The Shoreline Retreat and Spatial Analysis over the Coastal Water of Belawan

A. Perwira Mulia Tarigan[1,*]. Wiwin Nurzanah[2]

Abstract – An examination of shoreline retreat is conducted over the muddy coast in the vicinities of the port of Belawan. The related sea level rise is estimated using the well-known Bruun Rule based on the characteristics of mud profile prevalent along the eastern coast of North Sumatera Province. The spatial analysis involved is done utilizing the concept and procedure of GIS. The averaged shoreline retreat over the hot spot area of erosion, i.e. 18 m per year, implies that the relative rate of sea level rise is in the range of 14 to 18 mm per year, indicating an extremely severe rate. In addition, three other cases of simple GIS applications related to coastal water of the port are spatially demonstrated.

Keywords – coastal water, coastal erosion, sea level rise, and GIS

I. INTRODUCTION

Coastal waters in the vicinities of a sea port rest in the harshest environment when facing water quality degradation and habitat deterioration due to the impact damage from port operations. On the other hand, marine terminal infrastructure and equipment would quickly function much less effective when continuously exposed to the combination of natural and anthropogenic sea destructive forces. So a critical issue facing coastal managers in this sense is how to balance the need for the demand based port development with the expense of the health of the coastal environment.

Therefore managing coastal water environment as well as port infrastructure is of a considerable interest. A vital key to this matter is the integration of important infrastructure and hydrodynamics information in a robust and functioning information system based on a geographical reference. A tool that has proliferated within civil and port engineers is geographic information system [1].

Miles and Ho [1] specifically described several case studies to illustrate the breadth of GIS use across civil engineering including storm water pollution, sediment transport, solid waste collection, seismic slope stability, liquefaction, and distributed rainfall runoff.

Venigalla and Baik [2] concluded in their study that several complex engineering service management functions can be integrated and automated on GIS platform to increase productivity. In light of the spectrum of engineering application using this tool, the benefit of using GIS tool stems from the fact that GIS provides a virtual framework within which the integration of several layers of information can be developed. Hence engineers and decision maker scan explore their knowledge based options and evaluate competing management strategies in geospatial fashion.

[1]Civil Engineering, Master and Doctorate Study Program, Faculty of Engineering Universitas Sumatera Utara, Jalan Perpustakaan, Kampus USU, Medan, Indonesia
[2]Former Graduate Student, Civil Engineering Master Study Program, Faculty of Engineering Universitas Sumatera Utara, Jalan Perpustakaan, Kampus USU, Medan, Indonesia
*a.perwira.mulia@gmail.com, a. perwira@usu.ac.id

This study deals with several important matters related to the coastal waters of the port of Belawan. The approach is focused on the attempt to use spatial analysis for each specific site of the coastal water problem whereby the shoreline recession due to sea level rise is the main issue. This study is conducted in an atmosphere to promote GIS education in civil engineering as it offers important relevant skills in spatial analysis, reasoning, and data processing [3]. The principal study objective is to demonstrate a simple approach for GIS-based applications for assessing the coastal water related matters.

II. METHODOLOGY

A. Study Site Information

The port of Belawan is located 98°42' eastern longitude and 03°47' northern latitude and is situated 27 km north of the city center of Medan, the capital city of Sumatera Utara. The coastal water lays in the mixed estuarine waters of the Belawan River and the Deli River, although the port infrastructure is placed more on the estuarine mouth of Belawan waterways. Figure 1 shows the location of the port and the coastal water.

Fig 1: Location of Belawan Port near the mouth of Belawan estuary facing the strait of Malacca

Wave heights in the coastal water of the study area are typically low wave heights (less than 0.30 m). In a stormy weather with strong winds during the period of northeast monsoon, maximum wave heights entering the coastal area might be seen to likely reach up to 1 m to 3 m. However, common relatively steep wave heights during typical days are noticed due merely to the passing ships.

F4 = infection through the stem, grown in sterile soil,and F5 = infection through the stem, grown in non-sterile soil. Planting and maintenance of the plant following the planting and maintenance of tomato plants as is usually done by farmers.

The plant responses to the treatments of MF, fussarium, and seed soaking was observed by measuring the percentage of seed germination, plant growth rate on plant height, fresh weight, and dry weight.

