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ASSESSMENT OF FLUCTUATIONS IN THE CASPIAN SEA LEVEL UNDER THE INFLUENCE OF CLIMATE CHANGE FOR THE FUTURE UNTIL 2050

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The article considers the possible fluctuation of the Caspian Sea level in the future until 2050, taking into an account the climate changes. For this purpose, possible changes in the river inflow to the sea and meteorological parameters (precipitation, air temperature and evaporation from the water surface) were predicted. Changes in the meteorological parameters were estimated according to two climate scenarios RCP4. 5 and RCP8.5.

Keywords: level change, Caspian Sea, river water inflow, climate change scenarios, level forecast for the future

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INTRODUCTION

The Caspian Sea is the largest landlocked reservoir on the planet. It is a drainless salty lake, and is unique reservoir with many unique features. (Figure 1).

The most well-known feature is the fluctuation of its level under the influence of changes in natural and anthropogenic processes. Changes in the water balance of the enclosed sea, strongly affects the change in the volume of water and the fluctuations in the sea level.

Fig. 1. The Caspian Sea. NASA Satellite Image, June 2020.

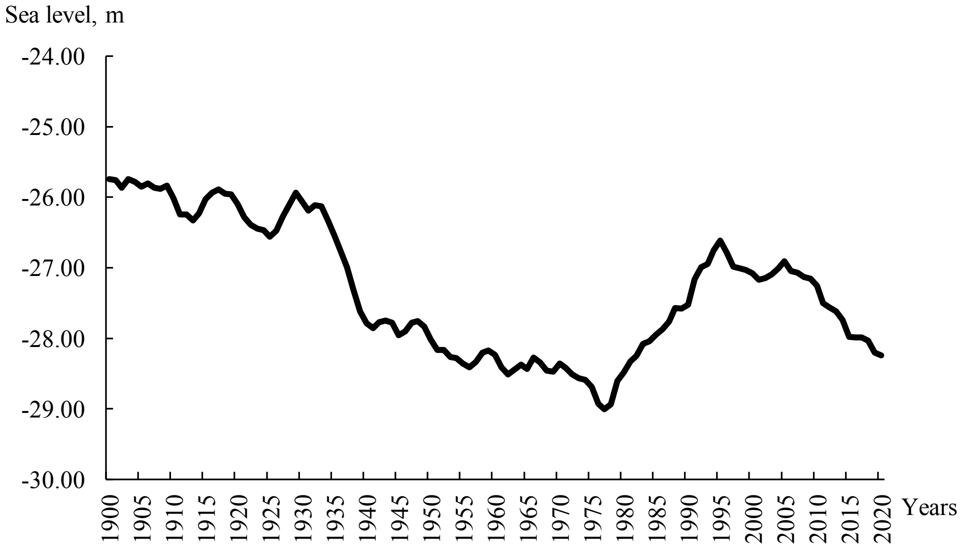


Fig. 2. Changes in the level of the Caspian Sea over the historical period, m BS.

Figure 2 shows the historical course of changes in the level of the Caspian Sea since 1900.

The Caspian Sea has always been characterized by its significant level changes. Over a long period of time, there were also certain periods of decline and rise in the level. Since the 2000-s, sea levels have been falling, as it can be seen in Figure 2. Significant fluctuations in sea level can affect the economy, people and nature. It can also lead to bad consequences in the environment [8]. Therefore, the assessment of sea level change in the future is of great scientific value. It is an essential information for oil-production, shipping, fishing and other enterprises.

The main components of the water balance of the Caspian Sea. The water balance is the ratio between the water that has entered the sea and its consumption. River runoff and evaporation are of the greatest importance for the Caspian Sea water balance. The ratio between the river runoff and evaporation mainly determines the interannual changes in the volume of water and the level of the reservoir. Studies of the relationship between the components of the water balance and the position of the sea level were conducted by a number of authors (Nesterov E.S. [3], Abuzyarov Z.K. [1], Bolgov M.V. [2], Shiklomanov I.A. [12] , etc.). These studies show that climate change in the Caspian Sea basin significantly affected the sea regime in the past, and is still affected in the present.

The input part of the average long-term water balance of the Caspian Sea consists of 20 % of atmospheric precipitation falling on its surface, 1 % – from the inflow of underground water through aquifers, and 79 % – from the river runoff [6].

