USE OF REMOTE SENSING TECHNIQUES AND NUMERICAL MODELLING TO PREDICT COASTAL EROSION IN VIETNAM

Marius Sokolewicz[1], Laura Bergsma[2], Loek Schemmekes[3], Hoan Nguyen[4] and Stef Boersen[5]

Accurate prediction of coastal erosion is of importance for the investment planning of measures enhancing resilience to natural hazards. Field data on historical is generally lacking. Recent advances in deriving historical shoreline position from freely available satellite images combined with numerical modelling of shoreline erosion provide a reliable method for prediction of coastal erosion. This paper discusses the available tools and presents their application in a study case in Quang Ngai City, Vietnam.

Keywords: coastal erosion; remote sensing; satellite-derived shorelines; typhoon modelling; profile evolution modelling

INTRODUCTION

Establishing reliable erosion predictions which is of large importance for the planning of measures increasing resilience of coastal communities to natural hazards is inherently difficult. Reliable field data is lacking while observations by the inhabitants of erosive zones do not distinguish between the short-term storm erosion and the long-term structural erosion. This is particularly difficult in coastal stretches with large short-term variations and relatively low long-term erosion rates (1-5 m/year). At the same time, there is a freely available library of hundreds of satellite images covering a period of more than 30 years. Recent advances in remote sensing techniques allow a quite accurate determination of historical shoreline positions. Trend analysis of historical shoreline positions, combined with numerical modelling of shoreline evolution help to develop a conceptual model of coastal evolution and to make a prediction of the future development which can be used in regional planning.

This paper describes how these research methods were applied in a case study in Quang Ngai, Vietnam, in an area suffering from significant erosion.

STUDY BACKGROUND

The Government of Vietnam, financially supported by the World Bank initiated a large regional investment planning study to reduce the vulnerability and to increase resilience of coastal communities to natural hazards. One of the studied locations was Quang Ngai City at the Central Coast of Vietnam (Figure 1). The coastal stretch of approximately 10 km is subject to erosion (Figure 2). In its center, the Quang Ngai coast is intersected by the outlet of one of the largest rivers of Vietnam, the Trà Khúc river with a very dynamic mouth (see the development and decay of sand spit in the mouth in Figure 3). The November 2017 typhoon Damrey has reportedly caused severe erosion of beaches damaging many houses and infrastructure (coastal road and sewer system). The first step in the development of adequate measures to mitigate the impact of this erosion hazard is to develop a thorough understanding of the observed coastal processes, their causes and to predict the behavior of the coast in the future.

[1] Rivers & Coasts, Royal HaskoningDHV, Laan 1914 no. 35, 3818 EX Amersfoort, The Netherlands. Email: Marius.Sokolewicz@rhdhv.com
[2] Rivers & Coasts, Royal HaskoningDHV, Laan 1914 no. 35, 3818 EX Amersfoort, The Netherlands. Email: Laura.Bergsma@rhdhv.com
[3] Rivers & Coasts, Royal HaskoningDHV, Laan 1914 no. 35, 3818 EX Amersfoort, The Netherlands. Email: Loek. Schemmekes@rhdhv.com
[4] Water, Royal HaskoningDHV, Level 3, 2 Market Street, Newcastle, NSW 2300, Australia. Email: Hoan. Nguyen@rhdhv.com
[5] Rivers & Coasts, Royal HaskoningDHV, Laan 1914 no. 35, 3818 EX Amersfoort, The Netherlands. Email: Stef. Boersen@rhdhv.com