As the coastal water is along side the Malacca Straits, the tide is of the semidiurnal type which includes two high waters and two low waters occurring in a day. Characterized by the four main tidal constituents, i.e., M2 and S2 (semidiurnal constituent) and K1 and O1 (diurnal constituents), the tidal pattern is dominated by the M2 constituent which have a period of 12 hr and 25 minutes [4]. The tidal regimes in the Straits of Malaca are actually due to the tidal waves generated in the Indian Ocean and the South China Sea entering the straits from 2 different, opposite directions. Both crest of semidiurnal tidal wave propagate through the Straits of Malacca, but tides from the South China Sea are damped much sooner than that from the Indian ocean. The tidal range is in the order of 2 to 3 meters with its current may reach up to 0.5 m/sec along the relatively narrow approach channel.

A critical issue to the port development associated with the coastal water is the increasing rate of siltation which may reach as thick as 2.6 m per year. It consequently causes enormous work of dredging activities to maintain a minimum design depth of 10 m and a minimum design navigational channel width of 100 m.Hence the offshore zone of the coastal water undergoes a situation of high rate of sedimentation, while on the contrary, the shoreline under study is observed to experience severe erosion. This is the reason why it is argued that sea level rise is the main cause of the erosion. Another problem over the coastal water is the water quality degradation which is indicated by the high concentrations of total suspended solid and the cuprum (Cu) in both the water and the sediment.

B. The Digital Base Map and Layers of Information

The base map is the initial important layer of information to which other layers were controlled and referred. The base map is produced by onscreen digitizing the selected raster analog image of bathymetric map issued by the Indonesian Navy. It is imperative to select a minimum of 3 strategic noticeable benchmarks that can easily be identified on the map and checked in the field (using GPS) and to select the same map projection system. Other relevant layers of information on, e.g., shoreline, water depth, current, and water quality parameters, can then be generated with reference to the same benchmarks and map projection. Geospatial data are obtained from aerial photos, Auto Cad files, and satellite images available from various resources, while relevant nongeospatial data areselected from various reports on the port projects.

After the completion of the relevant information layers, four cases of spatial analysis have been made in what follows for different purposes. The aim of the case analysis described herein is to highlight the applicability of each GIS analysis on the coastal water, the respective simple

implementation processes, and the pertinent assessment and conclusion drawn.

III. RESULTS AND ANALYSIS

A. Shoreline Erosion and Sea Level Rise

Based on the results of onscreen digitization of three bathymetric maps of the same source made for 4 different years, i.e. 1983, 1990, 2005 and 2010, the spatial pattern of erosion taking place along the shoreline can be observed for the period of years mentioned. It should be noted that, based on the overall observation of the maps, significant erosion is evident the along the northwest part of the coastal water, while comparatively slight sedimentation over the southeast part. Focusing on the shoreline movement on the northwest part, this study reveals that consistent shoreline retreat has occurred and it can be most likely related sea level rise as sea water encroachment has been observed in the coastal area.

98.662 , 3.929

98.779 , 3.768

Shoreline in 1983 ························
Shoreline in 1990 — · — · — · — ·
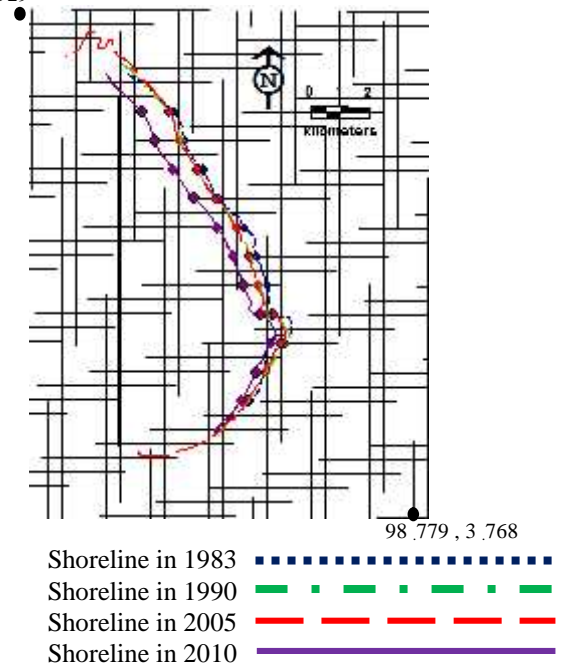Shoreline in 2005 — — — — — —
Shoreline in 2010 ————————

