

Investigation of Caspian Sea Level Fluctuations Based on ECMWF Satellite Imaging Models and Rivers Discharge

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ABSTRACT

Due to the great importance of sea level changes especially for coastal regions, identifying and studying the factors affecting these variations makes it easier to predict changes of sea level and will help to determine the riparian zone and changes in coastal lines. In this research, precipitation-evaporation is studied based on ERA-Interim model of ECMWF in order to estimate changes in Caspian Sea (CS) level and the validity of the results is evaluated in a period between 1980 to the end of 2015. Recorded data about the rivers entering the CS were also studied for better prediction of changes in water level. According to satellite and software analyses, in average evaporation has increased with a rate of $0.89 \text{ Km}^3/\text{year}$, while precipitation and rivers discharge have decreased by the rates of $1.09 \text{ Km}^3/\text{year}$ and $1.41 \text{ Km}^3/\text{year}$, respectively during the 36 years. The standard deviation of the sea level change caused by Volga discharge (normally entering $249.13 \text{ Km}^3/\text{year}$ into the sea alone) is closer to the recorded standard deviation obtained from change of CS level than the other two factors. Also, the lowest and the highest correlation coefficients relative to the recorded sea level changes were calculated considering simultaneous effect of precipitation-evaporation, and simultaneous effect of all parameters, respectively. As a conclusion, it can be said that the main reason for decreasing the CS level during recent years could be attributed to the rise of evaporation in comparison to precipitation and inlet rivers discharges.

1. Introduction

When the mean sea level is measured at different locations of the coast during a long period of time, it is understood that the sea level changes by time. This change is due to the general uplift in the mean sea level, also there is a possibility of tectonic uplift or subsidence of the coast [1].

It is believed that increment of harmful gases in the atmosphere including carbon dioxide has increased the effect of greenhouse gases, the most important of which is the melting of polar ice caps. Global warming and melting of polar ice caps have also affected the average temperature of the free waters and lakes; as a

result of which the distance between molecules comprising seawater has increased, which has led to increment water volume and sea level, consequently [2]. There are predictions regarding faster uplift of the general sea level over the next century, which will have significant impact on the coastline, if occur [3, 4].

In this regard, Clark *et al.* [5] reported the world has faced an increase in greenhouse gas emissions in twentieth and twenty-first centuries. Studies also show that today's global warming are related to previous periods. Therefore, greenhouse gas emission and its influence on the weather conditions in the present

century will have detrimental effects in the future as well.

Gornitz *et al.* [6] have also stated that a significant range of sea level change is linked with the impact of human factors on the hydrological system of the Earth. Creating more runoffs by deforestation, use of groundwater resources and other factors that increase the sea level by 0.6 to 1 mm per year. By storing water behind the dams, some water is absorbed by the ground and some is evaporated. These factors lower the sea level by 1.5 to 1.8 mm per year. The net rate of sea level changes caused by humans is reduction of about 0.8+0.4 mm per year. However, it could be observed that the actual sea level increases by 1 to 2 mm per year which suggests the existence of other factors.

Changes of lakes water levels (both small and large), depend on other factors in addition to global warming. The level of the Caspian Sea has changed enormously in different time periods. Changes of the Caspian Sea level may be due to several different factors such as global warming, changes in river flows, regional precipitations, evaporation, wind stress, changes in seabed morphology, changes in the pattern of atmospheric transport and human activities such as construction of dams on main rivers.

2. The Caspian Sea

The Caspian Sea is situated in a semi-arid area between Russia, Kazakhstan, Turkmenistan, Iran and Azerbaijan (36–47N, 47–54E). Its sea level has lied between 25 to 29 m below the mean level of oceans over past 150 years [7].

The Caspian Sea has the area of about 436000 km² [8]. The catchment area of the rivers flowing into the Sea is about 3 million km² (close to 2% of the global land) and about 80% of the river Discharge into the Sea is from the Volga river, supplying 237 km³ in average per year [9]. The Caspian Sea geographical position is shown in Figure 1.



Fig. 1. The Caspian Sea geographical position

The main difference between the Caspian Sea and open seas is in the way their levels change. As data show, open seas are continually experiencing rises in their levels, while in the Caspian Sea, there are both periods of rise and fall in water level. From 1977 to 1995, the Caspian Sea experienced a rise of 2.4 m, while from 1995 to 2015, it had a 0.8 m fall in its level [10]. Variations of the Caspian Sea level from 1980 to 2015 are shown in Figure 2.

3. Atmospheric Forecasting Models and Sea Water level fluctuations

For many years, changes of sea levels caused lots of damages to coastal ecosystems, residential, commercial and administrative, shipping and fishing units in different areas. Thus, studying the factors affecting the sea level changes and prediction of these variations have gained profound importance.

