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Fluctuations in the Black Sea Level in Varna and Burgas Bays in the Period from 1928 to 2011

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Abstract. The ordinary least squares regression is a parametric technique that is commonly used for analysis of time series. This method is very popular when the long-term trend of the change in a sea-level has to be estimated on basis of mareograph data. The main advantage of ordinary least squares regression is that this approach allow us to estimate the slope and the intercept of a regression line by parametric methods that are relatively simple. However, the ordinary least squares regression relies on the assumption about the normality of data. If this assumption is not met, the regression results may not be correct. Another disadvantage of the method is that it is very sensitive to impact of outliers in data. Analyzing the records of the Black Sea level, gathered by tide gauges in Varna in the period from 1929 to 2011, we can see that in 2005 and 2006 years we registered significantly low sea-levels, in comparison with those in the preview and in the next few years. Similarly, the Black Sea level near the tide gauge in Burgas, we also recorded significantly low sea-level in 2005 and 2006. The purpose of the current research is to recalculate these trends by the use of non-parametric regression, i.e., by the Theil-Sen robust estimator of simple linear regression. Using non-parametric regression, we calculated the slopes of the linear upward trends of the Black Sea in Varna and Burgas equal to 2.35 mm/year and 2.03 mm/year, respectively. The slopes of the linear trends of the Black Sea in Varna and Burgas, estimated by other Bulgarian researches, are about 1.2-1.4 mm/year and 1.5-1.6 mm/year, respectively. Contrary to the results, published by other researchers, we found that sea-uplift in Varna is greater than that in Burgas. Therefore, when we analyze oceanic data, which is likely to contain extreme data points, it is preferable to give more trust to non-parametric technics in order to obtain results that are more relevant than results obtained by ordinary regression under violation of its assumptions.

Keywords: Robust regression, ordinary least squares regression, sea level, black sea, time series

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INTRODUCTION

There are a dozen publications dedicated to the fluctuations of the Black Sea level, which are based on the data have obtained by the tide gauges in Varna and Burgas since 1928. There also a couple of values regarding the trends of the sea level rise in Varna and Burgas bays. For example, the estimated century trend in the sea level near Varna is 0.92mm/year [5], 1.2 mm/year [2], 1.4 mm/year [4, 8], 1.53 mm/year [6] and 3.5mm/year [2]. Similarly, the estimated century trend in the sea level near Burgas is 1.26 mm/year [5], 1.6-1.7 mm/year [3] or 2.00 mm/year [8]. Using the

same data, the differences between the abovementioned values of the Black Sea rise in Varna and Burgas can be explained by difference of the used mathematical approaches, mainly parametric. Analyzing the fluctuations given by Figure 1 and Figure 2, one can see that there are extreme values in 2005 and 2006 year. Those registrations of the mareographs in Varna and Burgas are supposed to be results of simultaneous malfunction of both tide gauge equipment's [5]. Regardless the reason for registering these low sea levels in 2005 and 2006, their values affect the results produced by parametric approaches similar to the ordinary least squares regression or the spectral analysis, and can be a reason for underestimation of the real level rise. In addition, according to publications [2, 3, 4, 5, 8], the speed of the sea level rise in Burgas is estimated to be greater than that in Varna, which seems suspicious regarding the natural water flow in and flow out of the Black Sea.

Taking into account the above facts, the main aim of the current research is to recalculate these trends by the use of non-parametric regression, i.e., by the Theil-Sen robust estimator of simple linear regression and to compare the obtained results with those of the publications [2, 3, 4, 5, 8].

MATERIAL AND METHODS

The current research is based on the mean annual levels of the mareograph data, collected by the tide gauges in Varna and Burgas. Figure 1 and Figure 2 present the fluctuations of the corrected sea levels in respect with the permanent drop in the mareograph laths in Varna and Burgas tide gauges, respectively. Figure 3 and Figure 4 illustrate the speed of the lath dropping in both mareograph stations.

