WORKING PAPER

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An aerial view of Baku, located on the shore of the Caspian Sea. September 24, 2023. (@Ozkan Bilgin / Anadolu / AFP)

Caspian Sea Fluctuations and Climate Change

Coordinated research is needed to understand how climate change is impacting Caspian Sea levels.

The Caspian Sea's water levels are declining. While the science of Caspian Sea fluctuations is complex, there is growing evidence that substantial further declines will occur in the next 50 years, with impacts on the environment, economies, infrastructure and sustainable development. Coordinated, scientific research is required across and beyond the Caspian Sea littoral states to address the relationships between changing temperatures, winds, evaporation, precipitation, discharge from rivers, human water use and diversions. Climate change is influencing all these variables and hence joint analysis of climate and adaptation science will also help Caspian states to understand the challenges, identify appropriate adaptation options and plan effectively for the future.

The Caspian Sea: An important and threatened ecosystem

The Caspian Sea is the largest inland water body in the world, by both area and volume. It is shared by five countries: the Republic of Azerbaijan, the Islamic Republic of Iran, the Republic of Kazakhstan, the Russian Federation and Turkmenistan. Its vast catchment covers approximately 3.6 million km2, including six climatic zones (see Caspian Basin, GRID Arendal (2012), page 3). The sea itself is approximately 10 per cent the size of the basin, at 392,600 km2, with depths ranging from 5–10m in the shallow northern section, to a maximum of 788m in the middle section, and over 1,000m in the southern section (Samant and Prange 2023). The mean salinity of the sea is 1.2 per cent (brackish).

An Iranian fisherman pulls in his almost empty net after an unsuccessful fishing trip in the Caspian Sea in Koshk Estalkh village . October 2013 (BEHROUZ MEHRI / AFP)

There are five main drainage basins flowing into the Caspian Sea, involving nine countries. The Volga River (Russian Federation) accounts for about 80 per cent of inflow, though this flow varies due to climatic and anthropogenic factors (Gorelits et al. 2022; Safarov et al. 2024). Other significant inflows include the Kura-Aras River (approximately 6 per cent, flowing through Azerbaijan, Armenia, Georgia, Iran and Türkiye), the Ural (approx. 3 per cent, flowing through the Russian Federation and Kazakhstan) and the Terek (2.5 per cent, flowing through Georgia and the Russian Federation) (Samant and Prange 2023). There are approximately 130 rivers in these main basins (Safarov et al. 2024). The sea has no natural outflow, thus the Caspian ecosystem is a closed basin. Without a natural connection to the globe's oceans, the average Caspian Sea level is currently approximately 28m below mean sea level, though this level is subject to small tidal ranges (Medvedev et al. 2020) and is continually fluctuating (Safarov et al. 2024).

The Caspian Sea delivers considerable ecosystem services to millions of people, supporting shipping and transport, commercially important fisheries, water for agriculture and industry, and work and recreation opportunities, including tourism (Janusz-Pawletta 2021). The Caspian Sea also provides air quality and temperature regulation for littoral countries (Abbasov et al. 2022).

An aerial view taken on May 5, 2021 shows a railway bridge over the Volga river and a port in the city of Astrakhan. (©Andrey BORODULIN / AFP)

The employment opportunities provided by port services, fishing, tourism and other industries are especially important in a context in which food and energy price spikes and regional uncertainties risk pushing more people into poverty, with impact on vulnerable groups including women, youth and marginalized groups (United Nations Development Programme 2022; World Bank Group 2022)..

There are 10 major ports and several minor ports on the Caspian Sea that are important for the economies of the littoral states (Akbulaev and Bayramli 2020). Ports are particularly vulnerable to changes in the sea level due to their high capital costs, fixed location and longevity (Wallingford 2024). The largest Russian Federation port on the Caspian Sea, Astrakhan, has used the 188km **Volga-Caspian Canal** for ships to travel between the port and the Caspian Sea for over 100 years and there may be implications on navigability with any changes to water levels in the Volga River and Caspian Sea (**Rosmorport 2021**).

Figure 1: The Caspian Basin. (Source: GRID Arendal/UNEP 2012. https://www.grida.no/resources/5732)

The Caspian Sea is home to at least 130 fish species and over 100 species of wetland birds. Its waters are also home to several threatened species, including an estimated 90 per cent of the planet's last remaining sturgeon. In the northern Caspian, shallow waters teem with molluscs, crustaceans, fish and birds. The Caspian Sea also hosts migratory and wintering birds. Endemic, endangered Caspian Seals raise their pups on winter ice that usually only forms in this part of the Caspian Sea (NASA 2022).

Caspian flora and fauna, including wetlands and shoreline ecosystems, are impacted by changes in the water level and other human-induced factors, including alterations in nutrient balance and organic matter due to agricultural expansion and the development of dams, overfishing and anthropogenic climate change. Warming trends and human activities have led to water column stratification, oxygen depletion and hypoxia, especially below 400 m depth (Lahijani *et al.* 2024). Species decline arising from multiple, cumulative stressors has been documented (Bodini *et al.* 2024).

