

The Effects of Sea Level Fall on the Caspian Sea Shoreline Changes

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ABSTRACT

The Caspian Sea level has experienced frequent fluctuations resulting in shoreline advance and retreat. Therefore, studying and predicting shoreline changes in the Caspian Sea are very important. The "Bruun Rule" was presented in order to predict shoreline variation due to sea level rise. In addition, to improve the predictions of the Bruun rule, added landward sediment transport to it, leading to more desirable results. In this research, the Bruun rule and its modified form, extended for landward transport, were investigated for the Caspian Sea level fall conditions. The modified equation in this study leads to the better results, which indicates that due to sea level fall and natural storms, there would be sediment deposition toward the shoreline. In terms of water level reduction, by applying the coefficient, the root mean squared error was obtained 3.447 meters for predicting shoreline changes in comparison to its natural changes. According to the results, the lowest difference in prediction is related to the Mahmudabad coast and the highest difference in prediction is related to the Dastak coast, which are equal to 0.059 and 4.849 meters, respectively. Based on this trend for forecasting shoreline changes by applying the coefficient and not having much difference in calculating the root mean square error based on the proposed equation of Rosati et al., it is possible to use the optimized equation in this study as a prediction of shoreline changes in terms of sea level fall; This coefficient has improved the forecasting trend of coastline changes in terms of water level reduction for each of the studied areas with direct deviations of D_{50} and H_B in the equation, and the results obtained from forecasting shoreline variations show a lower difference for each area.

1. Introduction

Most of the shorelines are covered with sands. At some point, a river, a tidal inlet or a rocky promontory cuts them. By breaking waves and running-up on shore face, the coastal surface changes continuously. Continuous changes in the shape of shores occur because the characteristics of a wave (its height, period and angle upon approaching the beach) scarcely remain constant for a certain period of time. These changes are made by currents, which are influenced by the waves developed in the breaking zone and by the direct wave actions through the turbulence caused by the broken waves and by the rising and falling of the water level at the coast. The simultaneous change in the shape of a shore happens

due to the sediment transferred by the approached waves and those that are either off or along a shore. Figure 1 shows an example of a coastal cross-section. In addition to profile changes of the coast caused by waves, if relative changes in the mean sea level occur (just as in most beaches around the world), there would be some changes in the beach profile. At the time of sea level rise along with the profile drowning, when sand is transported off the shore and the Mean Sea Level position on the shoreface moves landward, profile rearrangement occurs. Bruun explain this process and present a method for calculating the distance change of the shoreline upon even a slight rise in the Mean Sea Level [1, 2]. The Bruun rule depends on parameters such as sea level rise, closure depth, the distance from the closure depth to the

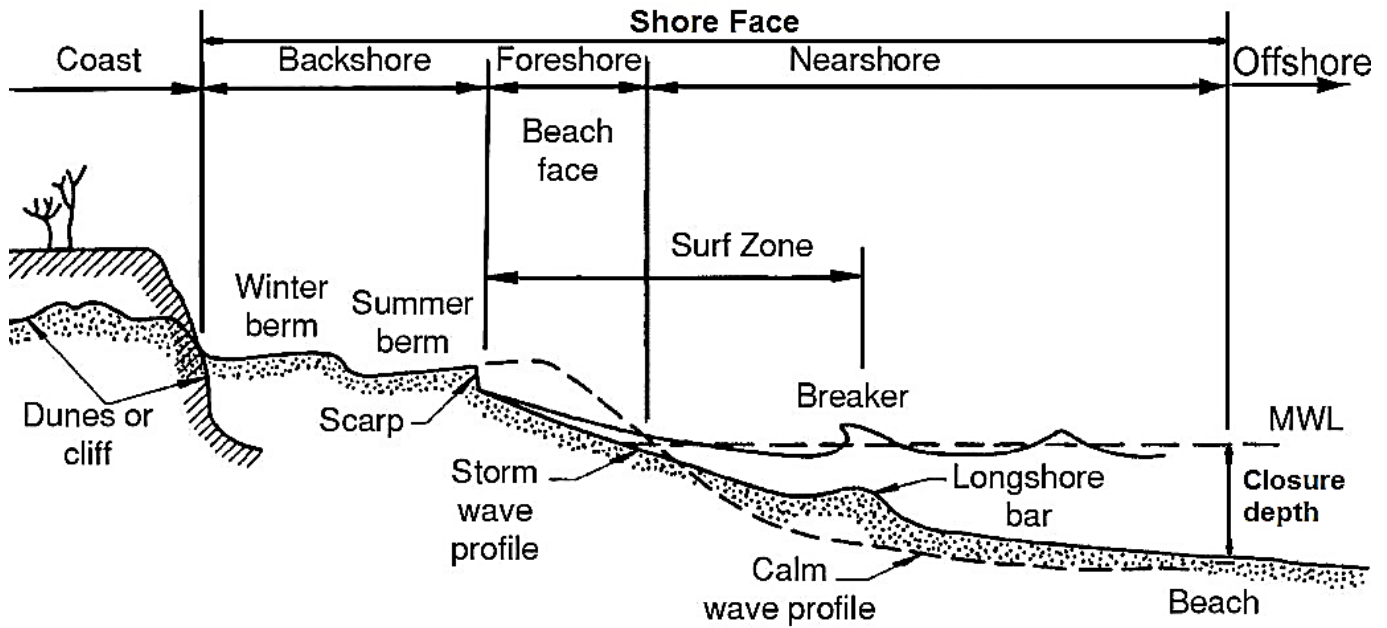


Figure 1. A typical beach cross-section with details [4]

shoreline and the maximum run-up height. Also, to improve the predictions made by the Bruun rule, Rosati *et al.* added landward sediment transport, which led to obtaining much-desired results [3].

Changes in shorelines (advancing or retreating) due to the mentioned factors are of great importance in coastal residential areas, especially, ports. Predicting the trend of these changes will determine the future of coastal cities and causes decisions to be made to confront and control the advance of shorelines toward residential areas and to prevent potential damages. Also, it will facilitate more logical planning to be done in terms of designing and the economy of important commercial and fishing ports.

