Shoreline Change Estimation from Survey Image Coordinates and Neural Network Approximation

Tienfuan Kerh, Hsienchang Lu, Rob Saunders

***Abstract*—**Shoreline erosion problems caused by global warming and sea level rising may result in losing of land areas, so it should be examined regularly to reduce possible negative impacts. Initially in this study, three sets of survey images obtained from the years of 1990, 2001, and 2010, respectively, are digitalized by using graphical software to establish the spatial coordinates of six major beaches around the island of Taiwan. Then, by overlaying the known multi-period images, the change of shoreline can be observed from their distribution of coordinates. In addition, the neural network approximation is used to develop a model for predicting shoreline variation in the years of 2015 and 2020. The comparison results show that there is no significant change of total sandy area for all beaches in the three different periods. However, the prediction results show that two beaches may exhibit an increasing of total sandy areas under a statistical 95% confidence interval. The proposed method adopted in this study may be applicable to other shorelines of interest around the world.

***Keywords*—**Digitalized shoreline coordinates, survey image overlaying, neural network approximation, total beach sandy areas.

I. Introduction

Due to the effect of global warming in recent years, the phenomenon of gradually rising of sea level may generate a slow type of disaster, and that may cause the possibility of losing land areas depended on the geographical location and land characteristics [1]-[3]. The dynamic variation of shoreline is an important research topic that must be considered particularly for a country that is composed of islands. It is better to check the pattern of accretion or erosion of sand line for preventing unwanted negative environmental and economic impacts on the specified coastal region.

To evaluate the variation of nonlinear shoreline correctly, it can be a very difficult task as there are many reasons such as extreme weather, tidal current, drifting sand, land subsidence, estuarine effect, and industrial development may cause a complex process to affect the shoreline area [4], [5]. To facilitate the shoreline change estimation, an easy and straightforward method is to use the spatial information on each beach for multi-period [6]. From comparison of digitalized images, the shoreline change may be observed and analyzed in further.

T.Kerh is with the Civil Engineering Department, National Pingtung University of Science and Technology, Pingtung 91207, Taiwan (phone: +886-933-325188; fax: +886-877-40122; e-mail: tfkerh@mail.npust.edu.tw).

H. Lu was with the Department of Civil Engineering, National Pingtung University of Science and Technology, Pingtung 91207, Taiwan (e-mail: M9933011@mail.npust.edu.tw).

R. Saunders is with the Faculty of Architecture, Design and Planning, University of Sydney, Sydney, NSW2006, Australia (e-mail: rob.saunders@sydney.edu.au).

Four major islands, namely Taiwan, Penghu, Quemoy now known as Kinmen, Matsu are included in the region of Taiwan, whereas most of economic activities for a population of about 23 millions are occurred in the major island Taiwan. Since this island is surrounded by oceans, there are many literatures have been published to deal with the issues of shoreline variation. It can be found that one major part of the papers uses the graphical image information obtained from satellite remote sensing technique, aerial survey map, and monitoring camera device, as the basis to analyze erosion problem in different shoreline areas [7]-[10]. The other part of papers is focused on the development of numerical model with the aid of hydraulic modeling experiment for a specified coastal region, to simulate and predict the possibility of shoreline variation [11]-[13]. These researches did provide a good reference to evaluate the suitability of designing or planning construction works along the shoreline. Since the existence of shorelines can be easily seen in many parts of the world, so a wide range of research topics for shoreline erosion problems can be found in various literatures [14]-[21]. Among those reports, the directly use of neural network with spatial information for predicting shoreline change is still rarely seen up to the present time.

In this study, the spatial information on each beach is obtained from survey images provided by Aerial Office of the Forestry Bureau in Taiwan for three different years (1990, 2001, 2010). Then, the information on the images is loaded into the software package AutoCAD, and the set fold function is used to compare the tendency of sand line variation for these different years. Whereas, the above method only provides sand line change based on the current available information, it requires a further analysis to predict the tendency for change of each sand line. Therefore, this study further evaluates the sand line long-term variation for major sandy beaches located around the island of Taiwan by using an artificial neural network model.