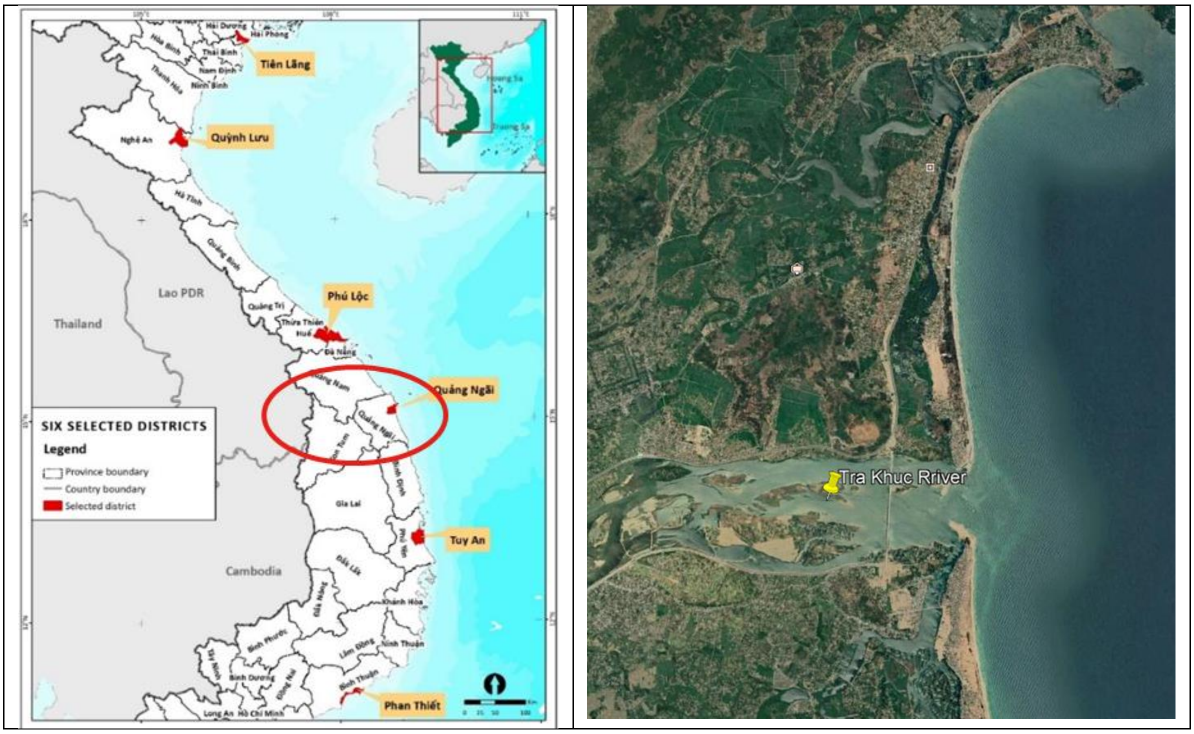

Figure 1. Location of the study area on the Vietnam's coast (left), and a photograph of Quang Ngai's coast (right).

Figure 2. Eroding beach causing damages to properties and infrastructure

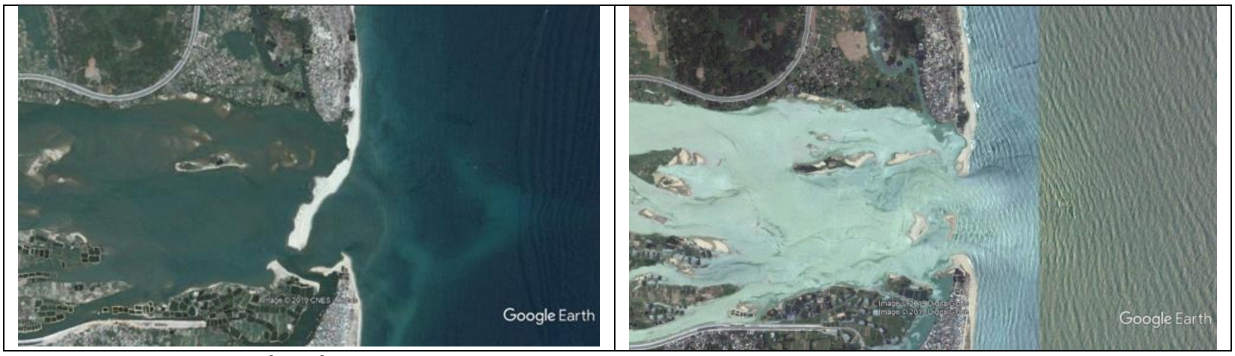

Figure 3. Dynamics of Trà Khúc river outlet (left: dry season; right: monsoon season)