Ignatove *et al.* [11] studied the evolution of the Caspian Sea coasts under condition of sea level rise as a result

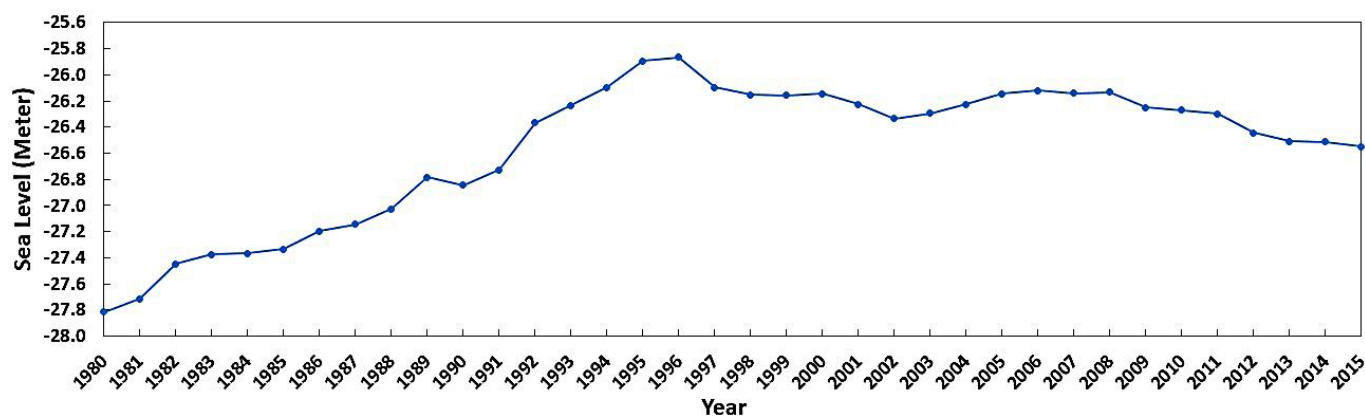


Fig. 2. Caspian Sea levels with respect to the high sea level [10].

of greenhouse gases. They investigated a large number of coasts of Caspian Sea and divided these coasts (with regard to profiles slope ($tg\alpha$)) into 6 major groups including: $tg\alpha \sim 0.0001$, $tg\alpha \sim 0.0005-0.001$, $tg\alpha \sim 0.005-0.01$, $tg\alpha \sim >0.01$, $tg\alpha \sim 0.01$ and $tg\alpha \sim >>0.01$. At first slope ($tg\alpha \sim 0.0001$), no dynamical or morphological changes were observed in the coastal zone and in such shores, the waves' energy be dissipated before the water's edge. Under higher inclinations ($tg\alpha \sim 0.0005-0.001$) where the slope is relatively sharp, the zone of wave break will be at some distance from the shoreline. In this case a longshore bar (and eventually a barrier) is formed in the surf zone, creating a lagoon. At third slopes ($tg\alpha \sim 0.005-0.01$), erosion process of the second slope is continued and with more erosion in the offshore slope a bigger barrier beach is developed and shifted toward land backing by a smaller lagoon. In greater inclinations ($tg\alpha \sim 0.01$), there would be no lagoon because the barrier beach is shifting toward the shore line not in the water. The mechanism is changed and one part of beach ridge is on the land and other part moves back to the sea slope, consequently. At the fifth slope ($tg\alpha \sim >0.01$), due to the increased inclinations, the erosion is started near the shoreline, and the offshore slope is filled up to the equilibrium state by way of accumulation of the material produced by erosion of the coast. Thus, the developing profile consists of an upper erosional part and of a lower accumulation part, *i.e.* it fully agrees with Bruun's scheme. Finally, the last profile ($tg\alpha \sim >>0.01$) illustrates the evolution of a former erosional coast that became inactive in the regressive period due to formation of the depositional terrace.

Naderi Beni *et al.* [12] studied the changes of Caspian Sea level during the last millennium (900 to 1850) by considering historical and geological documents of southern parts of that. During their investigations, they reconstructed Caspian Sea level with solar irradiance and with the fluctuation of lakes in Middle Asia and Europe, which shows a relatively good agreement between the different curves. Also, based on the anti-phase relationship between the Caspian Sea level changes and the solar irradiance during the last millennium, the main historical Caspian Sea level fluctuations have been caused by solar activities. Their studies showed some disagreements between the curves in some periods, which was due to the absence of data from the Caspian Sea level for that period of time, as well as regional irregularities, such as earthquakes and river avulsions.

The flow of rivers and P-E¹ are the most important factors in changes of the sea levels. Evaporation is so significant that almost all oceans would be dried if rainfall, runoff and groundwater areas' discharge didn't

exist. Most of the water evaporating from the oceans returns to the oceans through raining and snowing [13]. Rodionov [14] and Golitsyn [15] stated that evaporation over the Sea is a very important factor of the basin water budget. Elguindi and Giorgi [16] reported over 40% of the total water exchange that affects the Caspian Sea Level is related to evaporation. Different evaporation modeling may have significant effects on predicted changes of the Caspian Sea level. Renssen *et al.* [17] studied Caspian Sea level changes for the period 8ka to 2100 CE using a mixed model setup representing climate, hydrology and sea level. Their model predicts a drop of 5 m between 8 and 5.5ka, which means a decrease from -21.5 meter Baltic Sea level to about -26.5 meter Baltic Sea level. Considering presented documents, the amplitude of this model on the basis of reduction in sea level shows acceptable results, while considering former studies indicates that Caspian Sea level has reached as low as -30 meter Baltic Sea level, which is not reproduced by Renssen's model. They stated that according to the A1b scenario (IPCC Scenario), emission of pollutants caused a 4.5 m decrease in Caspian Sea level in the 21st Century mainly due to strong evaporation. The amplitude of this change is of the same order which was simulated for the last 8000 years. On the basis of relatively warm climate of the 21st Century, evaporation becomes the dominant factor of sea level changes in future, whilst during the period 8-5.5ka input from rivers and over-sea precipitation were more considerable in comparison with precipitation.

