

Trend analysis of sea levels along Turkish coasts

Burkay Şeşeoğulları

Hydraulic Division, Civil Engineering Department, Istanbul Technical University, 34469
Maslak Istanbul, Turkey

Ebru Eriş

Hydraulic Division, Civil Engineering Department, Istanbul Technical University, 34469
Maslak Istanbul, Turkey

Ercan Kahya¹

Hydraulic Division, Civil Engineering Department, Istanbul Technical University, 34469
Maslak Istanbul, Turkey

Abstract. Sea level changes can be considered as an indicator of environmental and climate change. Sea level becomes a factor of anxiety to those who fear the possible consequences of the earth warmed as a result of the buildup of greenhouse gases. Despite the cities along coastal lines cover less than five percent of the total surface area of Turkey; their total population is over 30 million with a rapid growing rate. A significant change in sea levels is extremely important to the coastal communities in Turkey. In literature, linear secular trends in annual mean sea level data are calculated as the least squares linear regression to a bivariate distribution of the data value versus year. The length of the time series is recommended to be 60 years or longer which sometimes is permitted to be as low as 25 years. In this study, we use a non-parametric approach to determine trends in sea levels as the available data comprises of rather short record length. At the same time, the nonparametric methods are more tolerable for the short records, computationally simpler and distribution-free. Therefore we investigated trend behaviors in sea level data measured along the Mediterranean, Aegean and Black Sea coasts of Turkey using nonparametric Mann-Kendall test. Annual sea level records, observed for eight typical stations, were used for the purpose of trend detection. As a result, five out of eight stations showed an upward trend as one of them showed a downward trend. No trend was found for the remaining stations. We also fitted a least squared line to quantify rate of change in sea level. Among the stations showing positive trends, the highest rate of change was computed in Trabzon (the Black Sea station) whereas the lowest was computed in Karşıyaka (the Aegean Sea station). The results confirmed a strong signal of sea level rise at global scale.

1. Introduction

A central element of current research in climate change and variability is the analysis of trends in climate variables from historical instrumental records. In this study, we considered sea level changes as an indicator which can be associated with possible climate change. Nowadays it is evident that sea level

¹ Hydraulic Division,
Civil Engineering Department,
Istanbul Technical University
34469 Maslak Istanbul, Turkey
Tel: (212) 285-3002
e-mail: kahyae@itu.edu.tr

rise receives more attention than sea level drop. There are two basic types of sea level change: first, eustatic (implying worldwide change in sea mean level because of decreasing or increasing ocean volumes) and second, local apparent change in mean sea level resulted from vertical crust movement. In this case, tide gauging records measure the net result of both changes going on at once: the combined vertical movement of land and sea. Nicholls and Leatherman (1995) summarized the physical effects of sea level rise into five categories: (i) inundation of low-lying areas, (ii) erosion of beaches and bluffs, (iii) salt intrusion into aquifers and surface waters, (iv) higher water tables, and finally (v) increased flooding and storm damage.

The sea level variations to be determined in the study of Zervas (2001) were the linear secular trend, the average seasonal cycle, and the residual variability. Due to the derived trends including the local vertical land motion, he stressed the spatial variability in trends, indicating that calculated mean sea level trends range from 9.85 mm/yr for Grand Isle to -16.68 mm/yr for Skagway using 117 stations around the US and Alaska. To examine the mean sea level change along the coasts of Turkey, Demir and Gürdal (2000) applied harmonic analysis using monthly data whose record length ranged from 4 to 14 years. They combined sea level data, GPS and precise leveling observation connecting tide gauges to estimate relations between mean sea levels as well as vertical crustal movements at Turkish coasts. It is shown that the mean sea level difference between the Black Sea and the Mediterranean Sea due to sea surface topography was about to be 40 cm.

In literature, linear secular trends in annual mean sea level data are calculated as the least squares linear regression to a bivariate distribution of the data value versus year. A record length greater than 60 years is desirable to determine trends in long-term sea-level changes (Douglas, 2001; Unnikrishnan and Shankar, 2007). However the sample length sometimes is allowed to be as low as 25 years (Zervas, 2001). In order to identify upward or downward trends, Reinhard et al. (2003) used the least squares regression model to explore long-term trend in tidal data statistics (i.e., highest water, mean high water, mean low water, etc.). The length of data was chosen as at least 20 years in their study. Even Woodworth et al. (1999) used mean sea level data with at least 15 complete years without gap for the trend analysis. For these shorter records, linear trend was used to determine measured trend and standard error on the trend, and standard deviation of the annual mean values.