The flow of the rivers determines the surface inflow to the sea and it is the main positive component of the water balance. River flow to the Caspian Sea is extremely unevenly distributed. More than 130 rivers, flow into the sea. Up to 85 % of the river flow is accounted for by the Volga and Zhaiyk (Ural), which flow into the Northern Caspian Sea. Rivers Kura, Samur, Sulak, Terek, etc, are rivers of the western coast of the sea., and provide up to 10 % of the inflow. Another 5 % of fresh water is brought to the Southern side of the Caspian sea by the rivers from the coasts of Iran. The eastern desert shores are completely devoid of constant fresh runoff. All rivers flowing into the Caspian Sea, with the exception of the Terek, have a regulated flow. The regulation of the flow affects the condition of the seasonal inflow into the sea and the fluctuations in the level.

River flow can vary. In the period from 1936 to 2019, with an average value of 292 km^3 / year, it varied from 393 km^3 to 207 km^3 per year. The year, with the lowest water level was 1975, and the year with the highest water level was 1990.

The Zhaiyk River (Ural) is the main river of the Caspian region in Kazakhstan. It originates in the spurs of the Ural Mountains in the territory of Bashkortostan (Russian Federation) and has a total length of 2428 km [11]. It is the second most important river that determines the inflow of water to the Caspian Sea, after the Volga. The flow of the Zhaiyk River has significantly decreased in recent decades due to climate change and an increase in anthropogenic pressure [5, 10]. The analysis of the flow of the Zhaiyk River for the future is given in

[7], where its flow is predicted until the year 2050. According to the conclusions made by the authors, the flow of the river will continue to decrease.

Precipitation is the second most important input part of the water balance. They are distributed unevenly over the area of the sea. The greatest amount of precipitation (up to 1700 mm/year) falls on the south-western coast of the sea in the humid subtropics of the Lenkoran Lowland, through which the main mass of Mediterranean cyclones passes from west to east. The lowest amount of precipitation falls on the eastern coast of the sea. In the central part of the west coast in its subtropical zone, the annual precipitation is 115...220 mm, decreasing in the direction of the sea (Oil Rocks –110 mm/year). On the most part of the east coast, the annual precipitation does not exceed 95...125 mm. The role of precipitation in the seasonal sea level fluctuations is relatively small compared to the river runoff and evaporation . The annual increase in sea level as a result of precipitation is approximately 20 cm [3].

The consumption part is determined by the amount of evaporation from the sea surface. The level of evaporation depends on the humidity, wind conditions, and on the outflow to the Kara-Bogaz-Gol Bay. Evaporation is ranked second in the intra-annual sea level fluctuations after runoff. Its value depends on the properties of the air masses over the sea and is determined by the thermal state of the underlying surface. The deviation of evaporation from the average long-term value in some years reaches ±10...20 cm, which corresponds to about 30...50 % of the amplitude of intra-annual level fluctuations. Due to evaporation, the sea level decreases by an average of 97 cm per year.

Changes in the interrelationships of these three components of the water balance, especially the river runoff and evaporation, have a great impact on long-term fluctuations of the sea level. The analysis of changes in the main components of the water balance of the Caspian Sea was carried out in [6]. In the period from 2006 to 2019, the Caspian Sea received the least amount of precipitation, and the evaporation processes were more intense. Due to a series of low-water years in the Volga River basin, the average water inflow was also at the lowest. The main reason for this lack of water is the increase in temperature which is the result of the global warming. Which has affected the entire northern hemisphere [4]. As a result, the amount of atmospheric precipitation, mainly the precipitation during the autumn-winter period, which forms the main volume of the Volga River runoff, has significantly decreased. Thus, fluctuations in the level of the Caspian Sea are mainly due to the ratio of the characteristics of the water balance that change under the influence of anthropogenic climate change.

Methods for estimating sea level change for the period up to 2050. The study which shows an impact of climate change in future on the level of the Caspian Sea takes into an account a variety of different factors. These include meteorological factors (atmospheric circulation, precipitation, and evapotranspiration in the catchment area), hydrological factors (flow of flowing rivers and visible evaporation), and anthropogenic factors (regulation of river flow and changes in the properties of the underlying surface for economic purposes [3, 9].