ASSESSMENT OF HISTORICAL COASTAL EROSION

Remote sensing techniques

Since the launch of Landsat-4 mission in 1984, there is a steadily growing library of satellite images which form an important source of information for coastal assessments (Figure 4). The Landsat images have a resolution of 30m. in 2015, the Sentinel-2 mission was launched, providing images with the resolution of 10m. These images have a high frequency (tens per year) and are freely available from Internet. There are also commercial satellite image providers (Figure 4), however these high resolution images come at a considerable cost which makes them less attractive for use in projects covering large areas and requiring tens of images for analysis.

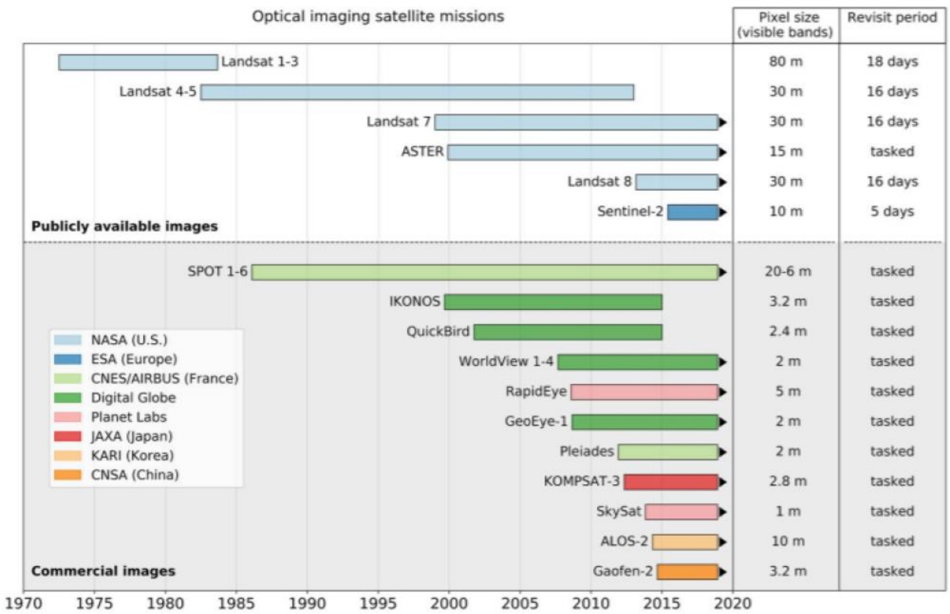

Figure 4. Publicly and commercially available satellite images with the available date range, pixel size and revisit period (Vos et al., 2019).

Recently a number of techniques have been developed that allow to determine the position of border between land and water using optical recognition. The first method was presented in Donchyts et al. (2016). It utilizes the Normalized Difference Water Index as proposed by Xu (2006) and Otsu's dynamic threshold (Otsu, 1979) to establish the shoreline position. This method forms the basis of the Internet application Aqua Monitor (https://aqua-monitor.appspot.com/). The method has been used to automatically determine the historical evolution of world's beaches in Luijendijk et al. (2018), and more recently to predict future shoreline, see Vousoukas et al. (2020). Both the historical trends and the predictions are available in the Aqua Monitor application, and the underlying shoreline positions are available from https://blueearthdata.org/.