Comparing with the above suggested length of data for deriving mean sea level trends, the available records along Turkish coasts is fairly short; thus, our objective in this study is to gain a rough picture of trend variation of mean sea levels using a nonparametric method.

2. Data

Monthly mean relative sea level data were obtained through the PSMSL website (www.pol.ac.uk). In order to properly represent the coast lines of Turkey, we selected eight typical tide gauging stations. The location of these gauges is given in Figure 1. It is obvious that there are 6 different locations around the Anatolia peninsula, spreading from the Mediterranean Sea through

the Aegean Sea-Marmara Sea and ending to the Black Sea. There are two nearby stations in two coastal cities (İzmir and Antalya). It should be noted that the timing of the records of paired stations at each city is in succession (Table 1).



Figure 1. Locations of tide gauges used in this study.

Under the responsibility of the General Command of Mapping (GCM), sea level monitoring activities in Turkish coasts started in 1930s. Sea level variations were recorded to daily or weekly charts with an analogous system. Readings were obtained through a float on a cable in a stilling well. Because of increased pollution and plunging in the stilling wells, gauge operation ceased during late 1970s. In late 1985, the GCM set up four gauging stations (Antalya II, Bodrum II, Menteş, and Erdek) (Demir and Gürdal, 2000). The basic descriptive characteristics of stations are presented in Table 1. The length of records ranges from 18 to 43 years. Since the reliable data begins at 1984, we marked those stations in bold in Table 1.

Table 1. Basic characteristics of tide gauging stations.

Code	Name	Location	PSMSL Data	Number of years of data availability
310/011	Trabzon	41 00 N 39 43 E	1956-1973	18
310/021	Samsun	41 17 N 36 20 E	1961-1983	23
310/038	Erdek	40 23 N 27 51 E	1984-2001	18
310/041	Karşıyaka	38 24 N 27 10 E	1936-1970	35
310/042	Menteş	38 26 N 26 43 E	1986-2004	19
310/051	Antalya	36 53 N 30 42 E	1935-1977	43
310/052	Antalya II	36 50 N 30 37 E	1986-2004	19
310/061	Iskenderun	36 37 N 36 07 E	1952-1973	22

In filling gap in a month with missing observation, we averaged the monthly values of the preceding and subsequent year of a missing data point. In two tide gauging stations (namely, Antalya and Iskenderun), we noticed dramatic change in sea level occurred in a particular year. Without having the detailed and reliable historical metadata of the stations, we assumed that caused by an anthropogenic change (most likely related to datum arrangement). This effect, of course, leads to draw a misleading conclusion of trend. The way that we followed to eliminate these inhomogeneous structure was first based on breaking the time series into two pieces; one before the year of abrupt change and another after the year of abrupt change. The difference in the mean values of the two pieces was then subtracted from the all observations of the first piece. The corrected time series of sea levels was subjected to the trend analysis.

3. Methods

The basic principle of Mann-Kendall test for detecting a trend in a time series is to examine the sign of all pair wise differences of observed values. It has been widely used to detect trends in hydrometeorological time series (e.g. Hirsch et al., 1982; Hirsch and Slack, 1984; Lettenmaier et al., 1994; Zhang et al., 2000; Yue and Hashino, 2003; Kahya and Kalaycı, 2004; Partal and Kahya, 2006). On the other hand, the Mann-Kendall non parametric test is not frequently applied to the sea level data; however, it has the following key advantages (Kahya and Kalaycı, 2004; Partal and Kahya, 2006):

- (a) It is free from an assumption of underlying probability distribution;
- (b) It is robust to the effects of outliers and gross data errors;
- (c) It allows the existence of missing data (as only ranks are used);
- (d) It also gives the point in time of the beginning of a developed trend (when its sequential version is used).

In this test, the null hypothesis, H_0 , states that the deseasonalized data (x_1, \dots, x_n) are a sample of n independent and identically distributed random variables (Yu et al., 1993). The alternative hypothesis H_1 of a two-sided test is that the distribution of x_k and x_j are not identical for all $k; j \leq n$ with $k \neq j$. The test statistic S is calculated with Eqs. (1) and (2) which

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (1)$$

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \quad (2)$$

has mean zero and variance of S , computed by

$$\text{Var}(S) = \left[n(n-1)(2n+5) - \sum_t (t-1)(2t+5) \right] / 18 \quad (3)$$

and is asymptotically normal (Hirsch and Slack, 1984), where t is the extent of any given tie and \sum_t denotes the summation over all ties. For the cases that n is larger than 10, the standard normal variate z is computed by using the following equation (Douglas et al., 2000).

$$z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

Thus, in a two-sided test for trend, the H_0 should be accepted if $|z| \leq z_{\alpha/2}$ at the α level of significance. A positive value of S indicates an ‘upward trend’ and a negative value indicates a ‘downward trend’.