Based on the available multi-period images, the feasibility of using neural network model is verified, and the long-term nonlinear variations of sand line at the beaches are estimated for the years 2015 and 2021. Besides, the total area of each beach is calculated, and a statistical result for the upper bound and lower bound is obtained to evaluate the change of each sandy area. It is hope that the application of neural network may offer a new approach for solving this type of nonlinear shoreline problem.

II. Research Area and Image treatment

Taiwan is located at 120°~122° in longitude, and 22°~25° in latitude, the length of this island is about 377km in north-south direction, and is about 142km in east-west direction. In addition, the total length of shoreline is about 1200km around the island. In east side of Taiwan, because of situating mountain and cliff near the coastal region, the slope of sea bottom is steep, and the scale of sand beach is relatively small in this side. On the other hand, the slope of sand beach along the shoreline in west side is much milder as the mountain is far away from the shoreline. Besides, due to most of rivers flow to west direction in Taiwan Strait, so a large amount of sand is accumulated in estuarine region and that may extend the scale of sand beach in this side.

Except natural reasons, some manmade factors such as land over development, over pumping of groundwater, and various economic activities in the coastal region, have caused serious shoreline erosion problems in recently years. To examine the shoreline change during the multi-period as mentioned in the years of 1990, 2001, and 2010, the chosen six major beaches (BH1-BH6) around the island of Taiwan is displayed in Fig. 1, where the names of these nine beaches, respectively, are BH1: Taoyuan Juway beach, BH2: Yenliao beach, BH3: Hualien Newsanfutien beach, BH4: Taitung Sanyuan beach, BH5: Kenting big bay beach, and BH6: Tainan Sisu gold beach. Note that BH7 to BH9 have extreme changes of shoreline during the studied time period, and those are not suitable for prediction, so these three beaches are skipped for further analysis.

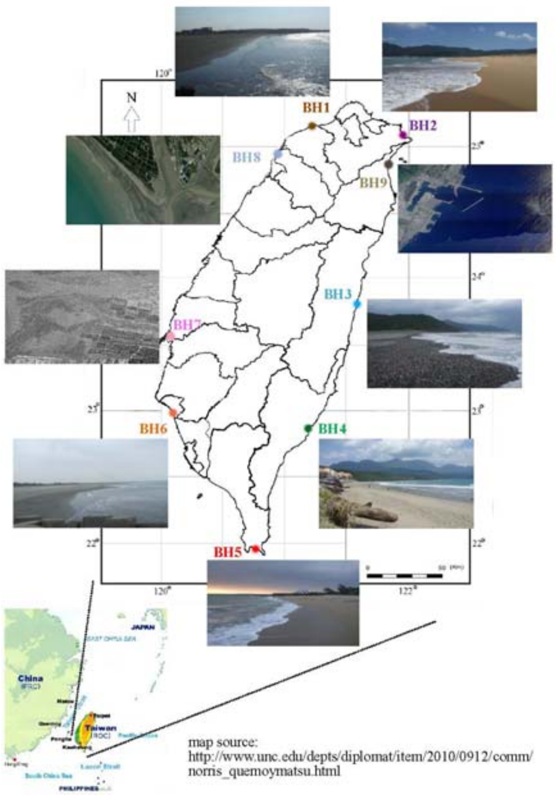

Fig. 1 Location of the chosen six major beaches in Taiwan

Generally, it is hope that aerial survey map of each beach can be obtained from its earliest year, but the quality of image may not be so reliable and the investigation time is not in consistent for each beach. Hence, this study tried to pick up available images those have a good quality and have the same investigation year for the chosen major beaches. Following the development of survey techniques, two types of images including aerial survey maps (1990) and orthophoto maps (2001 and 2010) are obtained for the chosen three different years. Further to say is that the aerial survey map does not have a standard proportion, whereas the orthophoto map is an aerial photograph geometrically corrected such that the scale is uniform [22], and that does have a fixed proportion 1:5000. Thus, these images require an adjusting work with the use of GIS (Geographic Information System) software to make sure all images are controlled in the same proportion and at the same position, which may be used for the sake of comparison.

