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APPLICATION OF EMPIRICAL ORTHOGONAL FUNCTION MODELS TO ANALYZE SHORELINE CHANGE AT BANGKALAN MADURA

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Abstract

Bangkalan's shoreline, especially on the opposite side of Surabaya, has been evaluated to determine the morphological changes due to wave attack, near-shore current, long-shore sediment transport and coastal configuration. This research aims to determine the dominant patterns of variation of Bangkalan's shoreline change, expressed by Eigen-function in empirical orthogonal function (EOF) models. That was started with data collection such as oceanographic data (wave and tidal), bathymetry and topographic map and sediment data. All data was used for forecasting two-monthly shoreline. Coordinate of two-monthly shoreline was used as input of EOF model. The first Eigen mode is a profile of shoreline equilibrium. The second Eigen mode shows pivot point that separates the different behaviors, which indicates a positive balance of shoreline from the direction of the dominant force. The models execution based on 1986's shoreline show the shoreline change significantly at some cells e.g. around Suramadu bridge (cell 1-40), Batuporon (cell 70-100), Jungdima (cell 142-170) and at Kamal port (cell 230-250). The model of shoreline change using EOF was validated with the One-line model and data of 1995's map's shoreline. The E.O.F. value of model RMSE, 0.02, is less than the root mean square error (RMSE) value of One-line model, 0.04, which shows that the EOF model performance better than One-line models.

Keywords: Bangkalan, Eigen-function, EOF, one-line model, shoreline change

1. Introduction

The shoreline is a meeting point between the back-shore and the sea water influenced by wave and tidal processes, which approximates the mean high water level (MHWL) [1-2]. Shoreline changes is strongly influenced by the processes that occur in the area around the beach (near-shore processes), where the shore is always adapting to various conditions that occur [3]. This process has been extremely complex, influenced by three factors, namely, a combination of waves and currents, sediment transport, and coastal configuration, which influence each other. Changes characteristic in each of these factors vary spatially and temporally which lasted for a long time [4]. The stability of coast at sites can be seen by observing the condition of vegetation and land use along the coast [5].

One of methods which developed and used for analysis of shoreline change spatially and temporally was empirical orthogonal function (EOF). This model was used to analyze the behavior of shoreline ordinate during space and time. It purposes to separate the temporal and spatial data linkage that may be generated as a linear combination of the corresponding function of time and space. That function objectively represents the variation of beach-related configuration changes to the distance and time on the shoreline during the study period [6]. In this study, EOF was used to describe a significant mode of shoreline variability in temporal and spatial data sets from shoreline change modeling by One-line model and validated by bathymetry data in Bangkalan 1986 and 1995.

The EOF methods were developed in the early 1900s by Pearson [7] and Hotteling [8], as a mean to extract the dominant patterns of a random set of data. In the coastal processes, EOF method has been applied to analyze changes in cross-shore profiles [1,9-11], as well as in some other studies to analyze shoreline change along shore. The EOF analysis to measure the variability of shoreline along shore has been done before by Munoz-Perez *et al*. [12]. Miller and Dean [13] also analyzed the variability of shoreline along shore in several locations in the United States and Australia. In addition, Rithpring and Tanaka [14] analyze topographic changes at Natori River estuary due to construction of the Yuriage port and around the Sendai port in Japan. Hsu *et al*. [15] developed a new two-dimensional empirical Eigen-function model as proposed previously by Hsu *et al*. [16] to predict the coastal change due to combining effect of long-shore and cross-shore sediment transport direction. Recently, Fairley *et al*. [2] used the EOF method to analyze shoreline change behind two type detached breakwater, using data from video recorded for 30 months, at Sea coast, England. While Munoz-Perez and Medina [12] apply the EOF method to compare the variation of long term, medium and short term changes of the beach profile. The EOF applications have been described above using either real data of field measurement or aerial photograph, which is difficult to be applied in Indonesia.

Therefore, to overcome these problems this research used shoreline data based on prediction of 10 years two-monthly shoreline data (from 1986 to 1995) which was obtained from One-line shoreline model. Moreover, it was performed a comparative analysis of shoreline change by EOF model, One-line model and the 1995's bathymetric map shows by root mean square error (RMSE).

2. Methods

The study area is located on the southern coast of Bangkalan, around the Suramadu bridge to the port of Kamal (Fig. 1.) with analyzed-coastline length is ±6250 meter divided in the 250 cells at intervals of 25 meters.