Fig 2: Digitized shoreline for the years of 1983, 1990, 2005 and 2010

Figure 2 shows the overlay setting of the shoreline movement. The rate of shoreline erosion can be computed using the simple linear regression fitted to the 11 shoreline positions denoted in Figure 2 as follows

$$\tilde{y}(t) = at + b \qquad (1)$$

where $\tilde{y}(t)$ is the shoreline position (m) at a given year, and a represents the shoreline change rate (m/year) with b just a constant of regression. The sign and magnitude of the quantity a indicate the direction (accretion or erosion) and rapidity of the change, respectively. Positive or negative values of a signify an accreting or eroding shoreline, respectively, whereas zero represents a stable shoreline over time. Based on the computation of Equation 1 for 11 base positions with 1 km interval along the shoreline, it is found that all shoreline positions yield negative signs with the total averaged $a = -18$ m/year, indicating consistent and significant, severe shoreline erosion. Note that the maximum rate is a = -30 m/year

occuring on the most nothern shoreline positition, whereas the minimum is a = -2 m/year occuring near the most southern shoreline position.

The shoreline recession is then related to the sea level rise using the well-know Bruun Rule which states

$$\Delta y = \frac{Sy_0}{h_0 + B} \qquad (2)$$

where S = the sea level rise, (y_0, h_0) = the offshore terminus, and B = the berm height. If $\tan \mathtt{S}$ is denoted as the average slope of the shore profile, the expression for the retreat can be represented as

$$\Delta y = \frac{S}{\tan \mathtt{S}} \qquad (3)$$

Taking Δy = - a = 18 m/year and $\tan \mathtt{S}$ = 0.001 which is a reasonable value for a typical very mild slope of mud shore profile the for the coastal area, it is found that the sea level rise S =18 mm/year. The computed S appears to be significantly large if compared with the predicted S reported for global average rate of sea level rise, hence it shall have a meaning as the relative rate of sea level rise. This relative rate may result from large-scale and global-scale changes in sea level and land levels coupled with regional and local changes [5]. The adverse impact of sea level rises is then compounded by the coastal storm surges and high wave conditions. Mangrove deforestation over the coastal shoreline would then magnify the impact of sea level rise on the shoreline erosion.

It should be noted however that Bruun [6] has adjusted Equation 1 to include the finest sediment to become

$$\Delta y = \frac{S(1+r)}{\tan \mathtt{S}} \qquad (4)$$

Based on the dynamics of mud shore profiles, Tarigan [7] suggested that the ratio constant r has a limit of 0.3. In light of Equation 4 with r = 0.3, the sea level rise S should be estimated lower than that computed above (S = 14 mm/year).

B. Disposal Site of Dredged Material

The increasing rate of siltation and the subsequent general increase in the work of dredging have created the need for assessment the existing and alternative dredged material dumping sites over the coastal water. To achieve maximum long-term benefits from the open water dredge disposal, the dumping site must considerably be positioned so that the dredged material does not return to the site of active dredging.

In order to avoid the return of the dredge material from the disposal site, the important hydrodynamics factors to be considered includes the depth h, the (average) tidal current V, the (minimum) fall velocity w of the dredge material. These factors can be included in the formula for estimating the travel distance L of sediment particle in a channel as follows [8].

$$L = \frac{hV}{w} \qquad (5)$$

The fall velocity would be much dependent on the fine particle size and is computed using the formula of Rubey

$$w = \frac{[\{(2/3) \, g \, (G_s - 1) \, d^3 + 36 \, v^2\}0.5 - 6 \, v]}{d} \qquad (6)$$

where G_s = the particle specific gravity, d = the particle size, and v= the kinematic viscosity. Based on the sieve analysis data for 18 observatory stations, it is found that average size of fine particle d_{10}= 0.070 mm and the spatial average of tidal current V = 0.50 m/s, resulting in the maximum travel distance L = 2092 m.

Fig 3: Disposal sites of dredged material

It can be concluded that 2 km is the minimum distance of the disposal site from the offshore end of the dredged site. Figure 3 shows the setting of the geospatial situation in which alternative disposal sites can be evaluated. To be conservative, the travel distance L estimated should be multiplied by a safety factor of 2 and measured from the offshore end location of the dredge site.