Fig. 2 shows an example of inserting image into AutoCAD interface and adjusting image proportion ratio. Fig. 3 shows an overlaying of sand lines from different periods. It can be seen that the change of sand region from overlapping lines in the set fold figures. From these figures, the sandy area of each beach can also be calculated and make comparison for the three different years, and the results will be discussed late with prediction results.

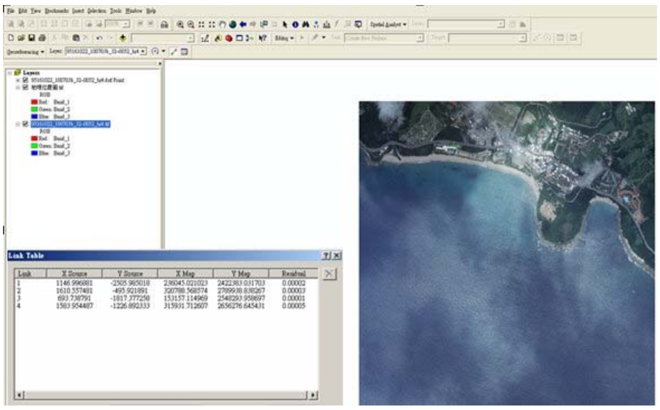

Fig. 2 Loading image into graphical software and adjusting image proportion ratio

Fig. 3 Variation of shoreline for beach BH4 in multi-period

III. NEURAL NETWORK APPROXIMATION

It is well known that neural network approach can be applied to solve various engineering problems, so it is no lack to see a wide range of relevant literatures [23]-[28]. From theory of neural networks, the basic equation and evaluation index are

$$Y_j = F(\sum W_{ij} X_i - \theta_j) \tag{1}$$

where Y_j is the output of neuron j, W_{ij} represents the connection weight from neuron i to neuron j, X_i is the input signal generated for neuron i, θ_j is the bias term associated with neuron j, and $F(x)$ is the nonlinear activation function.

The performance of a neural network model can generally be evaluated by using the following two equations:

$$\mathrm{CC} = \sum_{i=1}^{m}(x_i - \bar{x})(y_i - \bar{y}) / \sqrt{\sum_{i=1}^{m}(x_i - \bar{x})^2 \sum_{i=1}^{m}(y_i - \bar{y})^2} \tag{2}$$

$$\mathrm{RMSE} = \sqrt{\sum_{n}^{N}(T_n - Y_n)^2 / N} \tag{3}$$

where CC is the coefficient of correlation, x_i and $\bar{x}$ are the recorded value and its average value, respectively, y_i and $\bar{y}$ are the estimated value and its average value, respectively, and m denotes the number of data points in the analysis. In addition, RMSE is the root mean square error, N is the number of learning cases, T_n is the target value for case n, and $Y_n$is the output value for case n.

As shown in Fig. 4 is the sketch of neural network models used in this study, the model ($I_2H_nO_1$) takes coordinated information of the years of 1990 and 2001 as the inputs, and takes the coordinates of the year 2010 as the target values. Different numbers of neuron in the hidden layer are used to check the performance of neural network model based on coefficient of correlation and root mean square error. Since these input and output are all known coordinates from survey maps, the test result may verify the ability of developing model, and a relatively better one may be obtained for the beaches. Then, the model ($I_3H_4O_1$) with four neurons in the hidden layer is further taken for analysis, and an extension for including three input parameters is performed to predict sandy line of each beach in the years of 2015 and 2020. Now the performance of neural network models and the prediction results may be illustrated as follows.

For each of the beaches, the original coordinates along the shoreline have one thousand points, where one hundred evenly distributed points are taken for developing neural network model. Two types of data set, Type1: 60%-30%-10% and Type2: 70%-20%-10%, with coordination data randomly divided into three groups, are used for training (TN), verification (VF), and testing (TS) the model, respectively. To prevent the effect of extreme values in the data sets and to match the sigmoid type of transfer function, the input data can be normalized using the following equation:

$$C_S = (C_p - C_{\min}) / (C_{\max} - C_{\min}) \tag{4}$$

where C_s denotes the coordinate of sand line after transformation; C_p is the original position; $C_{\min}$ and $C_{\max}$ are the minimum coordinate value and the maximum coordinate value respectively for the sand line data set.

