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Investigating the Influencing Factors in the Fluctuations of the Caspian Sea Water Level

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***Abstract*-The rapid fluctuations of the Caspian Sea water level play an important role in determining the level of erosion risks, adverse environmental consequences, destruction and drying of coastal areas, wetlands and coastal bays, and the loss of economic resources and the destruction of marine industries. The purpose of this research is to investigate the influencing factors on the level of the Caspian Sea and predict the changes in the level of the Caspian Sea in the next 10 years. In this research, using ECMWF data from 1992 to 2021, which includes the amount of precipitation on the Caspian Sea, the amount of evaporation from it, and the average temperature of the surface of the Caspian Sea, the influencing factors in the fluctuation of the water level of the Caspian Sea were investigated. Reliable library sources were used to determine the amount of river water entering the Caspian Sea. Caspian Sea fluctuations data from the Ports Organization and to predict the Caspian Sea water level in the next 10 years, the time series and the specialized package Forecast of R software were used. The results showed that the amount of precipitation over the Caspian Sea is decreasing, and on the other hand, the amount of evaporation over the Caspian Sea is increasing. The main cause of the increasing trend of evaporation from the Caspian Sea is the increasing trend of sea surface temperature, which shows an increase of about 1.1 degrees Celsius during 30 years. One of the main reasons for the decrease in rain could be the intensification of the eastern winds and the weakening of the western winds, as a result of which the effects of the North Atlantic Ocean on the Caspian Sea are reduced. The Volga river water discharge shows a decreasing trend, which is due to the decreasing trend of precipitation and the construction of dams on the way of the rivers towards the sea. The prediction of the water level of the Caspian Sea in the next 10 years shows a decrease of 10 cm in the sea level. As a general result, climate change causes a decrease in precipitation, an increase in temperature and an increase in evaporation, and finally a decrease in the level of the Caspian Sea, so that this process will continue for the next few years.**

***Index Terms*- Caspian Sea, level surface, precipitation, evaporation, temperature**

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I. INTRODUCTION

The water level of the Caspian Sea, as the largest lake on earth,has had many changes and fluctuations. With the change of the water level of this sea, many low lands have gone under water or parts of the shallow beaches have come out of the water. Due to being closed, the water level of the Caspian Sea has always undergone fundamental changes and has varied from 35 to -20 meters from 5000 years ago to the present day. Since the formation of this sea, its minimum water level has reached -113 meters and its maximum has reached +50 meters. These changes, which are directly related to the amount of water in the rivers that flow into this lake, have had a significant impact on the human settlements around it [18]. Many countries are implementing or planning adaptation measures regarding sea level rise in light of the strong and consistent information on climate change. In contrast, the projected impact of global warming on the reduction of water levels in closed seas and lake systems due to continental drying in large areas of the world is much less considered [24]. The increase in the temperature of the earth's surface has caused the evaporation of water on land and lakes during the 21st century [4]. These changes decrease the water level of the lake and are aggravated by the decrease of rainfall in many parts of the world. Closed lakes such as the Caspian Lake, which have no outlet, are sensitive to climate change because their water levels are determined by a delicate balance between precipitation and the amount of river discharge and evaporation at the lake surface. While the drying of the interior climate of the continents is known as an important problem in terms of fresh water shortage [23], which affects the livelihood and economy of millions of people. The water level in the Caspian Sea will decrease between 9 and 18 m by the end of the 21st century in moderate to high global warming scenarios, which is caused by a significant increase in lake evaporation and is not balanced by an increase in discharge or river precipitation [13]. Based on these new projections, the Caspian Sea level decline in the 21st century will be twice as much as estimated by previous climate models [18]. The lowering of the Caspian Sea level, along