C. Water Quality Index

The growing environmental concerns have demanded the need for a comprehensive water quality assessment over the coastal water [9]. Environmental index for each selected, primary quality component can be developed to represent the quality status of each component within each polygon cellin the GIS format. Then based on the resulting composite index, thematic map of water quality zone can be developed to be used for coastal and port management in the decision making process.

The index parameters (components) involved in the development of the composite index are that of depth, tidal current, total suspended solid (TSS), and Cu concentration. The composite index $I_c$for the water quality can be formulated as follows

$$I_c = w_h i_h + w_v i_v + w_c i_c + w_s i_s \qquad (7)$$

where i_k and w_k are the depth index and its respective weight respectively, i_v and w_v the current index and its respective weight, i_c and w_c the Cu index and its respective weight, and i_s and w_s the TSS and its respective weight.

Before the resulting composite index can be assessed for each polygon cell, each individual index is processed in a linear fashion using the criteria listed in Table 1.The thematic map for each individual index has been made; however, the composite index and the respective thematic map developed from the individual ones have a more comprehensive sense in assessing the water quality status and the strategy to cope with related decision problems. Figure 4 shows the thematic map for the composite index over the coastal water.

Table 1: Descriptive criteria for the quality index

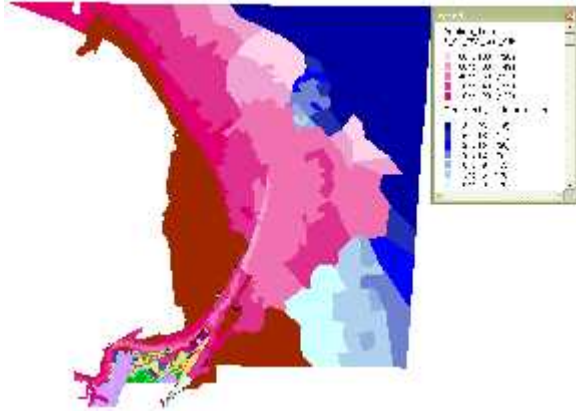| Index	Description	Management option
80 s/d 100	Excellent (superior)	To maintain sustainability
60 s/d 80	Very good (more preferable)	To nourish and maintain
40 s/d 60	Good (preferable)	To nourish
20 s/d 40	Poor (not preferable)	To repair and nourish
0 s/d 20	Very poor (inferior)	To restore and repair

Fig 4: Thematic map for composite index

It can be observed that the interior part (nearshore zone) of the coastal water studied mostly appears to be in the poor zone. This evidence is consistent with the finding by Sudjana et al. [9] who then presumed that the poor index in the coastal water indicated poor habitat which hardly sustained healthy living conditions of the surrounding people.

D. Offshore Mooring Location

The growing worldwide demand for energy and raw materials is creating a strong need for deepwater facilities able to handle a large deep-draft vessel, such as supertankers for transporting crude oil and liquid natural gas and superbulkers to transport dry bulk materials [10]. In the future more offshore terminals are needed to serve vessels of 65,000 to 70,000 dwt around 300 m in length, with drafts of 12 to 13 m. The offshore terminals can be linked to the shore facilities either by submarine pipelines or a bridge like trestle.

For the above purpose, offshore mooring locations are to be identified with sufficient depth, not too far from inland facilities, and no maintenance dredging required in the future. Environmental site conditions which are considered in this study include water depth, area, current, wind, and waves. Using GIS map, it is relatively easy to locate the deep water zone of more than 12 m. It is found that the distances from the shore facilities are in the order of 10 km or more. The area for the proposed location is to provide full swing of maneuver for the largest vessel, i.e. a relatively circular area with diameter 2 x 300 m, plus a safety factor if it is close to the navigation channel. The magnitude of tidal current over the offshore location is considered much less than the maximum tidal current of about 0.50 m/s in the interior part of the coastal water. The spatial variation of the tidal current speed and direction can also be easily identified from their respective GIS layers. The maximum wind speed is reported to have a speed of 25 knotsover the Malacca Strait with the strong winds usually occurring during the northeast monsoon in September to December. Using the GIS map, it is relatively