The averaged square value of correlation coefficient at different calculation stages for the two types of data arrangement is displayed in Table I. It is found that all models can get a very good performance as all CC^2 values are over 0.9, which means a high relationship between actual data and neural network estimation. Note that the model with four neurons in the hidden layer, in the type of data arrangement where 70% for training, 20% for verification, and 10% for testing, can achieve a relatively better performance (slightly higher CC^2 values) than that of the other models. Further, from the calculated root mean square errors as shown in Table II, it can also be found that the same model exhibit to have a smallest averaged RMSE = 0.0178. Therefore, this neural network model is preferable in the shoreline case studied herein. Fig. 5 shows an example for the rate of error convergence, and it proves to have a reasonable accuracy.

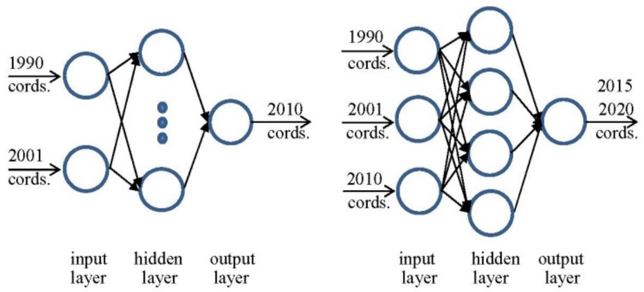

Fig. 4 Structure of NN models $I_2H_nO_1$ (left) and $I_3H_4O1_1$ (right)

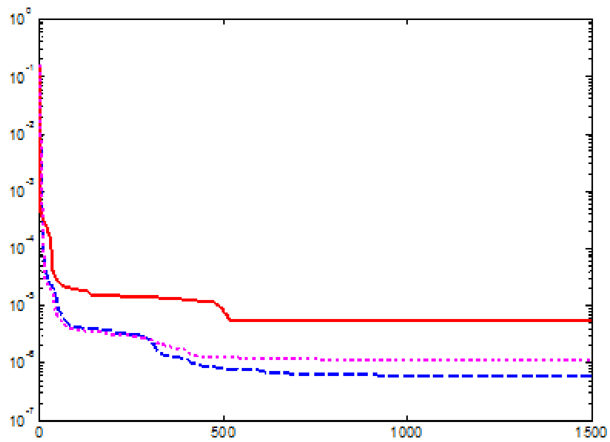

Fig. 5 The rate of error convergence (epochs vs. MSE)

To further examine the performance of neural network models, a comparison of sandy area in each beach is calculated and shown in Table III. The numerical result depicted that the above mentioned better model $I_2H_4O_1$ (Type2) can get a more accuracy result in most of beach cases. The averaged percent error for the six beaches is 0.800% for the use of data arrangement 70% for training, 20% for verification, and 10% for testing the model (Type2), which is better than that of percent error 1.265% for the model $I_2H_4O_1$, which uses 60% for training, 30% for verification, and 10% for testing the model (Type1). Therefore, this preferred neural network model will be taken for shoreline prediction in each beach.

IV. Shoreline Prediction Result Discussion

From illustrations of the above section, it proves that the use of previous shoreline information (1990, 2001) in the neural network model, can well predict a future shoreline change (2010). Now for forecasting shoreline variation in the future years (2015 and 2020), it requires basic reference shoreline coordinates for developing neural network model. By interpolating shoreline coordinates from previous years for the four models, NN1: 1990 and 2001, NN2: 2001 and 2010, NN3: 1990 and 2010, and NN4: 1990, 2001, and 2010. The coordinated differences (CL1, CL2, CL3, and average) of shoreline of each beach from these different years can help to get the reference data as well as to develop a new neural network model for forecasting work.