De Winter and Ruessink, examined the effects of sea level rise on the sand dunes with considering XBeach models in their research. According to their studies, with 0.4 meters increase in water level, the volume of eroded beaches of Noordwijk, and Egmon has been reached 52 and 80 m^3/m per m respectively [5].

Also, Vitousek *et al.*, developed flexible and multifaceted model as CoSMoS-COAST to predict long-term changes of shorelines. This model is used to predict changes of the coastline of Southern California (500 km) as a result of sea level rise. According to their forecast, by 0.93 to 2 meters rise in sea level until 2100, about 31 to 67 percent of the coasts of Southern California will be lost [6].

There have been numerous changes in the Caspian Sea level in different times. Sometimes, these changes have had a decreasing trend, while at others; they have been incremental [7]. Since the Caspian Sea level has experienced frequent fluctuations resulting in coastal advance and retreat; therefore, studying and predicting shoreline changes in the Caspian Sea is very important.

Neshaei *et al.* investigate sediment transport by the wind and its effect on changes in the shape of a coast and presented a calibrated model, whose predictions showed reasonable results. These predictions were performed based on three types of selected parameters, which are, average values, minimum values and maximum values. A majority of data points measured by surveying are located within a narrow band obtained by the last two set of model parameters. Using the average values for the model parameters, it showed reasonable predictions regarding to the complexity of the nature of the shoreline profiles [8].

Firoozfar *et al.* examined the behavior of the southern coasts of the Caspian Sea due to sea level changes. In their study, they carried out sedimentary characteristics, coastal hydrography, bed morphology and coastal profile up to a depth of 10 meters in three different periods from the coasts. In their research, they obtained a database of coastal gradients, sedimentary characteristics, and along shore flow patterns of the shoreline. Based on sea level changes and its results, the coastal area of the south of the Caspian Sea was classified into four categories: the west of Guilan province with a gentle slope near the coast and a steep slope in the coastal zone to a depth of 10 meters; the central region of the Guilan province and eastern province of Mazandaran with a steep slope near the coast and a gentle slope in the coastal zone to a depth of 10 meters; the western part of Mazandaran province with a steep slope near the coast and the coastal area to a depth of 10 meters, as well as Golestan province with a very gentle slope in its coastal area [9].

Bruun took the seaward transport of all eroded sand as a result of sea level rise into consideration. Many laboratory experiments have been conducted such as

Schwartz (1967 and 1987), Williams (1978) and Park (2009) [10-13]; and many numerical models have been developed in various studied based on the Bruun rule. These studies are included but not limited to Kobayashi *et al.* (1996), Tega and Kobayashi (2000), Davidson-Arnott (2005), Donnelly *et al.* (2006), Donnelly (2007), Donnelly (2008), Larson *et al.* (2009), Aagaard and Sorensen (2013), Houston and Dean (2014) and Tarigan and Nurzanah (2016) [14-23].

Cooper and Pilkey claim that the Bruun rule is based on incorrect fundamental hypotheses and cannot be used to predict shoreline changes [24]. Kaplin and Selivanov compared the Bruun rule with profile changes of the Caspian Sea during 1978-1991, in which the sea level rise of 1.8-2.5 meter has been noticed. Obtained results indicated that the Bruun rule was well-adapted to changes in shorelines. The authors of this paper assert that in order to reach more accurate results, longshore sediment transport, swash zone and sediments transported by the wind should also be considered in calculations [25].

Based on the Bruun rule, Leatherman *et al.* studied shoreline changes related to the sea level rise in five eastern coasts in the United States. The authors claim that the model proved to be correct; however, its domain was always two times greater than the rate of the sea level rise [26]. Zhang *et al.* conducted a more precise study on the Bruun rule and investigated shoreline changes based on sea level rise in five coasts similar to those studied by Leatherman *et al.*; The authors confirmed the Bruun rule, yet they stated that two zones with lower change rates (Long Island and Delmarva Peninsula) were naturally nourished. Still, no wind-related swash zone and sediment deposition were seen in their studies [27]. With considering Bruun rule, Ranasinghe *et al.* studied the shoreline changes in Australian coasts in terms of sea level rise

and estimated that these changes would be less than 8% by the year 2100 [28].

2. Methods

Bruun proposed an equation based on the equilibrium of eroded and deposited volume of cross-shore sediment transport [1]. The equation can predict shoreline changes based on sea level changes. Besides the eroded and deposition volume in a coastal region, Rosati *et al.* considered the landward sediment deposition volume as well [3].

2.1. The Bruun Rule

The Bruun rule considers the horizontal changes in a shoreline to be related to sea level changes, closure depth, the distance from the closure depth to the shoreline and of the maximum advancing of waves at the swash zone. Thus, the following equation has been suggested [1, 2]:

$$R_B = S \frac{W_*}{h_c + B} \quad (1)$$

Where, R_B is horizontal changes of shoreline (Bruun Rule), S is changes in the sea level, B is maximum run-up height and h_c and W_* are closure depth and the active profile length after sea level changes, respectively. W_* can be obtained from the following equation:

$$W_* = W + R_B \quad (2)$$

Where, W is active profile length before sea level changes. The Bruun rule's details are shown in Figure 2. To calculate the closure depth, the Coastal Engineering Research Center suggests the following relation [29]:

$$h_c = 6.75H_s \quad (3)$$

H_s is significant wave height in deep waters.