Cazenave *et al.* [18] performed the required studies with Topex-Posidon satellite altimetry. Results showed an increasing trend in the Caspian Sea level from January 1993 to July 1995 by $18.9 \pm 0.5 \text{ cm/yr}$. However, by moving from the south of the Caspian Sea to the Volga Delta, the trend increases by 3 cm/yr , demonstrating the dependence of Caspian Sea level on the geographic area. After July 1995, the trend was completely altered, experiencing a downward trend of $-24.8 \pm 1.4 \text{ cm/yr}$. Future Continual measurements can help to determine the transitional or long-term regime of the Caspian Sea level changes; Also, the probable relationship between water level fluctuations and temperature, precipitation, evaporation and rivers discharge may be defined.

Arpe *et al.* [9] studied existence of any relationship between the El-Niño phenomenon and the Caspian Sea level, as well as the prominence of the phenomenon observed in the numerical model. The main feature of the studies conducted by ECHAM4 numerical method software is studying the atmospheric circulation conditions while considering the water surface temperature as the boundary condition.

Arpe *et al.* [7] concluded that summer precipitation in the Volga Basin plays a major role in the sea level

¹ Precipitation and Evaporation

changes which could explain two major events in the 1930s and 1977s about the minimum and maximum level of the Caspian Sea levels. Also, the El-Niño phenomenon is the only stimulus playing the most important role in changes of sea level during the winter in the Northern Hemisphere. Based on the model, they concluded that: 1- Changes in the level of the Caspian Sea are affected by the Volga basin 2- The observed and modeled cases in the Volga basin are similar 3- Measurements of P-E along the Caspian Sea basin and the evaporation of the Caspian Sea are less than the Volga basin.

Arpe *et al.* [19] have studied the hydrology of the Volga basin and the Caspian Sea considering the effective water balance parameters. The research emphasis on 2010 data when a severe drought developed over European part of Russia. Studies were done on the basis of ECMWF²-ERA interim in the Volga basin and the Caspian Sea which indicates that the difference between precipitation and evaporation over Volga basin during July to September 2010 would decrease the Caspian Sea level by 22 cm, of which only 2 cm had been observed until the end of September. In fact, the remaining reduction of 20 cm *can* take months to follow if no other anomalies happen.

Arpe *et al.* [20] reviewed variations in the Caspian Sea level and factors affecting it, such as P-E and rivers, using data from ECMWF during a year (2012). Having considered the acceptability of the results according to the analyses, they concluded it is possible to utilize data obtained from ECMWF. Therefore, forecasts could be done for more than 6 months and it would be possible to consider the effect of Volga River runoff as one of the main rivers feeding the Caspian Sea, on the Caspian Sea level changes. In addition to precipitation - evaporation pattern, they have also proposed to consider the effect of watershed and changes in sea level and its relationship with sea surface temperature in forecasting the changes of the sea level.

Chen *et al.* [21] investigated Long-term Caspian Sea level change employed model predictions from the National Centers for Environmental Prediction Climate Forecast System. They studied the impacts of precipitation, evaporation and input from rivers on changes in the Caspian Sea level from 1979 to 2015. According to analysis of data, the model predictions agree very well with observed Caspian Sea level changes. They observed rapid increase in Caspian Sea level (about 12.74 cm/yr) and significant drop (~ -6.72 cm/yr) during the periods 1979–1995 and 1996–2015, respectively. They showed that increased evaporation rates over the Caspian Sea have played a dominant role in changes in Caspian Sea level.

In order to analyze the P-E, ERA-Interim's data from a subset of Categories of ECMWF [22] information are used. The information is processed based on satellite and 3D analysis software. At each step, the data were

monitored and adjusted by methods of error control with high reliability.

4. Rivers Discharge

In addition to the P-E, the rivers inflow and surroundings basins are very important as well. The basins around the Caspian Sea are divided into six categories including Volga Basin with an average flow of 237 Km³ (about 80%), Kura Araks Basin with an average flow of 17 Km³ (6.3%), Ural Basin with an average flow of 8.1 Km³ (About 3%), Terek Basin with an average flow of 7.4 Km³ (about 2.5%), and basins in Iran and Turkmenistan with an average 8% flow share of the total area per year [9, 23]. Figure 3 indicates the basins of rivers leading to the Caspian Sea based on the ILEC [23] studies.



