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Prediction of Shoreline Deformation around Multiple Hard Coastal Protection Systems

التنبؤ بمشكلات الشاطئ حول أنظمة حماية السواحل الصلبة المختلطة

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KEYWORDS:
Detached breakwater, LITPACK, Hard protection system, Groin system, morphological changes

الملخص العربي:-ناك عدة طرق لتمثيل التغيرات الشاطئية حول أنظمة الحماية الساحلية المركبة في المنطقة الساحلية. يحاول هذا البحث استقصاء والتنبؤ بالتغيرات في السواحل حول أنظمة حماية الشواطئ المركبة باستخدام برنامج LITPACK. يمثل النموذج حركة نقل الرواسب غير المتماسكة تحت تأثير الأمواج والتيارات والانحراف الساحلي واكتشاف الخط الساحلي. تم بحث تطور التغيرات المورفولوجية على طول الشواطئ شبه المنتظمة. تم تطبيق النموذج على قياس الأعماق الطبيعية للمنطقة الواقعة بالقرب من ميناء الحمرا في الساحل الشمالي الغربي لمصر. تم تطبيق النموذج العددي لتوضيح معدلات التآكل والترسيب المتوقعة حول المنشآت القائمة ومنشآت الحماية الإضافية المقترحة. تمت معايرة نتائج النموذج مع الخط الساحلي المقاس من 2015 إلى 2017 وتم التحقق منه ببيانات الفترة من 2017 إلى 2019. تم تطبيق النموذج للتنبؤ بالتغيرات المورفولوجية من 2015 إلى 2030. وقد تم التحقق على الخط الساحلي المحسوب والقياس لعام 2019 عن طريق حساب قيمة RMSPE لتقييم دقة الخط الساحلي المتوقع. وأخيرًا، تم اقتراح أنظمة صلبة لحماية السواحل، تتكون من ثلاثة حواجز بعيدة عن الشاطئ منفصلة واثنين من الرؤوس الحجرية الطويلة. تظهر النتائج المستمدة من نموذج LITPACK أنها موثوقة بما يكفي ومناسبة للاستخدام كنظم حماية مرتبطة.

Abstract—**There are several methods to represent the beach changes around the composite coastal protection systems at the coastal zone. This research try to investigate and predict shoreline changes around composite shore protection systems using LITPACK software.**

The model represents the movement of sandy soil sediment transport under the effect of wave and current interaction. The morphological changes development along quasi-uniform beaches are investigated. The model was applied on the natural bathymetry of area which located in the neighboring of El-Hammra port at the north western coast of Egypt. The numerical model was applied to clarify the predicted rates of erosion and accretion around the existing structures and the proposed additional protection structures. The model results were calibrated with the measured shoreline from 2015 to 2017 and verified with shoreline data from 2017 to 2019. The model was performed to predict the morphological changes from 2015 to 2030. Validation applied on the simulated and measured 2019 shoreline by calculating RMSPE value to evaluate the accuracy of the predicted shoreline. Finally, a hard coastal protection system has been proposed, consisting of detached breakwaters and two long groins. Results derived from the model show the reliability and suitability of the model to be applied as a correlated protecting systems for the similar regions.

I. INTRODUCTION

COASTAL areas became the center of social and economic activities. Coastal erosion problems are faced many countries worldwide. Accretion and erosion processes are affected by natural marine effects such as wave forces and storms occurrence as well as the human activities as the construction of coastal protection

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measures. This research study the different scenarios for construction protection structure and ask if these scenarios give the same results of predicted shoreline or it will improve or reduce. That to face the problem of erosion and accretion caused by natural changes and human actions. These coastal structures can be classified into; shore-parallel structures (detached breakwaters), and shore-normal structures (groins). In this research, the shoreline changes will be simulated by using **a numerical model, based on** the conservation of and volume equation to evaluate the study area. The one-line theory is based on the premise that the beach profile remains constant as it progresses so that volume change is directly related to changes in the shoreline [1]. The beach profile shape remains constant, this one of the basic assumptions common to all one-line models. The model is based on the assumption that longshore gradients in hydrodynamic and sediment conditions are negligible and that depth contours are parallel to the coastline. Thus the coastal morphology is solely described by the cross-shore profile. In this paper, one line model (LITPACK) will be applied on El Hamra port area at the Northwestern coast of Egypt. This numerical model include a more efficient calculation method for long-shore sediment transport, [2][3][4][5]. Calculations are conducted taking the hydrodynamic parameters into consideration. The numerical model is mainly applied in this research to calculate the erosion and accretion areas. In addition to, predict the shoreline responses to several proposed systems considered as hard measures such as shore connected groins and offshore breakwaters over the period from 2015 to 2030. This simulation is applied at two phases, first from 2015 to 2017 and the second is from 2017 to 2019. Considering 2015 as an initial year to predict 2019. Validation must be applied on digitized and measured 2019, then prediction can be applied.

II. HYDRODYNAMIC DATA

A. Study Area

The area of study selected for applications of shorelines changes is El-Hamra Port. The main reason for selecting this zone is the largest area risky to the main problems as erosion and accretion. It is an important area as the WEBCO cooperation for oil and petroleum established. Site is located on the northwestern Mediterranean Sea coast of Egypt at about 120 km west of Alexandria city at longitudes 28° 49` 57`` to 28° 51` 00`` E and latitudes 30° 55` 28`` to 30° 56` 33`` N. The shoreline of this area is oriented in the North/South direction (N/S), figure (1). The coastline Shape is undulate for length 4km. It is interrupted by small rocky headlands, forming small embayment and pocket beaches ranging from 20m to 150m length. Two barriers were constructed perpendicular to the shoreline in front of the company. First Barrier (Main groin) located in the south was constructed in 2006 with a length of 200m. Second Barrier (Temporary groin) was constructed in 2017 with a length of 150m. In 2017 Power station was constructed 1200 m south of the permanent groin. The station intake was dredged during 2018 to serve the station, figure (1).