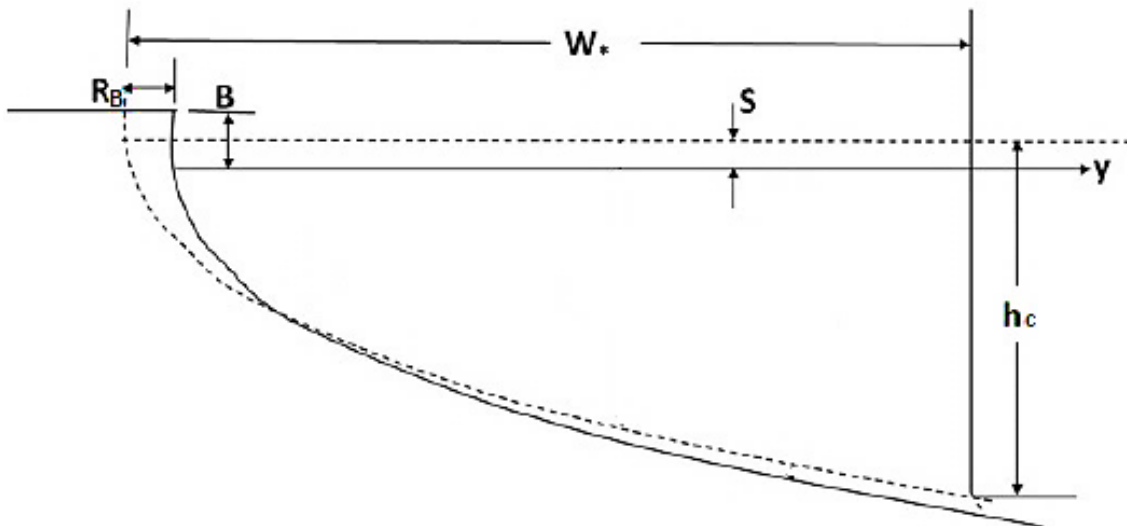


Figure 2. Bruun Rule definitions [1, 2]

The maximum run-up height can also be calculated by using the following equation [30]:

$$B = \frac{U_0^2}{2g} \quad (4)$$

Where, g is acceleration of gravity and U_0 is initial velocity of water on the shoreline, which is calculated using the following equation:

$$U_0 = C \sqrt{gH_B} \quad (5)$$

In this equation, H_B represent mean wave height in the breaker zone and C is Froude number. A natural beach is under the influence of wave breaking mechanism, and the value of $C \approx 1.4$ seems to be typical according to the results provided by Svendsen *et al.* [31]. Based on more laboratory studies, the value of C is between 1.18 and 1.48 [32, 33].

2.2. The Modified Bruun Rule Extended for Landward Transport

After conducting field studies in eastern coasts of Florida and analyzing the Bruun rule, Rosati *et al.* conclude that at the time of sea level rise both seaward and landward sediment transport will occur. With consideration of the landward sediment transport hypotheses that were put forward by Rosati *et al.*, the shoreline changes after changes in the sea

level can be calculated using the following equation [3]:

$$R_R = \left(W_* + \frac{V_D}{S} \right) \ln \left(\frac{h_c + B}{h_c + B - S} \right) \quad (6)$$

$$\approx S \frac{W_* + V_D/S}{h_c + B}$$

Where, R_R is horizontal changes of a shoreline (The Modified Bruun Rule Extended for Landward Transport by Rosati *et al.*) and V_D is volume per unit length of the landward deposition that is equal to $y_L \times S$, where y_L is width of landward sediment transport [3]. Based on Rosati *et al.* equations, characteristics of profile changes, which occurred after sea level rise can be seen in Figure 3.

3. Study Area

With its natural and regional conditions, the Caspian Sea is one of the best places to conduct coastal engineering studies. Numerous sea level changes during a short periods of time have made it attractive for conducting studies on beach profile and shoreline changes that happen due to sea level rise and fall. Therefore, the Caspian Sea can be considered a large-scale natural laboratory model. The Caspian Sea coast in Dastak and Anzali regions are shown in Figure 4.

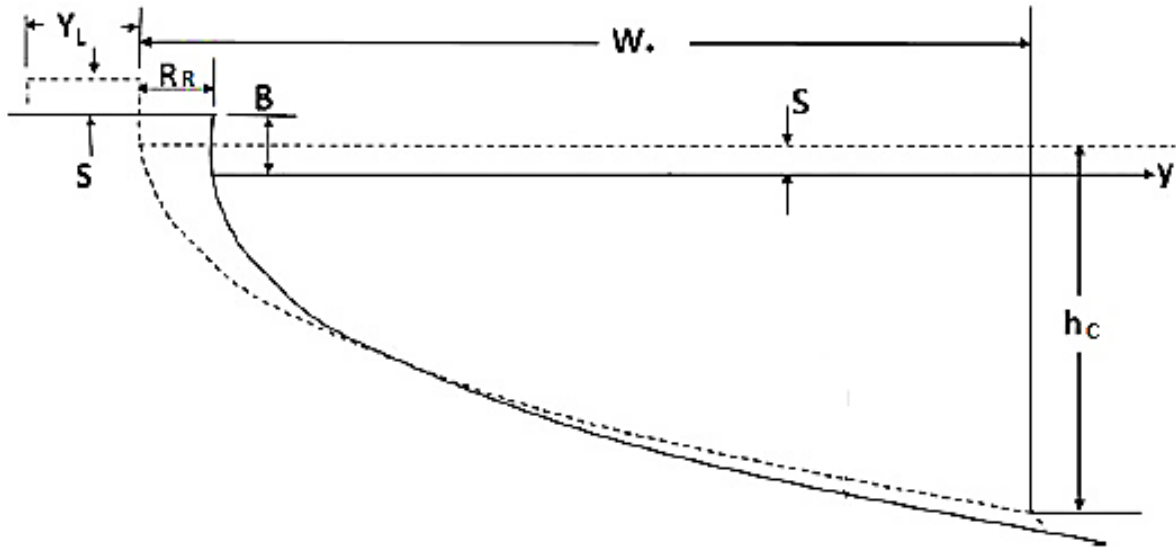


Figure 3. Characteristics of profile changes after the sea level rise [3]



Figure 4. Caspian Sea Coasts in the Dastak and Anzali Zones

In order to investigate the relation suggested by Bruun and Rosati *et al.* in a more accurate way, necessary information such as mean grain size (D_{50}), sea level changes (S) and cross-section profiles of the southern coasts were collected from Anzali and Dastak coastal regions in Guilan province, Namakabrood, Mahmudabad and Larim in Mazandaran province and also from Miankaleh in Golestan province during the 2013-2015 periods by the Caspian Sea National Research Center report [33]. The southern part of the

Caspian Sea and the studied coasts can be seen in Figure 5.