At first, the shoreline of the study area is extracted from the 1986's bathymetric map and divided by 250 cells. It is then analyzed using One-line shoreline change model as developed by Suntoyo [17] based on Komar [18] to obtain every two-monthly shoreline data for 10 years

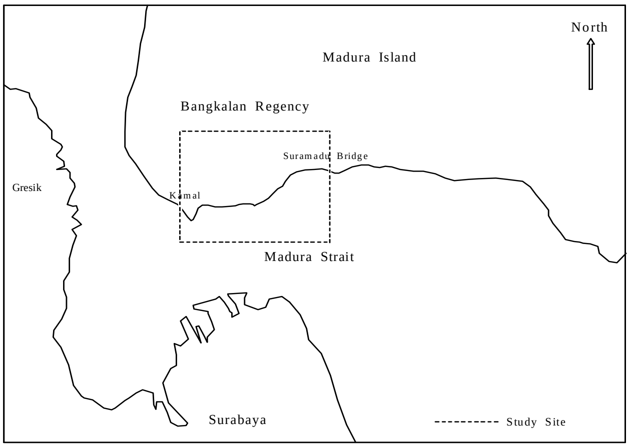

Figure 1. Study Area

(1986-1995) with the 1995's bathymetric map for model validation. In this model, the long-shore sediment transport proposed by Kamphuis [19] was used, by considering the sediment grain size it is assumed that the median grain size of sediment (d_{50}) is considered similar along the shore. Kamphuis equation [19] stated as:

$$Qs = 2.27 \times H_b^{2} \times T_p^{1.5} \times m_b^{0.75} \times D_{50}^{-0.25} \times \sin^{0.6} 2\alpha_b \quad (1)$$

where, H_b is the height of breaking wave, T_p is the wave period, m_b is cross-shore slope and d_{50} is the median grain size of sediment.

Furthermore, the prediction results from One-line models were used as an input of EOF models, to obtain an Eigen-function describing the dominant patterns of variation of shoreline change. Finally, a comparative analysis among the results of EOF analysis, One-line model and the data of shoreline in bathymetric map in 1995 was carried out.

Each dataset was analyzed using EOF model to identify the dominant patterns of variability in the data set. Before performing the EOF analysis, the mean value of each position was calculated and used to subtract by survey data [14]. Shoreline change can be expressed in the form of superposition Eigen-function as follows [4]:

$$y(x,t) = \sum_{k=1}^{n} e_k(x) c_k(t) \quad (2)$$

where y is the cross-shore distance, x is long-shore distance, $e_k(x)$ was spatial eigen-function, $c_k(t)$ temporal eigen-function, t time and k modes of variation.

The first mode states with the highest variance of data will be reduced by a higher mode. The combination of $e_k(x)$ and $c_k(t)$ describes the orthogonal mode of changes in data and its variation with respect to time [7]. In this study, EOF model using the numerical models were developed by the Environmental Hydrodynamics Laboratory of Tohoku University, Japan, as used by Rithpring and Tanaka [6,14].

3. Results and Discussion

Shoreline change variation from EOF analysis results is shown in Table 1 in five Eigen value that dominate the shoreline changes at the sites. These five Eigen-functions reached 91.26% of the variability total of the shoreline. The first mode of the eigen-function $e_1(x)$ dominates the variability of the shoreline. Percentage of each eigen-value in the table shows the dominance of the changes that occur in each mode to the overall shoreline change spatially and temporally.

The first mode shows an equilibrium profile of the shoreline. The second mode shows the pivot point which separates the different behavior, which showed a positive balance in the shoreline dominanted by wave direction.

Fig. 2 to 9 shows spatial and temporal eigen-function which describes shoreline variability at the sites. In the first mode, spatial eigen-function, $e_1(x)$ in Fig. 2, indicates the fluctuating change spatially in the most cells. along shore. While the temporal eigen-function $c_1(t)$ in Fig. 3. gave the positive value in the period 1986 to 1991, but experienced a very significant change in the period 1992 to 1995. This may be affected by the increased of construction activity in this region [16]. Combination of $c_1(t)$ and $e_1(x)$ reflects accretion or abration of shoreline depends on the sign of $c_1(t)$. Therefore, $e_1(x)$ describes the cross shore process that dominates the variability in this region based on the contribution value in Table 1.