with the loss of the seasonally ice-covered plateau north of the Caspian, will affect this unique ecosystem of the region, which is already under great pressure due to pollution, overexploitation and the introduction of invasive species. [11]. Reduction of sea ice area in winter affects areas of the Caspian seabass that are at risk of extinction [25]. The large-scale disappearance of sea ice destroys the shallow habitats of the Caspian Sea, which are the main sources of food (such as fish, migratory birds, and native jaws) and spawning grounds for endangered marine native species (such as sturgeon). destroys The decrease in the water level of the Caspian Sea poses a serious threat to the coastal ecosystems of the Caspian Sea, and any failure to manage these fluctuations causes irreparable damage, and dealing with them requires scientific and practical solutions. The water level of water basins is an important factor in the process of their natural activities, the volume and surface of the water basin and the shape of the shores are a function of the water level of the basin. The water level of water basins changes over time and in their extent. The long-term change in the water level of the oceanic basins and the seas connected to them occurs slowly and can happen mainly due to climate change and geological processes. The fluctuation of the water level of closed water basins occurs in a shorter time and in addition to the mentioned factors, human factors also show their effect quickly. The only way out of Iran's earth civilization from the challenge of the water crisis is the option of the Caspian Sea. Russia and Kazakhstan set up desalination plants in the Caspian Sea several years ago, Iran's diplomacy is important in using the Caspian Sea reserves. Observing the fluctuations of the Caspian Sea level, monitoring the amount of incoming water and the amount of outgoing water from the Caspian Sea can significantly help planners to decide on preventive measures to prevent fluctuations in the level of the Caspian Sea and subsequently the complications caused by the fluctuations. Therefore, in this research, we are trying to investigate the influencing factors on the water level of the Caspian Sea and predict the trend of changes in the water level of the Caspian Sea in the next 10 years.

II. BASICS OF RESEARCH

The examination of the changes in the water level of the Caspian Sea shows that the water level of this sea has decreased during the last 15 years, mainly due to the decrease of incoming water. Although the Caspian Sea has seen many decreases and increases in its history and this change is considered a normal change according to many researchers, but the water withdrawal from the rivers leading to this sea has never been to this extent, therefore, The current decline of the Caspian Sea due to climate change can be considered as an irreversible decline that threatens the largest freshwater sea in the world [12].

Reducing and adapting to falling Caspian Sea levels will be a challenge that similarly applies to falling water levels in lakes and inland seas elsewhere:

Global vs. Local: The decline is largely driven by global factors, but the implications are regional and local. Global mitigation measures such as reducing greenhouse gas emissions are likely to come too late, as the level of the Caspian Sea is falling at a rate of about 6-7 cm per year. Therefore, strong regional adaptation measures are needed [24].

Lack of awareness: There is a lack of awareness among the stakeholders about the existence of the problem of lowering the water level of the Caspian Sea. For example, they proposed the first Caspian Sea level assessment report from around 2010 onwards. None of the consolidated reports address this issue in detail. In addition, the Intergovernmental Caspian Environment Program assumed in 2011 that the level of the Caspian Sea will fluctuate only slightly in the future. As a result, there is no management at international, national and regional level for adaptation measures in the Caspian Sea level to falling Caspian Sea level [2].

Lack of studies: assessment of the risks and vulnerability of the ecosystem, economies and social systems of the Caspian region against the reduction of the Caspian sea level is largely absent. This problem is aggravated by the common wisdom that considers the periodic fluctuation of the Caspian Sea level as a self-regulating phenomenon.

Spatial optimism bias: Different communities and coastal countries may think that they are less affected than others by the Caspian sea level drop. Such bias can hinder concerted adaptation efforts.

The lack of public and political awareness of impending Caspian sea level decline applies equally to worldwide lake level changes caused or enhanced by global warming. An increasing number of scientific studies predict climate drying in many regions of the world, which will inevitably require a significant decrease in lake levels in Asian, African and American basins [3]. In addition, lake levels are also affected by human water abstraction, river damming, and diversions (the famous drying up of the Aral Sea is just one striking example of this), often masking climate impacts[26],[27]. Accurate models for future lake surface climate change are of great importance as a scientific basis for sustainable mitigation and prediction of adaptation strategies, but are largely lacking so far.

The effects of climate change in the Caspian Sea have caused many scientists to undertake research and scientific issues related to climate change in order to achieve their goals. These studies are conducted to determine

temperature, evaporation, salinity, pressure, density, wind direction, wind speed and other related phenomena [7].