Data for the Caspian Sea waves, including the height of waves and their corresponding periods in deep waters and a wave's breaker zone with a return period of 3 years were used from the Ports and Maritime Organization [34]. Information about the mean sediment particle size, sea level change and wave information have been given in Table 1.

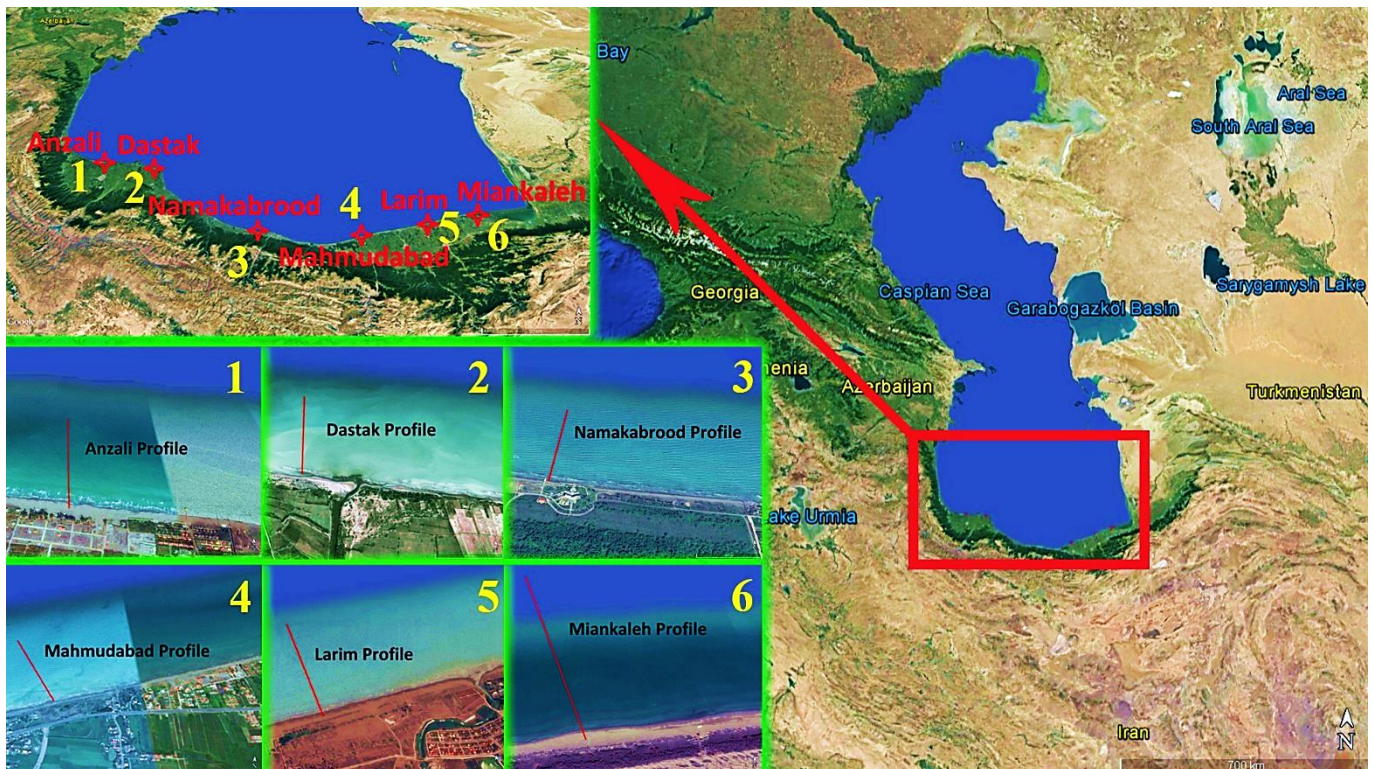


Figure 5. The southern part of the Caspian Sea and the studied coasts

Table 1. Measured data of the southern areas of the Caspian Sea [7, 33, 34]

Parameter/Zone	Anzali	Dastak	Namakabrood	Mahmudabad	Larim	Miankaleh
D_{50} (mm)	0.2	0.19	0.23	0.19	0.17	0.17
S (2013 to 2015) (m)	-0.132	-0.132	-0.132	-0.132	-0.132	-0.132
y_L (m)	154.5	174.5	115	160.5	199	100
H_s (m)	0.71	0.71	0.65	0.65	0.67	0.67
T_0 (Sec)	4.86	4.86	4.25	4.25	4.7	4.7
$H_{B\max}$ (m)	5.22	5.22	5.12	5.12	4.79	4.79
H_B (m)	0.68	0.68	0.65	0.65	0.66	0.66
T_{BP} (Sec)	13.1	13.1	11.9	11.9	12.19	12.19
T_B (Sec)	4.87	4.87	4.26	4.26	4.72	4.72

In Table 1, H_s is significant wave height in deep waters, T_0 is mean wave period in deep waters, $H_{B\max}$ is maximum wave height in the breaker zone, H_B is mean wave height in the breaker zone, T_{BP} is maximum wave period in the breaker zone and T_B represent mean wave period in the breaker zone. As it can be seen in Table 1, the mean particle size in the Caspian Sea coasts is about 0.0002 meters. With consideration of the data from the 3-year return period in the southern coasts of the Caspian Sea, the maximum wave height in the breaker zone would be about 5 meters. These shows that the Caspian Sea has a fairly stormy nature. Under natural conditions and taking waves' mean characteristics value into consideration for a 3-year period, the wave height in deep water is almost 0.67 meter with a period of 4.7 seconds, which is an indication of the Caspian Sea's normal behavior under normal and calm weather conditions.

4. Results

4.1. Bruun Rule and Landward Transport Analysis

To calculate the closure depth, Eq. (3) can be used. This equation has been suggested by the Coastal Engineering Research Center [10]. The outputs indicate the logical prediction of this equation. After calculating the closure depth, its distance from the shoreline was calculated based on the 2013 profiles. Also, the natural slope of the coast could be calculated based on closure depth values and their distance from the shoreline.