TABLE I
Divided Level of Factors Performance (CC^2) of Neural Network Models under Different Data Arrangements

NN model	$I_2H_2O_1$ (Type1)			$I_2H_3O_1$ (Type1)			$I_2H_4O_1$ (Type1)		
	TN	VF	TS	TN	VF	TS	TN	VF	TS
Averaged CC^2	0.979	0.973	0.972	0.986	0.977	0.976	0.986	0.981	0.980
NN model	$I_2H_2O_1$ (Type2)			$I_2H_3O_1$ (Type2)			$I_2H_4O_1$ (Type2)		
	TN	VF	TS	TN	VF	TS	TN	VF	TS
Averaged CC^2	0.976	0.977	0.975	0.986	0.990	0.987	0.987	0.993	0.983

TABLE II
Calculated Root Mean Square Errors for Each Beach with the Use of Different Models

NN model (Type1)	RMSE BH1	BH2	BH3	BH4	BH5	BH6	Averaged RMSE
$I_2H_2O_1$	0.0101	0.0101	0.0867	0.0195	0.0163	0.0090	0.0253
$I_2H_3O_1$	0.0067	0.0039	0.0717	0.0155	0.0146	0.0056	0.0197
$I_2H_4O_1$	0.0062	0.0024	0.0703	0.0152	0.0108	0.0056	0.0184
NN model (Type2)	RMSE BH1	BH2	BH3	BH4	BH5	BH6	Averaged RMSE
$I_2H_2O_1$	0.0098	0.0097	0.0878	0.0215	0.0158	0.0060	0.0251
$I_2H_3O_1$	0.0065	0.0038	0.0678	0.0169	0.0145	0.0056	0.0192
$I_2H_4O_1$	0.0069	0.0023	0.0656	0.0159	0.0106	0.0056	0.0178

TABLE III
Comparison of Actual Sandy Area and Estimated Sandy Area (2010)

2010 Beach	Actual sandy area (m^2)	$I_2H_4O_1$ (Type1) Estimated area(m^2)	Type1 error (%)	$I_2H_4O_1$ (Type2) Estimated area (m^2)	Type2 error (%)
BH1	31589	31471	0.373	31539	0.159
BH2	218476	218162	0.144	218118	0.163
BH3	99883	96311	3.577	99308	0.576
BH4	95079	96867	1.881	98657	3.763
BH5	69844	70855	1.447	69908	0.092
BH6	408235	407557	0.166	408042	0.047

To check the newly developed neural network model, the worst case of performance in beach BH3 from previous models is taken as an example, and the comparison result is shown in Fig. 6. The predicting results show that the model NN1 has the worst performance as it exhibits a discontinuity at some points. Whereas, the other models all exhibit to have a smooth prediction result. In general, the model NN4 ($I_3H_4O_1$, see structure sketched in Fig. 4) which uses information from three previous years may perform slightly better and more stable than the other models. Hence, this model is used for other beaches and for further comparisons.

It is understand that the shoreline for each beach may have a phenomenon of erosion or accretion at different local regions, so that the calculation of total sandy area is an important part to examine the change of nonlinear coastline. As displayed in Fig. 7 is the total sandy area for the six beaches in each year under a 95% confidence interval. It can be seen that all survey data (1990, 2001, and 2010); the total sandy areas are situated within the upper limit and lower limit. That is, no significant change of sandy area for each beach from statistical standpoint. However, if the future predicted data (2015, 2020) by neural network models are included in the plot, it can be found that two beaches, BH3 and BH6, the total sandy area for the former one may slightly over the limit, while the latter one may significantly exceed the upper limit in the year of 2020.

The results presented in this study seem to indicate that the erosion problem under currently conditions is not serious in the chosen beaches studied herein. Whereas, it is need to note that the investigated period from 1990 to 2020 is limited only for thirty years, As the time being, the effects of global warming and sea level rising may still have an influence on shoreline change in Taiwan region, it requires to check the shoreline as often as possible to prevent unwanted negative impacts. It is useful to check the currently shoreline condition for each beach, so that an onsite investigation of using GPS receiver (GPSmap 60CSx made by Garmin Corp.) is performed in the year of 2012. The comparison results do provide useful local information for each of the studied beaches. Note that the detail of onsite investigations is not included in this conference paper, but it will be available in an extended version of this paper.