4. Results and Discussion

For the Mann-Kendall test; the significance level (α) is generally set to be 0.05 (Yue and Hoshino, 2003). The summary of annual sea level trend results at this significance level is shown in Table 2. Five of eight stations (namely, Trabzon, Erdek, Karşiyaka, Menteş and Antalya II) exhibit an ‘upward’ trend whereas a ‘downward’ trend was only found in Samsun station. No trend was found in Antalya and Iskenderun stations.

Table 2. Summary of annual sea level trends at the 5% significance level.

Code	Name	S	Σ_t	Var (S)	Z	$Z_{0.05}$	Trend
310/011	Trabzon	115	0	697,00	4,32	1,96	Upward
310/021	Samsun	-105	18	1432,67	-2,75	1,96	Downward
310/038	Erdek	115	0	697,00	4,32	1,96	Upward
310/041	Karşiyaka	181	0	4958,33	2,56	1,96	Upward
310/042	Menteş	109	0	817,00	3,78	1,96	Upward
310/051	Antalya	-71	18	9129,33	-0,73	1,96	-
310/052	Antalya II	109	0	817,00	3,78	1,96	Upward
310/061	Iskenderun	-3	0	1257,67	-0,06	1,96	-

The plot of each individual gauging station records are illustrated in Figures 2, 3 and 4. It should be noted that visual inspection of the plot of the recorded observations is the first and important step in analyzing a possible trend behavior in the time series under consideration. We showed the least squared fit in the following diagrams just to represent linear trend in a time series, not a methodological alternative way.

The plots of Antalya and Iskenderun stations for both the original and corrected version are displayed in Figure 2. Before applying correcting procedures, Antalya station exhibited a ‘downward’ as Iskenderun station had an ‘upward’ trend. However, after the removal of sudden drop and jump in the

respective series, no trend was found in the two stations. The span of data for these stations was previously noted to correspond to a suspicious period.

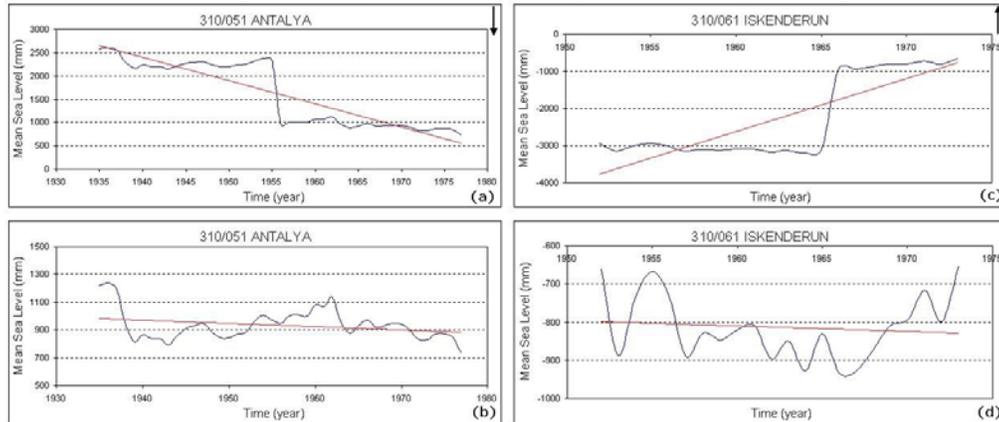


Figure 2. Annual sea level trends at the 5% level (a) Antalya station with original data; (b) Antalya station with corrected data; (c) Iskenderun station with original data; (d) Iskenderun station with corrected data. Downward trend is marked by ‘↓’ and upward trend by ‘↑’.

On the other hand, an ‘upward’ trend was found in Antalya II station which is nearby Antalya station. This causes an ambiguity in drawing a conclusion for these stations. Similar case related to mean sea level datum was reported by Zervas (2001) who indicated that at a number of stations in Texas and Alaska, where there were rapid rising or falling mean sea level trends, the datum was updated using 1990-1994 data in Texas and 1994-1998 in Alaska.

Herein Erdek, Menteş and Antalya II stations are presented in the same group in which the beginning time of records is almost the same. It was earlier noted that these stations comprised of a reliable observations. The trend diagrams at these stations are shown in Figure 3. An increasing trend behavior is quite evident in the three panels of Figure 3.

