NUMERICAL INVESTIGATION OF THE IMPACT OF A GROIN SYSTEM ON SHORELINE EVOLUTION

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The South-west Black Sea Coast is facing severe erosion problems that threaten both the population and the immediate eastside properties. Some locations, such as the Karaburun region, are especially vulnerable. In an attempt to reverse the present erosional trend, a coastal defense scheme involving a groin system was introduced in a phased manner. In the present work, the shoreline changes under the influence of a groin system of a sandy beach in Karaburun, Turkey, are studied by using a numerical simulation model (LITPACK). The work is motivated by the considerable erosion and siltation problems caused a sediment deposition near and inside the harbor entrance which prevented the boat traffic and caused a vital problem for the harbor operations. The study's scope is two-fold: to help in understanding the dynamics of the beach based on results of the field work and to study the responses of this beach by numerical simulation, utilizing the topographic and sediment field data and measured wave data. The validation and verification of the numerical model was performed by RTK-GPS measurements and satellite images.

Keywords: shoreline evolution; groin system; LITPACK, Black Sea coast

INTRODUCTION

The coastal zone is a physically dynamic and ecologically sensitive environment which is subject to a variety of human-induced pressures and natural events resulting in significant coastal erosion. It is often densely populated and is a region of commercial, industrial and recreational activity. It is an important environment to be monitored and managed effectively for sustainable use. For different intentions, such as protection of the shoreline against erosion, implementation of navigation channels, construction of harbors and human activities have changed the beach morphology at many locations around the world. Thus, the study of beach evolution in order to gain knowledge for application in coastal engineering projects is necessary. For that purpose, numerical models of beach evolution are useful tools in engineering projects. A number of numerical models have been developed through the years for simulating shoreline change and beach morphology evolution. Development efforts have expanded in a wide range of models at different scales from simple one-dimensional to sophisticated 3D models (e.g. Dally and Dean, 1984; Kriebel and Dean, 1984; Perlin and Dean, 1987; Larson et al., 1987; Larson and Kraus, 1989; Hanson and Kraus, 1989; Briand and Kamphius, 1990; Hanson and Larson, 1992; Fredsøe and Deigard, 1992; De Vriend et al., 1993; Roelvink et al., 1994; Larson et al., 1997; Dabees, 2000; Zyserman and Johnson, 2002; Hanson et al., 2003; Kobayashi, 2003; Lesser et al., 2004; Roelvink et al., 2010) and many of them have been applied in coastal engineering projects.

In this study, we focused on a numerical model that is used for shoreline evolution in one dimension with the emphasis on the response of the beach topography to coastal structures, such as breakwaters, jetties and groins. Shoreline evolution study was performed with a widely known numerical modeling system called LITLINE which is a module of LITPACK software package (DHI, 2016a). The model is based on one-line theory for shoreline change modeling. Consequently this study covers the modeling of the littoral drift (longshore sediment transport) and shoreline change with and without the influence of groins.

The shoreline change studies were employed for Karaburun which is a coastal town located near the Southwestern coast of Black Sea and 40 km Northwest of Istanbul (Figure 1). The shoreline has a WNW-ESE general orientation and stretches approximately 4.0 km. The fishery harbor of the village is at the western end of the 4 km sandy beach. The harbor operations are affected by the sedimentation problem due to the considerable rate of westward sediment transport towards the harbor entrance, which decreases the water depth and impedes navigation to and from the harbor.

The 4 km Karaburun shoreline was measured using a Real Time Kinematic Global Positioning System (RTK-GPS) for approximately 10 years (1996-2006) at seasonal intervals. Bathymetric surveys of the nearshore zone of the study area, which extended to levels of -10 m from mean sea level (MSL), were performed over the same time period. Volume differences between surveys were computed to obtain the average net longshore sediment transport (LST) rate from the accretion at the harbor, which acted as a total trap. In addition, LST rate in the respective research area was predicted by a comprehensive numerical model (LITPACK).

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Long-term observations of shoreline changes, measurements of sea-bottom topography and long-term analysis of wave, wind and sediment characteristics were performed. Additionally, IKONOS satellite images for two years (September 2002-September 2004) were analyzed to perform a qualitative assessment of the historical shoreline changes of the Karaburun coast. The shoreline changes at the research area were investigated in two steps: 1) the shoreline change without the influence of the groins 2) the shoreline change with only one groin.