The role of these factors in the long term period can be assessed according to certain scenarios of climate change and water consumption in the basin. The studies which show the factors that determine the natural fluctuations of the Caspian Sea level indicate that the main ones are river runoff (the main contribution is made by the Volga River) and visible evaporation.

The assessment of possible changes in the river flow of the Volga River was carried out using the results of modeling using the Community Land Model, which is part of the conglomerate of the Community Climate System Model (CCSM) and Community Atmosphere Model (CAM) models. This model was developed together by scientists from the National Center for Atmospheric Research (NCAR) and the CCSM Land Model Working Group [13...16].

The model is based on the principles of environmental climatology. It is an interdisciplinary framework which assesses the impact of natural and anthropogenic changes on the climate. The model takes into an account several components: biogeophysics; pydrological cycles; иiogeochemistry.

The CLM land surface model, in turn, includes a river flow module (RTM), designed to route the full flow of water to the oceans or seas, and allows you to close the hydrological cycle [11, 12]. This is necessary in order to model ocean convection and its circulation, which are affected by freshwater runoff. The module also allows you to compare the simulation results with the measurement data at the hydrological stations [14]. The RTM model uses a linear transport scheme-a grid with a resolution of 0.5 ° – to determine the direction of water flow from each grid cell to the next. Changes in the amount of river water in the RTM grid cell (flow rate-m³ / sec) are defined as:

$$\frac{dS}{dt} = \sum F_{in} - F_{out} + R, \quad (1)$$

where $\sum F_{in}$– is the total inflow of water from neighboring cells, F_{out}– is the outflow of water to neighboring cells, R – is the runoff calculated using the CLM model (surface runoff, groundwater, runoff from swamps, lakes, and melting glaciers). The outflow of water from the cell is calculated in 8 directions (north, northeast, east, southeast, south, southwest, west, and northwest). It is based on the use of the largest slope in the cell, obtained from the digital elevation model (DEM). The flow of water flowing out of the cell is calculated by the formula:

$$F_{out} = \frac{v}{d} S, \quad (2)$$

where v – is the effective water flow rate, d – is the distance between the centers of two adjacent cells, S – is the volume of river water in the cell. The effective water flow rate is assumed to be a constant equal to v = 0.35 m / s in accordance with the studies [13]. In the RTM model, calculations are performed with a larger time step than in the CLM model, which is due to computational limitations. Therefore, the total runoff R calculated from the land surface model is summed up until the RTM model is run. The value of R is determined from the ratio:

$$R = q_{over} + q_{drai} + q_{rgwl}, \quad (3)$$

where q_{over} – is surface runoff, q_{drai} – is underground drainage, q_{rgwl} – is runoff from glaciers, swamps, and lakes. The runoff calculated from the land surface model is interpolated into the grid nodes of the model and converted into the dimension m³ / s by multiplying by the cell area of the RTM model.

The RCP family of greenhouse gas concentration scenarios (Representative Concentration Paths) were used in the study basin to estimate future changes in air temperature and precipitation . The data of the river flow projection for the Volga River under the scenarios RCP4. 5 (which corresponds to the concentration of 650 p.p.m) and RCP8.5 (1370 p.p.m) up to 2100 are available on the website https://www.earthsystemgrid.org/. Data processing for the Volgograd reservoir alignment and its visualization was carried out using the IDV (Integrated Data Viewer) software product.

To determine the inflow of water to the Caspian Sea in the future, the dependence of the flow of the Volga River in the Volgograd reservoir on the inflow of river waters to the Caspian Sea for the period 1978...2019 was constructed. (Fig. 3). This dependence has a correlation coefficient of 0.96, which indicates a good tight connection and the ability to restore the inflow of river waters to the sea in the future. Taking into account climate change, using the flow of the Volga River in the Volgograd reservoir.