Spatial variability represented by $e_2(x)$ in Fig. 4 also still shows fluctuative changes in most cells and some cells tend to be stable. The values of $c_2(t)$ in Fig. 5 shows a different variation with the first mode, where there are constant changes in 1986 to 1992. Combination $e_2(x)$ and $c_2(t)$ reflects behavior similar to the first mode. Where $e_2(x)$ shows the variation of cross shore changes as a whole, while the temporal, $c_2(t)$ shows the dominance of changes that occur.

Furthermore, Fig. 6 and 7 show variability in the third mode gives a change contribution of 14.38%. As in the first and second modes, changes occur in some cells. Temporally, the shoreline changes incline to be an accretion in 1986 to 1989 and 1992 to 1993, whereas in 1989 to 1992 and 1993 to 1995 incline to be an abrasion. The combination of spatial and temporal changes, reflects the cross shore changes, according to the sign of $c(t)$. Sum of fourth-fifth modes variability on Fig. 8 and 9 only contributed 9.99% of variability. While, the temporal variation of both modes, show a more fluctuating changes.

Table 1. Eigenvalue Which Express the Percentage of Shoreline's Variability

Mode	$e_1(x)$	$e_2(x)$	$e_3(x)$	$e_4(x)$	$e_5(x)$	Others
Variability (%)	45.95	21.26	14.38	6.03	3.96	8.74