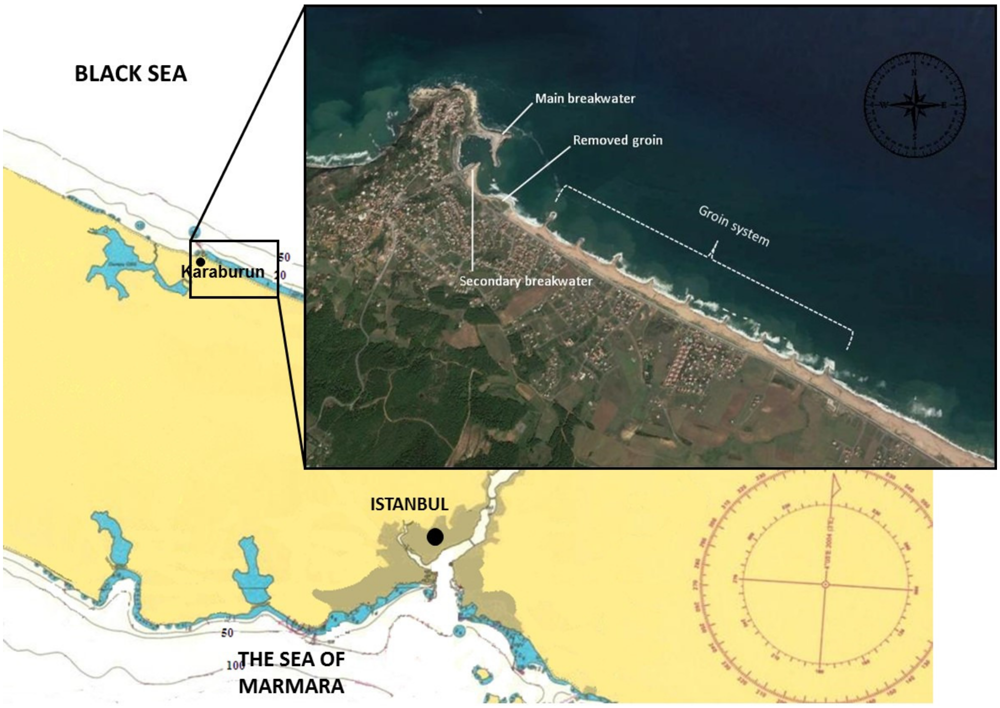

Figure 1. Location of Karaburun coastal village and the groin system

ENVIRONMENTAL CONDITIONS AT THE SITE

To determine the LST rates and shoreline evolution in this region, long-term observations of shoreline changes, sea-bottom topography, sediment properties, wind, wave and current measurement were performed.

Sediment Properties

Sediment samples were collected along the shoreline at three positions on the beach: at +2.0 m, -3.0 m and -8.0 m to MSL. The samples were taken at 4 different cross-sections and in 100 m intervals. In addition, three samples were collected from -8 m, -12 m and -16 m depths near the harbor. The grain size distributions of these samples were determined by method of sieving. The average median sand grain size was 1.53 mm updrift of the secondary breakwater. The beach sediment was characterized as mainly coarse sand (average D_{50}=1.50 mm) and well-sorted sand based on the ratio of D_{84}/D_{16}=2.

Wind Data

Wind data collected near the harbor showed that the dominant wind directions are north-north-east (NNE), north-east (NE), north (N), east-north-east (ENE), south-west (SW) and south-south-west (SSW). The dominant winds blow essentially in onshore and offshore directions along the site. Figure 2 reveals the annual wind and wave rose for the region.

Wave Data

Wave measurements were carried out at the site by a pressure and ultrasonic-type wave gauge for approximately 20 months between August 2003 and March 2005. The wave data were recorded 10 minutes in every two hours. From the measured time histories, water level changes, water temperature, wave height, wave period, wave direction, current direction and velocity values at the measurement depth were acquired.

Wave data for the research area were also obtained from a numerical model called MIKE 21 SW (DHI, 2016b), which was developed by DHI. In the numerical model, the wind fields obtained from the European Center for Medium-Range Weather Forecasts (ECMWF) were used. The wind data were obtained between January 1996 and December 2014. After the calibration and verification steps, the simulations were performed for these periods. The calibration factors were bottom friction, breaking parameters, white capping and wind data. For the optimization, different mesh resolutions were tried. The study site is subjected to both swell and locally generated waves with large incidence angles. The dominant incident wave directions for both swell and wind waves are north-north-east (NNE), north-east (NE), east-north-east (ENE) and north (N) (Figure 2). There is an angle of 27° clockwise from north to the coastline normal. Mean and median wave incidence angles of 56° and 45° from north, respectively, were found at -16 m depth. The waves approach the Karaburun coast from the northeastern directions for most of the year, which causes substantial long-shore sediment transport from east-south-east (ESE) to west-north-west (WNW).