To calculate the maximum run-up height (Eq. 4), the initial velocity of water at the shoreline (Eq. 5) should

also be calculated. This velocity is a function of the acceleration of gravity, wave height and the coefficient which depends on the bore collapse (Froude number) in the breaker zone. In order to estimate the bore collapse coefficient, some simplification conditions were considered, in which the value of the coefficient C was 1.4. Closure depth (Eq. 3), the horizontal distance of the closure depth from shoreline, the natural slope of the coast (S_0), the initial velocity of water in the shoreline and the maximum run-up height are presented in Table 2.

As it can be seen in Table 2, based on the equations, the water depth at the end of the active coastal zone is predicted to be about 4.5 meters. The horizontal distances of the closure depth from the shoreline in Mahmudabad and Namakabrood shores are less due to their steeper slopes in comparison with other zones. Also, a gentler slope at Miankaleh coasts leads to longer distances of the closure depth from the shoreline. It is shown that the maximum run-up height is near 0.65 meters. The values obtained for all coasts are close to this one.

The main difference between the Caspian Sea and open seas is in the way its sea level changes. As the data show, open seas are continually experiencing rises in their levels, whereas in the Caspian Sea, there are periods of both sea level rise and fall; From 1977 to 1995, the sea experienced a rise of 2.4 meters, while from 1995 to 2014, it experienced 0.8 meter fall [7]. These sea level fluctuations are shown in Figure 6.

Table 2. The calculated parameters of the Caspian Sea

Parameter/Zone	Anzali	Dastak	Namakabrood	Mahmudabad	Larim	Miankaleh
h_c (m)	4.793	4.793	4.388	4.388	4.523	4.523
W (m)	454.44	451.04	327.86	296.80	454.86	885.36
S_0	0.011	0.011	0.013	0.015	0.010	0.005
C	1.4	1.4	1.4	1.4	1.4	1.4
U_0 (m/s)	3.615	3.615	3.535	3.535	3.562	3.562
B (m)	0.666	0.666	0.637	0.637	0.647	0.647

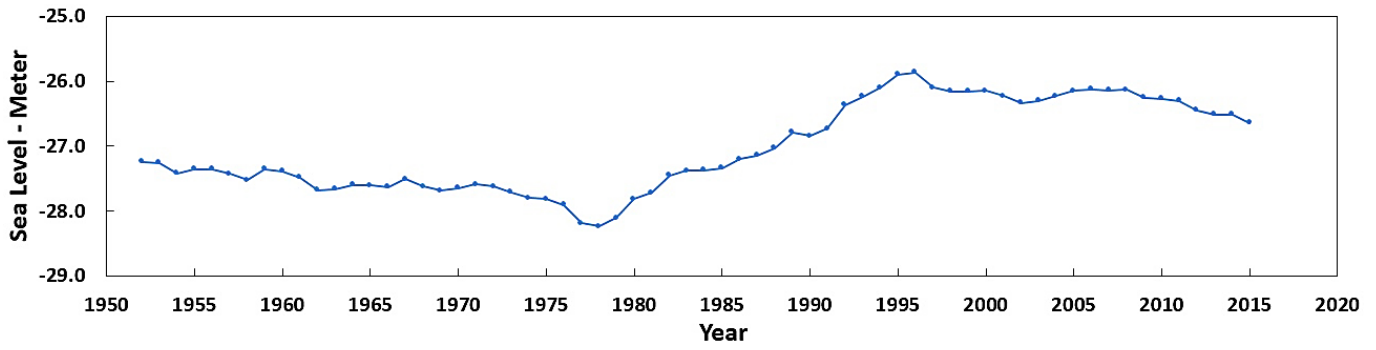


Figure 6. 60 years of the Caspian Sea level change according to the high sea level [7]

4.2. Adjustment of the Bruun Rule with Sea Level Fall Conditions

In order to investigate and apply the effects of sea level fall in the Eq.'s (1) and (6), the basic and simplified assumptions can be made to calculate the Bruun theory based on the volume of sediment deposition and accumulation as follows:

$$\Delta V_- = \Delta V_+ \Rightarrow R_B \times (h_c + B) = S \times (W + R_B) \quad (7)$$

$$\Delta V_- = \Delta V_+ \Rightarrow R_R \times (h_c + B) = S \times (W + R_R) + S \times y_L \quad (8)$$

Eq. (7) related to Bruun's theory and Eq. (8) related to the modified Bruun Rule theory by Rosati *et al.*

By considering simplified assumptions in Eq.'s (7) and (8) in terms of sea level fall and due to the insignificance of the changes in water level to the closure depth, the vertical elevation of the water as well as the advance of the shoreline, the left terms of the above equations can stay unchanged. Hence, it can be assumed that under the conditions of sea level fall,

the volume of washed-out sediments will act as the conditions for rising sea levels.

Due to the fact that in the new conditions (the reduction of sea level), in spite of increasing sea level, the shoreline progresses; therefore, in the right side of Eq.'s (7) and (8) (in the section of sediment accumulated in the sea bed), the terms $S \times (W + R_B)$ and $S \times (W + R_R)$ change to $S \times (W - R_B)$ and $S \times (W - R_R)$. Other terms on the left side of the equations can be considered unchanged. In order to get better understanding the process of reducing the sea level and shoreline changes are shown in Figure 7 by some simplification.

Figure 8 shows shoreline changes in the profiles measured in the studied coasts. Also, values of shoreline changes based on the Bruun Rule, the modified Bruun rule extended for landward transport and the shoreline changes based on profiles measured during the 2013-2015 period and the difference between shoreline changes measured and calculated from Eq.'s (1) and (6) are given in Table 3.