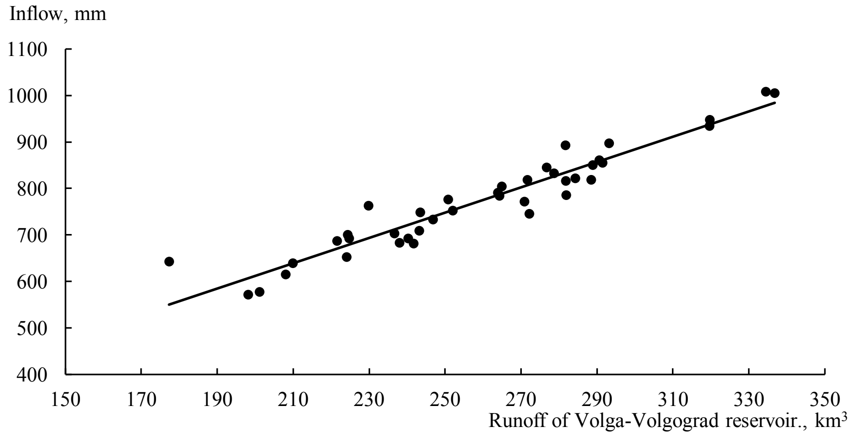


Fig. 3. Dependence of the inflow of river water to the sea on the flow of the Volga-Volgograd reservoir from the total inflow of river water to the Caspian Sea for 1978...2019.

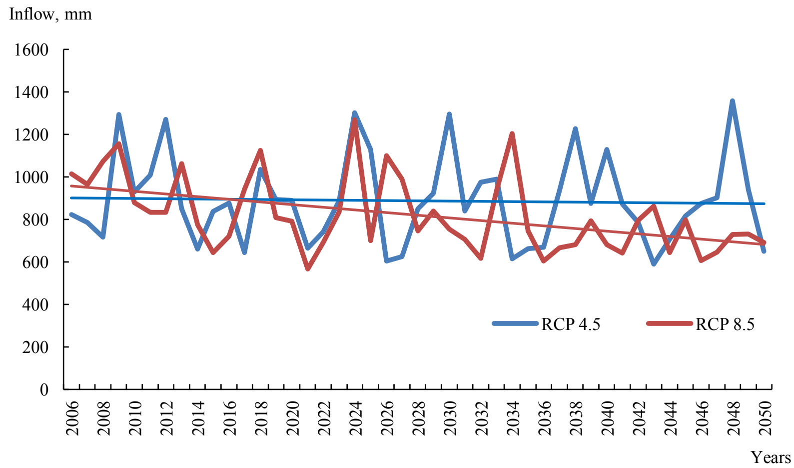


Fig. 4. The course of changes in the inflow of river waters to the Caspian Sea until 2050 under the scenarios RCP4.5 and RCP8.5.

Figure 4 shows the projections of changes in the inflow of the river water into the sea in the future under the scenarios RCP 4.5 and RCP 8.5.

As the results of the calculation showed above, the inflow of water to the Caspian Sea has no pronounced trend. Precipitation and evaporation in the Caspian region were also calculated for two selected climate scenarios, RCP4.5 and RCP8.5, based on an ensemble of climate models. The results are shown in Figure 5.

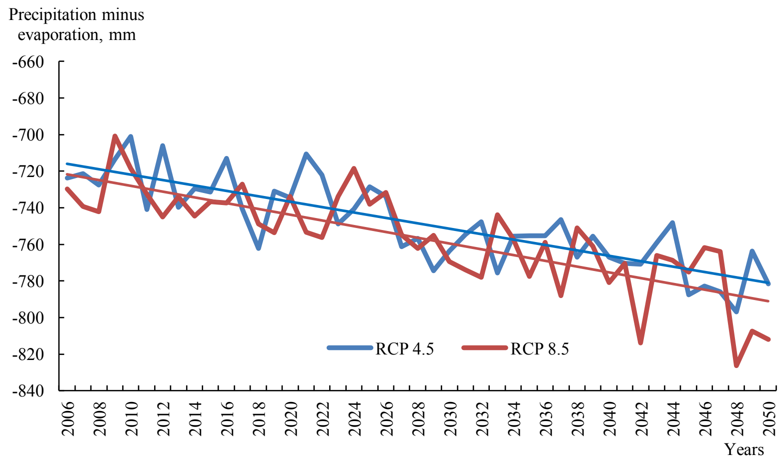


Fig. 5. Changes in the difference between precipitation and evaporation for the period up to 2050 in accordance with the climate change scenarios RCP4. 5 and RCP8.5.