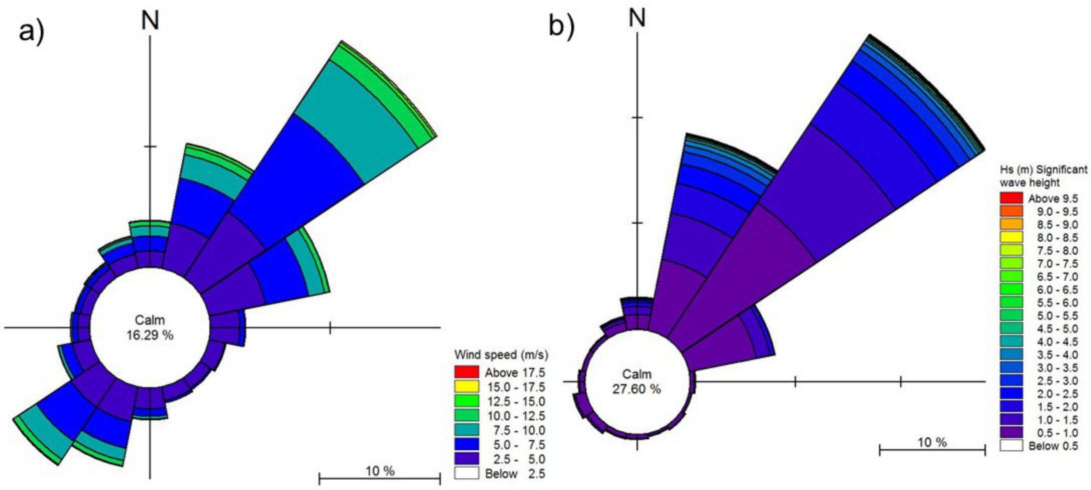

Figure 2. Annual a) wind and b) wave rose.

Current Regime

Current data were obtained from measurements performed by an Aquadopp Current Profiler at different locations along the coast. Tidal impact is negligible in the study field. From the water level measurements, it was observed that there was a maximum change in water level of 12 cm for one day and 27 cm throughout the measurement period. Mean wind-driven surface currents were in the order of 0.11 m/s to 0.17 m/s. According to the current measurements, the mean current velocity changes between 0.09 m/s and 0.35 m/s. The maximum current velocity was found to be 0.76 m/s and the minimum current velocity was 0.04 m/s. The general current direction was from east-north-east (ENE) to west-south-west (WSW).

Shoreline Changes

Twelve beach surveys were conducted along the shoreline between September 1996 and May 2006. There was a groin on the eastern side of the secondary breakwater, but it was removed before September 1996. After that, sand deposition increased towards the harbor. Beach profiles were surveyed along 19 fixed cross-shore lines. The measured profiles were analyzed to obtain the shoreline displacement and the area changes in the landward and shoreward zones. Figure 3 shows a close-up of the shoreline evolution near the harbor. The extreme shoreline change occurred between 1996 and 2000. The beach profile nearly reached its equilibrium shape between 2000 and 2004. On the date of 16 June 2005, the sand accumulated at the entrance of the harbor and near the secondary breakwater was dredged. Therefore, the shoreline change after this date does not represent the natural evolution. In addition, satellite images (IKONOS) which have radiometric solutions of 11 bytes and resolution of 1 m obtained between the dates of September 2002 and September 2004 were used to calibrate the numerical model.

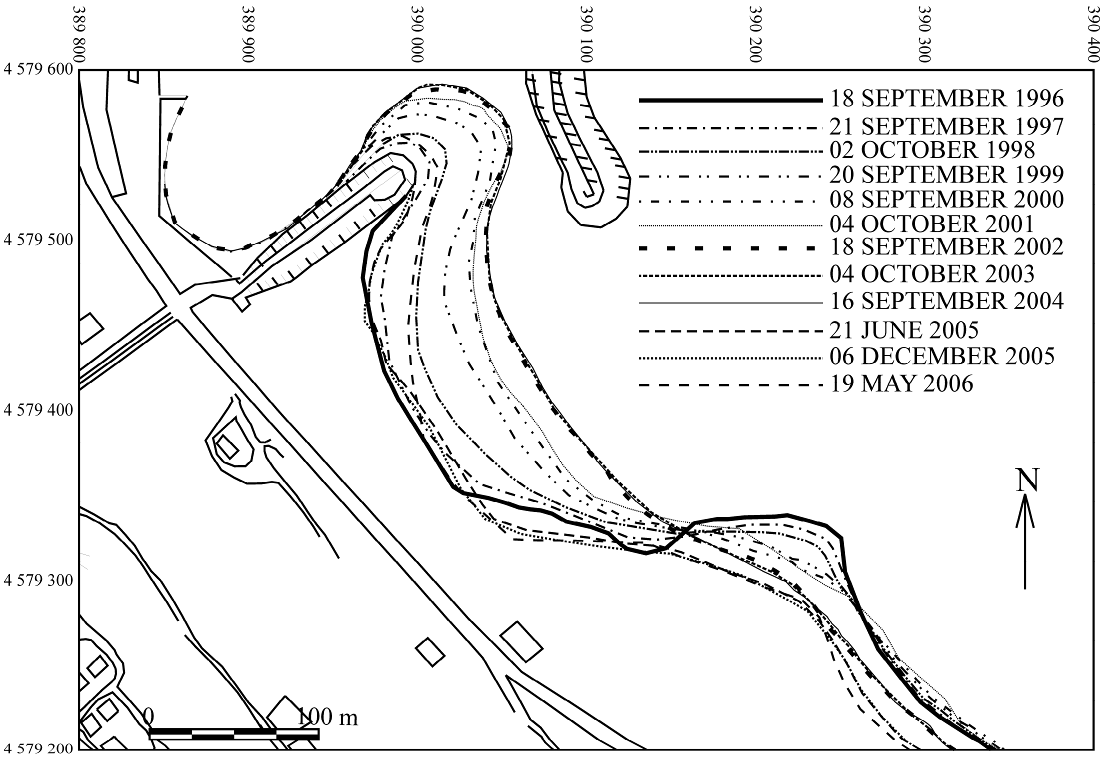

Figure 3. Close-up shoreline evolution near the harbor and survey dates (Arı Güner et al., 2013).