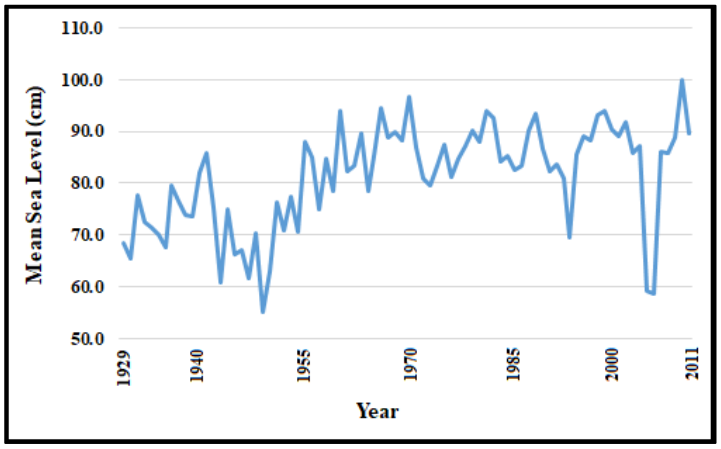

FIGURE 1. Fluctuations of the corrected sea level near Varna tide gauge in the period from 1929 to 2011.

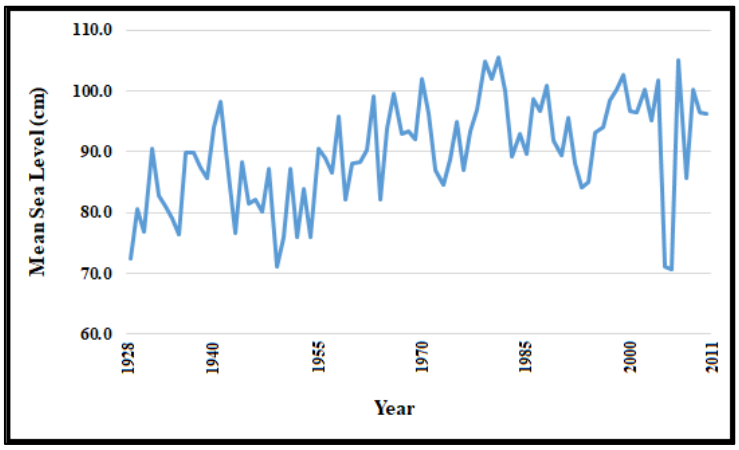

FIGURE 2. Fluctuations of the corrected sea level near Burgas tide gauge in the period from 1928 to 2011.