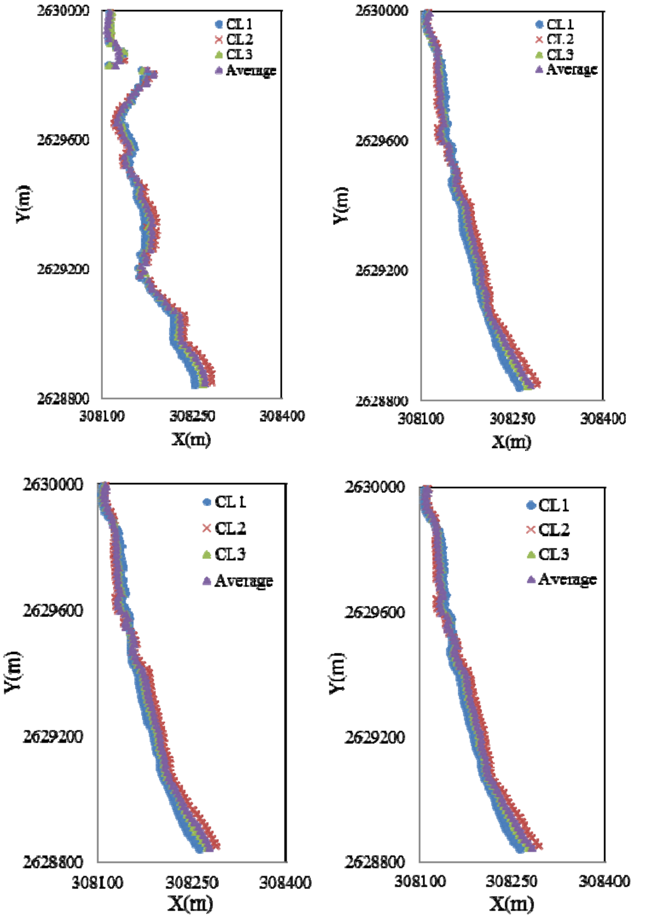

Fig. 6 Comparison of neural network models for predicting beach BH3 in 2015 (top: NN1, NN2; bottom: NN3, NN4)

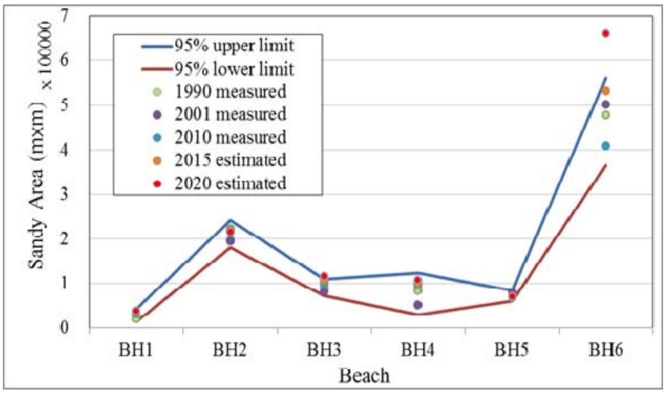

Fig. 7 Total sandy area for each beach in different years

It is useful to check the currently shoreline condition for each beach, so that an onsite investigation of using GPS receiver (GPSmap 60CSx made by Garmin Corp.) is performed in the year of 2012. As shown from Fig. 8 is an example of shoreline changes at different years. This beach has a phenomenon of erosion in the left hand side and accretion of sand at the right hand side, where there are +39m, and -26m for points A and B, respectively for the difference between the years of 1990 and 2012. Other beaches may exhibit a similar phenomenon, that is, both erosion and accretion may be found in different local regions of each beach, but as discussed in previous figure, the total sandy area of each beach has no significant changed from survey images.