Trends in the remaining stations (Trabzon, Samsun and Karşiyaka) are presented in another group in which the time span of records lasts by 1984. Moreover the reliability of the data is relatively low. The records of Samsun station showed a negative trend. There are many studies in which mean sea level trends from stations around the world are combined in determining the global mean sea level trend owing to the thermal expansion of seawater resulted from global temperature changes and glacial melting. Even though most coastal regions point out a mean sea level rise, some coastlines demonstrate rapidly falling mean sea levels. This is a result of water level gauging devices measuring relative mean sea level change, combining the effects of absolute mean sea level change and any vertical land movement Zervas (2001).

Since the recorded sea water levels are a combination of changes in the sea level and the vertical land motion at the gauge location, the trends are relative mean sea level trends. Thus they need to be considered valid only for a region near the gauge with uniform vertical land motion (Zervas, 2001). It is known that Turkey is placed in a tectonically very active area. Therefore, the knowledge of the location of vertical crustal movements is particularly important in finding out secular mean sea level changes. Demir and Gürdal (2000)

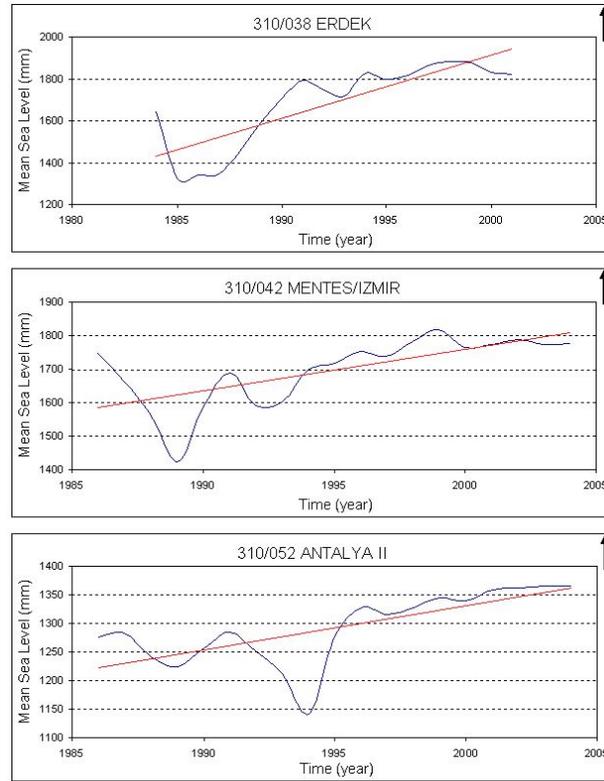


Figure 3. Annual sea level trends at the 5% level for Erdek, Mentesh and Antalya II stations. Downward trend is marked by '↓' and upward trend by '↑'.

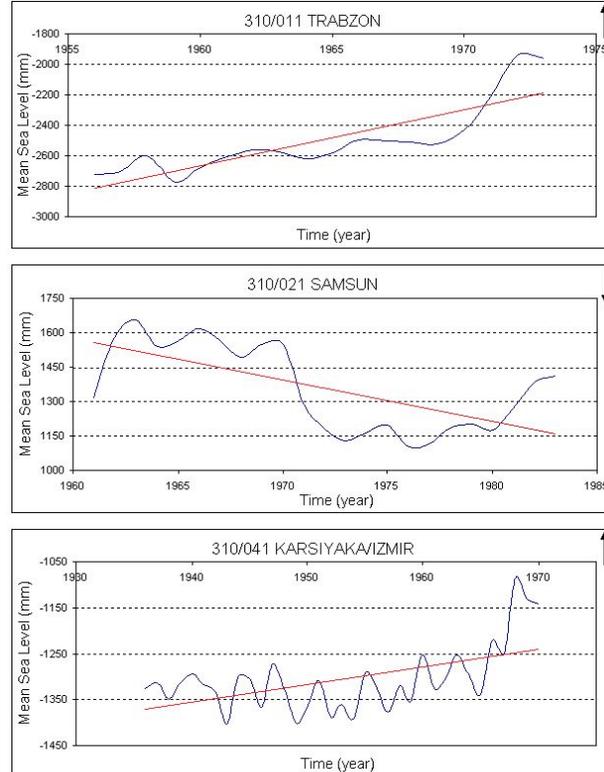


Figure 4. Annual sea level trends at the 5% level for Trabzon, Samsun and Karşıyaka stations. Downward trend is marked by '↓' and upward trend by '↑'.

carried out GPS measurement campaigns at existing four tide gauges, and showed that velocities at Antalya and Menteş tide gauge are irrelevant. Although the sea level data period is rather short, mean sea level trend and GPS measurements at Erdek tide gauge seems to verify the vertical crustal movements.