As it can be seen from the graph, there is a steady trend, which means that evaporation from the Caspian Sea will increase. This is due to the predicted increase in air temperature.

Based on the projected data on the inflow of river waters into the Caspian Sea, as well as the visible evaporation, the change in the level of the Caspian Sea was predicted until 2030 (table 1).

Table 1

Changes in the level of the Caspian Sea for the future up to 2050 according to two climate scenarios, m BS

Years/The script	RCP4.5 scenario	RCP8.5 scenario
2030	-29,23	-29,63
2050	-31,84	-33,67

Figure 6 shows a visual graph of the projected level of the Caspian Sea, taking into account two climate change scenarios (RCP4.5 and RCP8.5), as well as the actual level change (until 2020).

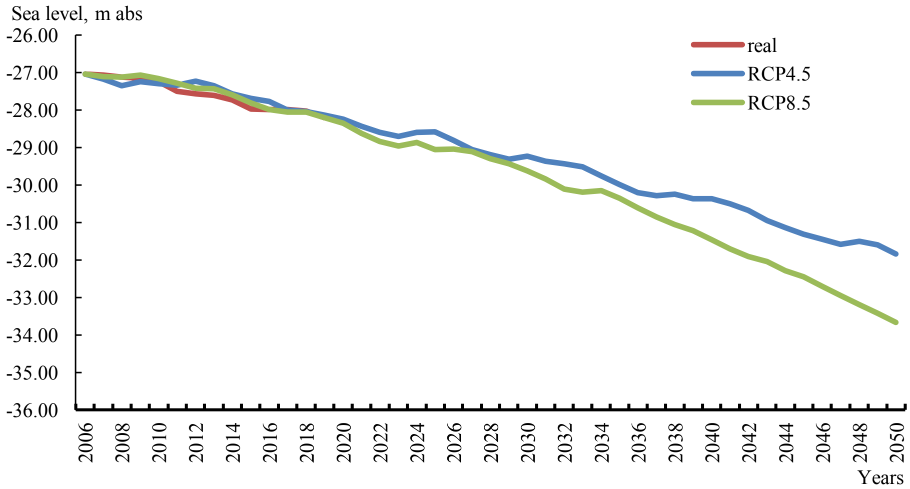
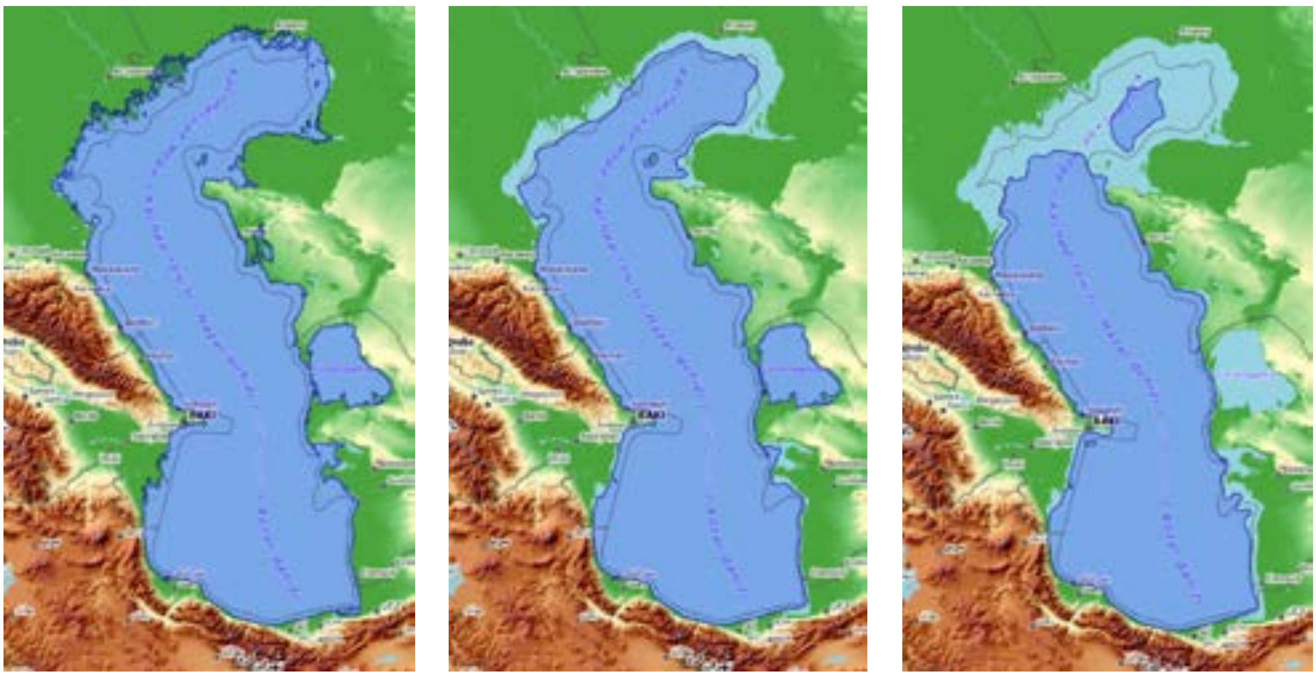


