultural land is in full swing.

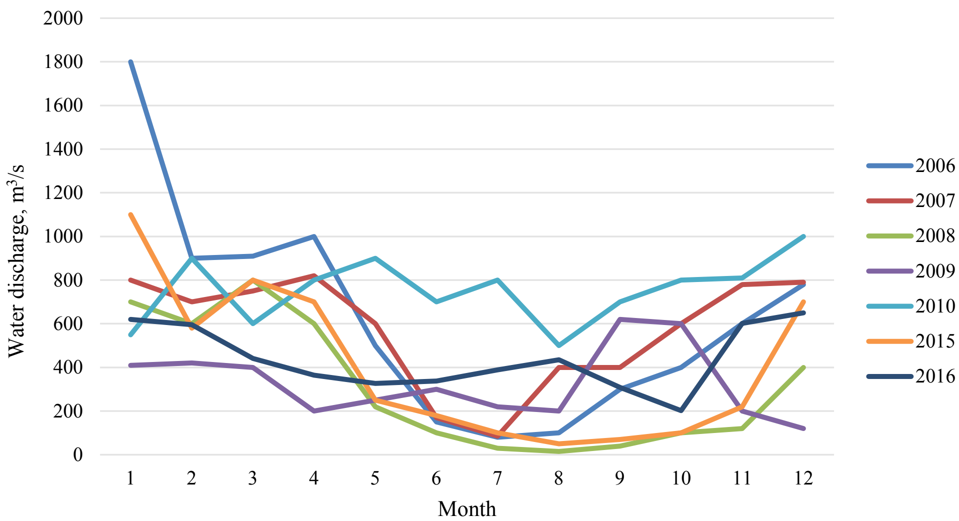

Figure 7 – The annual runoff distribution of the lower reaches of the Syrdarya river

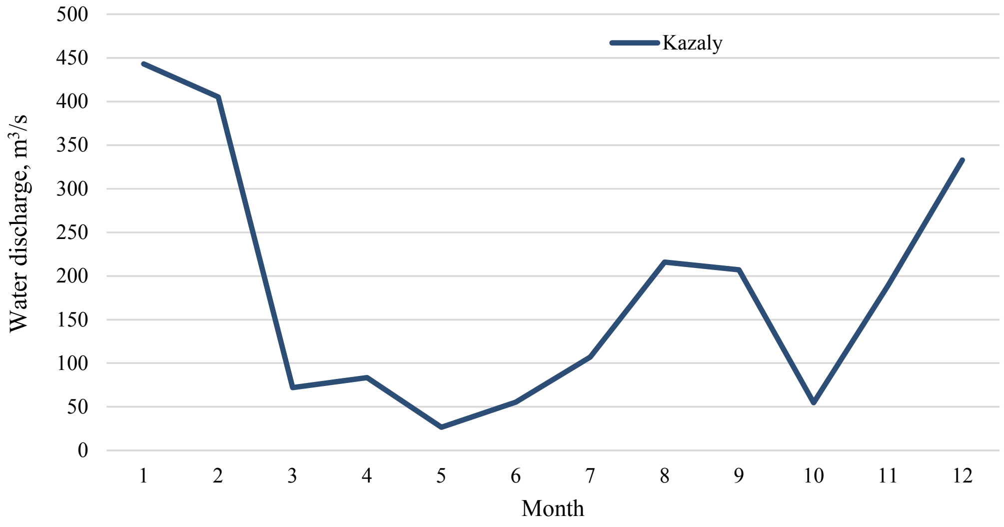

Figure 8 – Monthly distribution of runoff of the lower reaches of the Syrdarya – Kazaly gauging station for 2016 year

The dynamics of the average monthly annual runoff in the lower Syrdaria River is following: the loss of river runoff in the section from Kazaly to Karatereni (86 km), depending on the month, ranged from 55 to 358 m^3. Such a difference between runoff at the Kazaly and Karateren hydroelectric facilities is associated with the filling of lakes in the coastal zone. Losses associated with the transformation of runoff in the riverbed and floodplain of the river are to a large extent recoverable, if we consider not a short time interval, but a long period during which the water of detention in the section can drain through the lower closure target. Along with such losses, there are irretrievable losses of water in the area under consideration for filling numerous floodplain lakes and old lakes that do not communicate with the river, infiltration into the soil in the floodplain and evaporation.

Lower Syrdaria River in the second half of the last century, acutely felt a shortage of water, and about 30 years ago, runoff at its mouth decreased almost to zero. However, at the end of the 80s on the territory of the former USSR, people's views on the state of the environment changed dramatically, and the Syrdaria River delta became more careful about water resources. As a result, already in the early 90s, water along the river. The Syrdaria River began to flow regularly into the northern part of the Aral Sea. Although the volume of this water was about 2-4 times less than the amount of natural runoff (14.9 km^3), it was enough to flood a significant part of the modern "Small Aral" and there the desalination process began.

Conclusion

As a result, it should be noted that despite the serious shortage of these direct measurements of the main components of the water balance, such as the sea surface level and river runoff, the proposed method makes it possible to accurately predict the volume of waters of the Small Aral on the basis of open databases. The introduction of the factor of influence of the Kokaral dam into the model will help improve the quality of the forecast. The proposed technique can be used to obtain initial conditions in hydrodynamic simulation experiments, as well as to calculate climatic scenarios for the development of the hydrological system of the Aral Sea. Directions of further studies of the dynamics of the water volume of the Small Aral Sea are seen in the use of episodic data of field measurements for verification and more detailed adjustment of the model used, Syrdarya for the restoration of the values of natural water inflow into the Small Aral Sea.

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