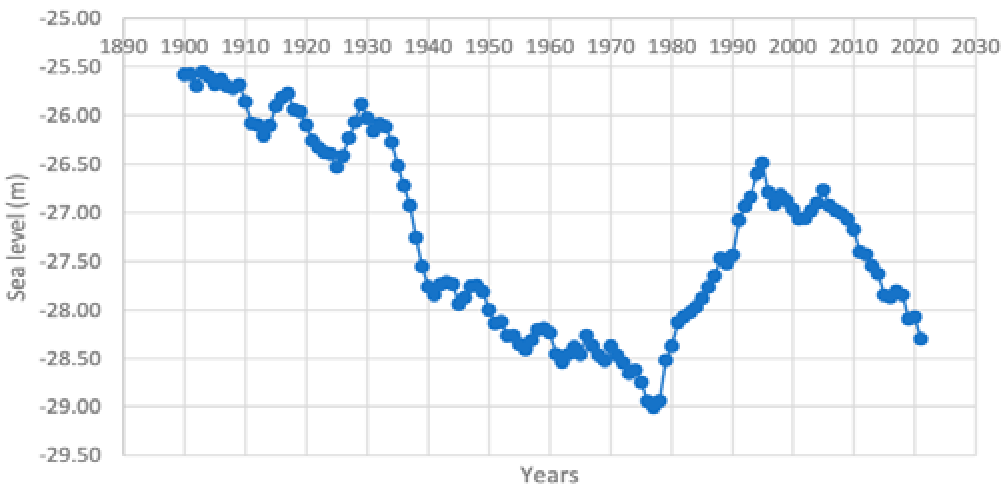
Historic Caspian Sea level fluctuations

Historically, water levels have fluctuated significantly, with variations of more than +/- 3m in the 20th century alone (Chen *et al.* 2017) and with even greater fluctuations over a longer timeframe (Koriche *et al.* 2021a).

Since 1900, the water level fell 3.5m from the highest recorded level to the lowest recorded level in 1977 (Figure 2).

From 1978 to 1995, the water level rose by 2.5m and between 1996 to 2015, the water level fell by approximately 1.5m (Chen et al. 2017). Since 2006, this decline appears to have accelerated (Samant and Prange 2023).

Figure 2: Changes in Caspian Sea levels (from Mahachcala hydrological station (Russian Federation) [Safarov et al. 2024])



Understanding why Caspian Sea levels fluctuate

The main factors affecting water levels in the Caspian Sea are inflow from the surrounding catchment (including flow from rivers), and precipitation and evaporation from the sea itself. Groundwater exchanges are believed to be negligible compared with the other factors (Firoozfar *et al.* 2012).

1. Inflow: This is primarily influenced by a combination of precipitation over the catchments (including snowfall in some areas); the operation of dams (including related changes in water consumption and evaporation); vegetation cover and runoff, including changes in seasonal runoff; and human withdrawals (e.g. for irrigation and industry). Discharge along the rivers of the Caspian Sea catchment is regulated by over 14,000 dams built during the past 90 years, which together have the capacity to store >75 per cent of the total discharge to the Caspian Sea (Akbari et al. 2020; Koriche et al. 2021a). Dam construction intensified from the 1950s to the 1980s in the whole catchment, and is currently continuing mainly in the southern catchment area (Lahijani *et al.* 2024). Some studies estimate that human diversions and withdrawals affecting the inflow have resulted in a Caspian Sea water level 1.5m lower than "natural" conditions (Safarov et al. 2024). However, considerable uncertainty about the historical drivers of sea level variation has arisen due to the lack of coordinated water monitoring systems at the catchment level (Koriche et al. 2021a). The vast latitudinal expanse of the basin results in a complex climatological setting, with seasonal variability of precipitation patterns in the northern and southern catchment regions. Within the Volga catchment, precipitation has varied significantly (see Figure 3, from Safarov et al. 2024).