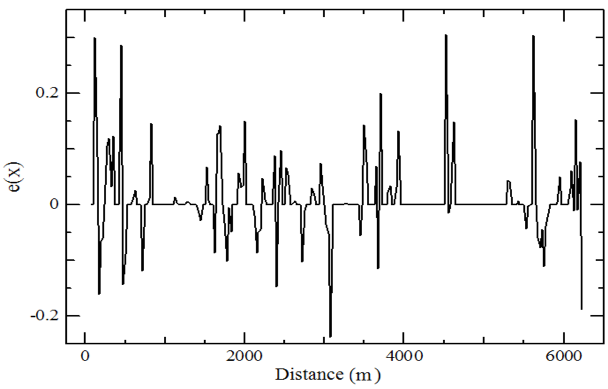

Figure 2. First Mode of Spatial Eigen-function $e_1(x)$

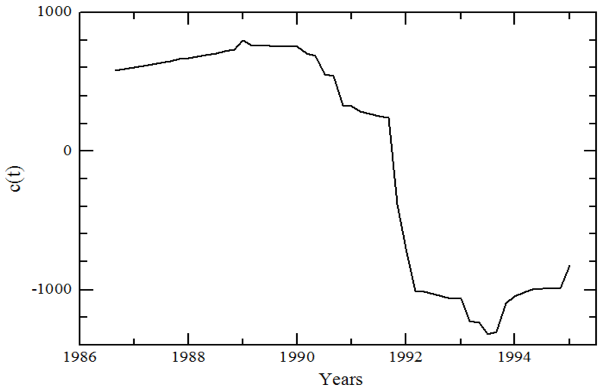

Figure 3. First Mode of Temporal Eigen-function $c_1(t)$

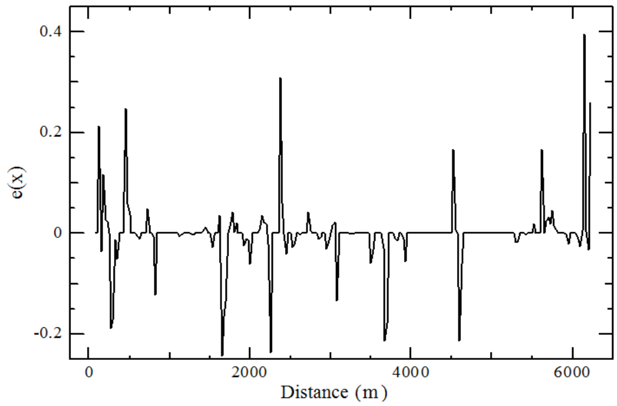

Figure 4. Second Mode of Spatial Eigen-function $e_2(x)$

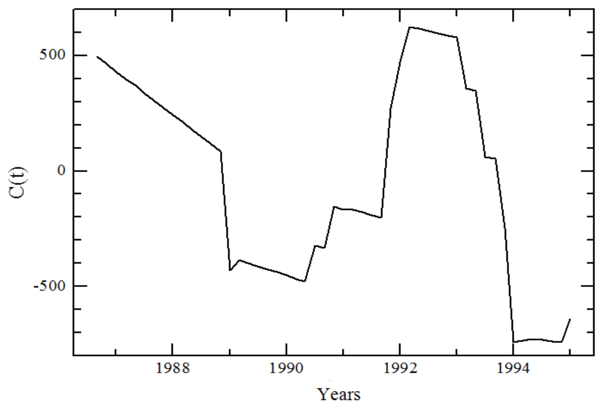

Figure 5. Second Mode of Temporal Eigen-function $c_2(t)$

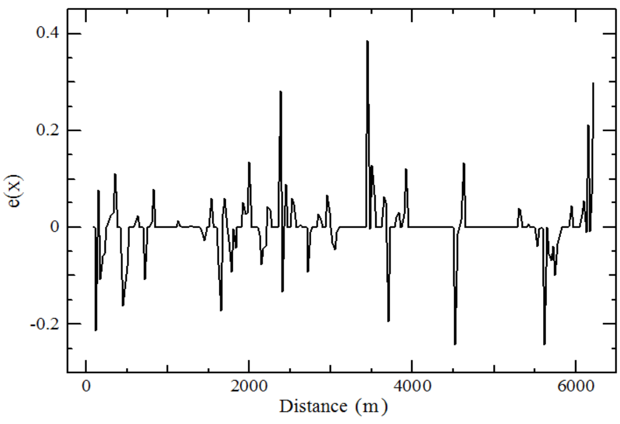

Figure 6. Third Mode of Spatial Eigen-function $e_3(x)$

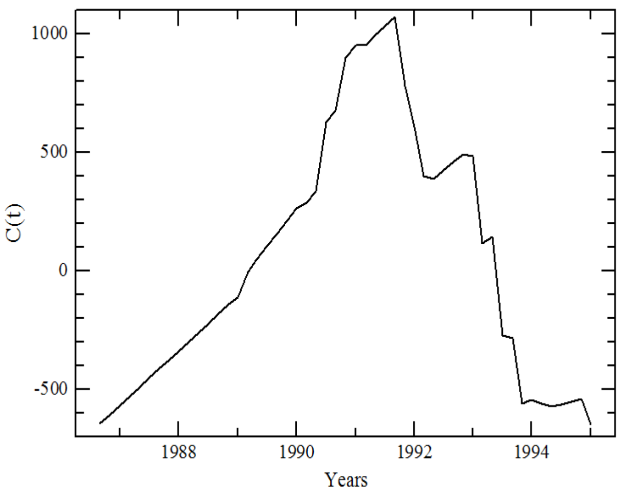

Figure 7. Third Mode of Temporal Eigen-function $c_3(t)$

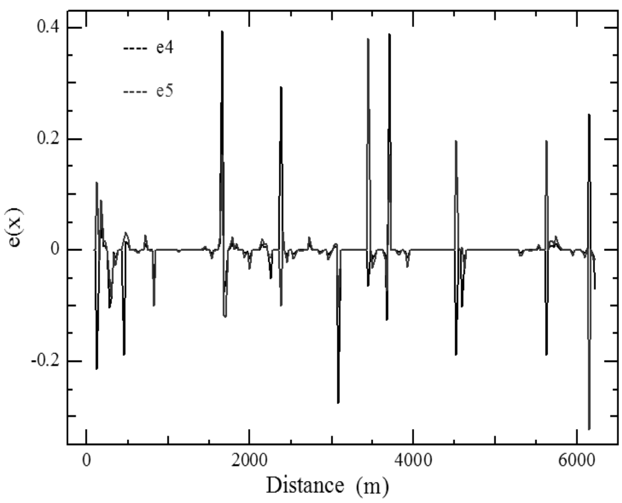

Figure 8. Fourth and Fifth Mode of Spatial Eigen-function $e_4(x)$ and $e_5(x)$

Fig. 10 shows the ratio of the number of multiplication of spatial to temporal eigen-function [$\Sigma e(x).c(t)$] with an average value (mean-shore) in *cell 10*. It can be seen that the value of $\Sigma e(x).c(t)$ gives a value close to the change of the mean value of shoreline change in the *cell 10*. It means that the calculation results of spatial and temporal eigen-function could describe the shoreline variability pattern that occur in the *cell 10*.