Sorkhabi et al. (2021) monitored changes in the Caspian sea level using deep learning-based three-dimensional reconstruction of the GRACE signal. In this research, GRACE data are analyzed using a deep neural network to investigate the changes made in the Caspian sea level. The proposed method has a significant correlation of 82% on average with satellite altimetry and data collected by three tide gauge stations, so it shows good compatibility. Hatami Bavarsad et al. (2021) studied the effect of storms entering the Caspian Sea on sea level fluctuations. In this article, the source and effect of the storms produced in the Caspian Sea from 2012 to 2017 have been investigated. The data required for this research includes water level data recorded at stations such as Amirabad port and other ports, and average atmospheric pressure at sea level and wind data from the ECMWF website. The results show that the source of low atmospheric pressure is from the southwest and west of the Caspian Sea and in 2016 from the northern region of this basin. In a research, Ataei et al. (2019) addressed the long-term changes in the level of the Caspian Sea based on the temporary ERA model and river discharge. In a study, Neshaei and Ghanbarpour (2017) studied the effect of sea level rise on the morphol ogy of the Caspian Sea coast. It is shown that the behavior of the coastal zone conforms to the equilibrium profile of Dean (1991). The comparison of equilibrium characteristics for different cases of sea level rise clearly shows that due to sediment transport caused by water level fluctuations, the characteristics of the beach in the surf zone will change and thus cause erosion in the inner surf zone.

In a research, Torabi et al. (2019) investigated the changes in the water area of Miankala and Anzali wetlands in relation to the changes in the Caspian sea level and precipitation by means of remote sensing techniques. In this study, the changes in the water level of Anzali and Miankala wetlands were investigated in relation to the changes in the Caspian Sea water level and rainfall in the Anzali and Miankala wetlands basin between 1999 and 2020. The results indicate that the changes in the Miankala and Anzali wetlands in the long term were affected by the water level of the Caspian Sea, but due to the appearance of small reservoirs in the approved area of the Anzali Wetland due to the growth of plant species in the dry areas and parts of the water zone. has separated it from the main basin, this wetland is more affected by the rainfall in the basin and finally by the rivers in order to change the surface area of its water zone.

Ozzam et al. (2019) in a research investigated the trend of dynamic topographical changes in the Caspian Sea water level and its effect on the changes of the Iranian coastline using satellite altimetry data. In this research, the anomaly data of sea level, geoid level and average sea level for a period of 20 years between 1993 and 2012 have been analyzed in order to investigate the changes in the coastline and water level of the Caspian Sea. In a research, Servati et al. (2017) investigated the geomorphological response models of the coastlines of Sedi Miankale Island to the rapid fluctuations of the Caspian Sea level. The results indicate that advance and regression models are formed during the periods of advance and regression of the sea level in the region, respectively. The models of in-situ narrowing and collapse simultaneously with the rise of the sea level and the rotational instability model also appear when the level decreases in the region. The lateral movement model has also appeared during the periods of progress and regression. Also, the findings show that the sea level has experienced six progressive-regressive stages during the period of 1374-1396. The analysis of satellite images and statistical data of sea level fluctuations show that since 1374, the sea level has entered the regression stage and has decreased by about 1.5 meters. The rate of regression and reduction of the level between 1374-1396 was calculated to be about 6.8 cm per year. Khairollahzadeh et al. (2016) investigated the factors affecting the changes in the water level of the Caspian Sea using spectral analysis of coastal tide gauge data. The aim of this research is to analyze the spectral changes in the level of the Caspian Sea and investigate the factors affecting it using coastal level survey data, in this study, the coastal tide gauge data of Neka station was used. Khoshravan and Vafaei (2015) studied the fluctuations of the Caspian Sea water level (past, present and future). The results show that climatic factors are the most important cause of water level changes during Helson period. During the late Pleistocene period to the end of the Holocene, the water level has changed by about 150 meters. If the global warming continues, it is estimated that the water level of the Caspian Sea will decrease by more than 3.5 meters by the year 2100.

2.research method

The area studied in this research is the Caspian Sea and the data used were received from the ECMWF organization and the country's ports organization. In this research, using the ECMWF data from 1992 to 2021, which includes the amount of precipitation on the Caspian Sea, the amount of evaporation from it, and the average temperature of the Caspian Sea area, the influencing factors in the fluctuation of the Caspian Sea water level were investigated. Reliable library sources were used to determine the amount of river water entering the Caspian Sea. Using Excel software, the data trends of precipitation, evaporation, temperature and river water flow from 1992 to 2021 were drawn. Caspian Sea fluctuations data from the Ports Organization and to predict the Caspian Sea water level in the next 10 years, the time series and the specialized package Forecast of R software were used.