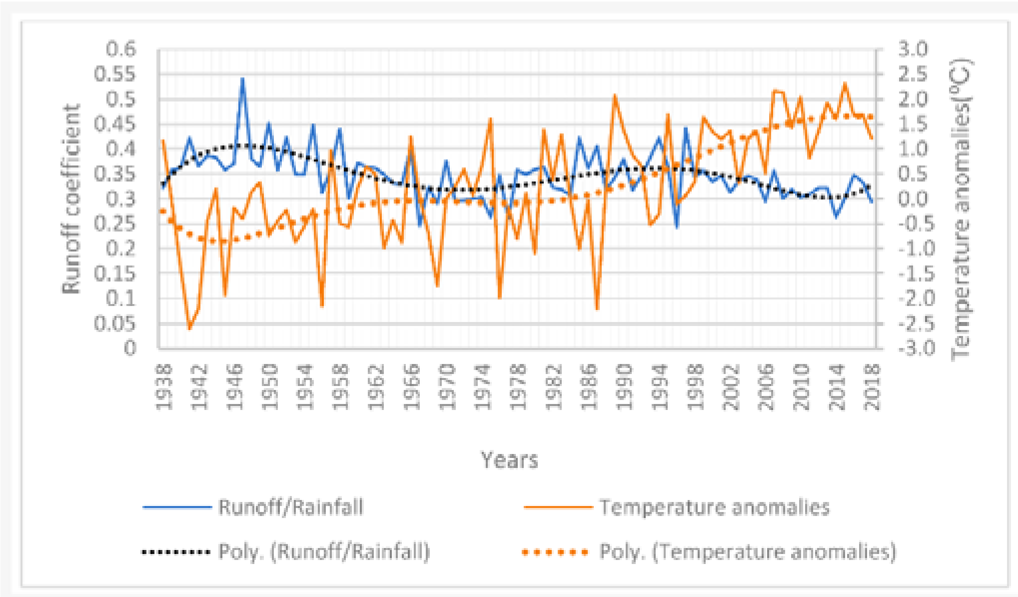
2. Precipitation and evaporation over the sea surface: As with precipitation over the catchment, the precipitation patterns over the Caspian Sea have varied significantly. Sea evaporation is influenced by air and sea surface temperatures, wind direction and speed, including the relative dominance of influences from the North Atlantic and Pacific oceans which impact wind direction and air temperatures (Serykh and Kostianoy 2020; Diansky *et al.* 2022). Generally, increases in evaporation from the sea surface as a result of climate change are expected to have more significance than increases in precipitation (Hoseini *et al.* 2024). Significant evaporation also occurs from the shallow and highly saline Garabogazköl lagoon, which is connected to the eastern edge of the Caspian Sea via a narrow channel (Tatarnikov and Ocheretny 2022). Climate changes to winds and temperatures are believed to have significantly increased evaporation from the sea (Lahijani *et al.* 2024).

The fall in Caspian Sea levels from the 1930s to the 1970s was partly attributed to a drop in precipitation over the Volga catchment (see Figure 3), and partly to the construction and filling of dams on the Volga for a mixture of hydropower, transport and water use (Koriche *et al.* 2021a). The average runoff volumes for the period of natural (1881–1957) and regulated (1961–2017) regimes according to the data of the Volgograd hydrological station are 256 km^3/year and 249 km^3/year, respectively (Migunov *et al.* 2023; Safarov *et al.* 2024).

Gorelits *et al.* (2022) analyse changing water consumption patterns in the Volga Basin, noting that from 1961 to the early 1990s water consumption increased due to regulation, irrigation, and industrial and municipal water supply. From the early 1990s, consumption levels slowed, and were restored to the previous volume only recently (Gorelits *et al.* 2022). The rise in sea level from 1978 to 1995 has been attributed to slightly increased precipitation in the Volga catchment during this period (see Figure 3, from Safarov *et al.* 2024). The filling of reservoirs may also have been completed by the late 1970s. Chen *et al.* (2017) note that analysis of the changing Caspian Sea levels is complicated by the lack of adequate *in situ* measurements of discharge from major rivers other than the Volga over the 1979–2015 period, and of outflow to Garabogazköl Bay.

Recent declines in the Caspian Sea level have been attributed to increasing evaporation, strongly linked to changing wind regimes (Chen *et al.* 2017; Arpe *et al.* 2020; Safarov *et al.* 2024). Figure 3 shows a slight decline in Volga Basin runoff/rainfall since the mid-1990s, accompanied by temperature anomalies starting in the same period (Safarov *et al.* 2024).

Figure 3: Time courses of runoff coefficient and air temperature anomalies of the Volga River Basin for the period 1938–2020 (Source: Safarov et al. 2024)



What is predicted to occur with future Caspian Sea levels

Efforts to forecast long-term variations in the Caspian Sea level have proven to be a formidable challenge (Interim Secretariat of the Framework Convention for the Protection of the Marine Environment of the Caspian Sea 2019; Lahijani *et al.* 2023; Hamid *et al.* 2024) even before the advent of anthropogenic climate change, which adds a further layer of uncertainty.

In the literature on climate-related changes to the Caspian Sea region, there is general but not absolute consensus that average precipitation will increase across the Caspian Basin (with significant variations within it, and increased intensity in some areas) (Georgiadi *et al.* 2022; Svetasheva *et al.* 2022; Zarrin and Dadashi-Roudbari 2022), and over the sea itself (ranging from a 2.3 per cent decrease to a 20 per cent increase in precipitation (Hoseini *et al.* 2024). This precipitation increase is not, however, expected to be as significant as the increase in evaporation (mainly over the Caspian Sea itself, but also because increasing temperatures exacerbate anthropogenic impacts such as irretrievable water consumption for municipal and agricultural needs increases [Safarov *et al.* 2024]): hence overall expected decreases in Caspian Sea level. Precipitation-evaporation trends are widely expected to be negative by 2100 (Koriche *et al.* 2021a; Samant and Prange 2023).

Projections of changes to sea level during the past few decades have varied significantly, with earlier estimates from +/- 1–2m (Bolgov *et al.* 2007), to others between 4m and 9m (Elguindi and Giorgi 2006; Elguindi and Giorgi 2007; Renssen *et al.* 2007), to more recent projections of declines between 8m and 14m and even as high as 20m to 30m (Nandini-Weiss *et al.* 2020; Koriche *et al.* 2021a; Ivkina and Galaeva 2022; Samant and Prange 2023). However, those predicting higher declines may be overestimates due to the complex relationship between water levels and sea surface area, and other feedback loops (Koriche *et al.* 2021a; Samant and Prange 2023). The significant differences in projected water level changes between the studies is influenced by selection of climate change models, socioeconomic pathways (**SSPs**), hydrological models, representation of sea surface area, modelling of sea-climate feedback loops and other analytical methods. Even among the considerable number of studies in the last five years alone, significant ranges and uncertainties related to projected water level changes are described.