Both the EOF model and One-line shoreline change model results were validated with the Bathimetry map of 1995. It can be seen that the EOF model results showed very close to the Bathimetry map and One-line model results (Figs. 11, 12, and 13). By overlaying these results with the initial shoreline (in 1986) showed that the most of cells remained stable and others change with varying values. Some relatively significant changes occurred in cells 1-40 located around the Suramadu bridges, cells 70 to 100, cells 146-170, and more varied near the Kamal port.

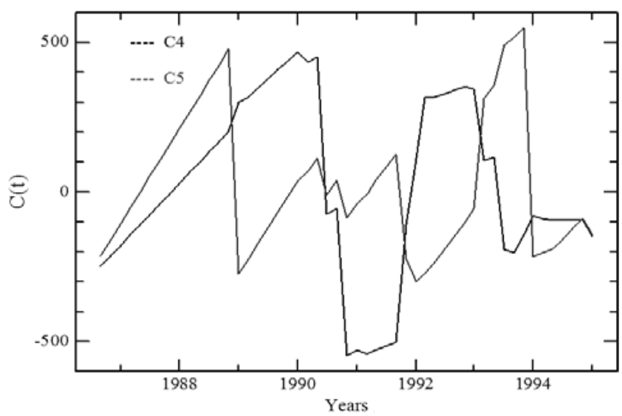

Figure 9. Fourth and Fifth Temporal Eigen-function $c_4(t)$ and $c_5(t)$

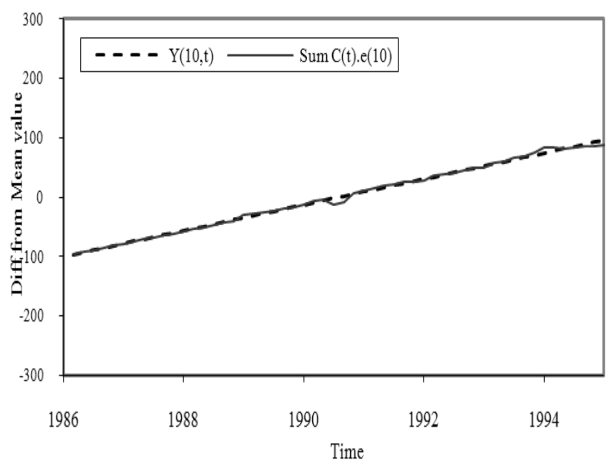

Figure 10. Checking Mean Shore Value with $\sum e(x).C(t)$

The performance comparison between EOF and One-line model on shoreline change prediction can be evaluated by using the RMSE, expressed by Eq. (3).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Y_{m_i} - Y_{p_i}\right)^2} \tag{3}$$

where, Ym_i is the shoreline ordinate of the model in the i^{th} cell; Yp_i is the shoreline ordinate of the 1995's map at the i^{th} cell, N is the total amount of cells, and i is the index. The best performance is close to the data shown in map in 1995 with the smallest *RMSE* value close to zero. In this study, the shoreline ordinates used was 250 data. The analysis was shown that *RMSE* of One-line model 0.047 higher than EOF model 0.026. Thus, it can be said that EOF model provides better performance than One-line model in shoreline change analysis on Bangkalan's shoreline.

In addition, the percentage of error calculation between 1995's EOF model and One-line model to 1995's map 1995 were calculated for each cells using absolute percentage error (*APE*), expressed by:

$$APE = \frac{|Y_p - Y_m|}{Y_p} \tag{4}$$

where Yp was the ordinate of shoreline from the map, and Ym was the ordinate of shoreline from the model.

Shoreline change can be caused by various factors, such as erosion and sedimentation due to some processes induced by currents, winds, waves, and tides. Bangkalan shoreline on the study area was identified as erosion,