The construction of the groin system began in 2007. The first groin was deployed at the western side of the shore next to the fishery harbor (Figure 4). The construction of all groins finished in 2009. Figure 4 depicts the groin system configuration on a satellite image taken in 2009. Figure 5 shows a more detailed view of the shoreline change next to the fishery harbor between the years of 2007 and 2014. On the downdrift side of the first groin, the maximum retreat of the shoreline between 2007 and 2014 was found to be 33 m.

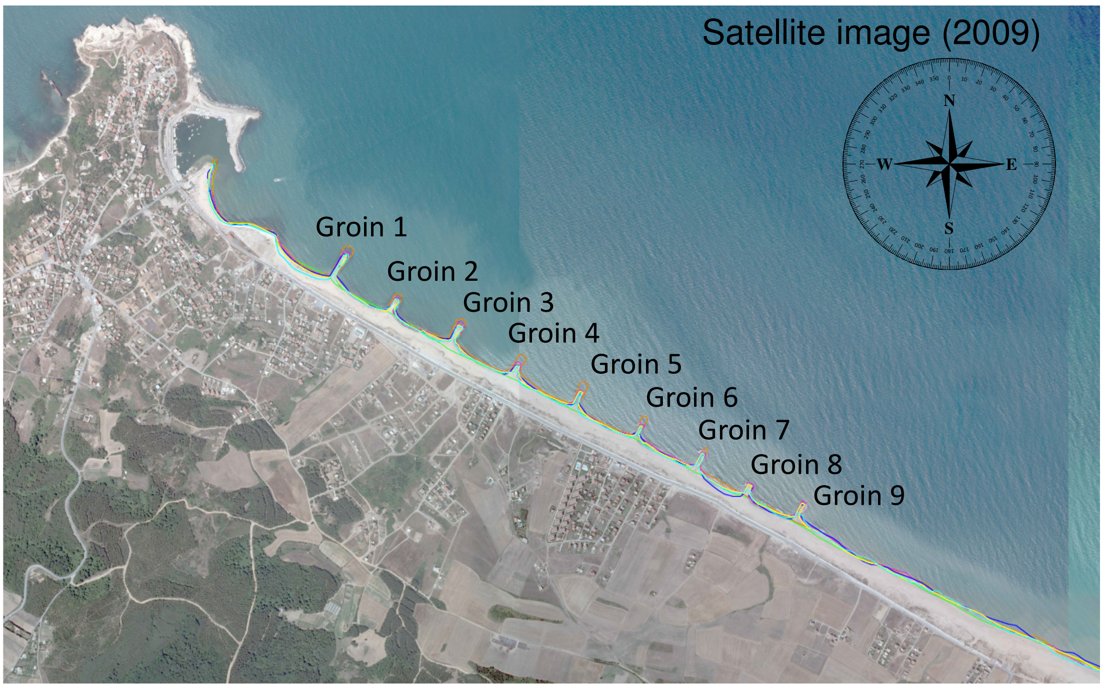

Figure 4. The groin system.

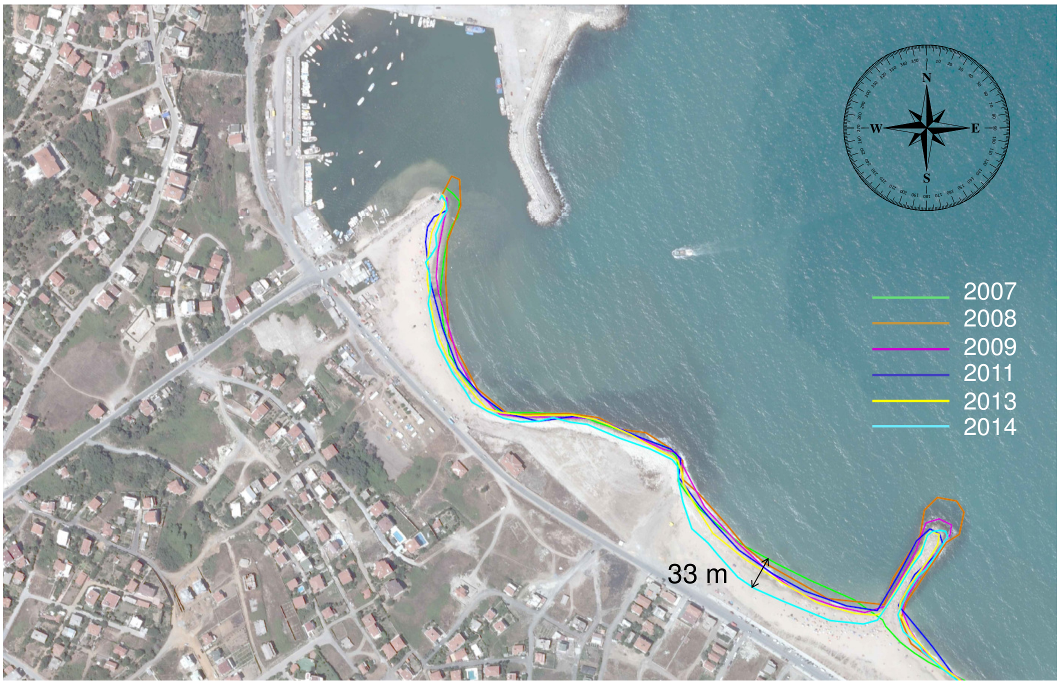

Figure 5. Shoreline evolution near the harbor entrance between the years of 2007 and 2014.