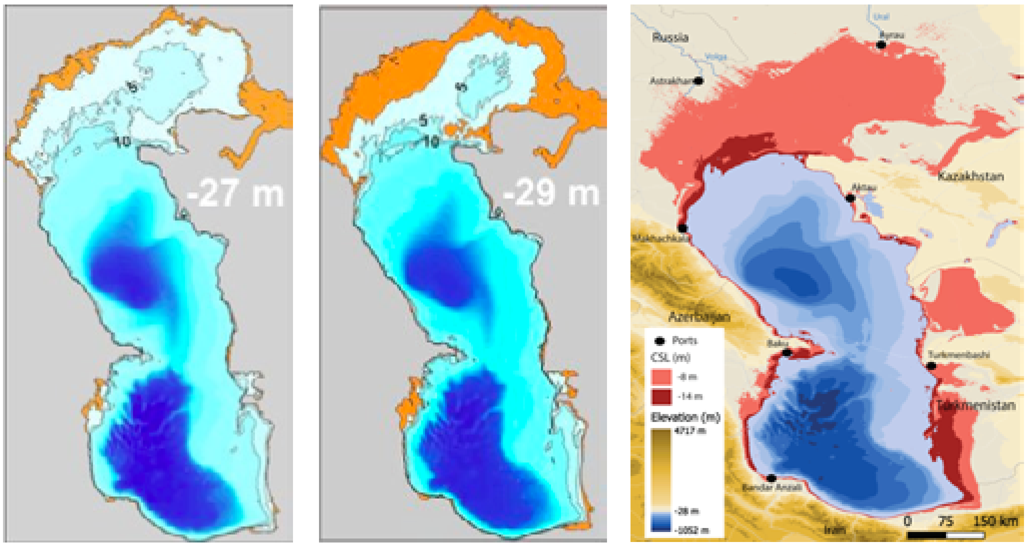
As an example, Samant and Prange (2023) analysed climate impacts on water levels to 2100 using 15 climate models and three SSPs, within the framework of the "Coupled Model Intercomparison Project Phase 6" (**CMIP6**). Based on an extrapolation of recent historic declines, and climate change impacts, the study projected total sea level reductions of about 8m (inter-model range 2–15m) under SSP245 (medium pathway), and about 14m (inter-model range 11–21m) under SSP585 (upper boundary, which is worth including considering the high socioeconomic, environmental and other impacts of associated changes in water level) (Samant and Prange 2023). As with most of the studies, the authors highlight considerable uncertainties in these estimates, with recommendations for future considerations and improvements.

Climate change is also expected to affect hydrological patterns, including a decrease in spring flood and summer-autumn flow of rivers in the basin. A recent study of hydrological and meteorological variability in the Volga River Basin in the context of climate change analyses these shifts, and projects an overall decrease in annual Volga Basin runoff of approximately 10 per cent relative to the 1970–99 period (Kalugin 2022). Higher temperatures and changing wind patterns may also lead to increased evaporation from the Caspian Sea surface (Arpe *et al.* 2020; Safarov *et al.* 2024): indeed, increased evaporation has already played a significant role in the recent decrease in water levels (Arpe *et al.* 2020; Safarov *et al.* 2024).

Complex feedback loops exist between changing sea surface area (with changing water levels), evaporation rates (strongly influenced by local and regional wind regimes, sea surface and air temperatures) and precipitation across the basin and beyond. Changes in water level significantly alter the surface area of the sea, especially in the shallow northern section, as well as in the south-eastern area under more significant declines (Figure 4). Koriche *et al.* (2021a), for example, note that a smaller Caspian Sea surface area could create a feedback loop whereby evaporation starts to decrease, while precipitation is still increasing due to warmer temperatures.

Figure 4:

Left and middle: Changes in Caspian Sea surface area, depending on water level (Medvedev et al. 2020). -29m was the lowest Caspian Sea level in the last 120 years, in 1977, and trends indicate this level may be reached again in the next 10–20 years. Orange depicts drying compared to -25m water level. Right: Impact on the Caspian Sea surface area for projected declines of 8 and 14m by 2100 (compared to pre-industrial (late 19th century) levels, under SSP245 and SSP585, respectively). Red regions show drying (Samant and Prange 2023).



Modelling sea-climate feedback loops, using current regional climate models, is extremely complex and requires significant further research, including further development and downscaling of global and regional climate models (Samant and Prange 2023). Coordinated research could help to deepen understanding of the changes.

