INTERGENERATIONAL EQUITY OF THE COASTAL AREAS

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Abstract

Over geological to historical time scales, changes in sea level have caused lateral migration by several tens of kilometers in the position of many of the world's shorelines. Nevertheless, shoreline change takes place over a wide range of time scales. At one extreme, the impact of tsunami waves on a shoreline can be devastating over just a minute or so. In contrast, the impact of global sea level change may be scarcely perceptible within the span of a monitoring program. The key question in the appraisal of the shoreline change is what is affecting the shoreline change. Regardless the answer, we must at least maintain the total coastal resource value and, preferably, enhance it for the benefit of future generations, that is, the concept of intergenerational equity. Driven by the general remarks, the estimation of the shoreline change rate is of crucial importance to manage, protect or develop a coastal area. Consequently, the main purpose of the present work is to compute the shoreline change rate of several coastal areas in Greece using all worldwide known statistical methodologies, namely, EPR, AOR, AER, OLS, JK, WLS, RWLS, MDL and LAD. The derived signals and noises of the computation of the shoreline change rate, point out which methodology has the merits to estimate the most accurate signal with the least noise and, therefore, to be used for the prediction of the future shoreline so as the intergenerational equity of the coastal areas can be preserved through localized sustainable actions.

Keywords: shoreline change rate, statistical methods, signals and noises.

1. Introduction

The movement of the shoreline over time usually consists of a predictable component of variation that can be regarded as the signal and a short-term variation or noise. The signal can be computed using the influence of long-term phenomena, such as a rise in sea-level or the shift in natural sediment supply. Short-term variations can be also emerged ranging from days to seasons. Meanwhile, both the long- and short-term trends are discernible, although it may be difficult to determine if the processes responsible for these changes function independently or dependently. Nevertheless, the estimation of the long-term depends on the purpose of the investigation, the availability of data and the temporal variability of the shoreline under study. Unfortunately, since few shorelines are undergoing changes at a constant and uniform rate, the time interval is an important consideration. Obviously, the longer the time interval and the accuracy of the available data the better the estimation of the future shoreline [4].

All methods used to calculate shoreline rates of change involve measuring the differences between shoreline positions through time. In the present work, all internationally used methods able to compute the shoreline change rate are presented, tested and compared.

2. Methods to compute shoreline change rate

2.1. End of Point Rate (EPR)

The EPR method uses only two data points to estimate the shoreline change rate, namely, the earliest and most recent shoreline positions. All intermediate positions are not taken into account, although present and available. Since the earliest shoreline position is very back in time, that means that erroneous positions can influence the calculated change rate accordingly. Nevertheless, combinations of shoreline data can be used to better determine the change rate and use the total shoreline positional information. Given n shoreline positions, then n(n-1)/2 end point rates can be calculated and then averaged to compute the change rate along the transects [1,2]. In this case, the standard variation uncertainty of end point rates calculated are given by [2]:

$$\sigma_{EPR} = (\sqrt{2})\, \sigma_{obs} / (T_i - T_j) \qquad (1)$$

where, T_i is the initial year and T_j the last year.

2.2. Average of Rates (AOR)

AOR method calculates individual EPRs from the shoreline position data when more than two shoreline positions are available. EPRs are calculated between any combinations of two shorelines. Not all shorelines can participate in the EPRs calculation unless they pass the minimum time criterion, namely [5]:

$$T_{min} = [(\sqrt{(E_1^2 + E_2^2)})]/R_1 \qquad (2)$$

where E_1 and E_2 are the measurement errors in the first and second point respectively and R_1 is the EPR of the longest time span for a particular transect. Only EPRs that survive the minimum time span can participate in the shoreline change rate estimation. Consequently, small rates in the denominator of eq. 1 produce long minimum time spans. If this happens, many consecutive shorelines cannot participate in the EPR determination since the minimum time span is not fulfilled. This is a disadvantage of the method and can eventually result in a simple EPR method.

2.3. Average of Eras Rates (AER)

AER is just like AOR except that consecutive shorelines are used each time.

2.4. Ordinary Least Squares (OLS)

The entire sample of the given shorelines is participating in this method. Positions along a transect of the shorelines are mapped on an XY coordinate system, where along the X-axis are the years and along Y-axis the positions of the shorelines. The line which best fits the positions is the regression line and its slope is the change rate along the specific transect (Fig. 1).