Table 1-Specifications of Nowshahr station and studied data

data	Time series period
Water level fluctuations	1992-2021
Rainfall	1992-2021
Evaporation	1992-2021
Temperature	1992-2021
The discharge of rivers	1992-2021

At first, the data of the last 30 years of water level fluctuations were collected and used for time series validation and modeling. Before entering the modeling stage, the time series are examined by the non-parametric Mann-Kendall test in order to evaluate the presence or absence of a trend.

III.Research findings

A. Factors affecting the changes in the water level of the Caspian Sea

Evaporation and precipitation

The diagram of the trend of evaporation along with precipitation in Nowshahr station and in the entire Caspian Sea region is shown in Figure 1. The graph shows that in Nowshahr station, evaporation increases to a height of 20 cm, while precipitation decreases to a height of 10 cm. The total amount of water removed from the Caspian Sea due to evaporation in 2021 is about 50 billion cubic meters more than in 1992, while the total amount of water entering the surface of the Caspian Sea in 2021 is about 40 billion cubic meters less than The year is 1992. As a general result, evaporation has increased while precipitation has decreased. It should be noted that the huge difference between annual evaporation and precipitation is balanced to some extent by the entry of river water into the Caspian Sea.

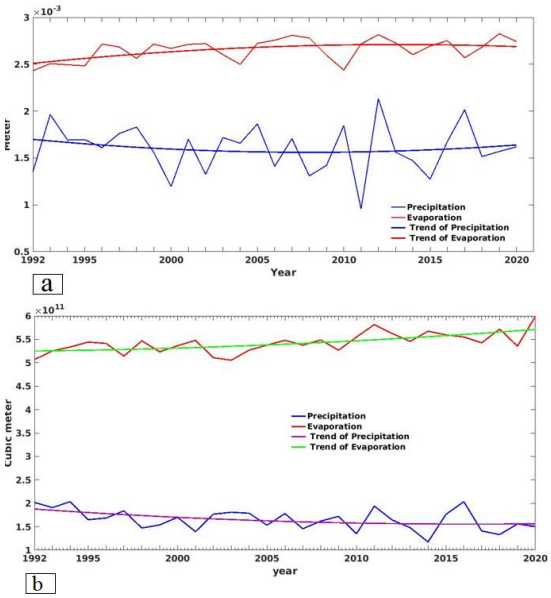

Figure 1- a) Evaporation and precipitation changes of Nowshahr station. b) Evaporation and precipitation changes of the entire Caspian Sea area (in the last 30 years using ECMWF data, source: author)

temperature

Sea surface temperature is also one of the main criteria in heat exchange and an index in evaluating the evaporation potential from the water surface, which is considered as one of the main components of the output in the Caspian water balance, in examining the process of water level changes and evaluating the causes of fluctuations in the studied Caspian. Placed. The increasing trend of the Caspian Sea water surface temperature, especially in recent years, has been one of the factors influencing the decrease of the water level.

The graph of sea surface temperature changes in Nowshahr station and in the entire Caspian Sea area is shown in Figure 2. The graph shows that in Nowshahr station, the sea surface temperature in 2021 has increased by 1 degree Kelvin compared to 1992. Also, the average sea surface temperature in the entire area of the Caspian Sea in 2021 has increased by 1.1 degrees Kelvin compared to 1992. The main reason for the increase in sea surface temperature is the increase in greenhouse gases, which has led to climate change. Therefore, the trend of temperature increase, which is directly related to the increase of water evaporation, in Nowshahr station and the whole area of the Caspian Sea, is one of the effective factors in increasing the fluctuations of the water level of the Caspian Sea, which has caused a decrease in the water level of this sea.