Environmental governance arrangements

The Framework Convention for the Protection of the Marine Environment of the Caspian Sea (**Tehran Convention**) (2003) is the first legally binding regional agreement relating to environmental protection in the Caspian region that has been signed by all littoral states. The objective of the Tehran Convention is the protection of the Caspian environment from all sources of pollution including the protection, preservation, restoration and sustainable and rational use of the biological resources of the Caspian Sea. In the Tehran Convention, Caspian littoral states acknowledged implications of Caspian Sea level fluctuation and agreed to "co-operate in the development of protocols to the Convention prescribing to undertake the necessary scientific research and, insofar as is practicable, the agreed measures and procedures to alleviate implications of the sea level fluctuations of the Caspian Sea" (Article 16).

Fluctuating Caspian Sea levels were also a key driver behind the creation by Caspian states of a **Coordinating Committee on Hydrometeorology and Pollution Monitoring of the Caspian Sea** (CASPCOM). CASPCOM was established in 1994 with a view to co-ordinating, standardizing, cooperating in and improving in the fields of hydrometeorology and pollution monitoring of the Caspian Sea. Its establishment was driven primarily by "the need for cooperation in the field of environment monitoring to deal with negative consequences of rapid sea level rise in 1980–1990, which led to flooding coastal territories." The Memorandum of Understanding between CASPCOM and the Tehran Convention interim Secretariat was signed on 27–28 November 2013. This Memorandum of Understanding aims to facilitate collaboration in addressing environmental challenges faced by the Caspian Sea, which is threatened by pollution, habitat destruction and climate change impacts. The **Agreement on Cooperation in the Field of Hydrometeorology of the Caspian Sea** (2016) and the elaboration and implementation of the Integrated Intergovernmental Programme on Hydrometeorology of the Caspian Sea aim to establish and develop an integrated regional system for obtaining and exchanging information on the state of the Caspian Sea.

In 2014, an **agreement** between the Caspian countries regarding cooperation in emergency response in the Caspian Sea was signed in Astrakhan, Russian Federation. This agreement aims to improve coordination among the Caspian states in the event of emergencies, such as marine environmental pollution, accidents at oil and gas extraction facilities and other ecological disasters.

The **Agreement** on the conservation and sustainable use of aquatic biological resources of the Caspian Sea was approved by the five Caspian littoral states in 2014. The Parties agree upon cooperation on (i) giving priority to the conservation of aquatic biological resources, (ii) sustainable use of aquatic biological resources, (iii) application of accepted international rules, (iv) ecosystem preservation and biodiversity protection, (v) conservation of aquatic biological resources in scientific research and use this as a basis of common aquatic biological resources management, and (vi) taking measures for sustainable use and conservation of aquatic biological resources in the Caspian Sea and for management of common aquatic biological resources. The agreement also includes provisions for cooperation by research studies, data collection, exchange of scientific and technical documents, experience and information, preventive measures for illegal, unreported and unregulated fishing and by development of short, medium and long-term programs for aquatic production and for their reintroduction into their natural habitats. The latter aims to maintain the ecological integrity of the sea while allowing for economic activities. It is also relevant to note the Aktau **Convention on the Legal Status of the Caspian Sea** (2018) (Aktau Convention), which provides a delimitation method of the Caspian Sea and defines and regulates the rights and obligations of the Parties in respect of the use of the Caspian Sea, including its waters, seabed, subsoil, natural resources and the airspace over the sea.

While the Aktau Convention does not make reference to the law of the sea as a legal model, it follows the UN Convention on the Law of the Sea, introducing equivalently named categories of maritime zones. The maritime zones are measures from baselines determined in accordance with the provisions of the Caspian Sea Convention. Some authors (for example Prange *et al.* 2020; Árnadóttir 2021) have noted that climate-related changes to the Caspian Sea level could lead to a shift in maritime zones (Aurescu and Oral 2020).[1]

While there are some management arrangements in place for most of the rivers flowing into the Caspian Sea, there is no overarching transboundary or regional institutional/legal mechanism to manage water withdrawals and the development of the rivers in the Caspian Basin.

Ongoing national and international research

In addition to the large volume of academic research being undertaken on the Caspian Sea, some littoral states have initiated research and analysis, sometimes with international support. For example, Azerbaijan has requested that the United Nations Environment Programme (UNEP) support a study on Caspian Sea levels, including the impacts of climate change. Kazakhstan has requested an analysis from the World Bank Group to describe various Caspian Sea level scenarios and implications for its ports and transport infrastructure, which is under way. The port infrastructure study will analyse the implications of climate change and other changes on Caspian Sea level (changing temperatures, precipitation, other hydrological change).

1 The International Law Commission has made preliminary observations that it is necessary to preserve existing maritime delimitations notwithstanding the coastal changes produced by sea-level rise and that sea-level rise cannot be invoked in accordance with article 62, paragraph 2, of the 1969 Vienna Convention on the Law of Treaties as a fundamental change of circumstances for terminating or withdrawing from a treaty that established a maritime boundary. Maritime boundaries enjoy the same regime of stability as any other boundaries. Sea-level rise in relation to international law: First issues paper by Bogdan Aurescu and Nilüfer Oral, Co-Chairs of the Study Group on sea-level rise in relation to international law, A/CN.4/740, para 141.