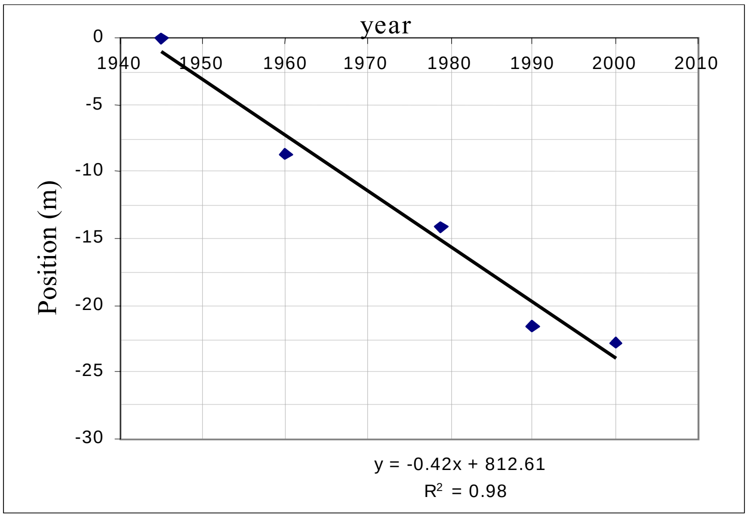

Figure 1. The linear regression line as the best fit to shoreline positions

The slope of the regression line or the shoreline change rate along a transect is given by [5]:

$$\rho = \frac{n \cdot \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \cdot \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i \right)^2} \tag{3}$$

where, n is the number of shorelines, χ_i the years and ψ_i the shoreline positions. The transects along the historical shorelines are shown in Fig. 2.

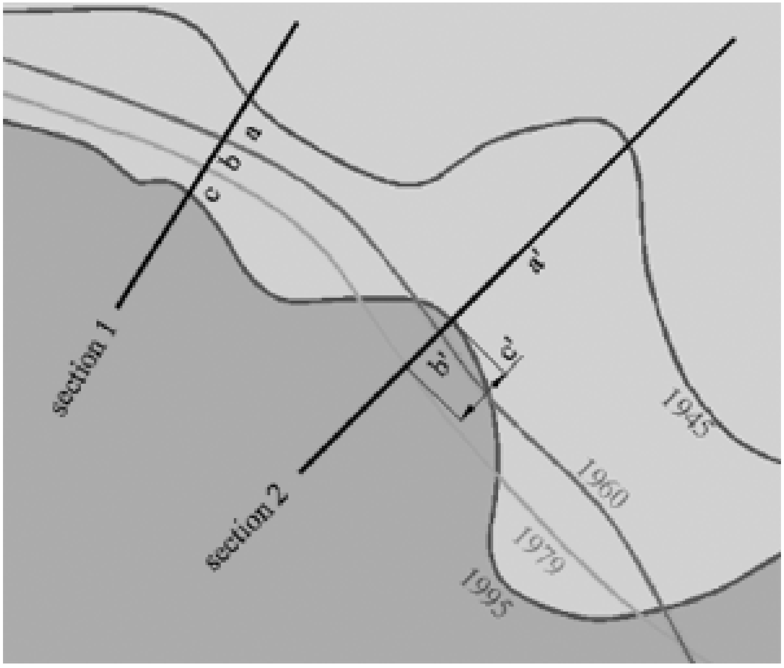

Fig. 2. Transecting the shorelines for Linear Regression computation

We have to underline here that as soon the positions of the shorelines are clustered some historical shorelines will have more influence on the regression line than others. It is well known that historical shorelines are dated back several decades and include positional errors much greater than recent shorelines (e.g. satellite imaginary). Rates computed from these kinds of data include great uncertainties.

2.5. Jackknife (JK)

Jackknife is just like OLS but the change rate along a given transect is computed using all combinations of the n shorelines omitting one at each iteration. Both methods are purely computational, include all available data and have statistical meaning. Nevertheless, the JK method has a lot of computational burden in case of many available shorelines.

2.6. Reweighted Least Squares (RLS)

This method runs in two steps. First, it identifies positions of shorelines that are outside the 1σ value. Points (or positions) outside the 1σ value are given a weight of 0 and points inside the 1σ value are given a weight of 1. With this reasoning, points (or positions) outside the 1σ value are treated as outliers and “noisy” data are excluded in the determination of the change rate.