Table 1 reveals the maximum and minimum shoreline changes between the respective groins which were obtained from the extraction of the coastlines from satellite images. The last raw indicates the location which is at the right hand side of the last groin at the eastern side. The maximum accretion was around 37 meters whereas the maximum erosion was 21.8 m.

Table 1. Minimum and maximum shoreline changes between the groins

Maximum Accretion						Maximum Erosion					
Groins	1 year (2007-2008)	2 years (2007-2009)	4 years (2007-2011)	6 years (2007-2013)	7 years (2007-2014)	Groins	1 year (2007-2008)	2 years (2007-2009)	4 years (2007-2011)	6 years (2007-2013)	7 years (2007-2014)
1-2	9.7	15.5	23.4	14.7	10.1	**1-2**	-10.0	-13.0	-10.5	-11.1	-13.6
2-3	29.9	26.4	30.8	24.0	19.5	**2-3**	-3.0	-6.3	-7.0	-6.5	-10.2
3-4	35.2	32.6	37.1	35.8	29.1	**3-4**	-	-	-	-	-
4-5	34.3	15.7	20.6	19.8	12.1	**4-5**	-	-	-	-	-6.8
5-6	17.3	24.2	28.5	23.6	10.7	**5-6**	-	-3.0	-5.9	-4.4	-10.2
6-7	15	23.5	19.7	17.7	17.1	**6-7**	-	-	-1.4	-2.8	-10.1
7-8	20.4	20.6	16.1	13.9	13.7	**7-8**	-	-0.9	-21.8	-3.8	-6.9
8-9	5.9	18.7	5	14.1	8.7	**8-9**	-	-9.3	-10.8	-4.5	-6.5
9-	22.8	28.4	32.5	22.2	36.8	**9-**	-	-	-9.1	-5.6	-4.1

Net Longshore Sediment Transport

Volume differences between surveys were computed to obtain the average net LST rate from the accretion at the harbor, which acted as a total trap, indicating that virtually no sediment should bypass or be transported through the harbor. Volume changes were calculated down to levels of -10 m to MSL over the survey period of 1450 days (September 1996 and September 2000). This time period was considered because the beach profile reached its equilibrium shape after September 2000 and sand accumulated at the entrance of the harbor was dredged on the date of 16 June 2005. As a result, the average net longshore sediment transport for the Karaburun region was found to be 72,000 m^3/year.

In the current work, cross-shore sediment transport was also evaluated. Beach profile variations caused by cross-shore sediment transport were assessed in terms of closure depths and equilibrium beach profiles. The mean closure depths calculated for wind waves and swell were found to be -3.6 m and -3.9 m to MSL, respectively, and the maximum closure depth was determined as -8 m to MSL (Arı, 2009). The cross-shore distance of each survey line was about 600 m. Each survey line was extended to a water depth of about 10 m, which was deeper than the maximum depth of closure of about 8 m. Thus, no sand was transported offshore and cross-shore sand transport did not cause significant net sediment loss.

MODELING OF SHORELINE CHANGE

Numerical Models

The numerical model used in the current work is the LITPACK package, which is an integrated modeling system for LITtoral Processes and Coastline Kinetics developed by the Danish Hydraulic Institute (DHI, 2016a). LITPACK is used for simulating non-cohesive sediment transport in wave and currents, littoral drift, coastline evolution and profile development along quasi-uniform beaches. It is an integration and enhancement of deterministic numerical models: non-cohesive sediment transport (STP), longshore current and littoral drift (LITDRIFT), coastline evolution (LITLINE), sedimentation in trenches (LITREN) and cross-shore profile evolution (LITPROF).

Calibration of LITDRIFT

The LITDRIFT module was used to estimate the LST rates in the study field. The module includes important sediment transport mechanisms, such as non-linear wave motion, the turbulent bottom boundary layer, wave breaking and sediment grading (DHI, 2016c). LITDRIFT consists of two major components: a hydrodynamic model and an intra-wave sediment transport model (STP).

The input data for the LITDRIFT module are the wave data from the calibrated wave model, bottom profiles at different coordinates, initial coastline and sediment characteristics. It is worth noting that variations of the bottom profile and the mean grain size of the sand grains along the coast occur but are not dramatic. Based on the site measurements, the median grain diameter (D_{50}) and the sediment spreading (geometric standard deviation) ($\sigma_g = \sqrt{D_{84}/D_{16}}$) were used as 1.5 mm and 1.4, respectively. The main calibration of the LITDRIFT model was performed by the net LST data obtained from shoreline changes determined by field surveys between the dates of September 1996 and September 2000.