The potential impacts of global sea-level rise would cause serious problems worldwide. Although Turkey would be one of the countries least vulnerable; yet even there, the consequences could be severe. The policymakers obviously need to take sea level rise into account (Karaca, 2000).

References

- Demir, Ç., and Gürdal, M. A., 2000: Sea level monitoring activities in Turkey. IOC Workshop Report No. 176, Annex IVa.
- Dietz, E. J., and Killen, T. J., 1981: A nonparametric multivariate test for monotone trend with pharmaceutical applications, *J. of the American Statistical Assoc.*, **76**, 169-174
- Douglas, B. C., 2001: Sea level change in the era of the recording tide gauge. In: Douglas, B.C., Kearney, M.S., Leatherman, S.P. (Eds.), *Sea Level Rise—History and Consequences*, Academic Press, 37–64.
- Douglas, E. M., Vogel, R. M., and Kroll, C. N., 2000: Trends in floods and low flows in the United States: impact of spatial correlation. *J. of Hydrology*, **240**, 90–105.
- Hirsch, R. M., and Slack, J. R., 1984: Non-parametric trend test for seasonal data with serial dependence. *Water Resour. Res.*, **20**(4), 727–732.
- Hirsch, R. M., Slack, J. R., and Smith, R. A., 1982: Techniques of trend analysis for monthly water quality data. *Water Resour. Res.*, **18**(1), 107–121.
- Hoeffding, W., 1948: A class of statistics with asymptotically normal distribution, *Annals of Mathematical Statistics*, **19**, 293-325.
- Kahya, E., and Kalaycı, S., 2004: Trend analysis of streamflow in Turkey. *J. of Hydrology*, **289**, 128–144.
- Karaca, M., 2000: Implications of Accelerated Sea-Level Rise (ASLR) for Turkey, *Proceeding of SURVAS Expert Workshop on European Vulnerability and Adaptation to impacts of Accelerated Sea-Level Rise (ASLR)*, Hamburg, Germany, 29-31.
- Kendall, M. G., 1975: Rank Correlation Methods, Charles Griffin, London.
- Lettenmaier, D. P., Wood, E. F., and Wallis, J. R., 1994: Hydro-climatological trends in the continental United States, 1948–88. *J. Climate*, **7**, 586–607.
- Libiseller C., and Grimvall, A., 2002: Performance of partial Mann-Kendall tests for trend detection in the presence of covariates. *Environmetrics*, **13**, 71-84.
- Mann, H. B., 1945: Non-parametric tests against trend, *Econometrica*, **13**, 245-259.
- Nicholls, R. J., and Leatherman, S. P., 1995: Global sea-level rise, in *As Climate Changes: Potential Impacts and Implications*, edited by K. Strzepek and J. B. Smith, Cambridge University Press, Cambridge, 92-123.
- Partal, T., and Kahya, E., 2006: Trend analysis in Turkish precipitation data, *Hydrological Processes*, **20**, 2011–2026.
- Reinhard, E. F., Murray, J. F., and Ewing, L. C., 2003: Trends in United States tidal datum statistics and tide range. *J. of Waterway, Port, Coastal and Ocean Eng.*, **129**(4), 155-164.
- Unnikrishnan, A. S., and Shankar, D., 2007: Are sea-level-rise trends along the coasts of the north Indian Ocean consistent with global estimates?, *Global and Planetary Change* (in press).
- Woodworth, P. L., Tsimplis, M. N., Flather, R. A., and Shennan, I., 1999: A review of the trends observed in British Isles mean sea level data measured by tide gauges. *Geophys. J. Int.*, **136**, 651-670.
- Yu, Y. S., Zou, S., and Whittemore, D., 1993: Nonparametric trend analysis of water quality data of rivers in Kansas. *J. of Hydrology*, **150**, 61–80.

- Yue, S., and Hashino, M., 2003: Temperature trends in Japan: 1900–1996. *Theor. Appl. Climatol.*, **75**, 15–27.
- Zervas, C., 2001: Sea level variations of the United States 1854-1999. NOAA Technical Report NOS CO-OPS 36, Maryland, p80.
- Zhang X, Vincent, L. A., Hogg, W. D., and Niitsoo, A., 2000: Temperature and precipitation trends in Canada during the 20th century. *Atmosphere Ocean*, **38**(1), 395–429.