Royal HaskoningDHV developed their own application, referred here as RHDHV Shoreline Tool. It is based on similar techniques as Aqua Monitor. The Canny edge detection algorithm (Canny, J., 1986) is used to detect the edges of the water mask for every image. Afterwards, the Canny edge detection algorithm is used again to determine the shoreline for each image using the water mask. The 'cannyThreshold' parameter determines the minimum gradient magnitude and the 'cannySigma' parameter is the standard deviation (SD) of a Gaussian pre-filter to remove high-frequency noise. To eliminate the impact of different tidal levels[6] on shoreline position at the acquisition time, images are selected to fit with a certain (approx. 0.2m) tidal window.

A third method considered in this paper is CoastSat. This method was developed by K. Vos in 2019 while he was working for the Water Research Laboratory, School of Civil and Environmental

[6] The tidal level at the acquisition time has large impact on the observed position of the shoreline. On a beach with 1:30 slope, 1 m difference in the tidal level leads to a 30m difference in the position of the shoreline which could be wrongly interpreted as erosion if not corrected for

Engineering in Sydney (Vos et al., 2019). CoastSat also uses the Modified Normalized Difference Water Index. CoastSat makes use of some freely available Python software packages. To access the satellite imagery the Google Earth Engine Python API package is used. Scikit-learn (Pedregosa et al., 2011) and scikit-image (van der Walt et al., 2014) are used to extract the shorelines from the satellite imagery. For this research a post-processing package developed internally by Royal HaskoningDHV in 2020 was used, which automatically corrects the shoreline position for the tidal level at the instance of image acquisition.

When comparing the basics of these three methods, they use a similar theoretical background and the same set of satellite images. Aqua Monitor uses a large number of images from one year to average out the tidal influences, the other methods make the tidal correction on separate images. This means that only a single annual average value of shoreline position is available, while the other methods deliver several positions within a year, which can be used to assess the seasonal beach dynamics.

Application to the study case

To determine which of the three methods gives the most reliable results, they have been applied to 3 transects drawn north of the Trà Khúc river mouth (Figure 5).