Calibration of LITLINE

LITLINE is the module that computes the changes of a shoreline over a period of time using spatially and temporally varying longshore transport (DHI, 2016d). LITLINE calculates the coastline position based on the input of the wave climate as a time series. The model is, with minor modifications, based on one-line theory, in which the cross-shore profile is assumed to remain unchanged during erosion/accretion. Through successive calls to LITDRIFT, the model calculates and tabulates transport rates as functions of the water level, the surface slope due to regional currents and wave period, height and direction compared to the coastline normal.

The calibration of the LITLINE model was initially performed using the field measurements. The Karaburun coastline was measured using RTK-GPS between the years of 2002-2004. The RTK-GPS measurements provided an accuracy of ±2cm horizontally and ±3cm vertically. The shoreline change between the dates of September 2002 and May 2003 was used to calibrate the LITLINE module. LITLINE simulated the shoreline change with a maximum absolute error of 2.8 m for this time period. Following this simulation, the second simulation phase from May 2003 to September 2004 was used to verify the calibrated model. A maximum absolute error of 3.5 m was found for this case. Second, the coastline change obtained from the LITLINE module was compared with coastlines extracted from satellite images. The IKONOS satellite images which have radiometric solution of 11 bytes and resolution of 1 m were used in this study. The calibration and the verification time scales for this simulation were chosen to be the same as for the previous stage (September 2002 to May 2003 for calibration, May 2003 to September 2004 for verification). A maximum absolute error of 5.0 m was found for the calibration phase and 4.3 m was found for the verification phase.

Model Set-up

The input data are the wind and wave data from the wave model, bottom profiles at different coordinates, initial coastline and sediment characteristics. Based on the site measurements, the median grain diameters (D_{50}) were in the range of 0.11 mm- 4.9 mm. The sediment spreading values are in the range of 2.52-10.33. The information about the roughness and the sediment characteristics are given in Table 2.

Table 2. Bed parameters applied for all profiles	
Parameter	**Value ranges**
Bed roughness (m)	0.00028-0.013
Median grain size (D_{50}) (mm)	0.11-4.9
Fall velocity (m/s)	0.009-0.223
Spreading factor for grain sizes (σ_g) ($\sqrt{D_{84}/D_{16}}$)	2.52-10.33

The model was set up using the characteristics given in Table 2. The sea currents and wind driven currents are not included as the wave driven currents dominate the other phenomena in the present case. A graded sediment description with five fractions was used to represent the gradation curve. The critical Shields parameter and the sediment porosity were set to 0.045 and 0.4, respectively. Concerning the wave theory it was chosen to use the Stokes approach with a wave spreading factor 0.5.

The bed roughness is one of the main calibration parameters in the LITDRIFT model. It represents the roughness of the bottom felt by the longshore current. It also represents the grain roughness as well as possible bed features. The bed roughness is taken to be equal to $2.5D_{50}$ for a plane bed and $2.5D_{50}+k_R$ for a ripple-covered bed, where k_R is the ripple related roughness (DHI, 2016c). According to the equations the bed roughness values were found between 0.00028 m and-0.013 m.

In addition, local wind effect was investigated. In the first simulation the wind speed and directions were used as input. In the second simulation the wind parameters were not specified. The results showed that the wind parameters' existence in the simulations had a very small effect on LST for the project site.

In LITLINE the "active height" of the profile is a main calibration parameter. The active height $h_{act}(x)$ of the cross-shore profile is composed of two components (DHI, 2016d): D_{act} is the active depth, which, as a function of the longshore position, is kept constant in time regardless of the contemporary water level, wave conditions etc. h_{beach} is the height of the "front beach" or berm. By altering the active depth in shoreline file, the final calibration can be performed. The active depth (D_{act}) varied between 10 and 15 m. The calibration performed against the measured shoreline data showed that the most suitable active depth was 12 m for Karaburun coastal region.

Calibration involved determining the sediment transport calibration parameters, appropriately representing the lateral boundary conditions and the cross-shore profile parameters.

RESULTS

After the calibration steps, two-years shoreline change simulations were performed. The real time simulations were two-fold: 1) the shoreline change without groins, 2) the shoreline change with one groin next to the fishery harbor. The preliminary results for each step are given in the latter headings.

With the hindcasted wave climates, the selected profiles and the grain size distribution along the profiles, the numerical model was used to simulate the annual net and gross sediment transport at Karaburun coastal region. The calculated annual net and gross sediment transports were 85,000 m^3/year and 155,000 m^3/year, respectively. The direction of the net longshore sediment transport is from North-west (NW) to South-east (SE).

The main observations at the study area are summarized as follows:

- The study area is an active beach with an annual net drift amount of 72,000 m^3/year.
- The annual net sediment transport direction is towards the harbor from east-north-east (ENE) to west-north-west (WNW).
- The removal of the groin after 1996 accelerated the accretion near the second breakwater and entrance of the harbor.
- The Karaburun shoreline reached its equilibrium shape between 2000 and 2004.
- The construction of the first groin (at the western side of the shore) began in 2007.
- The constructions of all groins finished in 2009.
- The groin system works well in general, however the eastern side of the harbor which is just downdrift side of the first groin is subjected to severe erosion.