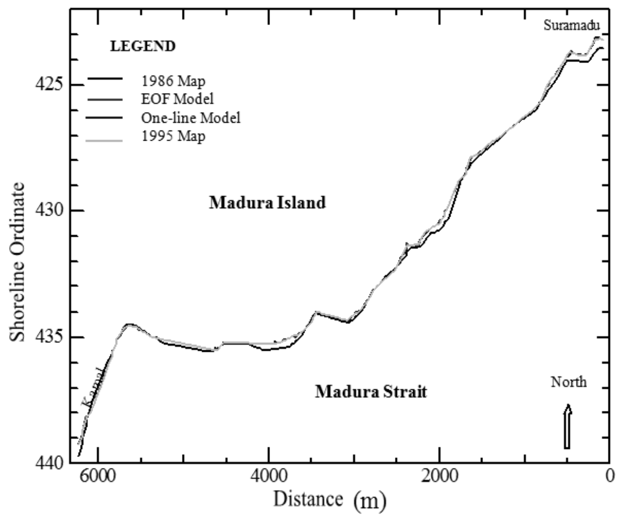

Figure 11. Comparison of the EOF Models, One-line Models and 1995's Maps

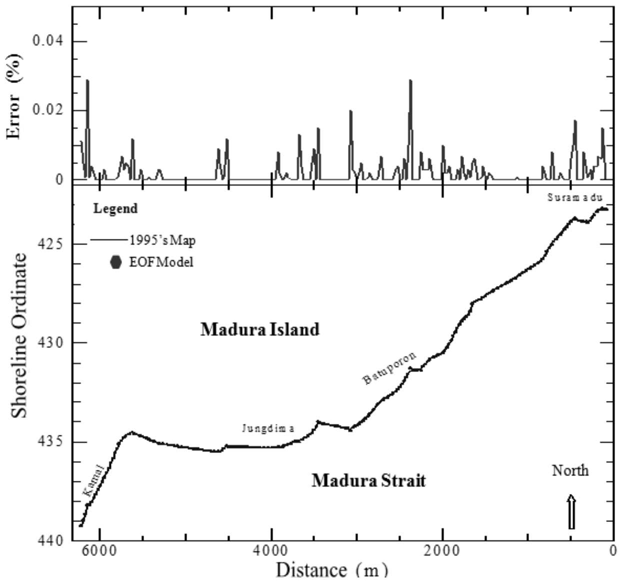

Figure 12. 1995's Shoreline by EOF Model with Maps Data

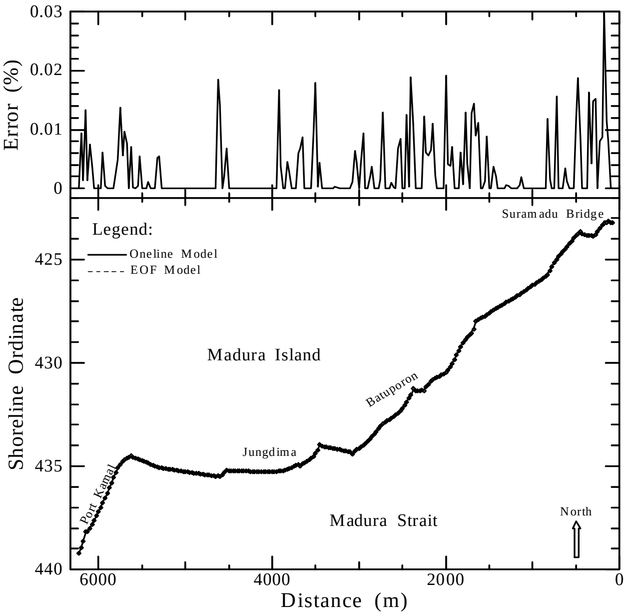

Figure 13. 1995's Shoreline by EOF Model with One-line Model

although it was not so significant, especially in Kamal port areas and around Suramadu bridge [20]. EOF analysis results based on the prediction of shoreline change with the initial shoreline data obtained from the bahymetric map showed that the main cause of erosion is the wave transformation and the environment condition with low bearing capacity causing damage on natural protective, such as a depletion thickness of mangrove plants near shore (see Fig. 14), which has been stated previously by Suwarsono *et al*. [5].