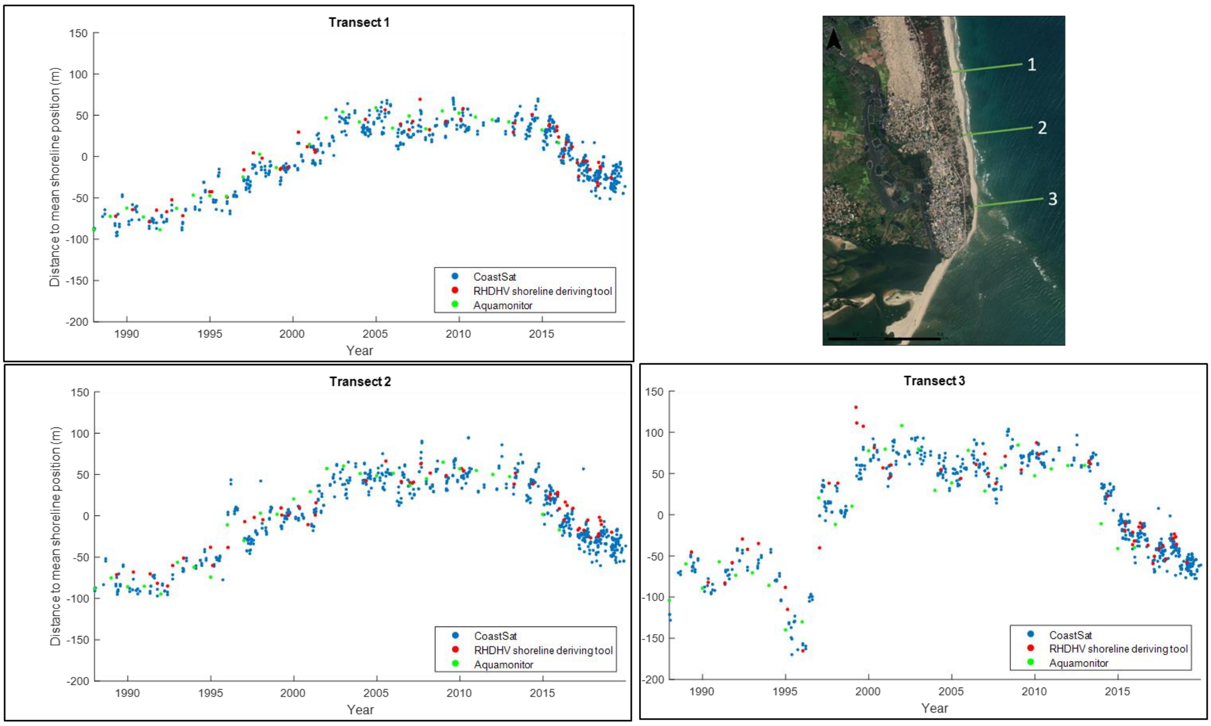

Figure 5. Comparison of shoreline positions derived from satellite images for 3 transects.

It can be seen that all 3 methods give reasonably similar results for the shoreline position. CoastSat uses the most data (blue dots) and this gives the largest bandwidth, however all methods show similar pattern when taking into account the accuracy of 30m of a single image pixel. Based on this comparison, no single method can be selected as performing significantly better than the others.

When looking at the actual results, we can see that in transects 1 and 2 there is a long period of accretion till 2005, then there is a 5 years long period of stability, and since 2010 an erosive trend is observed. Transect 3 is located close to the river mouth, and the outlet dynamics can be clearly seen in the results. In particular, around 1995 there have been apparently large changes in the river mouth, making the shoreline shift by more than 200m in a few years. Since then, the pattern of erosion and accretion remained similar in all transects. The erosion trend observed in the last 10 years is close to 10m/year.

The fact that three methods give similar results is not a proof of their accuracy as they are all based on the same theoretical assumptions. An independent, objective comparison is possible by comparing the historical change of the vegetation line along the beach. This line can be easily digitized from Google Earth images. These images do not have an exact time stamp, they cannot be corrected for tidal elevation and are therefore not suitable for the trend analysis of shoreline position. The position of the vegetation line, however, is independent of the tidal elevation, while it quickly follows the eroding shoreline. This analysis is shown in Figure 6. It can be clearly seen that the erosion along the considered stretch is around 100m over 18 years and 20m over 2 years period, which is in agreement with the average value of 10m/years found in the shoreline change analysis.

Figure 6. Change of the vegetation line north of Trà Khúc river mouth.

NUMERICAL MODELLING

Analysis of satellite images provides insights to the historical changes of the shoreline and therefore to the long-term large-scale development of the coast (structural erosion). However, also the short-term erosion caused by storms is very important as it can bring along large damages to the coastal communities. Understanding of the magnitude of these changes during a severe typhoon can be obtained by means of numerical modelling. First, the wave conditions along the coast need to be determined, and from there the profile evolution can be simulated. In our study, we used the parametric model (Ly et al., 2016) based on the Shore Protection Manual method (CERC, 1984) to determine wave height, wave period, and wave direction for an offshore area for all typhoons which passed Quang Ngai within 250 km. The Extreme Value Analysis was used to find a typhoon with a 1/100 year wave height offshore of the study area, and then MIKE21 SW model was applied to simulate the corresponding nearshore wave conditions. Figure 6 shows all typhoon tracks that passed the project site within a radius of 250km and a simulated wave field during the 1/100 years typhoon Trix (October, 1952).