easy to identify the fetch and the sea bottom configuration for the wave characteristics computation which is noted in the Shore protection Manual (SPM). Significant wave heights of the order 1 m to 2 m with periods in the range of 4 to 8 seconds are typically obtained for moderate design load of the mooring system. More severe storm and wave conditions with the wave heights in the range of 2 m to 4 m and their periods up to 15 seconds shall be considered for maximum wind and wave loads.
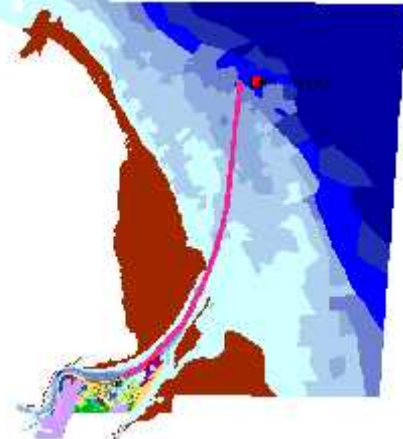

Fig 5: Offshore mooring locations

It should be noted that GIS in this study is practical in helping spatial view, analysis and reasoning. Figure 5 shows the proposed locations of the offshore mooring evaluated in this study.

IV. CONCLUSION

Four simple examples of coastal water related matters have been demonstrated. Despite simple approaches used, they provide illustrative assessment of relevant and critical issues facing the coastal and port managers dealing with balancing the needs for port infrastructure and with the anthropogenic impacts on the coastal water environment. GIS has been applied in all cases as a tool in displaying, analyzing, and reasoning the spatial information. It should be stressed that the base map is to be well processed in the first stage so that each other layers of relevant information can refer to it for accuracy. With the assumption that the available, relevant data are accurate and sufficient, it is found that the application of GIS technologies allows the port and coastal managers to plan comprehensive and effective programs on coastal environment management. However it is should be noted that GIS in all the current cases are mainly employed for simple spatial mapping and analysis, not for complex engineering modeling.

Nevertheless, in conclusion to the all assessment made the following can be stated:

- The shoreline retreat, at an average of 18 m/year over the shoreline positions, has indicated that the relative rate of sea level rise is in the range of 14 to 18 mm per year.
- A disposal site of dredged material shall be placed at least 2 km from the most offshore end of dredge site

to prevent the suspended material from spreading and returning to the site of dredging.
- The composite water quality index over the interior part of the coastal area ranges in the poor status due to siltation and heavy metal contamination; therefore, it needs a major environmental restoration.
- Preferable offshore mooring locations can be found at a distance about 10 km or more offshore from the shore facilities.

More in-depth investigation of each assessment concluded above may be a subject of further study.

V. Acknowledgement

References

[1] Miles, S. B. and Ho, C. L., "Applications and issues of GIS as tool for civil engineering modeling,"Journal of Computing in Civil Engineering, 1999, 13(3), pp.144-152.

[2] Venigalla, M. M. and Baik, B. H., "GIS-based engineering management service functions: taking GIS beyondmapping for municipal government," Journal of Computing in Civil Engineering, 2007, 21(5), pp. 331-342.

[3] Easa, S. M., Li, S., and Shi, Y., "GIS technology for civil engineering education," Journal of Professional Issues in Engineering Education and Practice, 1998, 124(2), pp. 40-47.

[4] Azmy, A. R., Isoda, Y. and Yanagi, T., "M2 tide and tidal current in Straits of Malacca,"Memoirs of Faculty of Engineering, Ehime University, 1992, 12-3, pp. 345-354.

[5] Woodworth, P. L., Church, J. A., Aarup, T., and Wilson, W. S., "Introduction" in Understanding sea-level rise and variability, edited by Woodworth et al., Kindle edition, Blackwell Publishing Ltd, 2010.

[6] Bruun, P., "Review of conditions for uses the Bruun rule of erosion," Coastal Engineering, 7, 1983, pp. 77-89.

[7] Tarigan, A. P. M., "Modeling of shoreline evolution at an open mud coast."Ph.D. thesis, UniversitiTeknologi Malaysia, Malaysia, 2002.

[8] Prakash, A., "Water resources engineering, hand book of essential methods and design.", ASCE Press, 2004.

[9] Sudjana, P., Hidayati, Syahrin, A., and Tarigan, A. P. M., "Index development for assessing water environment in Belawan estuary," Proceedings of the 8th International Symposium on Southeast Asian Water Environment", Phuket, Thailand, 2010.

[10] Tsinker, G. P.,"Port engineering", John Wiley & Sons, Inc., Hoboken, New Jersey, 2004.