B. Data Used and parameters

Continuous records of the waves were collected by the coastal research institute. They record the directional wave spectrum every six hours in a water depth of 10.50 m. The Waves in the study area has a seasonal effect with a predominated direction from the north to the northwest. The low energy waves of 50 cm height with 5-8 sec period were noticed during the summer season (June to August). The calm waves found during October and May. The Storms occur during the winter season during (November to April). The predominated wave height is 1.00 m with corresponding wave period ranged from 6 to 8 sec. The maximum wave height reaches 2.00 m with the probability of occurrences for one time per year, Figure 2. Wind speed and direction were studied monthly from 1979 to 2017. The predominant wind direction (50%-80%) of the year is from the NW directions, while a wind from SE and NE takes (5%-10%) of the year. The average wind speed is seasonal in intensity being 0.77-9 m/sec in summer and 3-13 m/sec in spring with a higher speed from the NW direction. The parameters of first step are beach position which depend on the coordinates of shoreline exported from AutoCAD. Sand dune along the backshore zone reaches 4m height. Dunes in the study area are high enough to protect the shoreline from wave force. The survey data were used to collect details of the region's bathymetry. Bathymetric map shows parallel and uniform shoreline contours. The tidal range varies from 0.22 (neap tide) to 0.8 m (spring tide). The currents velocity is very small and can be neglected. The bed sample analysis shows that the bed consists of 95.6% sand, and 4.4% silt and clay. The mean diameter of grain size (D50) is 0.007 mm. the wave data of the past 10 years measured by ships plying in the offshore region between latitude 30° 55.0` N and longitude 28° 57.0` E is used in this study. [Beach Protection Authority].

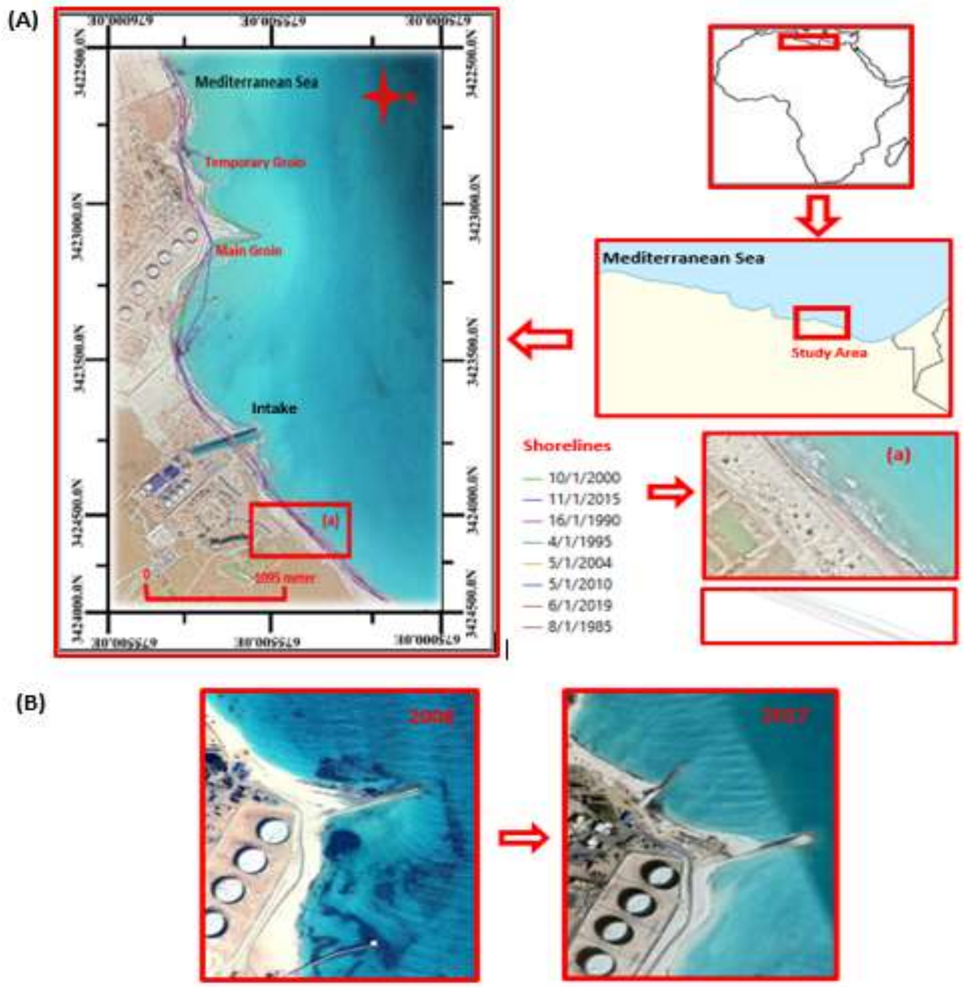

Fig. 1. Location of the Study Area (A) shoreline changes at EL-Hammra port from 1985 to 2019 [6]. (B) The part of study area that focused in this paper at 2006 with the main groin only and at 2017 with the temporary groin

