

CASPIAN SEA LEVEL CHANGE AS AN INDICATOR OF GLOBAL AND REGIONAL GEOLOGICAL PROCESSES

Tarana H. Tahmazova¹, Firuza Z.Mehdizadeh²

¹Baku State University, 33, Z. Khalilov str. AZ 1148 Baku, Azerbaijan

²Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences, 25, Nigar Rafibeyli str.,AZ1001, Baku, Azerbaijan

<https://doi.org/10.30546/209805.2025.2.4.2034>

Abstract

The article examines changes in the level of the Caspian Sea as a result of predominantly endogenous factors, including tectonic subsidence and uplift of the seabed, as well as quasi-periodic variations in the stress state of lithospheric plates, manifested through regimes of compression, extension, and stabilization. Exogenous influences are also analyzed, such as river inflow volume, water balance, evaporation rates, wind effects, and other climatic parameters. The potential connection between long-term sea level fluctuations and variations in solar activity is discussed. As an empirical basis, the study uses data from statistical analyses of historical and archaeological sources, along with the results of instrumental observations of the Caspian Sea level.

Keywords: Caspian Sea, level change, tectonic processes, lithospheric plates, exogenous factors, solar activity, historical and archaeological data, instrumental observations

*Corresponding author.

E-mail address: taranatahmazova@bsu.edu.az (T.H.Tahmazova)

fikerimova@yahoo.com (F.Z.Mehdizadeh)

Introduction:

Fluctuations in ocean and sea levels are among the most important indicators reflecting the complex interaction of geological and climatic processes. The level of the World Ocean is influenced by both long-term changes, driven by tectonic movements, isostatic fluctuations, and global cycles of glacier accumulation or melting, and by shorter-term variations associated with increases in water volume, mass redistribution in the atmosphere, and changes in the freshwater balance. However, not all water basins respond to global factors in the same way. Regional, and especially isolated, marine basins—such as the Caspian Sea—demonstrate a specific type of level dynamics, determined, on the one hand, by local climatic conditions and precipitation regimes, and on the other hand, by the hydrological balance, geodynamic features, and tectonic movements[1, 2, 4].

The Caspian Sea, as the largest enclosed body of water on the planet, represents a unique object for studying intracontinental mechanisms of water level fluctuations. Its behavior often deviates from global trends and requires a comprehensive analysis of numerous natural and anthropogenic factors [3, 4, 7, 8].

Materials and discussion:

In preparation of this article, data from scientific papers and monographs dedicated to the geological structure of the Caspian region were systematized. Special attention was given to the analysis of existing hypotheses regarding the formation of the South Caspian Basin and the assessment of the geological history of the region within the context of the central segment of the Mediterranean geodynamic belt. This approach enables a comprehensive understanding of the geodynamic processes influencing changes in the Caspian Sea level [5, 6].

It is well known that the Caspian Sea has undergone geological evolution over hundreds of thousands of years. This evolution follows a sinusoidal pattern of subsidence and uplift cycles, with long-term processes of seabed lowering and rising occurring over tens of thousands of years. As for shorter cycles, if we consider changes over a 150-year period, such fluctuations are periodic and occur in small cycles lasting approximately 50–55 years. In 1905, the Caspian Sea reached its highest recorded level at –22.4 meters, while by 1925 the level had dropped to –24.4 meters. If we analyze sea level changes over the past 150 years, the lowest level (–29 meters) was observed in 1977. The rise in sea level began in 1978. There have even been cases when the Caspian rose to levels as high as –20 to –22 meters, only to drop again to –29 meters [2].