2.7. Weighted Least Squares (WLS)

In Least Squares, we assume that the variances in Y-axis (shoreline position) and in X-axis (time of shoreline) are the same. With this method different variances are introduced along the two axes.

2.8. Reweighted Weighted Least Squares (RWLS)

RWLS is the same as the RLS except that the uncertainties of each shoreline position are taken into account.

2.9. Least Absolute Deviation (LAD)

The reasoning in this method is the same as in LS, but the residuals are not squared and the distribution of errors is assumed to be a Laplace distribution. That means that since it is not Gaussian, it is less sensitive to outliers [6].

2.10. Minimum Description Length (MDL)

It assumes Gaussian error distribution and tries to find out which model is the best fit to the data. It can be first order (e.g. line) or higher (e.g. quadratic). If the model is linear, then MDL results in an LS method. If it is non-linear, then two lines are produced: the zero-weight line which uses only recent data and disregard old data and the low-eight line which gives weight to older data [1].

3. Results

Six coastal regions in Greece were studied, two with low dynamics (< 1m/y), two with medium dynamics (1-3m/y) and two with high dynamics (> 3m/y) in order to evaluate and compare the estimated signals and noises of the ten described above methodologies. The results are listed in Table 1.

METHOD	REGIONS WITH LOW DYNAMICS (< 1m/y)		REGIONS WITH MEDIUM DYNAMICS (1-3 m/y)		REGIONS WITH HIGH DYNAMICS (> 3m/y)	
	I	II	III	IV	V	VI
EPR	-0.21 ± 0.68	-0.28 ± 1.00	-3.18 ± 1.10	-1.30 ± 0.65	-3.48 ± 3.33	-9.81 ± 1.00
AOR	-0.43 ± 0.49	-0.36 ± 1.84	-0.58 ± 0.34	-1.47 ± 0.49	-3.29 ± 4.47	-10.74 ± 0.94
AER	-0.35	-0.54	0.08	-1.49	-3.20	-8.51
OLS	-0.42 ± 0.001	-0.26 ± 0.001	-1.60 ± 0.001	-1.39 ± 0.001	-3.57 ± 0.01	-11.98 ± 0.002
JK	-0.46 ± 0.001	-0.25 ± 0.001	-1.42 ± 0.001	-1.41 ± 0.001	-3.29 ± 0.01	-12.81 ± 0.002
RLS	0.74 ± 0.12	-0.95 ± 0.002	2.65 ± 0.10	0.16 ± 0.01	-1.64 ± 0.34	-2.49 ± 0.09
WLS	-0.14 ± 0.04	-0.14 ± 0.07	3.04 ± 0.02	-1.78 ± 0.06	-3.57 ± 0.47	-14.97 ± 0.08
RWLS	-0.13 ± 0.04	-0.14 ± 0.07	3.11 ± 0.02	-1.70 ± 0.06	-3.57 ± 0.47	-14.97 ± 0.08
LAD	-0.30	0.61	-0.01	-2.00	-2.00	-1.28
WLAD	-0.30	0.47	1.00	-1.00	-1.00	-1.00

Table 1. Shoreline change rates (m/y) and noises (m/y) estimated from different methods

4. Conclusions

From the obtained results, we can draw the following conclusions:

A. The EPR, AOR and AER methodologies estimate the shoreline change rate with such a noise that exceeds the computed signal. Consequently, it is advisable that these methods should not to be followed in shoreline change rate studies.

B. The weighted Least Squares techniques e.g. RLS, WLS and RWLS, compute a signal that is far from the "average" value of the shoreline change rate. As the average value can be taken the mean of the rest methodologies (EPR, AOR, AER, OLS and JK). This difference can be double or even more of the average signal. Consequently, it is advisable that these methods should not to be followed in shoreline change rate studies.

C. The signals of LAD and WLAD methodologies are far from the average value of the shoreline change rate and, often, present different physical processes, that is, they compute accretion instead of recession. Unless more studies are undertaken for refining the methods, they should not to be followed in shoreline change rate studies.
D. OLS and, similarly, JK methodologies compute the signal of the shoreline change rate with small noise and prove to be rigorous and robust to study the dynamics of the moving shoreline. Consequently, they are the proper methods and can be followed especially in coastal areas of rich historical geoinformation, e.g. many shorelines spanning over 60 years back.

5. References

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