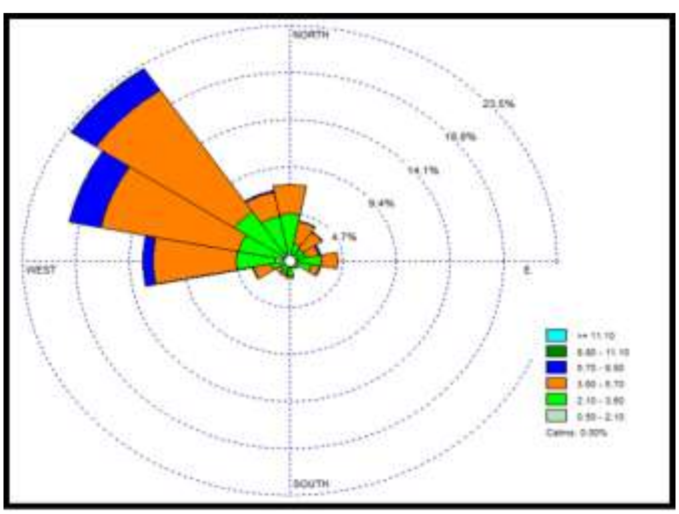

Fig. 2. Wave rose along El-Hammra Coast: average wave values during the period from 2007 to 2015

III. MODEL SETUP AND SIMULATION PROCESS

The shoreline changes around El-Hammra port coastal area, in the western northern coast of EGYPT, are studied. The period from 2015 to 2019 are simulated using the DHI-LITLINE Model to predict the shoreline changes along the coastline. To estimate the sediment transport alongshore and cross shore, the surf zone model in the DHILITDRIFT is used. The natural data of hydrodynamic process for 2015 year like waves, currents and tidal are considered.

The Study area is about 4km which substitutes the active erosion length is about 1km. The active accretion length is about 3km [6]. The observed shoreline in 2015 is used as the initial condition for the model. The grid step was used 25 m to build the model. The groins and jetties are defined as perpendicular to the datum as baseline which parallel to the longitude lines, as is clearly shown in figure 3. Five profiles are used to evaluate the changes in the bed bathymetry. The model was focused at first 2000m (2km) as the protection structure located. Profiles are located at 300, 600, 800, 1200 and 1600m respectively from the reference line.

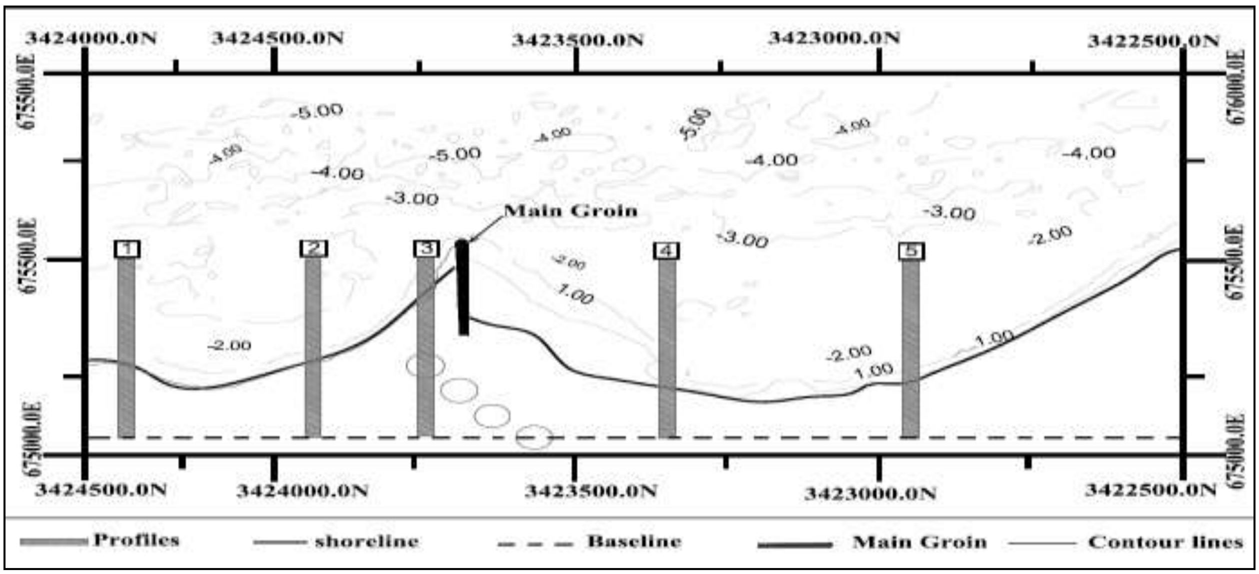

Fig. 3. LITPACK 1D model setup

The simulation starts with data input considering the initial shoreline, the profile series cross shore profiles, the time series wave climate and the characteristics of the sediments. The sediment characteristics is applied to the model as collected from the field measurements, (Table 1). Figure .4 shows the initial steps of the simulation process. Results are computed by using the LINTABL and LITDRIFT module.

TABLE 1
SEDIMENT CHARACTERISTICS ALONG THE PROFILES [3].