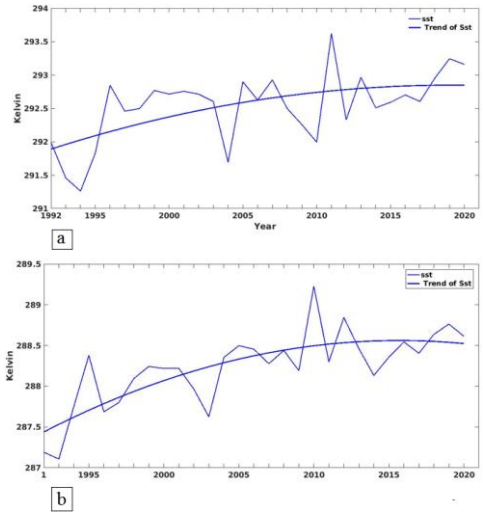

Figure 2- a) Sea surface temperature changes at Nowshahr station b) Caspian Sea surface temperature changes (in the last 30 years using ECMWF data, source: author)

River water and closing dams

The Volga River alone supplies 80% of the water entering the Caspian Sea, followed by the Aral and Kura rivers. According to this issue, the changes in the above-mentioned rivers' inlets were investigated. These studies show that the discharge of the Aral and Kura rivers has been slowly decreasing in the past years. However, it seems that the changes of the Volga River played the main role in this regard. The changes in the flow of the Volga River show that the changes in the level of the Caspian Sea are completely dependent on it, so that the decrease in the flow of the river in the 70s led to the minimum sea level in the last century, and its increase in the 90s led to an increase in the sea level in the 90s. has caused In the same direction and due to the reduction of Volga river discharge since the beginning of the 21st century, the sea level has also decreased again since 2005. In this regard, the role of increased evaporation due to global warming in the last century cannot be ignored, although the extent of this effect requires more detailed investigations [14]. The average annual inflow of Volga water into the Caspian Sea is about 240 billion cubic meters, and the annual estimate of the total inflow of the rivers leading to the Caspian is 300 billion cubic meters. From other important rivers such as Kura, Ural, Etrak, Sefidroud, Haraz, a total of 34 billion cubic meters of water enters the Caspian Sea. The recent decrease in water level is while the amount of water entering the Volga River, as the supplier of most of the river water to this sea, has decreased by 22% in 2019, which can be considered as one of the effective causes of the recent decrease in water level. The results of the surveys have shown that in 2019, the flood period of the Volga River, which usually lasts from mid-May to early August, was shorter and its water level was lower than the long-term average. The volume of water entering the rivers is considered as a very important indicator in the water balance of the Caspian Sea and its annual changes are affected by climatic factors, hydrological regime and exploitations.

According to the above information, it seems that the changes in the level of the Caspian Sea are strongly dependent on the climate and precipitation in the region, especially the Volga catchment area. Although the excessive withdrawals from the incoming waters in the past decades cannot be without effect in this regard. Also, the construction of numerous dams on the way of the rivers entering the Caspian Sea is considered to be another factor in reducing the water of the Caspian Sea through the Sefid River and other rivers in the north of the country. The use of river water for agricultural purposes is also very effective in reducing water entering the sea.

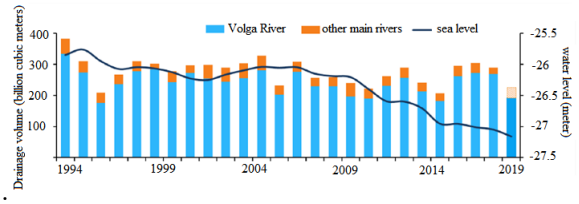

Figure 3- Comparison of sea level changes with the flow volume of important rivers in the Caspian Sea catchment area

Climatic influences of the Pacific and Atlantic Oceans

The PDO (Pacific Decadal Oscillation) index is a climatic phenomenon that is associated with the stability of two-phase climate patterns in the North Pacific Ocean and fluctuates with time periods of the order of 50 years. This index consists of two phases, cold and warm, and one of the known consequences of the occurrence of warm and cold phases in this index is the occurrence of changes in the wind pattern in the upper levels of the atmosphere. The PDO index can remain in a certain phase for 20 to 30 consecutive years, but the cycles of the Enso index can last for 6 to 18 months at most. The standardized values of decadal oscillations of the Pacific Ocean are shown in Figure 4.