Fig. 3. The basins of rivers leading to the Caspian Sea based on the ILEC [23] studies

² European Centre for Medium-Range Weather Forecasts

Table 1. The monthly and annual flows of Volga River with cubic kilometers unit between 1980 and 2015 [24]

Years	Months												Annual Discharge
	January	February	March	April	May	June	July	August	September	October	November	December	
1980	20.6	18.5	21.7	15.9	36.7	31.1	15.5	17.2	17.8	17.3	19.7	20.7	252.69
1981	18.4	19.2	23.1	20.6	56.8	48.0	19.6	17.5	15.1	14.9	17.3	17.9	288.24
1982	16.8	14.1	16.9	15.8	40.2	22.7	15.6	14.7	13.6	16.3	15.4	17.4	219.25
1983	13.8	12.0	16.2	22.6	43.4	18.6	18.3	16.2	15.2	16.7	15.4	17.8	226.28
1984	19.3	19.0	24.4	14.3	35.1	20.0	13.7	14.6	13.8	14.6	15.4	20.4	224.64
1985	21.6	17.3	22.0	18.0	47.1	45.9	26.0	18.6	15.7	16.7	16.4	17.7	282.90
1986	17.6	18.0	21.5	25.5	61.3	33.4	19.2	19.4	17.4	20.4	16.9	18.5	289.24
1987	17.4	15.2	20.0	18.9	43.4	49.5	20.1	16.5	16.1	18.1	18.4	20.0	273.45
1988	13.2	14.8	13.8	16.8	49.6	26.2	17.2	15.2	13.2	14.0	15.8	16.0	225.71
1989	13.4	11.1	13.3	17.7	46.3	27.0	16.3	15.9	14.0	13.8	14.4	19.1	222.19
1990	12.8	11.1	14.6	36.0	53.3	44.8	26.2	16.1	15.8	24.0	29.0	25.0	308.82
1991	18.1	16.2	21.7	38.1	69.1	40.4	19.8	16.2	14.4	14.6	16.6	17.8	302.98
1992	14.7	13.8	19.9	24.4	49.6	31.4	16.2	14.9	14.0	13.6	13.0	14.1	239.70
1993	14.4	14.9	19.4	21.2	52.0	31.9	22.0	20.8	18.5	23.3	22.7	15.3	276.15
1994	16.0	16.5	18.8	29.5	61.9	45.4	35.9	30.3	22.7	19.1	18.6	19.2	333.92
1995	17.8	16.4	20.4	32.9	68.0	33.4	17.8	16.8	15.6	12.9	10.2	11.7	274.07
1996	12.7	13.5	11.2	13.2	31.3	16.6	12.9	13.7	13.3	13.6	12.0	12.1	176.20
1997	12.5	11.7	12.5	13.2	48.5	43.0	20.1	17.4	14.3	13.3	15.6	14.5	236.66
1998	14.2	14.4	17.9	19.6	46.1	51.6	20.4	18.3	19.5	17.8	18.1	19.3	277.11
1999	18.2	19.0	25.3	30.6	57.3	36.5	18.0	18.4	16.5	14.5	12.7	16.4	283.51
2000	11.9	11.4	13.4	18.6	55.4	33.2	20.7	16.5	16.1	15.9	14.4	14.4	242.02
2001	14.5	15.6	21.2	22.1	57.6	44.3	19.9	15.9	15.8	14.5	14.2	17.0	272.68
2002	15.8	15.8	16.4	22.8	52.8	39.7	20.1	15.5	14.1	13.4	12.9	15.2	254.40
2003	17.5	15.6	16.8	20.6	46.3	31.1	18.3	16.7	15.0	15.5	15.0	16.1	244.38
2004	17.0	17.2	16.5	23.4	47.7	27.2	22.4	19.7	15.8	15.8	15.4	17.6	255.60
2005	18.9	17.0	22.2	26.2	61.9	43.3	19.2	17.2	15.4	14.1	12.0	12.9	280.23
2006	12.8	12.9	13.5	11.9	37.2	26.4	15.5	14.1	13.1	13.3	13.2	18.2	202.19
2007	19.0	19.7	28.1	33.4	45.3	36.3	19.5	17.5	15.9	14.9	13.1	13.0	275.67
2008	12.7	12.6	15.7	24.6	49.3	22.3	15.6	15.3	14.3	13.9	13.7	20.0	229.95
2009	19.5	17.3	18.0	16.5	45.8	24.0	15.2	15.3	14.4	13.8	13.3	15.7	228.92
2010	12.2	12.4	14.9	14.0	45.0	26.4	13.1	13.0	11.7	11.6	10.8	11.8	196.97
2011	12.0	11.3	13.4	13.2	43.1	16.5	13.6	13.2	12.6	13.3	12.2	15.3	189.60
2012	13.6	12.9	14.5	13.6	49.6	31.1	16.2	13.6	12.6	12.8	14.7	25.0	230.19
2013	18.9	16.3	18.5	28.0	52.8	36.0	16.2	13.3	12.6	13.2	14.4	17.2	257.46
2014	16.4	15.9	21.5	18.7	42.9	18.0	13.7	12.7	14.0	13.3	12.0	13.3	212.54
2015	12.6	10.9	13.1	11.9	29.7	18.9	13.9	14.2	14.8	13.8	13.1	15.2	181.65

As shown in Figure 3, the Volga River has the highest inflow to the Caspian Sea compared to other basins. According to the data extracted from the CSNRC³ report [24], the average inflow of Volga River to the Caspian Sea from 1980 to 2015 was $249.13 \text{ Km}^3/\text{year}$. Regarding the average inflow of $237 \text{ Km}^3/\text{year}$ (from 1840 to 1980) provided by Arpe *et al.* [9] and the ILEC [23], it is clear that the average inflow of Volga River to the Caspian Sea from 1980 to 2015 has increased compared to previous years. In the studied years, the highest annual flow of Volga River was in 1994, with $333.92 \text{ Km}^3/\text{year}$, while its lowest annual flow was in

1996, with $176.20 \text{ Km}^3/\text{year}$. The monthly and annual flows of Volga River within the period of 1980 to 2015 are presented in table 1.