Depth (m)	d_{50} **(mm)**	**Roughness of seabed**	**Fall Velocity (m/sec)**	**Spreading factor** $\sigma_g = \sqrt{1.50 d_{50}}$
“+2:0”	0.812	0.012	0.085	0.901
“0:-2”	0.406	0.008	0.052	0.637
“-2:-4”	0.134	0.004	0.013	0.366
“-4:-6”	0.025	0.004	0.001	0.158
“-6:-8”	0.007	0.004	0.000	0.084

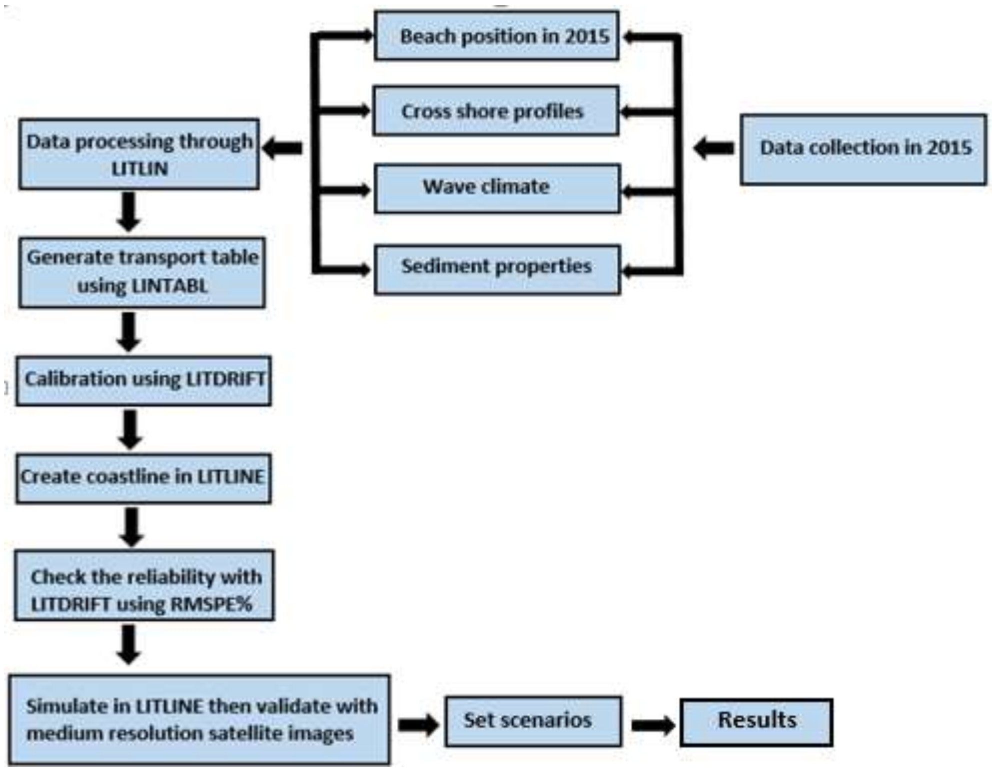

Fig. 4. Processing flowchart of the simulation

IV. MODEL CALIBRATION AND VALIDATION

In the study area, the changes of the shoreline are simulated during the period 2015-2019. Model's calibration process was conducted using the measured shoreline in 2015 as reference to simulate the shoreline of 2019, then the measured shore of 2019 is used for the comparison with the predicted one. During the calibration process, the depth of closure is considered as the most important factor affecting the width of the surf zone, which is the most efficient area of sediment transport movement. The calibration is conducted by changing the extension of sediment transport tables using 0.0, 15, 30, 45, and 60 m values. Figure (5.a) indicates the assumed active depth to be 6m, this distance is approximately equal to the width of the surf zone. The RMSPE (Root Mean Square Percentage Error), is derived to calculate the errors of simulations results by Equation (1). [7]

$$RMSPE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(100\frac{(y_s)_i-(y_o)_i}{(y_o)_i})^2} \quad (1)$$

Where, y_s refers to the perpendicular distance from the simulated shoreline to the baseline.

y_o is the distance from the baseline to the observed shoreline, and N is the number of sectors. Figure (5-b) indicates the RMSPE results related to the transport parameters. The calculated RMSPE values for extension of transport for 0.0, 15, 30, 45 and 60m are 0.04321, 0.15223, 0.16068, 0.13859 and 0.13858 respectively. The smallest value calculated of RMSPE is 4.32% which related to value of 0.0 m from the sediment transport table. That's why, the value 0.0 m is suitable for a parameter to calculate the shoreline changes. Figure (5.c), clarify the calibration results using 2019 shoreline observation at 0.0 m from the extended transport table. Model enables us to predict several accretion rates varying from +0.93 to +8.04 m/year and erosion varying from -0.395 to -3.35 m/year By DSAS work [6]. The digitized shoreline from the image of satellite in 2015, 2017 and 2019 with a value of 0.0 m from the extended transport table are used to carry out the validation test. Figure (6-a&b) represented the calculated RMSPE values for 2-years from 2015 to 2017 and 4-years from 2015 to 2019 are equal to 0.087574 and 0.009177 respectively. In figure (6-a) RMSPE is high because of construction of temporary groin in 2017 (from history of study area) as shown in the measured line. In figure (6-b) RMSPE is lower the previous due to the erosion of the submerged temporary groin. As the shoreline seemed to be returned to its normal. So, the temporary groin not appeared recently in 2020.