What next? Understanding the contributions, implications and management actions for sea level changes

Protecting the Caspian Sea is critically important for all littoral states' environments, economies and societies. Further sustainable development of the sea and coastal areas will be needed to help regional states meet the Sustainable Development Goals, including (but not only) climate action goals. Sustained, inclusive economic growth can be accomplished only if the Caspian Sea's biodiversity and water resources are protected. Gender equality including reducing a gender-related pay gap can be advanced via supporting women's participation in traditionally male-dominated sectors relating to the Caspian economy, such as **shipping** and port management.[2]

Given the economic, environmental and social significance of future Caspian Sea level changes, and the uncertainties surrounding the likely climatic and anthropogenic impacts in the 21st century, there is a need for further comprehensive and coordinated research to support decision making. UNEP recommends the following:

a. Convene regional scientists to review ongoing research. The current Working Paper, which was prepared in advance of UNFCCC COP29, provides a brief overview of some of the recent, relevant peer-reviewed science. Given the seriousness of climate-related risks to people and the environment of the Caspian Sea, a more comprehensive review of ongoing research into Caspian Sea levels in the context of climate change is warranted. This could lead to strengthened coordination among researchers (see point b).

b. Consider options for research cooperation and coordination to enhance coherence on research assumptions and increase comparability. At present, research is being conducted mainly at the national level, using a range of methods and processes, which impedes progress towards understanding environmental change in the basin. All basin countries should have a say in identifying gaps and developing shared approaches and methods. Future coordinated studies may consider, amongst other issues:

    - the coupling of dynamic sea level models with climate models to correctly incorporate bathymetry of the Caspian Sea, changes in the sea surface area, sea water temperature and circulation and sea-climate feedbacks

    - simulating regional hydroclimate using high-resolution regional climate models

    - analysis of direct anthropogenic influences like irrigation, other water uses (Koriche et al. 2021a; Koriche et al. 2021b; Samant and Prange 2023)

2 The Organisation for Security and Cooperation in Europe has been conducting a Women in Port Management training course to strengthen their professional skills and advance their careers in the logistics and maritime sectors. See **OSCE 2022. In 2023, the World Bank Group launched a technical assistance and capacity building program "Strengthening women's human capital for their better labor market outcomes: 2023-2024" in Azerbaijan (World Bank Group 2023).**

- likely changes to wind speed and direction, including those arising from climate change impacts on North Atlantic and Pacific oceans, and their influence on evaporation (Safarov et al. 2024)

- vegetation shift: drying of an extensive surface in the North Caspian would damage wetlands leading to the release of pollutants and carbon, and contributing to soil destabilization

- decrease of nursery/refugium for freshwater fish that use the extensive wetlands during their lifecycle.

c. Conduct environmental and socioeconomic impact assessments to understand the impacts of the decline in Caspian Sea levels on ecosystems and biodiversity, including a dedicated review of the impact of climate and environmental changes in the Caspian Sea and coastal areas, including endemic and endangered species, as well as common freshwater fish that have significant socioeconomic value to communities living around the Caspian Sea. Assessments could focus on important changes and their impacts, potentially including (i) salinity, temperature and turbidity of the sea and its impacts on survival and reproduction of certain species; (ii) changes in precipitation in the broader catchment and impacts on economic activities, including agriculture and possible use of more adapted varieties; and iii) analysis of the gender dimensions of expected socio-economic and environmental changes.

Migratory birds are seen at Miankaleh Wildlife Refuge in Mazandaran Province, northern Iran, on February, 2010 (@Hossein Fatemi / AFP).

d. Foster cooperation on adaptation planning: Adaptation to changes in Caspian Sea levels is now identified as a need, given projections of sea level decline and other environmental changes. Adaptation and resilience measures for Caspian Sea ports, for example, could easily extend to several US$100 million (Wallingford 2024). At COP28, Parties to the Paris Agreement **recognized** that "climate change impacts are often transboundary in nature and may involve complex, cascading risks that can benefit from collective consideration and knowledge-sharing, climate-informed transboundary management and cooperation", and emphasized the need to strengthen "regional and international cooperation on the scaling up of adaptation action and support among Parties." Adaptation approaches should consider transboundary impacts and seek to identify areas in which joint management decisions would deliver co-benefits. UNEP's experience in facilitating other transboundary adaptation processes could inform the co-design of a cooperative process. The Tehran Convention Secretariat provided ad interim by UNEP could convene the Parties, based on existing commitments of the Parties under Article 16.

e. Enhance linkages between the Tehran Convention Secretariat and other regional seas secretariats, to optimise opportunities for mutual learning of lessons, helping to maximise the potential benefits of science-based cooperation.

UNEP can support Caspian Sea littoral states in undertaking these steps, subject to the availability of resources, and in line with relevant mandates and responsibilities including United Nations Environment Assembly Resolution **6/13** and in its role as Secretariat to the Tehran Convention, provided *ad interim*.

References

Abbasov, R., Karimov, R. and Jafarova, N. (2022). The Caspian Sea and its values in Azerbaijan. In Ecosystem Services in Azerbaijan: Value and Losses. Cham: Springer International Publishing. 1-28.

Akbari, M., Baubekova, A., Roozbahani, A., Gafurov, A., Shiklomanov, A., Rasouli, K. et al. (2020). Vulnerability of the Caspian Sea shoreline to changes in hydrology and climate. Environmental Research Letters 15, 115002. https://iopscience.iop.org/article/10.1088/1748-9326/abaad8.