The main observations related to numerical modeling are summarized as follows:

- The most important calibration factor is the <u>net annual drift</u>. The numerical model must be tuned according to the actual sediment transport and its calibration parameters.
- The other calibration parameter is the <u>active depth</u>. In the current work, the active depth of the research area was found to be 12 m by altering the values.

- Lateral boundary conditions are also very important. In this study one boundary condition was employed. The geometry of the fishery harbor was not compatible with the LITLINE model. However, representing the harbor as a single breakwater gave reasonable results. But, the active length of the breakwater had a significant influence on the shoreline change. The most fitting length of the breakwater was found to be 350 m. This corresponds to the active depth location.

Model results without groins

The first simulation results without any groin are revealed in Figure 6, Figure 7 and Table 3. This "do-Nothing" scenario was implemented to see what would happen when the groin system were not constructed. The figures cover a 3.3 km distance from the starting point which corresponds to the place where the old groin was removed (Figure 7). The whole simulated shoreline length was 4 km. Accretion can be seen at the downdrift side whereas there is erosion at the updrift side of the beach. The maximum shoreline retreat was 7.3 m between the 6th and 7th groins, whereas the maximum accretion was 13.4 m at the updrift side of the last groin (Groin 9) at the first simulation period (between 2007 and 2008). The maximum shoreline retreat was 9.0 m again between the 6th and 7th groins, while the maximum accretion was found to be 21 m at the updrift side of the last groin between the years of 2008 and 2009. Because of the restrictions of the numerical model related to the geometry of the existing marine structures, the fishery harbor side could not be simulated efficiently.

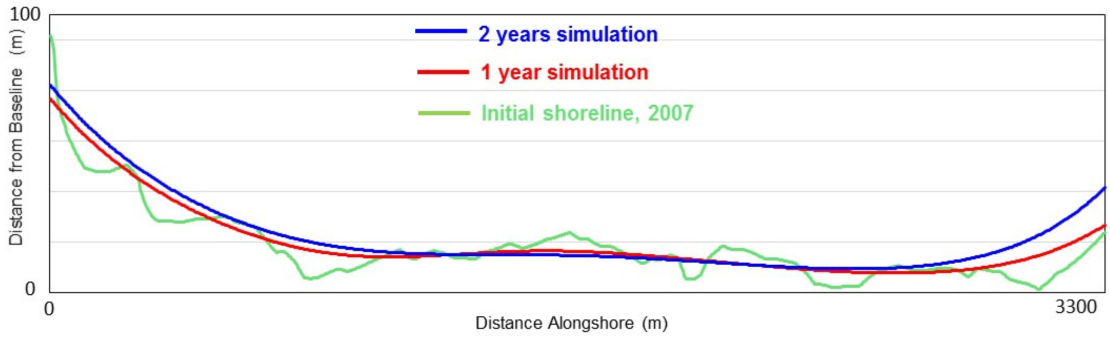

Figure 6. Shoreline evolution without groins between 2007 and 2009.

Figure 7. Shoreline evolution near the harbor entrance without groins.

Table 3. Minimum and maximum shoreline changes between corresponding groin locations without using any groin

Maximum Accretion			Maximum Erosion		
Groins	1 year (2007-2008)	2 years (2007-2009)	Groins	1 year (2007-2008)	2 years (2007-2009)
1-2	11.9	15.8	**1-2**	-1.0	-
2-3	7.7	11.0	**2-3**	-3.6	-0.2
3-4	11.1	14.4	**3-4**	-0.5	-
4-5	1.8	2.3	**4-5**	-2.9	-1.4
5-6	0.9	0.2	**5-6**	-5.3	-6.9
6-7	2.4	1.3	**6-7**	-7.3	-9.0
7-8	7.9	7.2	**7-8**	-1.0	-1.8
8-9	2.9	-	**8-9**	-6.4	-6.8
9-	13.4	21	**9-**	-3.0	-2.4

Model results with only one groin

The second simulation results under the influence of one groin are shown in Figure 8, Figure 9 and Table 4. This "one-groin" scenario was tried to see what would happen if one groin were constructed instead of a groin system. These figures also show the 3.3 km distance from the starting point which corresponds to the place where the old groin was removed. A similar shoreline change pattern can be seen from the figures. The effect of the groin was significant in this case since a maximum accretion of 30 m took place at the updrift side of the groin in two years simulation period. However, there was no significant change at the updrift of the shore which implies that the groin has a positive effect on shoreline evolution. The maximum shoreline retreat was 8.7 m between the 6th and 7th groins, whereas the maximum accretion was 13.4 m at the updrift side of the last groin (Groin 9) within two years.