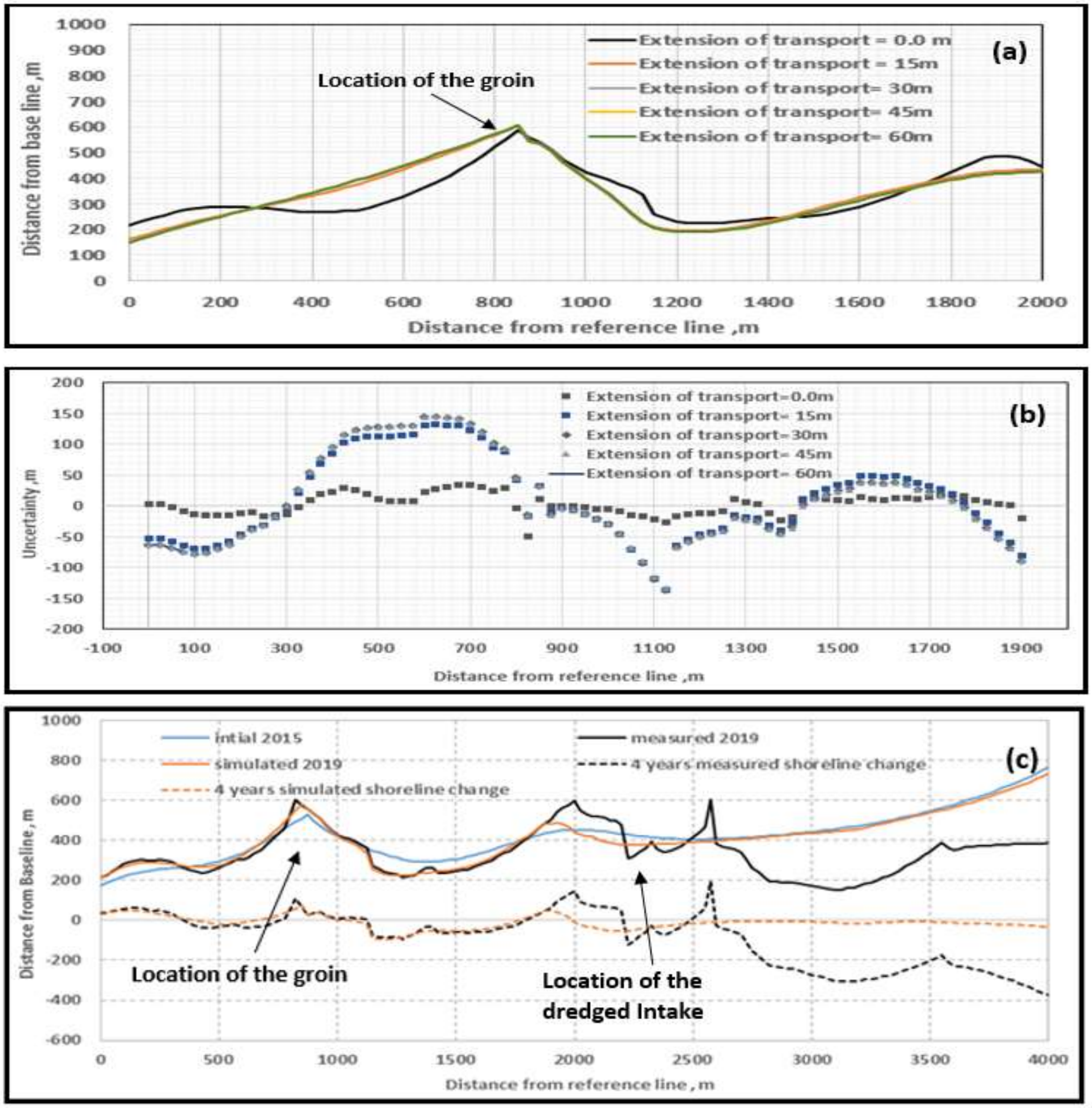

Fig. 5. Results of calibration. (a) The shoreline observation in 2015 ; (b) The uncertainty shoreline and RMSPE; and (c) The simulated shoreline changes during 4-years for the whole area.