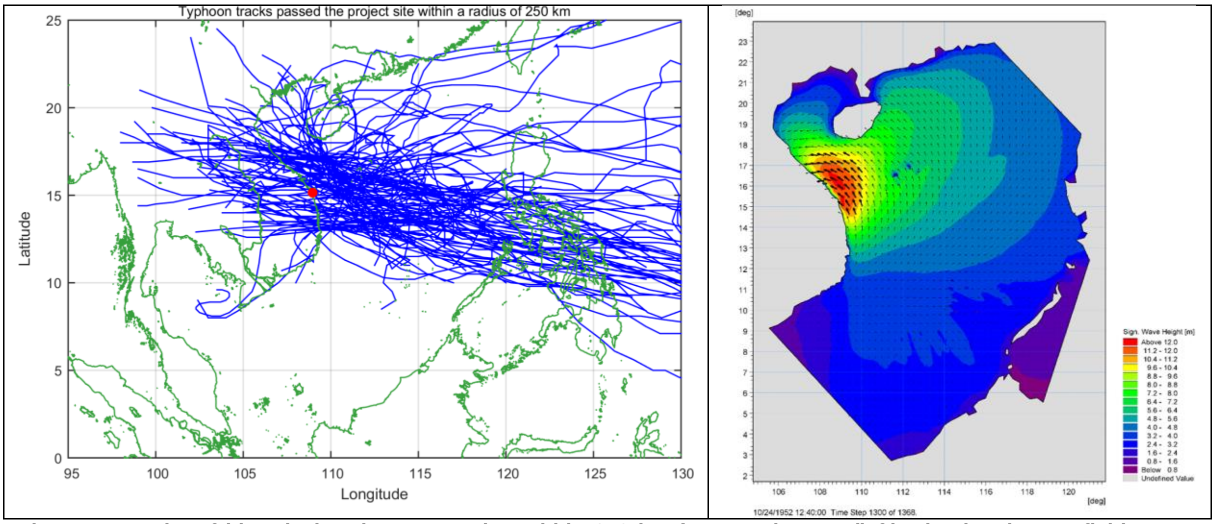

Figure 7. Tracks of historical typhoons passing within 250 km from study area (left), simulated wave field during the 1/100 years typhoon Trix.

The nearshore wave heights found in the simulation drop from more than 10 m offshore to less than 6 m nearshore. These wave heights were used as input to the cross-shore evolution model LITPROF (a module of LITPACK software). The evolution of the considered cross-shore profile after more than 72 hours with typhoon Trix are presented in Figure 8. It can be seen that the profile erosion during a severe typhon is about 30 m.

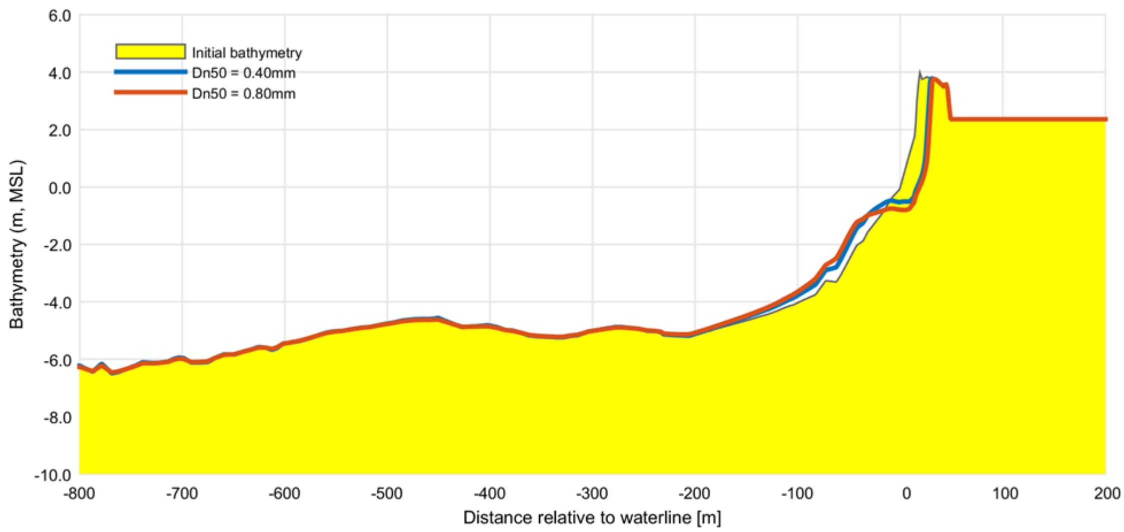

Figure 8. Cross-shore profile evolution during 1/100 years typhoon (not to scale).