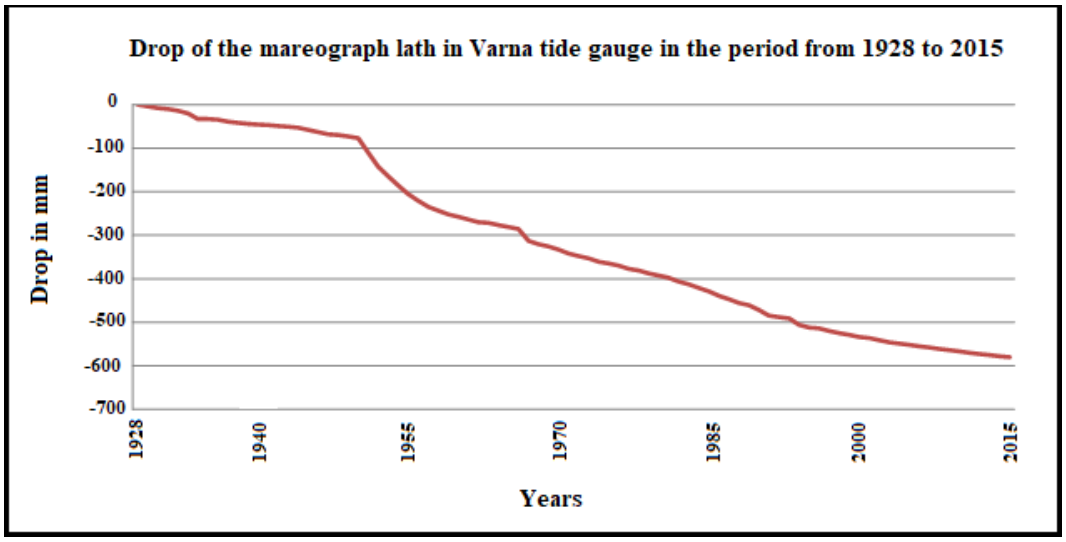

FIGURE 3. Drop in mm of the mareograph lath in Varna tide gauge in the period from 1928 to 2015.

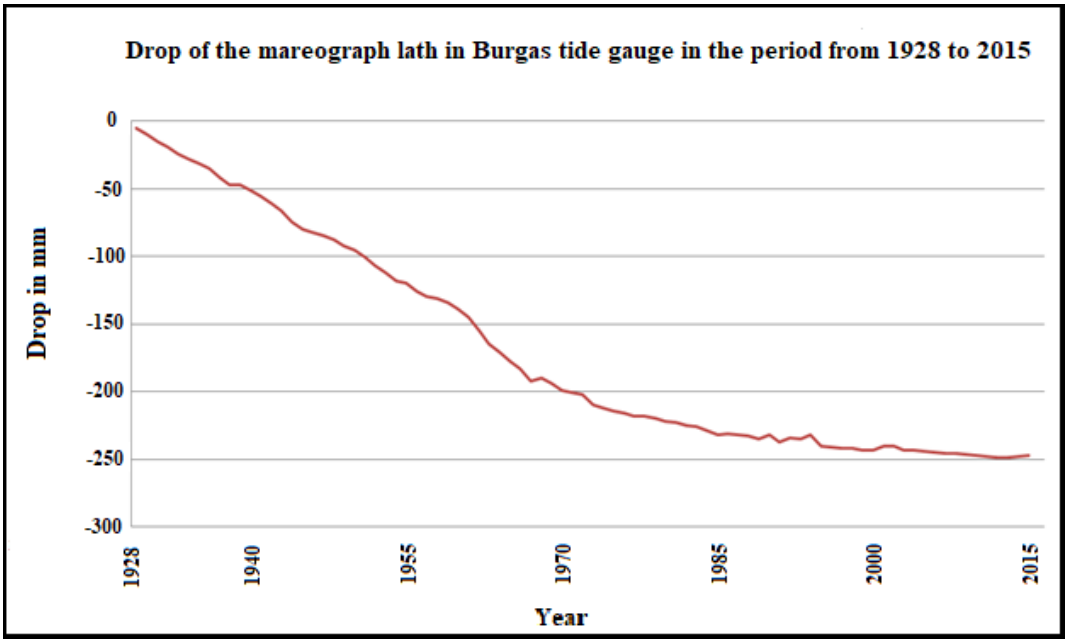

FIGURE 4. Drop in mm of the mareograph lath in Burgas tide gauge in the period from 1928 to 2015.

In order to minimize the effect of the extreme annual levels, such as registered in 2005 and 2006, we used a non-parametric regression approach, i.e., the Theil-Sen robust estimator of simple linear regression. The algorithm of this non-parametric method for constructing a linear relationship between two variables is deeply explained and analyzed [1, 7]. With the aim of comparison of the accuracy between the trends of the sea levels, obtained by the abovementioned non-parametric approach and the results published by other researcher, we constructed regression lines with trends equal to 1.3 mm/year and 1.6 mm/year, respectively for the data of Varna and Burgas tide gauges. This comparison is based on the following statistics: Root Mean Squared Error /RMSE/, Mean Absolute Error /MAE/ and Median Absolute Deviation /MAD/.

RESULTS

The linear models of the sea level trends, produced by Theil-Sen's estimator /TSE/, the Ordinary Least-Squares Regression and the models with trends equal to 1.3mm/year and 1.6mm/year, respectively in Varna and Burgas bays, are given in Table 1 and Table 2. Table 1 and Table 2 also contain the accuracy of these models, estimated by different estimators. Figure 5 and Figure 6 visualize the differences between the models.