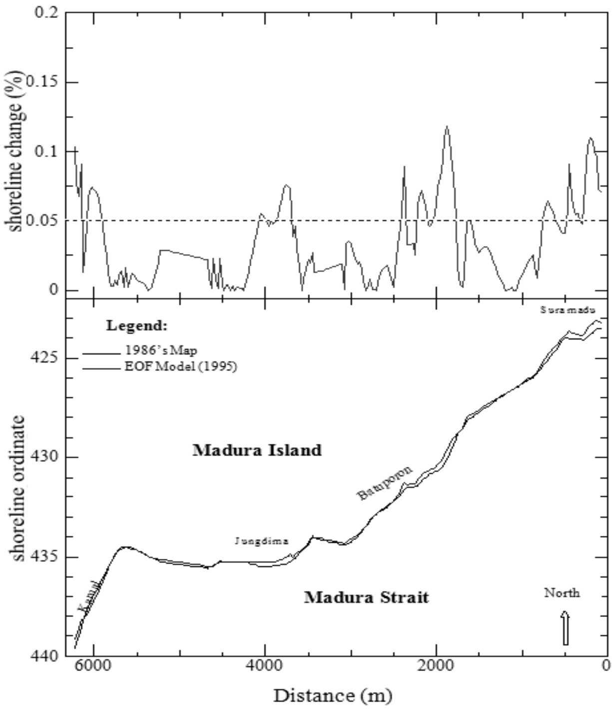

Figure 14. Shoreline Conditions EOF Analysis of 1986 Map

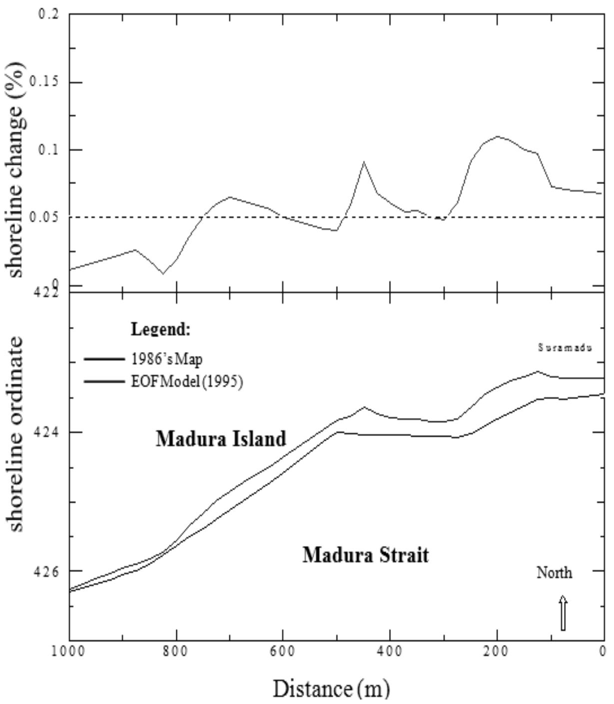

Figure 15. Shoreline Conditions: Details on Cells 1-40

EOF model analysis has been successfully used to describe the variability of Bangkalan's shoreline. This analysis is a statistical technique that separates the orthogonal modes, spatial and temporal, of the occurred changes. The change modes have no physical meaning, and the interpretation must be done carefully [2]. EOF analysis results in 1995 showed the most cells were considered to tend in a stable condition, with the percentage change in the shoreline in an average of 0.05%. However, some cells showed a significant level of change with the percentage of shoreline change more than 0.05% to 0.12% as shown in Fig. 15. The cells near the foot bridge of Suramadu show a significant change, the more westward the percentage of shoreline change decreases. The regions of Batuporon near the pier at the cells number of 70-100 showed a very significant change with the percentage of change of the shoreline reached 0.12%. (Fig. 16). Fig 17 showed that other significant changes also occurred in cells 142-170, Jungdima vicinity, and the cells around Kamal port. The significance changes in some areas were caused by high human activity and the reduced of mangrove population [20].