CLIMATE CHANGE IMPACT

The impact of climate change on coastal erosion is primarily related to the Sea Level Rise (SLR). The SLR impact can be estimated using the Bruun's rule (Bruun, 1954), USACE (2012)). The estimated shoreline retreat due to SLR has been estimated at 2 m in 2030 and 15 m in 2070. SLR cannot explain the erosion observed in the last 10 years.

CONCEPTUAL MODEL

The storm erosion shown in Figure 8 is related to the seasonal dynamics of the coast, which retreats during the storm season and then recovers during the calm season, and is of temporary nature. If this recovery on the long term is insufficient, structural erosion occurs indicating an imbalance in the sediment transport along the coast. This is clearly the case in Quang Ngai coast which has been showing a continuous erosion trend over the last 10 years.

All analysis elements described in this paper can be combined into a conceptual model. This model can be summarized as follows:

1. The dynamics of the coast near the Trà Khúc river mouth depends strongly on the sediment dynamics of the river outlet.
2. This outlet is very active, with sediment output strongly varying with the seasons and a sand spit growing during the dry period and decaying during the period of high river flow.
3. Active sand mining in the recent years strongly reduced the sediment input to the longshore transport.
4. The historical trend of the shoreline change shifted around 2010 from accreting to eroding, with a nearly constant erosion rate of 10 m/year. This trend change is unlikely to be caused by natural phenomena and is most probably related to the substantial sand mining in the Trà Khúc river.
5. Severe storms can cause a retreat of shoreline up to 30 m.
6. Expected Sea Level Rise is likely to cause the shoreline to retreat by 15 m.

PREDICTION OF FUTURE EROSION

The width of the future erosion risk zone in Quang Ngai in 2070 (approx. 550 m, see Figure 9) has been predicted as a sum of:

- 30 m storm erosion +
- 10 m/yr x 50 years = 500 m permanent erosion +
- 15 m SLR impact

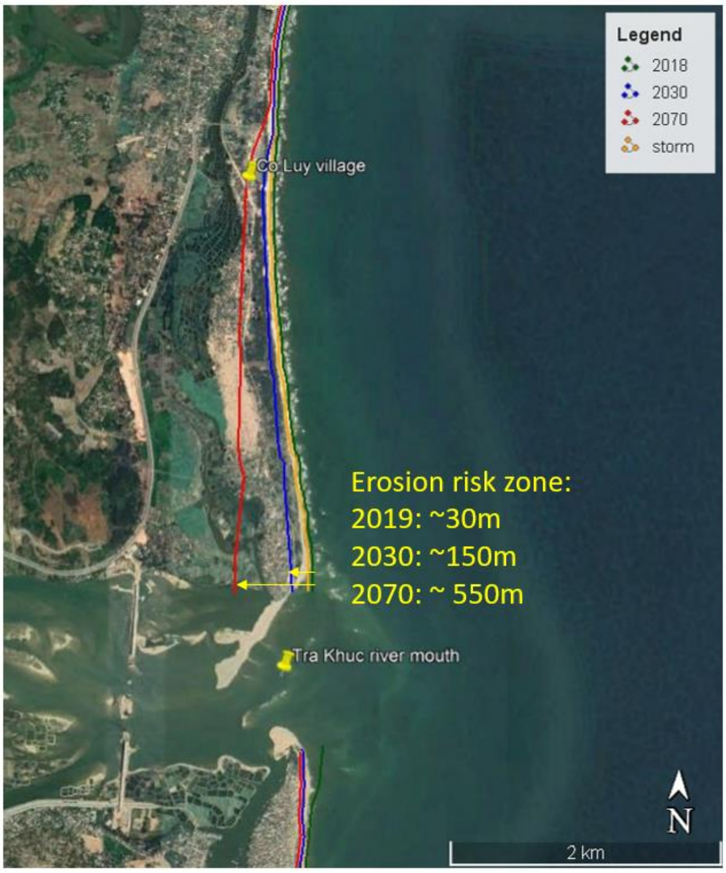

Figure 9. Predicted width of erosion risk zone.