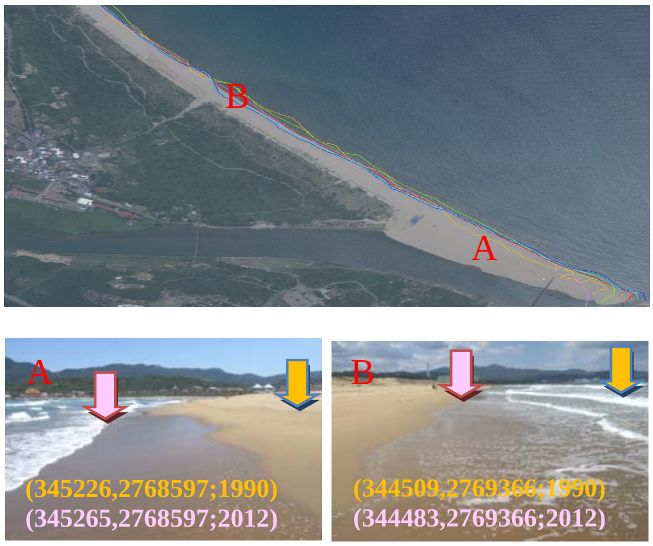

Fig. 8 Shoreline change in different years and onsite beach condition for beach BH2

V. Conclusion

The shoreline erosion problem may be considered as a slow type of disaster, which may cause of losing a land area and may even endanger the existence of a country which is composed of islands. From the chosen beaches studied, the currently results show that there exists a phenomenon of sand erosion and accretion at some local regions of each beach, but the total sandy area of each beach is not significantly changed under a 95% statistical confidence interval. However, the prediction results show that there are two beaches have a tendency of increasing sand areas in the future year.

Note that the investigated period in this study is limited only for thirty years. As the time going on, the effects of global warming and sea level rising might still have an influence on the shoreline change in Taiwan region. Thus, it is better to check and evaluate the shoreline change as often as possible for preventing unwanted negative impacts.

Without going for complicate procedures, this study tried to apply a method as easy as possible to examine the shoreline change problem, thus only the time factor (multi-period aerial survey maps) is considered in the comparison analysis and model development. The reliability of result obtained might be questionable, but other influencing reasons on shoreline change such as wave motion, sea current, tide rise and fall, and land use in watershed, might all end up and involve in the time factor.

Hence, the present study might still provide a valuable reference for the studied region and may be applicable to other coastlines of interest around the world.

ACKNOWLEDGMENT

Support of National Science Council under project number NSC102-2221-E-020-027 is greatly appreciated. The orthophoto images and aerial survey maps provided by Aerial Office, Forestry Bureau of Taiwan is also acknowledged.