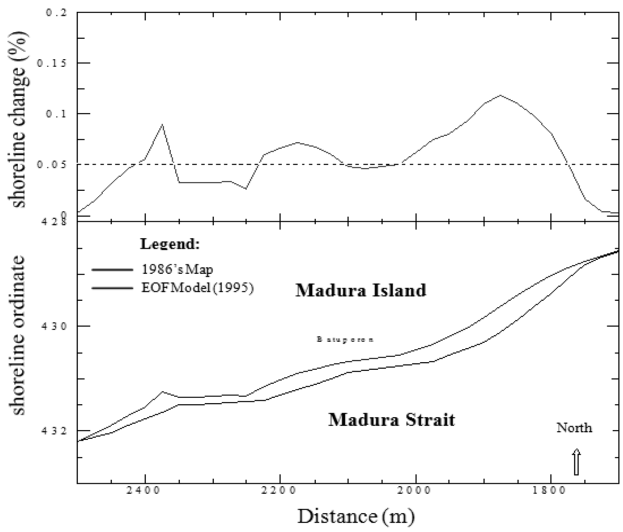

Figure 16. Shoreline Conditions: Details on Cells 70-100

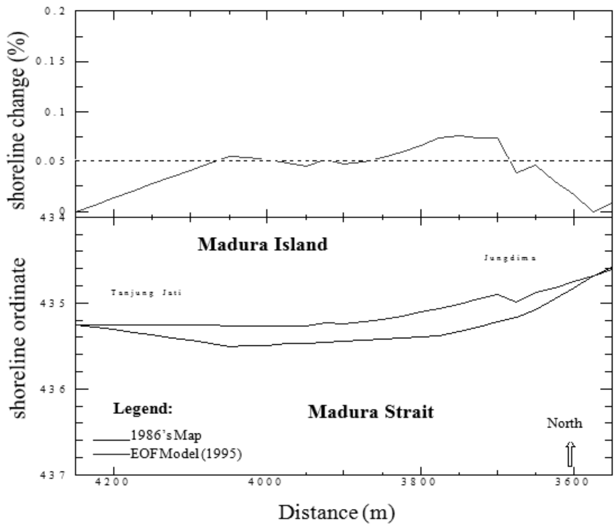

Figure 17. Shoreline Conditions: Details on Cells 142-170

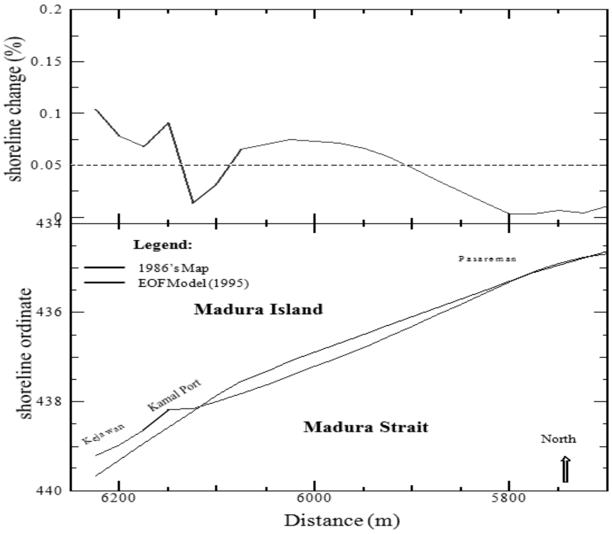

Figure 18. Shoreline Conditions: Details on Cells 230–250

EOF Model results shows that the trend of abrasion occur in the vicinity of Suramadu bridges in which the dynamics change may be caused by the reduction of the mangrove community in the area. Sediments in this area consists a mixture of fine sand and silt substrate which is the dominant characteristics of mangrove forest area. It was easyly eroded and sedimented depends on the dominant parameters that influence the coastal environmental.

Based on field observation, cells 142-170 located between areas namely Jungdima and Tanjung Jati in west of a pier. Here, the dominant wave conditions came from east direction, which is very susceptible to abrasion. It was appropriate with results of the model which indicate trend of abrasion, as shown in Fig.17. Also, Fig. 18 shows the situation of Kamal area due to the dominant wave direction. The results showed that the acretion and sedimentation occur from Pasareman area to vicinity of Kamal port.

4. Conclusion

In this study, EOF analysis was applied to analyze the shoreline change at Bangkalan beach. The main conclusions are as follows. EOF analysis produced five eigen-values with variability reaches 91.26% of the total variability. The first mode of the eigen-function $e_1(x)$ dominates the variability of the coastline. Percentage of each eigenvalue shows the dominance of the changes occurring in each mode to the overall shoreline change spatially and temporally. The combination of temporal and spatial variability on each mode change back and forth to depict the shoreline, where the results of the shoreline change model indicated the majority of cells observed to be stable, only few regions have the models detected with significant changes, with the percentage of shoreline change between 0, 0.5% to 0.12%. Beaches in regions of Batuporon near Batuporon Pier at cells number of 70-100 showed a very significant change with the percentage of change of the shoreline reached 0.12%. Whereas, other significant changes also occurred in cells 142-170, Jungdima vicinity, and the cells around the Kamal port. The significant changes in some areas were caused by high human activity and the mangrove population reduction. EOF model validation against 1995's bathymetry maps and One-line model showed that the EOF models prediction in 1995 are very close to the shoreline ordinate on the 1995's map model and the results of One-line model in 1995. It was shown that the value of RMSE from One-line model is 0.047 that is higher than the value of RMSE from EOF model in the ammount of 0.026. Thus, it can be said that the EOF model provides better performance than One-line model in analysis of shoreline change on the Bangkalan's shoreline.

Acknowledgments

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