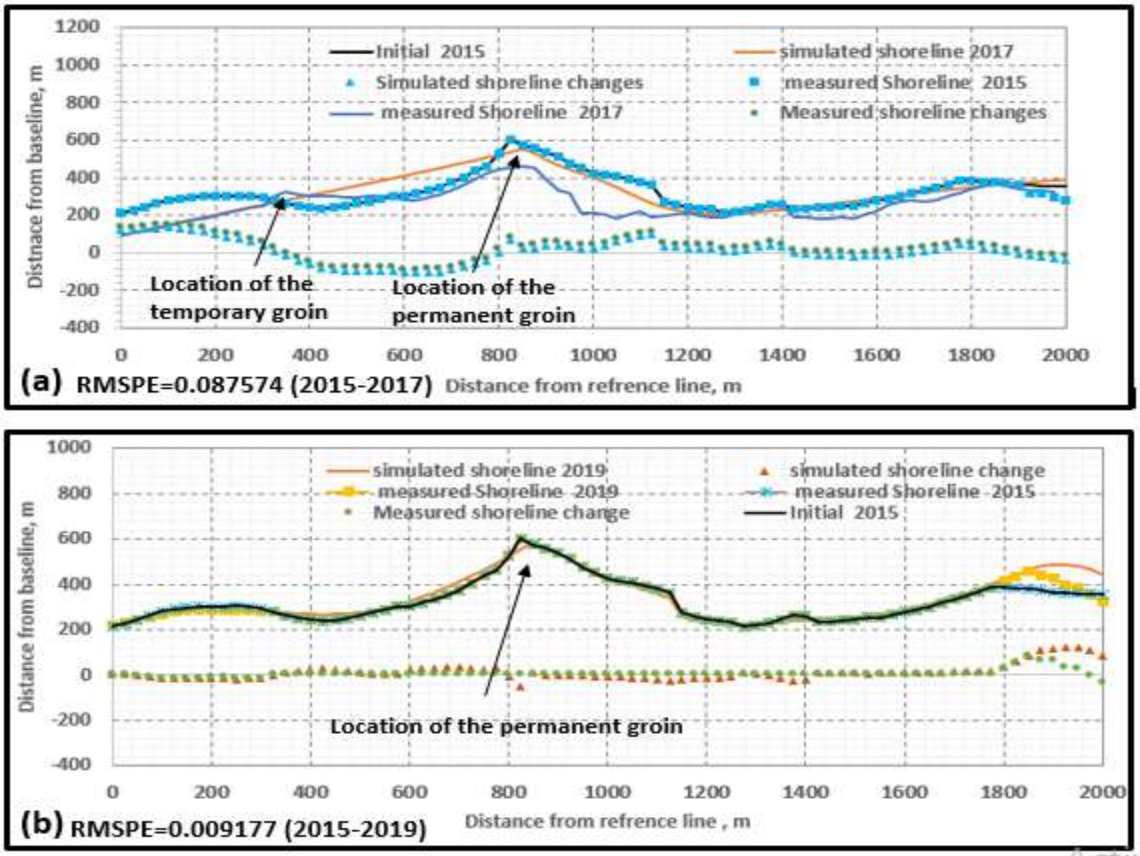

Fig. 6. Simulated shoreline changes along the study area using LITPACK model compared to the measured one with RMSPE for (a) a 2-years simulated (from 2015 to 2017), (b) 4-years simulated (from 2015 to 2019)

The model is used to simulate and predict the effects of composite hard coastal structures on shoreline changes. Many proposed scenarios were taken into consideration representing the hydrodynamic factors as water levels, littoral drift and waves along the whole period from 2015 to 2030.

V. PROPOSED SCENARIOS

A. SCENARIO 0- THE CURRENT SITUATION

Model is applied near the port, along 4000 meters distance. The LITLINE model simulates the shoreline changes from 2015 to 2030, and the maximum observed accretion pattern is +63,383 m over a 15-year period as shown in figure .7.

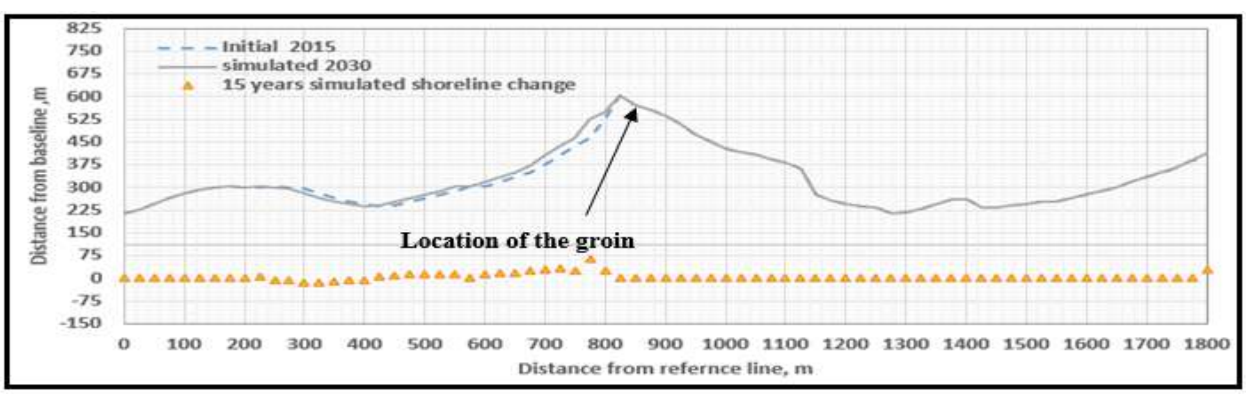

Fig. 7. Simulation results of shoreline changes for 15 years without protection measures

B. SCENARIO 1-

TWO GROING CONSTRUCTION

Two groins G1 & G2 are proposed to be constructed at the east of the two existed groins with 200 m length. G1 is located at 500m from the east of the permanent one. G2 is located at 500 m away from G1, at distance of 1350m and 1850m respectively from the reference line. Figure .8 evaluate the result of simulation of the two groins; compared with the results of current situation scenario. The area between the two groins are fluctuated between erosion and accretion. The results of the simulation update a total area of erosion was 1266.62 m2 and the area of accretion was 26645.20 during the 15 years; In the meantime, the total area of erosion without that groins is 7340.06 m2 and the area of accretion was 11280.70m2, implication that the use of these groins will decrease the area of erosion and increase the accretion by 19305.04 m2 and 10014.08 m2 respectively.