According to the data recorded by CSNRC report [24], Iran basin includes Sefidrood, Polrood, Haraz, Chaloos and Babolrood rivers, and the average inflow of these rivers to the Caspian Sea is $5.33 \text{ Km}^3/\text{year}$. Accordingly, between 1980 and 2015, the highest annual flow rate of Iran's rivers returns to 1994, with $11.22 \text{ Km}^3/\text{year}$ and the lowest annual flow rate dates back to 2001, with $1.98 \text{ Km}^3/\text{year}$. The annual flow rates of Iran's rivers in the period of 1980 to 2015 are listed in table 2.

³ Caspian Sea National Research Center

Table 2. The annual flow rate of Iran's rivers with cubic kilometers unit in the period of 1980 to 2015 [24]

Years	Sefidrood	Polrood	Haraz	Chaloos	Babolrood	Annual Discharge
1980	4.36	0.39	0.83	0.35	0.42	6.35
1981	5.42	0.52	0.78	0.43	0.35	7.50
1982	3.93	0.51	0.69	0.36	0.41	5.90
1983	4.82	0.44	0.86	0.34	0.55	7.00
1984	3.51	0.60	0.70	0.38	0.68	5.87
1985	5.23	0.44	0.93	0.40	0.60	7.61
1986	2.94	0.35	0.92	0.38	0.49	5.08
1987	4.32	0.54	1.15	0.56	0.59	7.17
1988	8.18	0.61	1.04	0.61	0.76	11.19
1989	2.44	0.38	0.66	0.42	0.41	4.31
1990	2.91	0.48	0.59	0.39	0.49	4.85
1991	2.59	0.34	0.76	0.34	0.47	4.50
1992	6.22	0.61	1.28	0.86	1.05	10.02
1993	5.88	0.57	0.90	0.51	0.73	8.59
1994	8.17	0.72	0.81	0.62	0.91	11.22
1995	4.36	0.45	0.91	0.47	0.39	6.58
1996	5.03	0.47	0.79	0.57	0.63	7.50
1997	2.46	0.36	0.67	0.37	0.63	4.48
1998	3.48	0.52	0.93	0.64	0.53	6.10
1999	0.72	0.19	0.48	0.28	0.42	2.09
2000	1.13	0.25	0.55	0.31	0.53	2.78
2001	0.66	0.29	0.44	0.22	0.37	1.98
2002	1.09	0.36	0.81	0.43	0.58	3.27
2003	3.65	0.64	1.25	0.56	0.66	6.77
2004	2.09	0.56	1.28	0.55	0.55	5.02
2005	2.16	0.57	1.56	0.52	0.53	5.35
2006	1.11	0.39	1.00	0.38	0.42	3.30
2007	2.46	0.58	1.19	0.52	0.59	5.34
2008	1.20	0.28	0.75	0.25	0.34	2.83
2009	0.54	0.48	0.93	0.30	0.52	2.76
2010	1.16	0.37	0.82	0.26	0.22	2.83
2011	1.23	0.56	0.85	0.40	0.25	3.30
2012	1.93	0.48	1.17	0.48	0.26	4.32
2013	1.09	0.30	0.71	0.27	0.48	2.85
2014	0.94	0.38	0.59	0.26	0.30	2.46
2015	1.00	0.43	0.72	0.33	0.33	2.80

5. Analysis of P-E Processes in the Caspian Sea Surface

In this study, information of evaporation and total precipitation containing raining and snowing statistics are analyzed from 1980 to the end of 2015. In order to achieve a higher accuracy in the analysis, the level of

the Caspian Sea has been divided into 4 sections. Furthermore, each section is divided into 0.75×0.75 degrees, based on the accuracy of surface analysis of the software. In total, the Caspian Sea is divided into 184 levels; and in each year, 134320 data were collected from the sea surface. Table 3 shows the P-E data of the Caspian Sea surface.

Table 3. P-E Data of the Caspian Sea surface area [22]

Years	Volume of Evaporation (Km^3)	Volume of Precipitation (Km^3)	Average column of Evaporation (Cm)	Average column of Precipitation (Cm)
1980	-294.30	161.65	-67.50	37.08
1981	-267.92	170.37	-61.45	39.08
1982	-277.62	157.94	-63.68	36.23
1983	-247.54	136.25	-56.78	31.25
1984	-284.38	144.43	-65.23	33.13
1985	-287.98	140.07	-66.05	32.13
1986	-270.54	112.05	-62.05	25.70
1987	-283.07	142.57	-64.93	32.70
1988	-289.40	158.81	-66.38	36.43
1989	-282.42	120.88	-64.78	27.73
1990	-280.24	133.42	-64.28	30.60
1991	-286.23	132.76	-65.65	30.45
1992	-284.82	148.57	-65.33	34.08
1993	-315.88	141.92	-72.45	32.55
1994	-299.86	137.99	-68.78	31.65
1995	-296.37	112.71	-67.98	25.85
1996	-289.18	124.15	-66.33	28.48