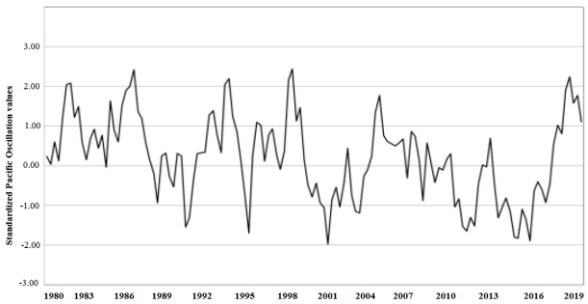

Figure 4- Standardized values of the Pacific Oscillation

The AMO (Atlantic Multidecadal Oscillation) index is the oscillation of the Atlantic Ocean based on the normalized sea level pressure difference (P) between the subtropical and low pressure regions of Iceland. The AMO oscillation takes

the form of changes in the abnormal patterns of sea surface temperature in the Atlantic Ocean (especially the waters of southern Greenland) with warm (+) and cold (-) phases for 20 to 40 years. In general, the warm phase of the index is associated with a decrease in precipitation and an increase in temperature, and its cold phase is associated with an increase in precipitation and a drop in temperature in autumn. When the AMO is in its warm phase, droughts tend to increase in frequency or intensity (duration).

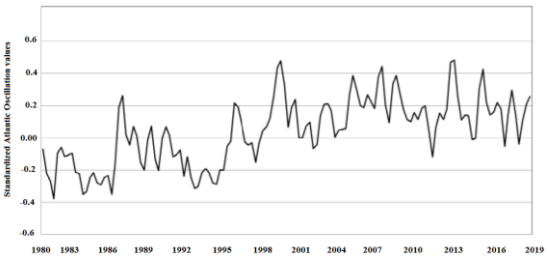

Figure 5- Standardized Atlantic Oscillation values
Caspian Sea water level prediction

In recent years, the study of the interaction between weather factors in the land, ocean and atmosphere has attracted the attention of many meteorologists and climatologists. Various researches have shown that temperature changes on the surface of large water areas can have a significant effect on precipitation fluctuations on the land surface of the earth. The initial values of the surface temperature of the Caspian Sea from the portal of the Climate Prediction Center show the direct influence of the weather of the Pacific and Atlantic Oceans on the initial temperature of the surface of the Caspian Sea. The increase in temperature has caused more evaporation of sea water and a decrease in the water level of the Caspian Sea.

After going through the described steps, the series values are predicted for the next 10 years.

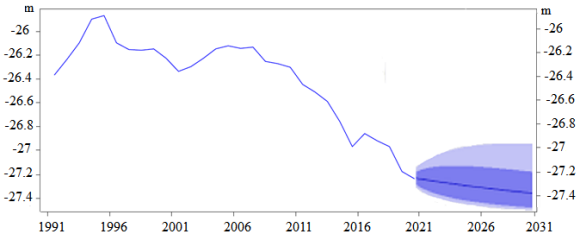

Figure 6-Future value prediction chart

By comparing the actual and predicted values of 2019, the correctness of the relevant model is proven because these values are almost close to each other and if there is a difference in them, it is due to the amount of error that the software has. The model shows a 10 cm reduction in the Caspian Sea water level fluctuations in the next 10 years. It should be mentioned that the fluctuation of water level was very high until 2015, while the decreasing trend of water level in the second half of 30 years was much more.

Therefore, if the calculations were done based on the last 15 years, it would show a greater decrease. The changes in the graph show a change of 10 cm in the next 10 years. The ten-year changes of the Caspian Sea water level are given in Table 2.

Table 2- Caspian Sea water level prediction and comparison with Sharbati and Ganqormah research

Year	The water level of the Caspian Sea	Sharbati and Ganqormah researches (2014)	Error rate
2021	-27.25	-27.26	0.0003
2022	-27.265	-27.28	0.0005
2023	-27.272	-27.285	0.0004
2024	-27.278	-27.29	0.0004
2025	-27.284	-27.294	0.0003
2026	-27.289	-27.33	0.0015
2027	-27.294	-27.37	0.0027
2028	-27.32	-27.46	0.005
2029	-27.35	-27.52	0.0061
2030	-27.35	-27.606	0.009

In Table 2, it can be seen that the calculations of the water level of the Caspian Sea for the next ten years are compared with the research done by Sharbati and Qanqormeh (2014) and it was done with a very small percentage of error. In the reviews made in other articles, most of the predictions are made for the next 50 years or 100 years. In the research of Saberi et al. (2017), the level of the Caspian Sea was calculated for the years 2030, 2060, and 2100, which was -28.88, -66.23, and -144.20 meters, respectively.