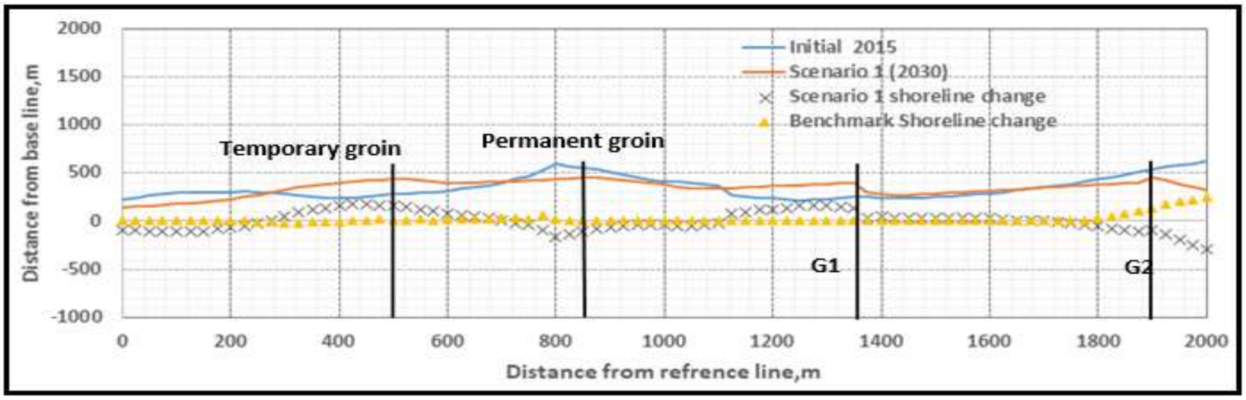

Fig. 8. Scenario-1 prediction of shoreline changes for 2030

C. SCENARIO 2-

THREE DETACHED BREAKWATER CONSTRUCTION

Three detached breakwaters B1&B2&B3 are simulated at distance between 950m and 1850m from the base line. The total length of each breakwater is 150m, a gap width 150 m, and depth of closure is 6.0 m. The distance between breakwaters and shoreline is 160 m at right angle approximately to the orthogonal direction of the prevailing waves, as is shown in figure .9. From the figures, there is a relation between the salient growth and the current, wave run up and wave crests intersects at the shadow zone of the breakwaters. The results of the simulation update a total area of erosion of 3028.58 m2 because of the great wave energies transmitted by the gaps. The area of accretion is 2293.79 m2 over a span of 15 years. The total area of erosion without breakwaters was 7340.06 m2. The total area of accretion without breakwaters was 11280.70m2 over a span of 15 years. Implication that the use of three detached breakwaters will decrease the area of erosion and increase the accretion area by 5046.27 m2 and 8252.12m2respectively.

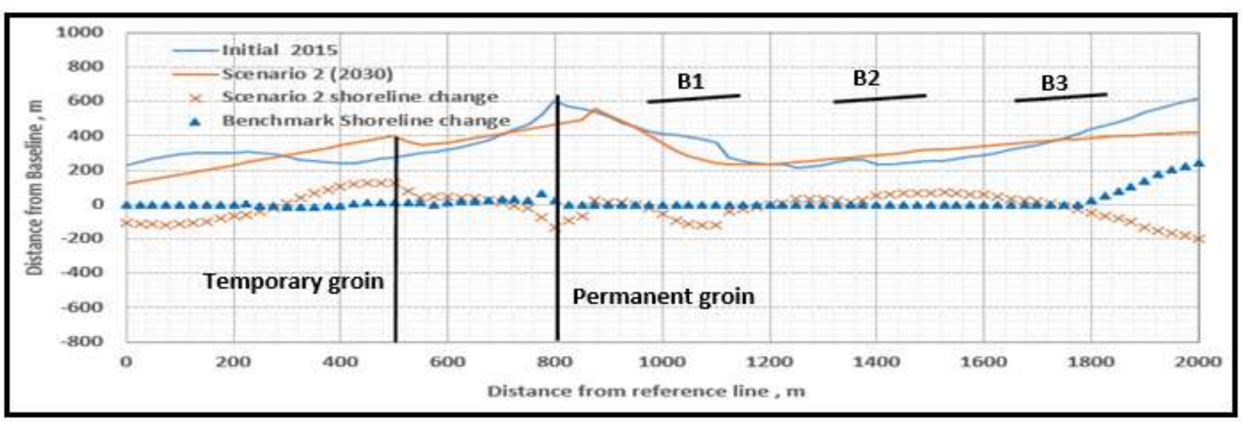

Fig. 9. Scenario-2 Prediction of shoreline changes for 2030

D. SCENARIO 3-

Construction of two long groins with three detached breakwaters

This scenario introduces a composite hard system consists of groins and detached breakwaters, and the results are plotted in figure (10). The use of detached breakwater in combination of long groins has significant role in reducing the erosion relative to groin usage. Circulation currents bring eroded sediments in vigorous salient between the groins into the protected region behind the breakwaters. The results of simulation of this scenario show that the eroded and accreted area became 546.562 m2 and 302.732 m2 respectively over the span of 15 years. Implication that combines scenarios will decrease the area of erosion and accretion by 6794.038 m2 and 10977.968 m2 respectively.