Table 3. P-E Data of the Caspian Sea surface area [22] – Continue

Years	Volume of Evaporation (Km^3)	Volume of Precipitation (Km^3)	Average column of Evaporation (Cm)	Average column of Precipitation (Cm)
1997	-296.81	136.80	-68.08	31.38
1998	-305.09	119.03	-69.98	27.30
1999	-292.12	126.66	-67.00	29.05
2000	-316.97	125.68	-72.70	28.83
2001	-296.81	120.12	-68.08	27.55
2002	-305.31	137.56	-70.03	31.55
2003	-282.64	144.32	-64.83	33.10
2004	-301.71	130.36	-69.20	29.90
2005	-304.33	113.69	-69.80	26.08
2006	-301.17	132.33	-69.08	30.35
2007	-310.32	113.69	-71.18	26.08
2008	-299.97	115.54	-68.80	26.50
2009	-288.74	122.63	-66.23	28.13
2010	-312.18	106.93	-71.60	24.53
2011	-308.69	132.54	-70.80	30.40
2012	-303.13	112.82	-69.53	25.88
2013	-291.47	116.09	-66.85	26.63
2014	-305.09	90.47	-69.98	20.75
2015	-305.09	127.20	-69.98	29.18

According to table 3, in the 36-year period (from 1980 to the end of 2015), based on the ECMWF software and the satellite analysis of the ERA-Interim data series, the highest evaporation rate is observed in 2000, with the rate of $316.97 \text{ Km}^3/\text{year}$ (72.70 Cm water column), while the least evaporation rate occurred in 1983, with $247.54 \text{ Km}^3/\text{year}$ (56.78 Cm water column). Also, the highest and lowest precipitations were observed in 1981 and 2014, with $170.37 \text{ Km}^3/\text{year}$ (39.08 Cm water column) and 90.47 (20.75 Cm water column), respectively. Based on available data, the average evaporation and precipitation rates are $293.15 \text{ Km}^3/\text{year}$ (67.24 Cm water column) and $130.68 \text{ Km}^3/\text{year}$ (29.97 Cm water column), respectively. Thus, it could be stated that evaporation rate is more than twice than that of precipitation at the Caspian Sea level, indicating the more significant effect of evaporation than precipitation on the changes of Caspian Sea level.

6. Data Analysis and Discussion

In order to examine the P-E, rivers discharge and scientific measurements between these factors, the histogram in Figure 4 has been drawn.

According to Figure 4, during the 36-years period under study, precipitation is much less than those of evaporation and rivers discharge. During 1980-1994, evaporation occasionally exceeded rivers discharge and vice versa. However; since 1995, evaporation was always more than rivers discharge. In general, evaporation rose with the rate of $0.89 \text{ Km}^3/\text{year}$, while the equivalent figures for precipitation and river discharge declined at the rate of 1.09 and $1.41 \text{ Km}^3/\text{year}$, respectively, which aroused concerns. Figure 5 shows independent effect of each parameter (Volga discharge, P-E) on the Caspian Sea level.