IV. Conclusion

Prediction of sea level fluctuations is a very efficient tool for comprehensive sea management and protection of coastal areas. On the other hand, the use of concepts governing time series in forecasting has been evaluated as very suitable. The surface level plays an important role in every water area and is an important quantity in measuring climate changes. This matter becomes even more important when the area in question is a closed area like the Caspian Sea because the fluctuations of the surface level are 100 times that of the oceans. This research examines the factors affecting the fluctuations of the Caspian Sea level in Bandar Nowshahr

station, and using time series to predict the fluctuations of the Caspian Sea level in the next 10 years.

Many countries are implementing or planning adaptation measures regarding sea level rise in light of the strong and consistent information on climate change. In contrast, the projected impact of global warming on the reduction of water levels in closed seas and lake systems due to continental drying in large areas of the world is much less considered [24]. In table 3, while stating the challenges related to the fluctuations of the Caspian sea water level, scientific and practical solutions have been discussed.

Table 3- Scientific and practical solutions for fluctuations in the Caspian Sea water level

Dimensions	Challenges	Solve the challenge
global	This decline is mainly due to global factors, but its consequences are regional and local. Global mitigation measures such as reducing greenhouse gas emissions are likely to come too late, as the level of the Caspian Sea is currently falling at a rate of about 1-2 cm per year.	Strong regional adaptation measures are needed and can help solve this environmental problem by planning and implementing measures.
Lack of knowledge	There is a lack of awareness among stakeholders about the existence of the problem of lowering the water level of the Caspian Sea. For example, they proposed the first Caspian Sea level assessment report from around 2010 onwards. None of the consolidated reports address this issue in detail. In addition, the Intergovernmental Caspian Environment Program assumed in 2011 that the level of the Caspian Sea will fluctuate only slightly in the future.	Management at the international, national and regional level for adaptation measures in the level of the Caspian Sea with the reduction of the level of the Caspian Sea has been established and scientific research should be carried out to solve the problem of the reduction of the water level of the Caspian Sea.
Lack of studies	Assessment of the risks and vulnerability of the ecosystem, economies and social systems of the Caspian region against the decrease of the level of the Caspian Sea is largely absent. This problem is aggravated by the common wisdom that considers the periodic fluctuations of the Caspian Sea level as a self-regulating phenomenon.	Using the existing stations in the southern part of the Caspian Sea and taking into account the effects of various factors on the level of the Caspian Sea, this problem can be solved to some extent.
Spatial optimism	Different communities and coastal countries may think that they are less affected by the Caspian sea level drop than others. Such bias can hinder concerted adaptation efforts.	Public and political awareness of the imminent decline of the Caspian Sea level and the global effects of changes in lake level caused or amplified by global warming can help solve this dilemma.
Damming rivers and taking water by humans	Lake levels are affected by human water withdrawals, river damming, and diversions (the famous drying up of the Aral Sea is just one striking example of this), often masking the effects of climate.	It is possible to open the mouth of the dam during the designated period during the year when there is no need for agriculture and horticulture.

The results showed that the amount of precipitation over the Caspian Sea is decreasing, and on the other hand, the amount of evaporation over the Caspian Sea is increasing. The main cause of the increasing trend of evaporation from the Caspian Sea is the increasing trend of sea surface temperature, which shows an increase of about 1.1 degrees Celsius during 30 years. The Volga river water discharge shows a decreasing trend, which is due to the decreasing trend of precipitation and the construction of dams on the way of the rivers towards the sea. The prediction of the water level of the Caspian Sea in the next 10 years shows a decrease of 10 cm in the sea level. As a general result, climate change causes a decrease in precipitation, an increase in temperature and an increase in evaporation, and finally a decrease in the level of the Caspian Sea, so that this process will continue for the next few years.

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