It is noted that the assumption that the present erosion trend will continue unchanged in the future is very crude but is considered acceptable for planning purposes as it shows where risk mitigation is urgently needed.

CONCLUSIONS

The following general conclusions can be drawn:

1. Automated, remote-sensing methods of shoreline prediction provide indispensable information for planning purposes.
2. All methods considered in this paper provide results in the same range and show similar erosion trends and temporal patterns.
3. A good understanding of physical process governing coastal erosion is indispensable for the correct interpretation of results.
4. Trend analysis and numerical modelling help to build this understanding.

ACKNOWLEDGMENTS

The data and some illustrations used in this paper have been obtained from the project "Development of Coastal Multi-Hazard Mapping, Vulnerability and Risk Assessments and Investment Framework for Coastal Interventions in Selected Coastal Communities in Vietnam" executed in 2017-2019 by Royal HaskoningDHV under assignment from the World Bank in support to the Government of Vietnam. The authors express their gratitude to the World Bank for permission to use these materials.

REFERENCES

Bruun, P. 1954. Coast erosion and the development of beach profiles. Beach erosion board technical memorandum. No. 44. U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS.'

Canny, J., 1986. A computational approach to edge detection, *IEEE Trans. Pattern Anal. Machine Intell.*, vol. PAMI-8, pp. 679-698.

Donchyts, G., Schellekens, J., Winsemius, H., Eisemann, E., and van de Giesen, N. 2016. A 30 m resolution surface water mask including estimation of positional and thematic differences using Landsat 8, SRTM and OpenStreetMap: A case study in the Murray-Darling Basin, Australia. *Remote Sensing*, **8**(5), 386.

Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G. and Aarninkhof, S. 2016. The State of the World's Beaches. *Sci Rep* **8,** 6641.

Ly, N. T. H., Hoan, N. T. and Dung. N. M. 2016 A practical approach to determine typhoon-induced design wave conditions at nearshore areas, *Ninth International Conference on Coastal and Port Engineering in Developing Country*, Rio de Janeiro, Brasil.

Otsu, N. 1979. A Threshold Selection Method from Gray-Level Histograms. I*EEE Transactions on Systems, Man, and Cybernetics* Vol. SMC-9, No. 1.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., Duchesnay, E., 2011. Scikit-learn machine learning in Python. J. Mach. Learn. Res. 12, 2825–2830.

USACE. 1984. Shore protection manual. Coastal Engineering Research Center (CERC), US Army Corps of Engineers Research and Development Center, Coastal and Hydraulics Laboratory, v. 2, Vicksburg, Mississippi.

USACE. 2012. Coastal Engineering Manual, EM 1110-2-1100, US Army Corps of Engineers, April 2002.

Van der Walt, S., Schonberger, J.L., Nunez-Iglesias, J., Boulogne, F., Warner, J.D., Yager, N., Gouillart, E., Yu, T., 2014. scikit-image: image processing in Python. PeerJ 2, e453.

Vousdoukas, M.I., Ranasinghe, R., Mentaschi, L., Plomaritis, T.A., Athanasiou, P., Luijendijk, A. and Feyen, L. 2020. Sandy coastlines under threat of erosion. *Nat. Clim. Chang.* **10,** 260–263

Vos, K., Splinter, K.D., Harley, M.D., Joshua, A.S., Turner, S.I. 2019. CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. Environ. Model. Softw., 122, 104528.

Xu, H., 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int. J. Remote Sens. 27, 3025–3033.