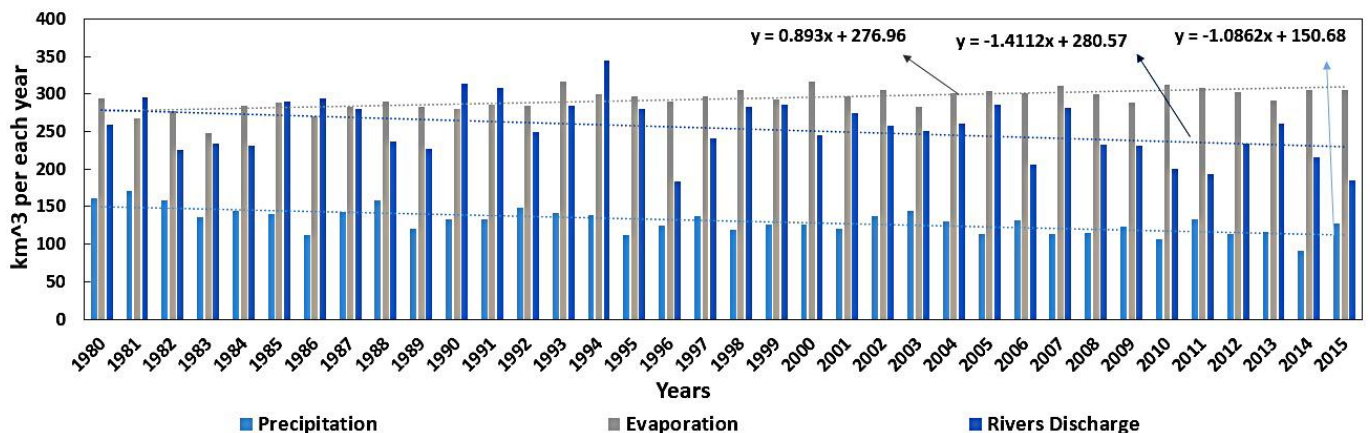


Fig. 4. Annual volumes of rivers discharge and P-E in the Caspian Sea

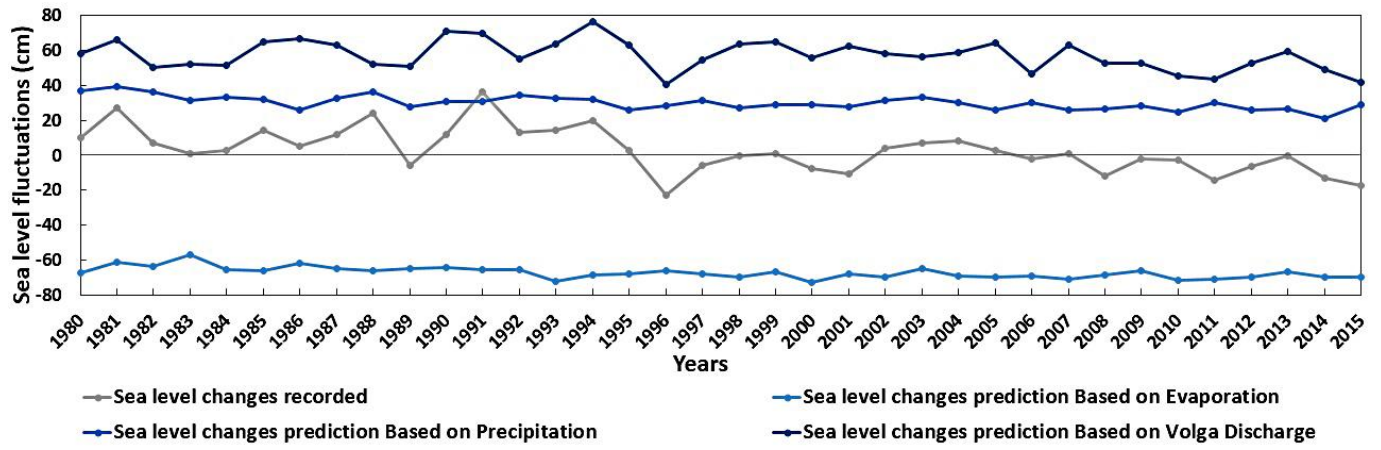


Fig. 5. Independent effect of each parameter (Volga discharge and P-E) on the Caspian Sea level

As Figure 5 suggests, evaporation decreases sea level, while precipitation and Volga discharge increase it. Meanwhile, effect of evaporation and Volga discharge on the Caspian Sea level is much higher than that of precipitation.

One common method for data analysis and proximity of their variations is the standard deviation method, which is as follows:

$$S_N = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2} \quad (1)$$

In Eq. (1), S_N is the standard deviation, N is the number of data and \bar{x} is the mean. Using Eq. (1), the standard deviations for each set of outputs provided in Figure 5 are presented in table 4.

As shown in table 4, the standard deviation of the sea level from Volga discharge is closer to the standard

deviation of the recorded Caspian Sea level than other two factors. Based on this study, it could be concluded that Volga discharge is more effective on Caspian Sea level than other factors. Furthermore, changes in Volga discharge can make significant changes in the Caspian Sea level. Therefore, proper ordering and monitoring the Volga discharge process is very important. In order to have a better analysis of the Caspian Sea level, other factors were also evaluated. Approximately 5 cubic kilometers of water seep into the ground each year. Also, 18 cubic kilometers of water are annually entered into the Kara Bogaz Gol Gulf (except for 1982 to 1992, due to closure of the dam) [8].

Simultaneous effect of all mentioned environmental factors were also for more accurate analysis. The change of Caspian Sea level caused by rivers discharge, precipitation, evaporation, water penetration into the land and water outflow through Kara Bogaz Gol Gulf are shown in Figure 6.

Table 4. The standard deviations of each set of outputs shown in Fig. 5

	Sea level changes recorded	Sea level changes prediction Based on Volga Discharge	Sea level changes prediction Based on Precipitation	Sea level changes prediction Based on Evaporation
Standard deviation	12.48	8.43	3.83	3.29