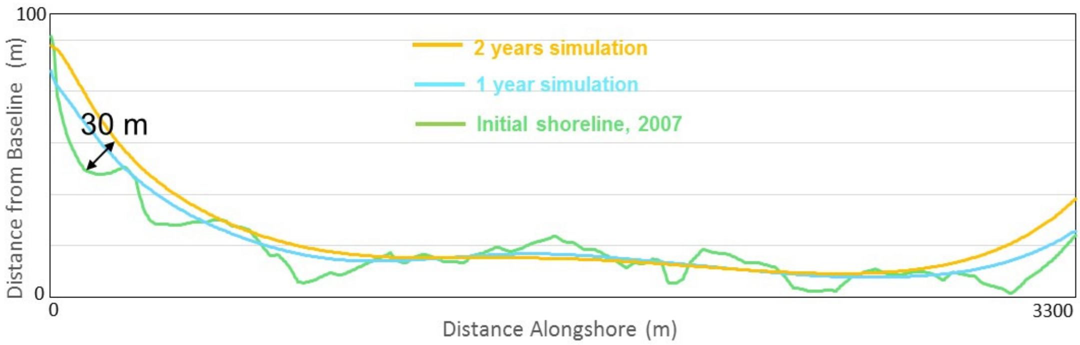

Figure 8. Shoreline evolution with one groin between 2007 and 2009.

Figure 9. Shoreline evolution with one groin near the harbor entrance.

Table 4. Minimum and maximum shoreline changes between corresponding groin locations with only one groin

Maximum Accretion			Maximum Erosion		
Groins	1 year (2007-2008)	2 years (2007-2009)	Groins	1 year (2007-2008)	2 years (2007-2009)
1-2	12.1	17.4	**1-2**	-1.4	-
2-3	7.4	10.4	**2-3**	-4.0	-0.7
3-4	10.8	13.8	**3-4**	-0.7	-
4-5	1.9	2.1	**4-5**	-3.1	-1.6
5-6	1.0	0.3	**5-6**	-5.0	-6.7
6-7	2.5	1.4	**6-7**	-7.1	-8.7
7-8	7.9	7.3	**7-8**	-0.9	-1.7
8-9	-	-	**8-9**	-6.5	-6.8
9-	12.8	19.5	**9-**	-3.1	-2.6

Figure 10 compares the results of different numerical model scenarios and the satellite images. Blue line depicts the existing state of the groin system in 2009 obtained from the satellite image whereas black line shows the extracted shoreline from the satellite image in 2007. Red line is the result of a two-year period simulation without using any coastal defense structure. Green line is the result of a two-year period simulation under the influence of one groin. Model results have similar trends especially on the updrift side of the shore but draw apart on the downdrift side of the first groin. The positive impact of one groin can readily be seen at the downdrift side. However, to use a groin system over the whole coast did not change the results significantly, except on the updrift side of the 9th groin. On the contrary, the erosion between the 1st and 2nd groins and at the downdift side of the first groin seems to be significantly large with the existing groin system.

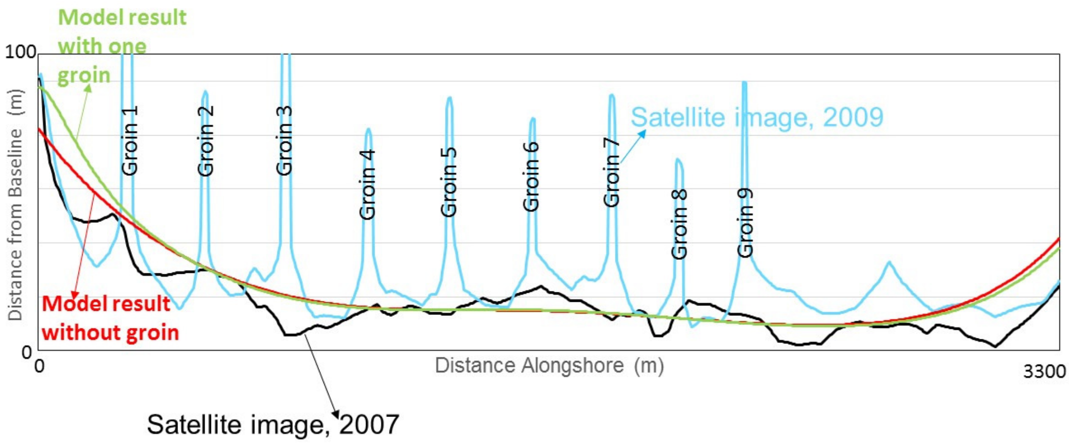

Figure 10. Comparison of the numerical results for two year period.

CONCLUSIONS

This paper presents a numerical study on the impact of a groin system on the Karaburun coast. A section of a sandy beach of Karaburun, Turkey, was studied using in-situ measurements and topographic profiles, laboratory sediment analysis and the software package LITPACK, which simulates the sediment transport and shoreline evolution under the action of waves and currents. The LITPACK model can be successfully applied for simulating, calculating and forecasting the shoreline changes due to erosion and sedimentation process.

Two scenarios were investigated, considering the presence or absence of coastal defense structures. The introduction of one-groin promotes accretion on the downdrift side of the groin (between the groin and the secondary breakwater of the harbor) and provides a similar solution with the groin system. However, there is no exact or easy solution to the chronic erosion problems. In the long-term, the results from this preliminary work will enable better planning of coastal works. Future work will include simulation of other hard measures like detached breakwaters and soft measures to improve the protection of the Karaburun shoreline.

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