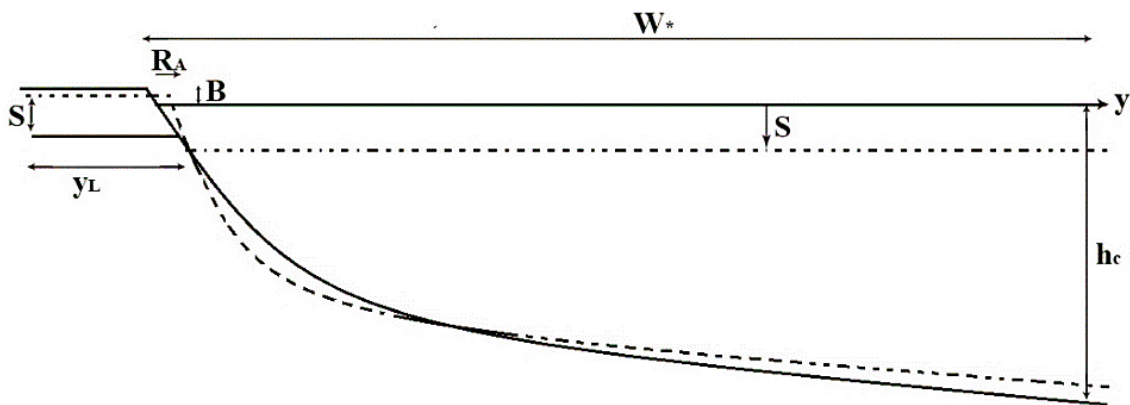


Figure 7. Characteristics of profile changes after the sea level fall

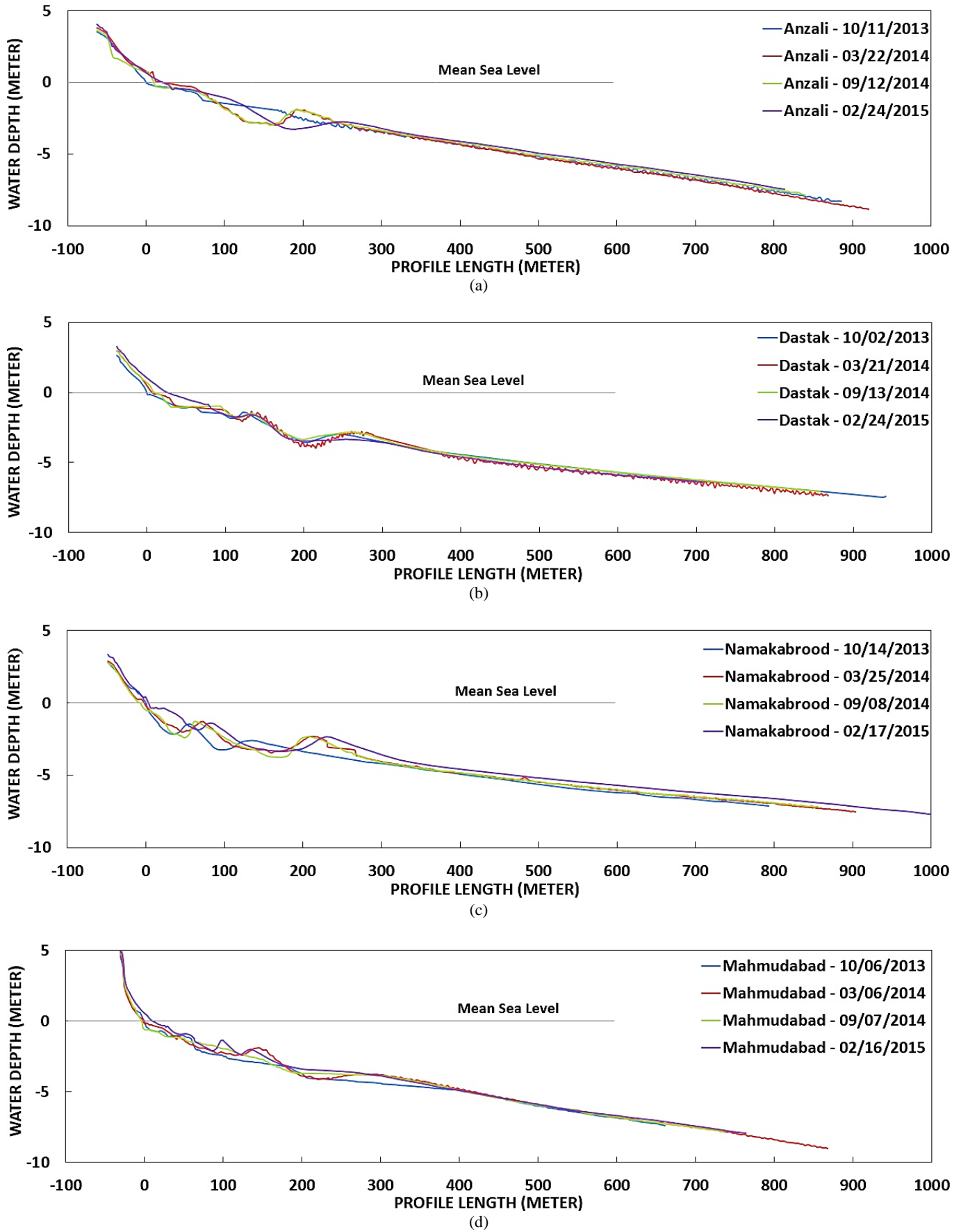


Figure 8. Shoreline variations for observed profiles in the studied coasts; a) Anzali, b) Dastak, c) Namakabrood, d) Mahmudabad, e) Larim, f) Miankaleh