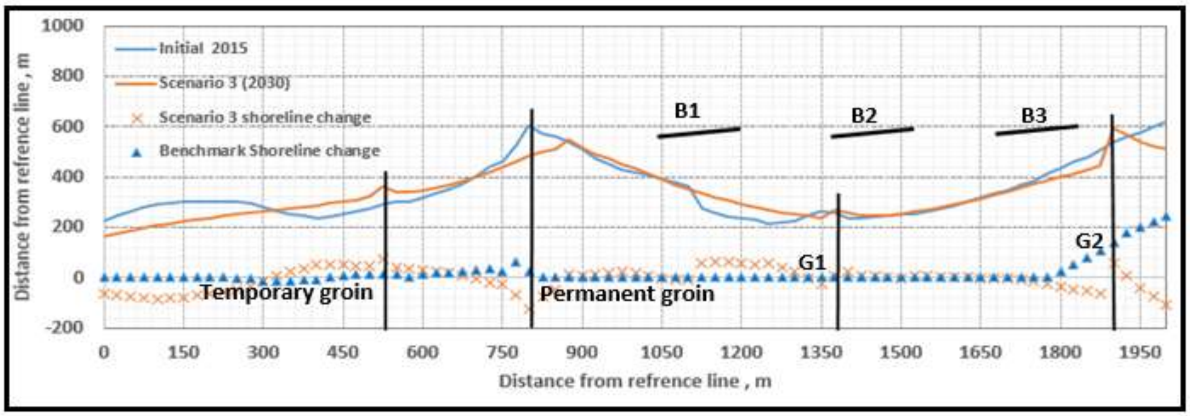

Fig. 10. Scenario-3 Prediction of shoreline changes for 2030

VI. CONCLUSION

The 1D model of LITPACK is applied in the vicinity of the two groins along 2 km under the effects of groins and detached breakwaters during the period 2015 to 2030 of 15 years. This simulation is done to evaluate the erosion and accretion field, taking into account the hydrodynamic parameters. The structure system is selected based on the simulated and calculated results, (scenario 3) which includes three detached breakwaters with length of 150 m, gap width 150 m, and 6.0 m depth of closure. Two permeable long groins 200m length at a distance of 500 m from the reference line is the most efficient and suitable as counter measure for the study area as shown in table 2. Figure (11), shows a comparison of the three proposed scenarios.

TABLE 2
COMPARISON BETWEEN SIMULATION RESULTS (2015 TO 2030)

Simulated scenarios	**Eroded area (down-side)** Area (m2)	**Scenario efficiency** *(%)*		**Accretion area (up-side)** Area (m2)
Benchmark	**7340.06**	**-**	**-**	**11280.70**
Scenario 1	1266.62	*82.74*	*36.20*	26645.20
Scenario 2	3028.58	*58.73*	*79.66*	2293.79
Scenario 3	546.562	*92.55*	*97.31*	302.732

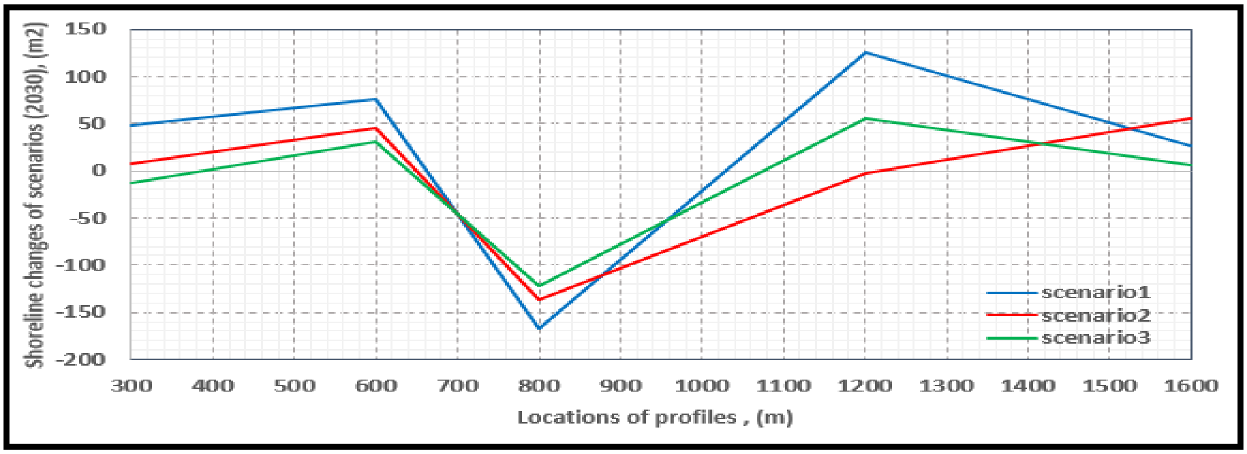

Fig. 11. Comparison of the three scenarios for the shoreline changes prediction for 2030.

REFERENCES

[1] Frihy, et al., (2012). "Erosion chain reaction at El Alamein Resorts on the western Mediterranean coast of Egypt. ", IEEE Trans. coastal engineering, 69, 12-18.

[2] Thomas, R. C., et al. (2013). "Shoreline change modeling using one-line models: General model comparison and literature review", Engineer Research and Development Centre, Coastal and Hydraulics Lab.

[3] Nassar, K., et al. (2018), "Numerical simulation of shoreline responses in the vicinity of the western artificial inlet of the Bardawil Lagoon, Sinai Peninsula, Egypt." IEEE Trans. Applied Ocean Research, 74, 87-101.

[4] Noujas, V., (2019). Shoreline management plan for embayed beaches: A case study at Vengurla, west coast of India." Ocean & coastal management, IEEE Trans. 170, 51-59., International Water Technology Journal, Vol. 2 – No. 4, pp 268-283.

[5] Nguyen, N. T. et al., (2007), "Studying shoreline change by using LITPACK mathematical model (case study in Cat Hai Island, Hai Phong City, Vietnam). IEEE Trans. Applied Ocean Research.

[6] SARHAN, T., MANSOUR, N., EL-GAMAL, M. A. H. M. O. U. D., & NASAR, K. (2020). HISTORICAL SHORELINE TREND ANALYSIS IN THE VICINITY OF EL-HAMMRA PORT AT NORTHWESTERN COAST OF EGYPT. Journal of Sustainability Science and Management, 15(3), 36-50.

[7] Liu, et al., (2011, "The effect of aerosol vertical profiles on satellite-estimated surface particle sulfate concentrations", Remote sensing of environment, 115(2), 508-513.