Fig. 6. Forecast values of the Caspian Sea level for two climate change scenarios (RCP4.5 and RCP8.5) for the future until 2050.

Calculations have shown that the level of the Caspian Sea has a steady downward trend. This will be especially clear in the second third part of the 21st century. According to our calculations, the level of the Caspian Sea may reach -29.4...-29.6 m by 2030.

Under the RCP4.5 scenario, the level may approach minus 32 m by 2050, and under the more pessimistic RCP8.5 scenario, the level may fall below minus 33 m (Fig. 7).



a) b) c)

Fig. 7. Visual representation of spatio-temporal changes in the level of the Caspian Sea and its coastline.
a) 2020 year, b) 2030 year, c) 2050 year
(Visualization was performed by Natalia Mamaeva, as part of the Master's thesis project " Visualization of changes in the Caspian coastline").

It should be noted that the forecast values of the Caspian Sea level may change, depending on the receipt of additional hydrometeorological information.

Conclusion. Studies have shown that the input part of the water balance of the Caspian Sea will not undergo any major changes until 2050. At the same time, the expenditure part will increase significantly. This may lead to a further drop in the water level of the Caspian Sea and a reduction in its area. The reduction of the area, in turn, will have a very negative impact on the Kazakh part of the sea. This is due to the fact that the Kazakh part of the Caspian Sea has a small depth and even a smaller decrease in the level, which leads to the water slipping away from the coast for considerable distances. This complicates the work of oil-producing enterprises, shipping, and also will have a negative affect the flora and fauna.

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ОЦЕНКА КОЛЕБАНИЙ УРОВНЯ КАСПИЙСКОГО МОРЯ ПОД ВОЗДЕЙСТВИЕМ ИЗМЕНЕНИЯ КЛИМАТА НА ПЕРСПЕКТИВУ ДО 2050 ГОДА

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В статье рассматривается возможное колебание уровня Каспийского моря на перспективу до 2050 года с учетом климатических изменений. Для этого были спрогнозированы возможные изменения речного притока в море и метеорологические параметры (осадки, температура воздуха и испарение с водной поверхностистока). Изменение метеорологических параметров оценивалось согласно двум климатическим сценариям RCP4.5 и RCP8.5.

Ключевые слова: изменение уровня, Каспийское море, приток речных вод, сценарии изменения климата, прогноз ууроня на перспективу

2050 ЖЫЛҒА ДЕЙІНГІ ПЕРСПЕКТИВАДА КЛИМАТТЫҢ ӨЗГЕРУІ ӘСЕРІНЕН КАСПИЙ ТЕҢІЗІ ДЕҢГЕЙІНІҢ АУЫТҚУЫН БАҒАЛАУ

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Мақалада климаттық өзгерістерді ескере отырып, 2050 жылға дейінгі перспективада Каспий теңізі деңгейінің ықтимал ауытқуы қарастырылады. Ол үшін теңізге өзен ағысының өзгеруі және метеорологиялық параметрлер (жауын-шашын, ауа температурасы және су бетіндегі булану) болжалды. Метеорологиялық параметрлердің өзгеруі RCP4.5 және RCP8.5 екі климаттық сценарий бойынша бағаланды.

Түйін сөздер: деңгейдің өзгеруі, Каспий теңізі, өзен суларының ағыны, климаттың өзгеру сценарийлері, перспективаға деңгейдің болжамы