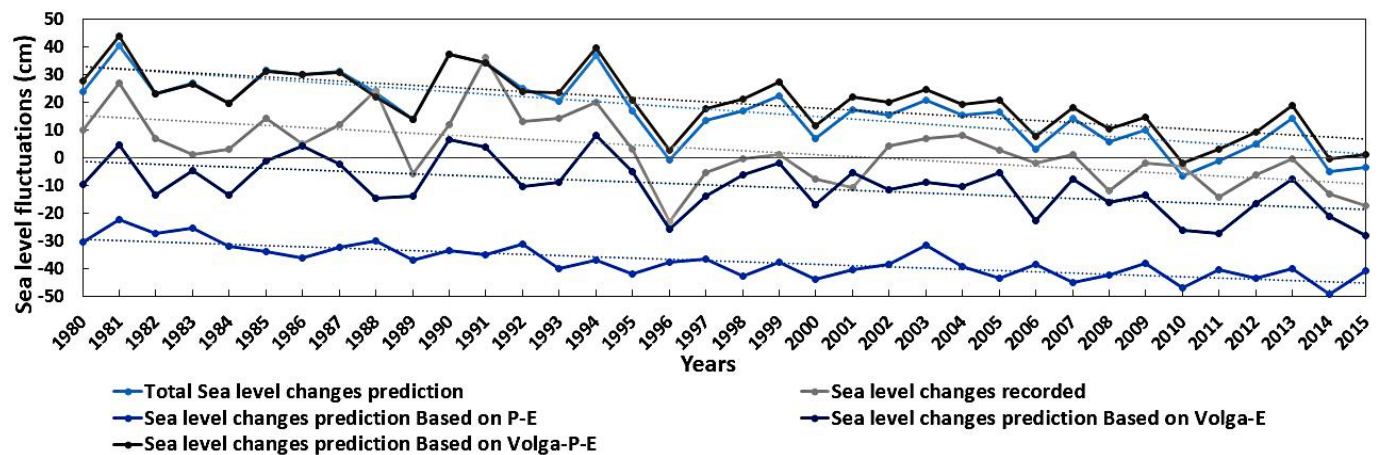


Fig. 6. The Caspian Sea level change due to the rivers discharge, precipitation, evaporation, water penetration into the land and water outflow through Kara Bogaz Gol Gulf

Table 5. The correlation coefficient of each set of outputs shown in Fig. 6, and recorded changes of Sea level

	Sea level changes prediction Based on P-E	Sea level changes prediction Based on Volga-E	Sea level changes prediction Based on Volga-P-E	Total Sea level changes prediction
Correlation Coefficient	56.94%	70.56%	80.30%	82.67%

According to Figure 6, it can be seen that considering simultaneous effect of all parameters, increase of evaporation rate and reduction in precipitation and rivers discharge generally reduced the Caspian Sea level (linear trend line); which is confirmed by the sea level changes recorded in the tide gauge of Anzali port (Sea Level changes recorded parameter in Figure 6). To evaluate the results obtained by effect of environmental factors on sea level with actual recorded changes in sea level, correlation coefficient could be calculated as follows:

$$CC = \frac{\sum_{i=1}^N (x_i - \bar{x}) \times (y_i - \bar{y})}{\sqrt{\sum_{i=1}^N (x_i - \bar{x})^2 \times \sum_{i=1}^N (y_i - \bar{y})^2}} \quad (2)$$

In Eq. (2) CC is the correlation coefficient, N is the number of data of each set, \bar{x} and \bar{y} are data average. Base on Eq. (2) the correlation coefficient of each set of outputs shown in Figure 6, as well as recorded changes of Sea level are presented in table 5. Based on the results shown in table 5, the lowest correlation coefficient with respect to recorded changes of sea level is obtained for the simultaneous effect of P-E. Also, the highest correlation coefficient is observed for the simultaneous effect of all parameters, with 82.67%.

7. Conclusions

In this research, the P-E of the Caspian Sea have been analyzed based on the ECMWF satellite weather forecast model of. Also, the rivers discharge, water infiltration and exfiltration through Kara Bogaz Gol gulf bed, between 1980 and 2015, have been investigated. Due to the great importance of sea level changes especially for coastal regions, identifying and studying the factors affecting these variations makes it easier to predict changes of sea level and will help to determine the riparian zone and changes in coastal lines.

The basins around the Caspian Sea was divided into six categories including: Volga Basin, Kura Araks Basin, Ural Basin, Terek Basin, and Basins in Iran and Turkmenistan. The highest value was observed for Volga Basin with an average flow of $249.13 \text{ Km}^3/\text{year}$. According to the satellite and software analysis, in the 36-year period, the average evaporation rate was $293.15 \text{ Km}^3/\text{year}$ and the average precipitation was $130.68 \text{ Km}^3/\text{year}$. Therefore, it could be stated that evaporation rate has been more than twice the

precipitation rate at the Caspian Sea level, indicating more significant effect of evaporation than precipitation on the Caspian Sea level. In the course of the whole period, in average evaporation increased with a rate of $0.89 \text{ Km}^3/\text{year}$ and precipitation and rivers discharge decreased by the rates of 1.08 and $1.41 \text{ Km}^3/\text{year}$, respectively.

Standard deviation method was used to assess the effect of each factor on the sea level changes and its validation with regards to the actual sea levels recorded. The standard deviation of the change in sea level caused by Volga discharge was closer to standard deviation of actual recorded amounts than other two factors. Therefore, Volga discharge had more dramatic effect on the process of Caspian Sea level change than other factors. Furthermore, correlation coefficient was utilized to examine the results obtained by effect of environmental factors on sea level with actual recorded changes in Sea level. Based on the results, the lowest correlation coefficient with respect to actual recorded changes of sea level was obtained for the simultaneous effect of P-E. Also, the highest correlation coefficient was observed for the simultaneous effect of all parameters, with 82.67%.

Based on the available analyses it can be concluded that the ERA-Interim series of ECMWF set does not have sufficient accuracy for scientific studies and accurate forecasts of Caspian Sea level changes. However, it could be devised for long-term review and forecasting the Caspian Sea level changes. In particular, the current study shows that the main reason for decreasing the Caspian Sea level during recent years could be attributed to the rise of evaporation in comparison to precipitation and inlet rivers discharges.

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