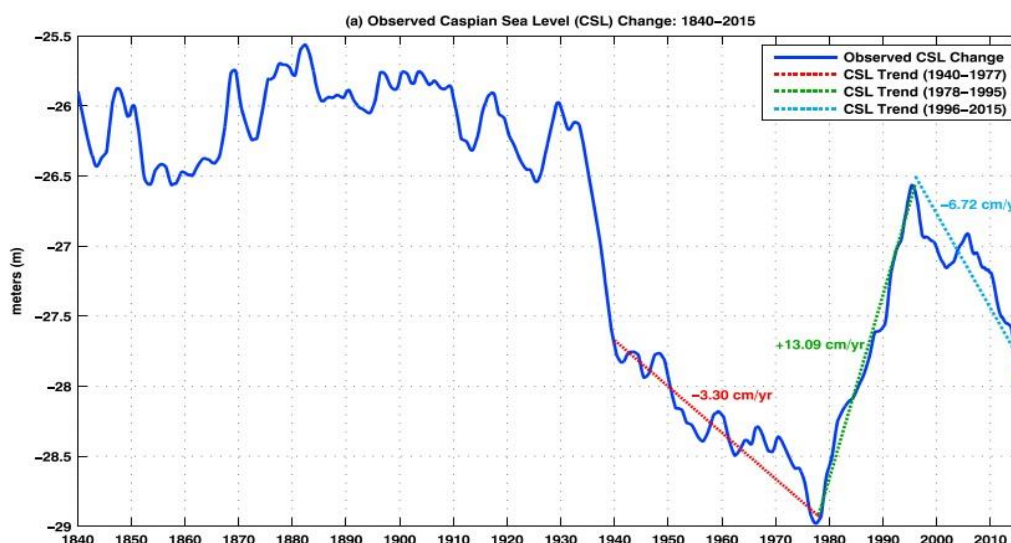


Fig.1. Caspian Sea Level Change 1840-2015 [2]

In the table below, data are presented on the changes in the level of the Caspian Sea over approximately the last 100 years (approximately 1925–2023), collected from reliable scientific sources, with an indication of absolute values, events, and references to publications:

Table 1

Changes in the Caspian Sea level over the past 100 years

Period	Level (m, Baltic system)	Change (m)	Average trend (cm/year)	Character of Dynamics	Source / Publication (year, pages)
1925–1930	≈ -25.8	—	—	Stable	Khoshravan et al., 2020 (Int. J. Mar. Sci.), pp. 14–16
1930–1941	-27.7	-1.9	~-17	Rapid drop	Khoshravan et al., 2020; Lavrova et al., 2011
1941–1977	-29.0	-1.3	~-4	Gradual decline	Lavrova et al., 2011 (Remote Sens. Lett.), pp. 87–92
1978–1995	-26.5	+2.5	~+14	Transgression	Kostianoy & Kosarev, 2005 (Springer), pp. 450–456
1995–2005	-27.5	-1.0	~-10	Rapid decrease	Lebedev, 2004 (COSPAR 35th)
2005–2021	-28.7	-1.2	~-8.8	Steady decline (satellite era)	Chen et al., 2023
2021–2023	≈ -29.0	~-0.3	~-7	Ongoing decline	Projection from CMEMS/ESA data (Nature Comm., 2023), pp. 2–4

Note: The levels are given according to the Baltic system (zero mark corresponds to the level of the Baltic Sea). For clarity, trends are rounded to whole numbers. The table uses data from instrumental observations (up to 1992) and satellite observations (after 1992).

The period of intense sea level decline corresponds to the years 1932–1945. During this time, the sea level dropped by 1.85 meters. In the following decade, starting from 1956, the sea level decreased by an additional 0.5 meters, reaching -28.5 meters. Due to the reduction of water volume in the sea by 1,000 km³, its surface area decreased by 27,000 km².

Table 2
Variation of the area of the Caspian Sea

Sea level (m)	Northern Caspian (km ² x1000)	Middle Caspian (km ² x1000)	Southern Caspian (km ² x1000)	Entire Sea (km ² x1000)
-25.97	111.0	138.6	151.4	401.0
-26.97	104.0	138.2	149.9	392.1
-28.0	90.30	137.7	148.5	376.5
-29.0	72.8	137.3	146.9	357.0
-30.0	62.8	137.0	145.3	345.1

However, in separate periods, the rise in the level can also be accompanied by short-term relative decreases. One such case was, in particular, after the Baku earthquake of November 25, 2000. As a result of the earthquake, the sea level dropped and the submerged piers on the coast were exposed due to the withdrawal of water. According to calculations, there was a subsidence on the southern coast of Absheron due to the earthquake and the sea level dropped by 50 cm [2]. It has been established that when earthquake energy is accumulated, that is, on the eve of an earthquake, the water level in the wells usually rises and the amount of radon gas in the water also increases. After the energy is released, the water level in the well drops and the amount of radon decreases. It is assumed that after the November 25 earthquake, the sea level dropped due to such a regularity and the water withdrew from the coast. As a result of such a rise in the Caspian Sea, in 1998, a coastal strip from 500 meters to 4-5 km, that is, an area of 20-25 thousand hectares of land was flooded. Furthermore, as sea level rises, Cl, Na salinization is expected to occur instead of the previous Cl, Mg, Na type salinization.