Akbulaev, N. and Bayramli, G. (2020). Maritime transport and economic growth: Interconnection and influence (an example of the countries in the Caspian Sea coast; Russia, Azerbaijan, Turkmenistan, Kazakhstan and Iran). Marine Policy 118, 104005. https://doi.org/10.1016/j.marpol.2020.104005.

Árnadóttir, S. (2021). Fluctuating boundaries in a changing marine environment. Leiden Journal of International Law 34(2), 471-487.

Arpe, K., Molavi-Arabshahi, M. and Leroy, S.A.G. (2020). Wind variability over the Caspian Sea, its impact on Caspian seawater level and link with ENSO. International Journal of Climatology 40(14), 6039-6054. https://doi.org/10.1002/joc.6564.

Aurescu and Oral (2020) Sea-level rise in relation to international law: 1st issues paper: addendum / by Bogdan Aurescu and Nilüfer Oral, Co-Chairs of the Study Group on Sea-level Rise in Relation to International Law, A/CN.4/740. https://digitallibrary.un.org/record/3865701?ln=en&v=pdf.

Bodini, A., Pereira, A. and Scotti, M. (2024). The decline of kilkas, sturgeons and seals in the Caspian Sea: The potential of qualitative loop analysis for the cumulative assessment of multiple drivers of stress. Marine Pollution Bulletin 200, 116091. https://doi.org/10.1016/j.marpolbul.2024.116091.

Bolgov, M.V.; Krasnozhon, G.F.; Lyubushin, A.A. Caspian Sea: Extreme Hydrological Events; Nauka: Moscow, Russia, 2007; 3Inp.

Chen, J.L., Pekker, T., Wilson, C.R., Tapley, B.D., Kostianoy, A.G., Cretaux, J.-F. and Safarov, E.S. (2017). Long-term Caspian Sea level change. Geophysical Research Letters 44, 6993–7001. https://doi.org/10.1002/2017GL073958.

Diansky, N.A., Vyruchalkina, T.Y. and Fomin, V.V. (2022). Effect of long-term variations in wind regime over Caspian Sea region on the evolution of its level in 1948–2017. Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region. 121-22.

Elguindi, N. and Giorgi, F. (2006). Projected changes in the Caspian Sea level for the 21st century based on the latest AOGCM simulations. *Geophysical Research Letters,* 33(8). https://doi.org/10.1029/2006GL025943.

Elguindi, N. and Giorgi, F. (2007). Simulating future Caspian Sea level changes using regional climate model outputs.

Climate Dynamics 28(4):365-379. https://doi.org/10.1007/s00382-006-0185-x.

Firoozfar, A., Bromhead, E.N. and Dykes, A.P. (2012). Caspian Sea level change impacts regional seismicity. *Journal of Great Lakes Research* 38(4), 667-672. https://doi.org/10.1016/j.jglr.2012.09.004.

Georgiadi, A.G. and Milyukova, I.P. (2022). Volga water flow under conditions of Holocene optimum and scenario anthropogenic climate changes in the 21st century. *Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region*. 49-51.

Gorelits, O.V., Ermakova, G.S., Zemlyanov, I.V.; Sapozhnikova, A.A. and Milutina, I.Y. (2022). Volga delta hydrological regime under conditions of modern climate changes. *Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region*. 59-60.

GRID Arendal/UNEP 2012. Available at: https://www.grida.no/resources/5732.

Lahijani, H.A.K., Ghaffari, P., Leroy, S.A.G., Beni, A.N., Yakushev, E.V., Abtahi, B., Saleh, A. and Behravesh, M. (2024). A note on the silent decline of the Caspian environment. *Marine Pollution Bulletin* 205, 116551.

Hoseini, S.M., Soltanpour, M. and Zolfaghari, M.R. (2024). Climate change impacts on temperature and precipitation over the Caspian Sea. *International Journal of Water Resources Development* 1–26. **https://doi.org/10.1080/07900627.2024.2313050**.

Interim Secretariat of the Framework Convention for the Protection of the Marine Environment of the Caspian Sea (Tehran Convention) (2020). *Caspian Sea: State of the Environment 2019*. Geneva and Arendal: Tehran Convention Secretariat and GRID-Arendal.

Ivkina, N.A and Galaeva, A.V. (2022). Possible fluctuation of the Caspian Sea level up to the year 2050, considering climate changes. *Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region*. 126-128.

Janusz-Pawletta, B. (2021). Geography, Politics, and Economy in the Caspian Region. In *The Legal Status of the Caspian Sea: Current Challenges and Prospects for Future Development*. 2nd edition. **https://doi.org/10.1007/978-3-662-63540-7_2**.

Kalugin, A. (2022). Hydrological and Meteorological Variability in the Volga River Basin under Global Warming by 1.5 and 2 Degrees. *Climate* 10(7), 107. **https://doi.org/10.3390/cli10070107**.

Koriche, S.A, Singarayer, J.S. and Cloke, H.L. (2021a). The fate of the Caspian Sea under projected climate change and water extraction during the 21st century. *Environmental Research Letters* 16, 094024. **https://doi.org/10.1088/1748-9326/ac1af5**.