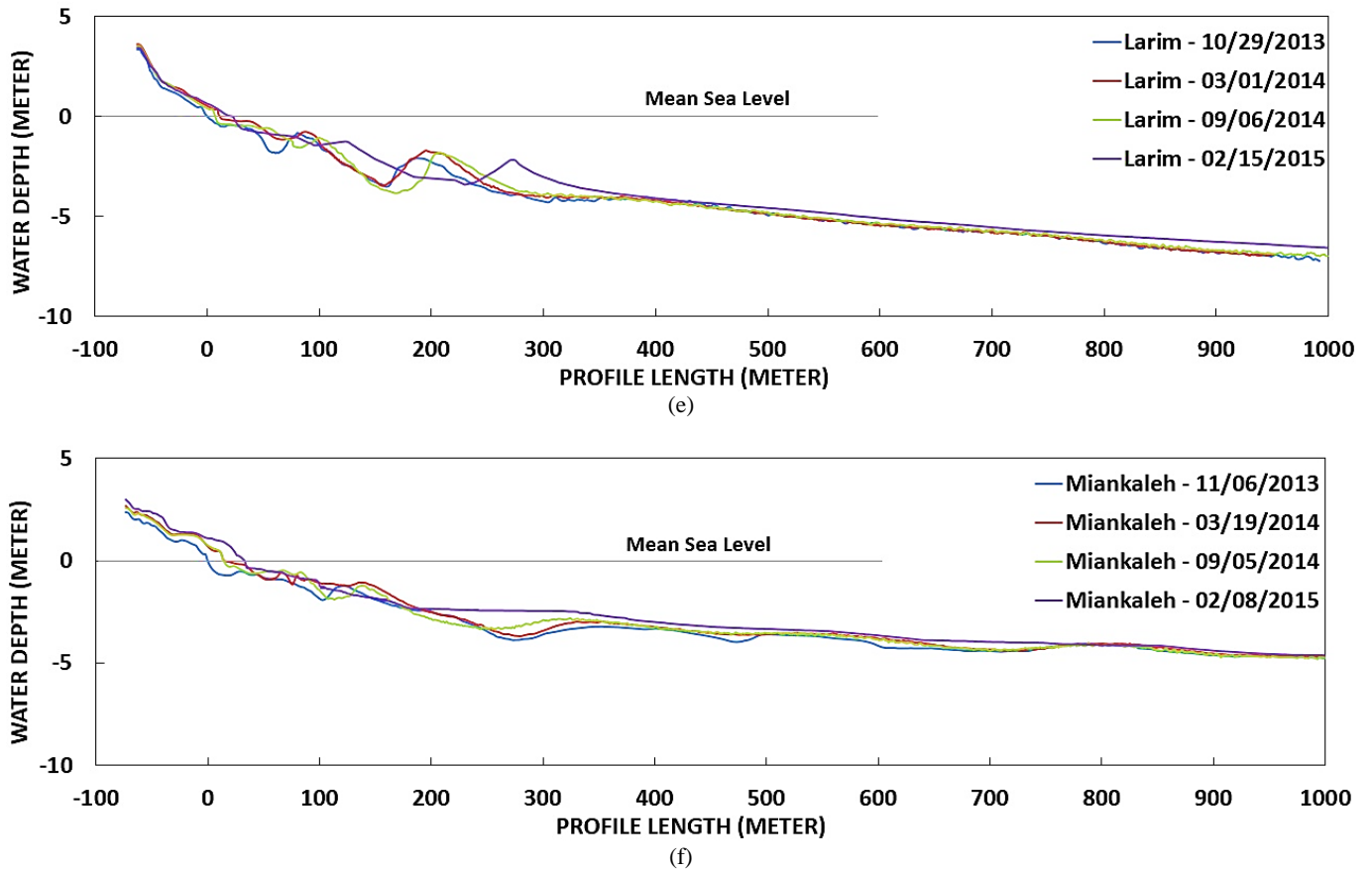


Figure 8. Shoreline variations of observed profiles in the studied coasts; a) Anzali, b) Dastak, c) Namakabrood, d) Mahmudabad, e) Larim, f) Miankaleh - Continue

Table 3. Calculated parameters of shoreline changes according to Bruun Rule, it's modified for landward transport, Shoreline changes based on the obtained profiles during the years 2013 to 2015

Parameter/Zone	Anzali	Dastak	Namakabrood	Mahmudabad	Larim	Miankaleh
$R_{Natural} (m)$	11.367	20.479	6.322	11.919	16.491	23.298
$R_B (m)$	10.729	10.649	8.392	7.597	11.324	22.042
$R_R (m)$	14.377	14.769	11.336	11.705	16.279	24.532
$R_{Natural} - R_B (m)$	0.638	9.830	2.070	4.322	5.167	1.256
$R_{Natural} - R_R (m)$	3.010	5.710	5.014	0.214	0.212	1.234

In Table 3, the calculated values of the difference between the natural change of the shoreline and the shoreline correction calculated based on equations in a positive state (absolute value) are given in the last two rows of the table.

With the results obtained from Table 3, prediction of shoreline changes based on the Bruun Rule in all coasts except Namakabrood is less than its measured value, while given the values of sediment deposition in Anzali, Namakabrood and Miankaleh coasts, the modified Bruun rule extended for landward transport, predicts changes to be more than their natural limits. Moreover, in Root Mean Square Error (RMSE), it is observed that the prediction error for shoreline changes based on the equation given by Rosati *et al.* would be smaller than the Bruun's equation [35].

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (R_{Natural} - R_{B, or, R})^2}{n_{Numbers\ of\ data}}} \quad (9)$$

Based on Eq. (7), the RMSE for horizontal changes of shoreline of the Bruun rule and the modified Bruun rule extended for landward transport would be 4.971 and 3.377 meters, respectively, i.e. a difference of 1.594-meter between these equations and a higher accuracy of the equation suggested by Rosati *et al.*, which would make the prediction closer to reality.

As it can be seen in the previous investigations, equations for shoreline changes have been defined based on sea level rise. However, these equations have shown good results under the conditions, when the level of the Caspian Sea falls as well. In order to improve the prediction of Rosati *et al.* equation and to optimize it, basic parameters that play a fundamental role in the behavior of the profile and shorelines have

been studied. For this reason, basic parameters such as mean grain size (D_{50}), sediment scale parameter (A) and natural slope of a coastal region (S_0), which are among effective factors related to wave height in a coastal region, have been examined against the mean wave height in the breaker zone (H_B).

The natural slope of a coast at its shallow zone is one of the factors that play a significant role in determining the location of the waves break. Also, particle size of the bed and type of particles play an important role in waves' break, when the waves come (in contact with the seabed according to their domains) at the shallow zone [36, 37]. When waves carry sediment particles of different gradations and create erosion at the seabed, this process affects their energy, height and their break. Sediment scale parameter also depends on the seabed particle size and particle deposition velocity, which would affect wave height in the breaker zone [38, 39].