It is known that the change in sea level depends, first of all, on the tectonic subsidence and elevation of the seabed, and, secondly, on the amount of water balance brought by rivers flowing into the sea, the rate of water evaporation, the influence of wind and a number of other factors. However, this issue has not been studied precisely so far. When analyzing the impact of the tectonic factor on the change in the level of the Caspian Sea of modern and new tectonic movements, it becomes possible to include it among the main factors. Thus, the study of the Caspian Sea with high-precision methods will allow obtaining certain information about this [6, 7].

Studies show that modern movements affecting the seabed over a period of 12-15 years have caused a change of 12-15 cm. The maximum subsidence was on the coasts of Baku and Chelekan. According to materials published in the literature, subsidence or rise was not the same everywhere over a period of 16 years [4, 5].

The variability of the Caspian level is attributed, on the one hand, to endogenous, and on the other hand, to exogenous processes, and in some cases it is characteristic that they are complex. Therefore, in order to form different opinions, it is necessary to consider both the concepts of exogenous and endogenous changes in the level, specify the territory, separately evaluate the role of factors in the change, and finally, determine the regularity of the change and its forecast for the future. Here, the main attention should be paid to the endogenous concept of level change.

Without denying the influence of exogenous processes on the change in the level of the Caspian, we can say that this is an extremely complex, various processes occurring at different depths of the Earth, in terms of changes in the level of the seas and oceans, cause the inflow of water into the hydrosphere, and a change in the volume of basins. According to expert calculations, during the history of the Earth's development, about 4.2 billion km³ of water has been released from the mantle during the processes of melting and degassing. Dehydration in the Earth's interior continues to the present day, resulting in the annual inflow of 360 km³ of interplanetary water into the World Ocean. This causes the level of the World Ocean to rise by 0.6 mm per year. Naturally, this process will be reflected to varying degrees in the level of the World Ocean and its associated water basins [4, 8].

As mentioned above, the change in the level of the Caspian Sea is determined by the autonomous reaction of the basin to exogenous and endogenous processes. Here, priority is also given to climatic-anthropogenic factors. However, the assumed regularity is explained by the concept of geodriftogenic. In geodriftogenic morphogenesis, special geochrons are distinguished. Each entire geochron cycle, in turn, is divided into morphodiversal, morphoconvergent and morphoanvergent stages. As a result of the analysis of geodriftogenic regularities, it can be seen that the complexity of the Caspian region, its special geological-geomorphological structure and geodynamic conditions are closely related to the conditions of the collisional evolution of the relief. According to this concept, the presence of ophiolite-associated magmatogenic rocks, horizontal displacement of the layers of the alpine sedimentary cover, seismotectonic activity, intensity of mud volcanoes, variation of geophysical fields, etc. processes occur.

The relationship between the level of the Caspian Sea and long-term changes in solar activity is among the issues under discussion. To determine this, an analysis of the given parameters was conducted. First, let's note what we mean by the concept of solar activity. Dark areas periodically form on the surface of the Sun. Such spots exist from several hours to several months. Spots form with a hidden periodicity. This process was discovered by Max Wolf in 1850 and was eventually called solar activity. Various indices are used to quantitatively characterize solar activity. The most widely used among them is the Wolf number:

$$W = k (f+10g) \quad (1),$$

where: W—Wolff number; f—total number of spots; g—group number of spots; k—proportionality coefficient depending on the resolving power of the telescope.

The Wolff number varies from day to day and during the minimum of activity reaches from 0 to 11 units, and during the maximum of activity—from 40 to 200, and can reach even higher units. Usually, when talking about solar activity, an 11-year cycle is meant. The development of spots formed on the surface of the Sun takes from 7 to 17 years between the two maximum phases. The 11-year period is an average statistical period. For the analysis, the average annual values of solar activity and the level of the Caspian Sea are taken.

Then, the given parameters are calculated for periods of 50 and 100 years. The change in solar activity and the level of the Caspian Sea occurs in opposite phases - with increasing solar activity, the level of the Caspian Sea decreases [2, 3, 7].