TABLE 1. Linear models of the sea level in Varna bay and their accuracy.

Description	TSE	OLSR	Trend of 1.3mm/year
Model	Level = -380.686 + 0.2346.Year	Level = -347.919 + 0.2179.Year	Level = 75.940 + 0.130.(Year-1929)
RMSE	8.41	8.51	8.77
MAE	5.89	5.93	6.47
MAD	4.46	4.50	5.08

TABLE 2. Linear models of the sea level in Burgas bay and their accuracy.

Description	TSE	OLSR	Trend of 1.6mm/year
Model	Level = -308.948 + 0.2028.Year	Level = -255.563 + 0.1754.Year	Level = 83.270 + 0.160.(Year-1928)
RMSE	7.48	7.52	7.63
MAE	5.61	5.79	5.82
MAD	4.21	4.59	4.85

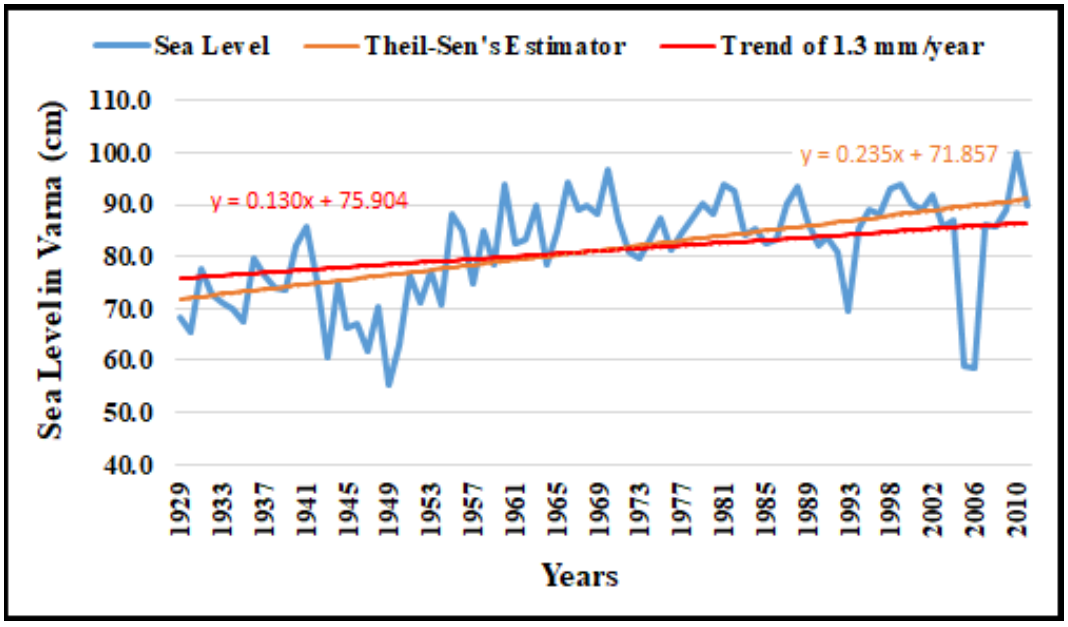

FIGURE 5. Comparison between Theil-Sen's Estimator and the trend given by equation Y=0.130.X+75.904 concerning the data from Varna tide gauge in the period from 1929 to 2015.