REFERENCES

[1] Carlson, A.E. and & Winsor, K., Northern Hemisphere Ice-sheet Responses to Past Climate Warming, Nature Geoscience, 5(2012): 607-613.
[2] Thatcher, C.A., Brock, J.C. and Pendleton, E.A., Economic Vulnerability to Sea-Level Rise along the Northern U.S. Gulf Coast, Journal of Coastal Research, 63(2013): 234-243.
[3] DiNezio, P.N. and Tierney, J.E., The Effect of Sea Level on Glacial Indo-Pacific Climate, Nature Geoscience, 6(2013): 485-491.
[4] Chiu, Y.F., Coastal Erosion and Protection Strategy in Taiwan, Civil Technology, 3(3), 1999: 102-110.
[5] Hsu, M.Y., A Study on the Coastal Erosion and Backward at East Side of Taiwan, Civil Technology, 2(3), 1999: 64-89.
[6] Kerh, T., Hsu, G.S. and Gunaratnam, D., Forecasting of Nonlinear Shoreline Variation Based on Aerial survey Map by Neural Network Approach, International Journal of Nonlinear Sciences & Numerical Simulation, 10(9), 2009: 1211-1221.
[7] Leu, L.G., Study and Application of Coastline Mapping and Area Estimation, Journal of Coastal and Ocean Engineering, 4(1), 2004: 71-88.
[8] Wang, H.W., Wang, C.T., Chen, K.S. and Lin, Y.L., Analysis Change Detection Waterline in West Taiwan Using Satellite SAR Imagery, Journal of Photogrammetry and Remote Sensing, 12(2), 2007: 107-119.
[9] Chen, Y.H., Shen, S.M., Chan, Y.C. and Hsieh, Y.C., Application of LiDAR-Derived Data on Detecting Coastal Geomorphic Change in Taiwan, Journal of Photogrammetry and Remote Sensing, 14(2), 2009: 157-170.
[10] Liang, P., Chuang, Y.C., Wu, C.D., Jan, J.F. and Liao, H.M., Application of Multi-source Remote Sensing Images in Detecting Shoreline Change Along Yilan Coast, Journal of Geographical Research, 55(2011): 47-68.
[11] Liao, H.Z., Chu, C.T. and Lin, S.K., Application of Numerical Model in Coastal Management and Planning – A case of Kaohsiung Chijin Coastline, China Technology, 53(2002): http://www.ceci.org.tw/book/53/ch53hp.htm.
[12] Yang, W.H., Lu, C.S. and Lin, Y.C., The Numerical Modeling for Coastal Evolution on Taipei Port Coastal area, Proceedings of the 28th Ocean Engineering Conference in Taiwan, (2006): 563-568.
[13] Chan, C.W., Huang, W.P., Chang, T.C. and Tsao, Y.H., Erosion Study of Hsinchu Kang-Nan Coast by Numerical Modeling, Proceedings of the 33rd Ocean Engineering Conference in Taiwan, (2011): 365-368.
[14] Adegoke, J.O., Fageja, M., James, G. Agbaje, G. and Ologunorisa, T.E., An Assessment of Recent Changes in the Niger Delta Coastline Using Satellite Imagery, Journal of Sustainable Development, 3(4), 2010: 277-296.
[15] Armah, F.A., GIS-based Assessment of Short Term Shoreline Changes in the Coastal Erosion-Sensitive Zone of Accra, Ghana, Research Journal of Environmental Sciences, 5(7), 2011: 643-654.
[16] Callaghan, D.P., Nielsen, P., Short, A. and Ranasinghe, R., Statistical Simulation of Wave Climate and Extreme Beach Erosion, Coastal Engineering, 55(2008): 375-390.
[17] Ferreira, O., Garcia, T., Matias, A., Taborda, R. and Dias, J.A., Integrated Method for the Determination of Set-Back Lines for Coastal Erosion Hazards on Sandy Shores, Continental Shelf Research, 26(2006): 1030-1044.
[18] Jadidi, A., Mostafavi, M.A., Bédard, Y., Long, B. and Grenier, E., Using Geospatial Business Intelligence Paradigm to Design a Multidimensional Conceptual Model for Efficient Coastal Erosion Risk Assessment, Journal of Coastal Conservation, (2013): doi 10.1007/s11852-013-0252-5.
[19] Millar, D.L., Smith, H.C.M. and Reeve, D.E., Modelling Analysis of the Sensitivity of Shoreline Change to a Wave Farm, Ocean Engineering, 34(2007): 884-901.
[20] Quartel, S., Kroon, A. and Ruessink, B.G., Seasonal Accretion and Erosion Patterns of a Micro Tidal Sandy Beach, Marine Geology, 250(2008): 19-33.
[21] Ravens, T., Jones, B., Zhang, J., Arp, C., and Schmutz, J., Process-Based Coastal Erosion Modeling for Drew Point, North Slope, Alaska, Journal of Waterway, Port, Coastal, and Ocean Engineering, 138(2), 2012: 122-130.
[22] Wikipedia, Orthophoto, Wikimedia Foundation, Inc., 2013: https://en.wikipedia.org/ wiki/Orthophoto.
[23] Galushkin, A.I., Neural Networks Theory, 2007: 1-396, Springer, ISBN 978-3-540-48125-6.
[24] Kerh, T., Lin, Y. and Saunders, R., Seismic Design Value Evaluations Based on Checking Records and Site Geological Condition Using Artificial Neural Networks, Abstract and Applied Analysis, 2013: http://dx.doi.org/ 10.1155/2013/242941.
[25] Rafiq, M.Y., Bugmann, G. and Easterbrook, D.J. Neural Network Design for Engineering Applications, Computers and Structures, 79(2001): 1541-1552.
[26] Sarghini, F., de Felice, G. and Santini, S., (2003), "Neural Networks Based Subgrid Scale Modeling in Large Eddy Simulations," Computers and Fluids, Vol. 32, pp. 97-108.
[27] Yeh, Y.C., Application and Practice of Neural Networks, Rulin Publishing Company, Taiwan, 2009.
[28] Wu, S., Chou, L., Lee, S. and Chang, B.Z., MATLAB Neural Networks Simulation and Application, Science Publishing Company, China, 2003.