Koriche, S.A., Nandini-Weiss, S.D., Prange, M., Singarayer, J.S., Arpe, K., Cloke, H.L. *et al.* (2021b). Impacts of variations in Caspian Sea surface area on catchment-scale and large-scale climate. *Journal of Geophysical Research: Atmospheres* 126(18), e2020JD034251. **https://doi.org/10.1029/2020JD034251**.

Lahijani, H., Leroy, S.A.G., Arpe, K. and Crétaux, J.-F. (2023). Caspian Sea level changes during instrumental period, its impact and forecast: A review. *Earth-Science Reviews* 241, 104428. **https://doi.org/10.1016/j.earscirev.2023.104428**.

Lahijani, H., Ghaffari, P., Leroy, S.A.G., Beni, A.N., Yakushev, E.V., Abtahi, B., Saleh, A. and Behravesh, M. (2024). A note on the silent decline of the Caspian environment. *Marine Pollution Bulletin* 205. **https://doi.org/10.1016/j.marpolbul.2024.116551**.

Medvedev, I.P., Kulikov, E.A. and Fine, I.V. (2020). Numerical modelling of the Caspian Sea tides. *Ocean Science* 16, 209-219. **https://doi.org/10.5194/os-16-209-2020**.

Migunov, D.A., Terskii, P.N., Gorelits, O.V., Ratkovich, E.L. (2023). Current River Runoff Distribution in the Volga Delta: Analysis and Modeling. *Russian Meteorology and Hydrology* 48, 1038–1047.

Nandini-Weiss, S.D., Prange, M.; Arpe, K., Merkel, U. and Schulz, M. (2020). Past and future impact of the winter North Atlantic Oscillation in the Caspian Sea catchment area. *International Journal of Climatology* 40, 2717–2731.

https://www.doi.org/10.1002/joc.6362.

NASA (2022), The Caspian Sea's shrinking coastline. Accessed on 29 October 2024. Earth Observatory. Available at: **https://earthobservatory.nasa.gov/images/150452/the-caspian-seas-shrinking-coastline**.

Prange, M., Wilke, T. and Wesselingh, F.P. (2020). The other side of sea level change. *Communications Earth and Environment* 1, 69. **https://doi.org/10.1038/s43247-020-00075-6**.

Organization for Security and Cooperation in Europe (OSCE) (2022), OSCE and IPER launch first women in port management training for Caspian and Black Sea ports, 31 May 2022, **https://www.osce.org/oceea/519312**.

Renssen, H, Lougheed, B.C., J.C.J.H. Aerts, H. de Moel, P.J. Ward, J.C.J. Kwadijk (2007). Simulating long-term Caspian Sea level changes: The impact of Holocene and future climate conditions. *Earth and Planetary Science Letters*, 261, 3–4, 685-693. **https://doi.org/10.1016/j.epsl.2007.07.037**.

Rosmoport (2021), Ministry of Transport of the Russian Federation, Astrakhan Branch, accessed on 29 October 2024: https://www.rosmorport.com/filials/asf_news_main/39336/

Safarov, E., Safarov, S. and Bayramov, E. (2024). Changes in the Hydrological Regime of the Volga River and Their Influence on Caspian Sea Level Fluctuations. Water 16(12), 1744. https://doi.org/10.3390/w16121744.

Samant, R. and Prange, M. (2023). Climate-driven 21st century Caspian Sea level decline estimated from CMIP6 projections. *Communications Earth and Environment* 4, 357. https://doi.org/10.1038/s43247-023-01017-8.

Serykh, I.V. and Kostianoy, A.G. (2020). The Links of Climate Change in the Caspian Sea to the Atlantic and Pacific Oceans. *Russian Meteorology and Hydrology* 45, 430–437. https://doi.org/10.3103/S1068373920060060.

Svetasheva, D.R., Tatarnikov, V.O., Azmukhambetova, D.Kh., Gontovayaa, I.V. (2022). The river flow projection in the Russian part of the Caspian Sea catchment basin. *Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region*. 91-93.

Tatarnikov, V.O. and Ocheretny, M.A. (2022). Long-term forecast of the Caspian Sea level in the face of global warming. *Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region*.

United Nations Development Programme (2022). *Addressing the cost-of-living crisis in developing countries: Poverty and vulnerability projections and policy responses*. New York: United Nations Development Programme.

Wallingford (2024). Improving the resilience of port infrastructure, shipping and logistics to climate-related risks and disasters in the Caspian Sea: Inception Report.

World Bank Group (2022). *Europe and Central Asia Economic Update, Spring 2022: War in the Region.* Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099517406012214353/IDU0e3baf4c505b0104d8e08bc9054428139f5ab.

World Bank Group (2023). *Azerbaijan – Country Climate and Development Report*. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099112723161524095/P17904806938f5083093a707fa0352e87a5.

Zarrin, A. and Dadashi-Roudbari, A. (2022). Projected changes in precipitation intensity in the southern coast of the Caspian Sea using a CMIP6 multi-model ensemble. *Proceedings of the Scientific Conference on Climate Change in the Caspian Sea Region*. 97-100.

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