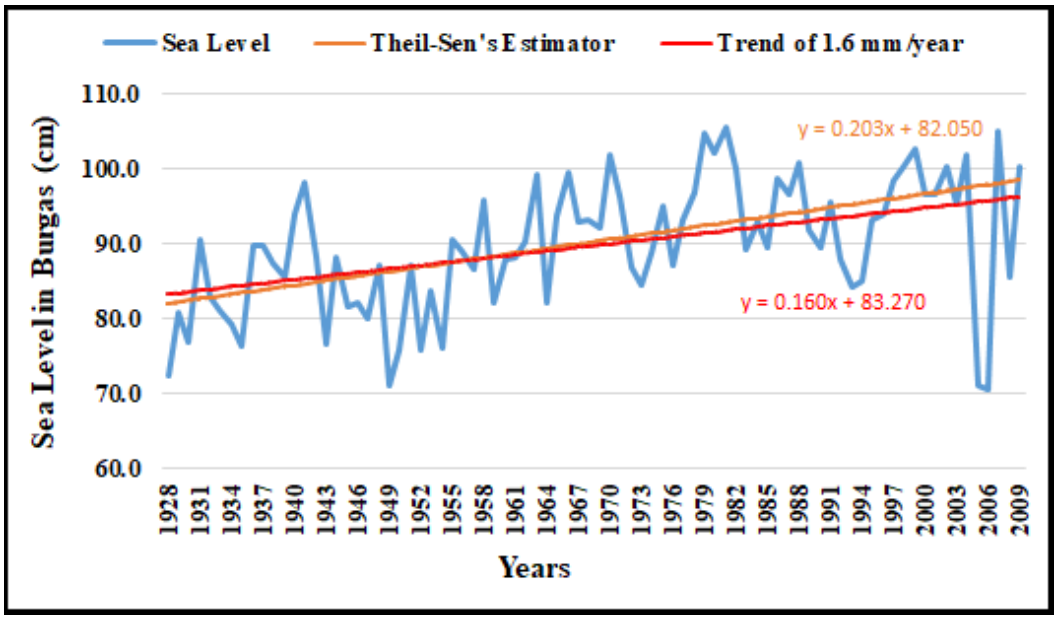

FIGURE 6. Comparison between Theil-Sen's Estimator and the trend given by equation Y=0.160.X+83.270 concerning the data from Burgas tide gauge in the period from 1928 to 2015.

According to Table 1 and Figure 5, the estimated by Theil-Sen's estimator trend of the sea level in Varna bay is 2.35 mm/year, which is almost twice greater than the trend of 1.3 mm/year [2, 3, 4, 5, 8]. According to Table 2 and Figure 6, the estimated by Theil-Sen's estimator trend of the sea level in Burgas bay is 2.03 mm/year, which supports the value, given by [8]. A comparison of the accuracy of the analyzed models shows that the RMSE, MAE and MAD estimators have the least values it the case of the models based on the Theil-Sen robust estimator of simple linear regression.

CONCLUSION

Because the fact that the robust methods are not sensitive to the values located at the tails of the sample distributions, they limit the effect of outliers or the extreme values in samples. As a result, the obtained results are more plausible than those ones, obtained by parametric approaches under violations of their basic assumptions. The use of statistical tool can turn general conclusions about the magnitude of the investigated process. In the current article, we showed that the rise of the sea level in Varna bay is greater than that in Burgas bay, contrary to previously announced by other Bulgarian scientists [2, 3, 4, 5, 8]. This finding seems trustful according to the follow facts:

- The deltas of the Danube, the Dniester and the Dniepr river, which are the greatest ones that flow in the Black Sea, are more closely to Varna than to Burgas;
- The direction of the Western Black Sea flow is counterclockwise;
- The direction of the Black Sea water flow in the Sea of Marmara is positive (Black Sea - Wikipedia).

The values of the sea level rise in Varna and Burgas bays are more closely to the values of the Black Sea rise, determined by satellite altimetry and estimated to 3.2 mm/year [5, among others]. Analyzing the radar mareograph data in Varna for the period from May 2003 to January 2022, Ivanov found that the Black Sea rise in Varna bay is 3.5 mm/year. The last result is in a good concordance with the satellite altimetry results. On the basis of the presented results, we can conclude that if we analyze oceanic data, which is likely to contain extreme data points, it is preferable to give more trust to non-parametric technics in order to obtain results that are more relevant than results obtained by ordinary regression under violation of its assumptions.

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