From this, it can be concluded that the change in the level of the Caspian Sea is a regular process. The obtained data allow us to build a model of the change in the level of the Caspian Sea.

Based on the results of the statistical analysis of historical-archaeological data and instrumental observations of the change in the level of the Caspian Sea, it can be seen that the assumed numerous and noted changes have occurred throughout the entire geological history of the basin. This, of course, will be repeated in the future. Therefore, the study of the relationship of sea level changes with geodynamic factors and its prediction remains an urgent problem. The periodic level variability observed in the Caspian Sea is closely related to the quasi-periodic change in the tension of lithospheric plates and the compression, divergence and stabilization regime.

Thus, the next stabilization may last until 2030-2035, then the level may begin to decline for 8-10 years, and stabilization may begin again at about -29 m during 2045-2085.

Conclusion:

The results of the analysis allow us to state that the change in the Caspian Sea level is caused by the combined effect of endogenous and exogenous factors, with the dominant role of deep geodynamic processes. The greatest influence is exerted by tectonic subsidence and uplift of the bottom, as well as quasi-periodic changes in the stress-strain regime of lithospheric plates, manifested in the alternation of compression, extension and stabilization phases within the Caspian region. Exogenous components—including river runoff, evaporative losses, wind effects and other hydroclimatic parameters—form a dynamic manifestation of level fluctuations, reflected in short- and medium-term changes in the water balance. A possible correlation between long-term changes in solar activity and the Caspian Sea level regime requires further verification within the framework of an interdisciplinary approach, involving instrumental observations and independent sources of paleogeographic information.

Aggregation of statistical analysis data of archaeological evidence and results of long-term observations of sea level confirms the need for a comprehensive approach to studying level fluctuations. The set of presented assessments creates a methodological basis for developing prognostic models of marine dynamics in the context of ongoing regional and global geodynamic transformations.

References:

- [1] Alexander N. Makarov, Elena V. Kharitonova (2023). Long-Term Changes in the Level of the Caspian Sea and Modern Forecasting Methods. *Bulletin of the Russian Academy of Sciences*. Volume 83, issue 6, pp. 1224-1236. DOI: 10.31857/S2587556623060067
- [2] Chen, Y., Liu, Q., & Huang, Q. (2023). Caspian Sea level change observed by satellite altimetry. *Remote Sensing*, 15(3), Article 703, pp. 1–20. DOI: [10.3390/rs15030703](https://doi.org/10.3390/rs15030703)
- [3] Dmitry V. Zaytsev, Alexey V. Soloviev, Maria V. Ivanova (2023). Satellite Altimetry Observations of Caspian Sea Level Changes (1993–2021). *Remote Sensing*. Volume 15, pp. 703 (1-19). DOI: 10.3390/rs15030703
- [4] Igor V. Petrov, Natalia S. Kuznetsova (2024). Climate Change Impacts on Temperature and Precipitation Over the Caspian Sea. *International Journal of Water Resources Development*. Volume 40, issue 4, pp. 702-718. DOI: 10.1080/07900627.2024.2313050
- [5] Khoshravan, A., Esmaili, A., Jabbari, H. (2020). The hydromorphology of the Caspian Sea. *International Journal of Marine Science*, 10(1), pp. 14–22. DOI: [10.5376/ijms.2020.10.0001](https://doi.org/10.5376/ijms.2020.10.0001)
- [6] Nasrollahi, N., Rahimzadeh, F., ZareAbyaneh, H. (2023). Projected long-term desiccation of the Caspian Sea under climate change. *Nature Communications Earth & Environment*, 4, Article 17, pp. 1–10. DOI: [10.1038/s43247-023-01017-8](https://doi.org/10.1038/s43247-023-01017-8)
- [7] Samir M. Hasanov, Aysel G. Abbasova (2023). Impact of Caspian Sea Water Level Decrease on Gull Species in Gizilaghaj Bay. *Journal of Wildlife and Biodiversity*. Volume 7, issue 2, pp.56-63. DOI: 10.5281/zenodo.11105711
- [8] Tural R. Aliyev, Leyla M. Huseynova (2025) Consequences of the Sharp Lowering of the Caspian Sea Level in the Coastal Zone of Azerbaijan. *Hydrometeorology and Ecology*. Volume 116, Issue 1, pp. 38–44. DOI: 10.54668/2789-6323-2025-116-1-38-44