In this research a coefficient was applied, which depends on the mean wave height in the breaker zone and the particle size of the bed, in the equation for the prediction of shoreline changes, it would become as follows:

$$R_A = A_s \times \frac{S \left(W_* + \frac{V_D}{S} \right)}{h_c + B} \quad (10)$$

In the above equation, R_A is horizontal changes of shoreline that modified in this research and A_s is a coefficient, which depends on mean wave height in the breaker zone and the mean particle size of the bed and could be obtained from the following equation:

$$A_s = 2.963 \times 10^{-4} \left(\frac{H_B}{D_{50}} \right) \quad (11)$$

The number 2.963×10^{-4} in above equation is intended as a calibration that optimized coefficient was extracted using coding in MATLAB software with trial and error method. Therefore, the prediction of shoreline changes that were obtained from the studied regions using the modified equation of Rosati *et al.* has been given in Table 4.

As it can be observed in Table 4, by applying A_s coefficient into the equation, the prediction of shoreline changes is obtained with similar error compared to before applying this coefficient (Table

3). After applying this coefficient into the equation, predictions for three regions, Dastak, Namakabrood and Mahmudabad became better acceptable in comparison with the primary equation presented by Rosati *et al.* and the values were closer to the actual data. In Anzali region, due to the fact that measured profiles were near breakwaters at the port and Anzali lagoon, the predictions were overestimate than those of the primary equation. Due to the sediment regime of this region, the existence of breakwaters and the lagoon near the place, in the areas where profiles are measured, the calculated errors has increased.

The increase in the prediction of shoreline variation within the Miankaleh area is also due to the fact that the field measurement area is close to the Amirabad and Neka ports; the presence of these two ports impairs the natural functioning of the coast due to environmental factors.

In general, no change was made by applying the A_s coefficient to Eq. (6) in the mean square error value for all areas under study (the root mean square error of the difference in predictions based on Eq.'s (6) and (10) is equal to 3.377 and 3.447 meters);

Nevertheless, by applying this coefficient (applying the parameters of the mean size of sediment particles and the mean height of the waves in the breaking area) and providing optimized Eq. (10), the shoreline changes for all studied regions are become more logical and acceptable.

The difference in forecasting the shoreline variation has not reached up to 5 meters on any of the coasts; while, according to the Bruun equation, the predicted difference for the shores of Dastak and Larim are 9.830 and 5.167 meters respectively and based on Rosati *et al.* the predicted difference for shores of Dastak and Namakabrood are 5.710 and 5.014 meters, respectively.

Based on the results presented in Table 4, the least difference in prediction is related to Mahmudabad shore and the most difference in prediction is related to the Dastak shore, which is respectively 0.059 and 4.849 meters.

Based on improvement for forecasting shoreline changes by applying the A_s coefficient and not having much difference in calculating root mean square error based on the Rosati *et al.* proposed equation, we can use Eq. (10) as an optimized equation in terms of sea level fall.

Table 4. Calculated parameters of shoreline variations according to the modified Bruun Rule extended for landward transport after A_s coefficient applying and shoreline changes based on the obtained profiles during the years 2013 to 2015

Parameter/Zone	Anzali	Dastak	Namakabrood	Mahmudabad	Larim	Miankaleh
$R_{\text{Natural}} (m)$	11.367	20.479	6.322	11.919	16.491	23.298
$R_A (m)$	14.480	15.639	9.531	11.861	18.656	28.115
$R_{\text{Natural}} - R_A (m)$	3.113	4.849	3.208	0.059	2.159	4.812
RMSE (m)	3.447					

5. Conclusions

In order to predict shoreline changes due to sea level rise, presented and developed an equation, in which shoreline changes were related to parameters such as sea level rise, closure depth, the distance from the closure depth to a shoreline and the maximum run-up height. Many relevant laboratory and field studies have been conducted. These results indicated that the Bruun rule gave a logical prediction. This rule was investigated and analyzed in this research and with consideration of the Caspian Sea level fall, good predictions were made in the studied regions. Minimum and maximum prediction differences for shorelines were 0.638 and 9.830 meters, respectively, compared with the actual values that illustrated on the profile figures. The obtained RMSE value was 4.971 meters.

Following extensive investigations, Rosati *et al.* concluded that landward sediment transport played a significant role in determining shorelines and by applying it into the Bruun rule equation, prediction of shoreline changes could be improved. The equation suggested by Rosati *et al.* was completely investigated in this research and analyses indicated even more desirable predictions compared with those of the Bruun rule. In this study, minimum and maximum prediction differences for shoreline advances were 0.212 and 5.710 meters, respectively in comparison with their actual values and the obtained RMSE value was 3.377 meters.

In order to improve predictions, the A_s coefficient was defined. This coefficient is related to the mean wave height in the breaker zone and the mean particle size of the seabed.

In terms of water level fall, by applying the A_s coefficient, the mean squared error to predict shore changes in compare to its natural variation was obtained 3.447, which did not make a large change in the mean squared error of the values obtained from Rosati *et al.*

However, according to the results, the least difference in prediction is for the Mahmoodabad coast and the greatest difference in prediction is related to the Dastak coast, which is respectively 0.059 and 4.849 meters, which makes the range of predictions difference less and more logical compared to Rosati *et al.*

The difference in forecasting the shoreline variation has not reached up to 5 meters on any of the coasts; while, according to the Bruun equation, the predicted difference for the shores of Dastak and Larim is 9.830 and 5.167 meters respectively and based on Rosati *et al.* The predicted difference for shores of Dastak and Namakabrood is 5.710 and 5.014 meters, respectively. Based on the improvement for forecasting shoreline changes by applying the A_s coefficient and not having much difference in calculating the root mean square error based on the Rosati *et al.* equation, we can use

the proposed equation in this study to predict shoreline changes as an optimized equation in terms of sea level fall.

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