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RESEARCH ARTICLE - HYDROLOGY

Climate change impacts on sea surface temperature (SST) trend around Turkey seashores

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Abstract
This paper focuses on sea surface temperature (SST) trends due to the importance of temperature difference in climate change impact research. These trends are not only essential for climate, but they are also important for marine ecosystem. Immigration of fish population due to the temperature changes is expected to cause unexpected economical results. For this purpose, both classical Mann–Kendall, (MK) (Mann in Econom: J Econom Soc 13:245–259, 1945; Kendall in Rank Correlation Methods, Charless Griffin, London, 1975) and innovative trend analysis (ITA) (Şen in J Hydrol Eng 17(9):1042–1046, 2012) methodologies are applied for the SST data records. Monthly SST data are considered along the Black, Marmara, Aegean, and Mediterranean coastal areas in Turkey. SST data are categorized into five clusters considering fish life as "hot," "warm-hot," "warm," "cold," and "very cold." According to ITA, SST in all coastal areas tends to increase except for winter season during "very cold" (0–10 °C) temperatures. The temperature changes in both winter and summer seasons are expected to change the marine life, fish population, tourism habit, precipitation regime, and drought feature.

Keywords Climate change · Sea surface temperature (SST) · Innovative trend analysis · Mann–Kendall · Turkey's seashore · Marine life

Introduction

Sea surface temperature (SST) records are the most important variables, and they are related to the climate change impact and variability. SSTs play significant role in the general circulation model (GCM), which depends on atmosphere and land surface hydro-meteorological variables. GCM scenario projections are necessary for future climate behaviors in which there are different seasonality, trend, and stochastic components. From the climate change point of view, the most significant component is possible trend existence. Throughout history of planet Earth, several changes have been taken place on Earth crust and in the atmosphere. These changes can be observed in the form of sea level fluctuations, global temperature increase, warming in oceans, shrinking in ice sheets, melting of Arctic Sea ice, glacial retreat, extreme weather events, ocean acidification, and decrease in snow cover (Renner et al. 2014). Today, some of these changes are more significant than before, and they are especially due to human related changes as rapid and unplanned urbanization, industrialization, population growth and economic developments. The Southeast Asian records recently indicate interesting

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regional changes in the relative sea level (Meltzner et al. 2017). Smith et al. (2020) estimated that ground ice loss was on the average about 320 gigatons per year from 2003 to 2019 causing to 14 mm sea level rise. Ocean acidification has also occurred in the ocean surface over the past 100 years (Caldeira and Wickett 2003; Gattuso et al. 2014). SST changes are fundamental drive for climate change assessments. SST trends and their relationships with climate change can guide to sustainable designs and healthier future social and environmental aspects than past and present. It is, therefore, necessary to invest and figure out global and regional temperature changes in air, soil, and water as well to maintain and to protect natural life by trying to keep temperature increment within acceptable limits.

SST trends affect marine life, habitats, oceanographic events, and ecosystem directly or indirectly, and therefore, their refined assessments provide significant information for various social, economic, and commercial activities. Gürarslan (2010) showed that climate change significantly affects Black Sea anchovies and Sezgin (2016) investigated the effects of temperature on the sex of loggerhead sea turtle (*Caretta caretta* L.). Mol and Doğruyol (2012) indicated the mass fish deaths due to the SST trends in the seas around Turkey. Similarly, Kayhan et al. (2015) mentioned that the change in SST adversely affects the marine ecosystem, fish stocks, fisheries, and aquaculture.

Trend identification behavior on the SST data has been analyzed by several researchers using variety of methodologies (Trenberth et al. 2010; González et al. 2013; Bouali et al. 2017; Amos et al. 2017; Şişman 2021). Robertson et al. (2002) considered the trend identification in deep waters of the Weddell Sea, which lead to important implications such as ice melting, water formation and regional ocean–atmosphere heat transfer. Johannessen et al. (2004) examined the Arctic climate change and modeled the temperature and sea-ice variabilities. Haylock et al. (2006) used the link between trends in South American total and extreme rainfalls and SST records. Barbosa and Andersen (2009) investigated the trend patterns in global SST by trend-empirical orthogonal function (EOF) analysis to isolate low-frequency variability of SST anomalies in the 1982 SST records. Al-Rashidi et al. (2009) investigated the SST trends in Kuwait Bay and Arabian Gulf. Goikoetxea et al. (2009) observed the southeastern Bay of Biscay over the last 60 years with trends identification and anomalies in the SST records. Deser et al. (2010) are concerned with the patterns and mechanisms of SST variability. On the other hand, Park et al. (2015) provided spatial and temporal variability patterns of SST and warming trends in the Yellow Sea. Shaltout (2019) examined the trends on Red Sea surface temperature using the data from 1982 to 2016. Erişmiş (2019) determined the trends in SST values in the Mediterranean Sea, the Aegean, and the Black Sea using classical trend analysis methods.

There are also SST trend studies concerning some of the seas around Turkey. Kazmin and Zatsepin (2007) studied the long-term winter mean SST variability in the Black Sea between the years 1950 and 2005. Güçlü (2013) showed that change of SST anomalies at the Black Sea Region during 1971 and 2010. Shaltout and Omstedt (2014) analyzed recent SST records and future scenario time series for Mediterranean Sea. Dogan et al. (2015) used the sea level anomalies related with North Atlantic Oscillation (NAO) along the west coasts of Turkey and their consistency with SST trends. Zveryaev (2015) investigated the seasonal differences in inter-seasonal and inter-annual variabilities in the Mediterranean SST values. Sea level trends and the impact of the North Atlantic Oscillation (NAO) on annual mean sea level data are assessed for the Black Sea and the Eastern Mediterranean Sea by Aksoy (2017).

Recently, innovative trend analysis (ITA) method suggested by Şen (2012, 2014) has been successfully applied to several hydro-meteorological variables (Saplioglu et al. 2014; Dabanli et al. 2016; Mohorji et al. 2017). This method has no assumption in contrast to the Mann–Kendal (MK) methodology. ITA method is comparatively simpler and straighter forward than other trend techniques. The ITA and its new version techniques were also applied by several research in the field of time series analyses (Dabanli and Şen 2018; Güçlü et al. 2018, 2019, 2020; Alashan 2018; Almazroui et al. 2019; Şen et al. 2019; Güçlü 2020).

Among the objectives of this study are trend holistic and partial behavior identifications in the SST records from Mediterranean, Aegean, Marmara, and Black seashores around Turkey. For this purpose, the classical Mann–Kendall test and Şen's ITA approaches are used comparatively.

Methodology

The internal structures of the climatological and hydrological data whether dependent or not, can be figured out in a variety of disciplines by trend analyses. Herein, Mann–Kendall and ITA methodology are applied to Turkish SST records.

Innovative trend analysis (ITA)

The application of ITA method requires the division of the original time series into two segments of equal length. Subsequently, both segments are sorted separately in the ascending order and the first segment values (X_i, $i = 1, 2, 3, \ldots, n/2$) are plotted on the x-axis versus the other half series (X_j, $j = 1, 2, \ldots, n/2$) on the y-axis on the Cartesian square coordinate system (Fig. 1). If scatter points fall on the 1:1 (45°) straight

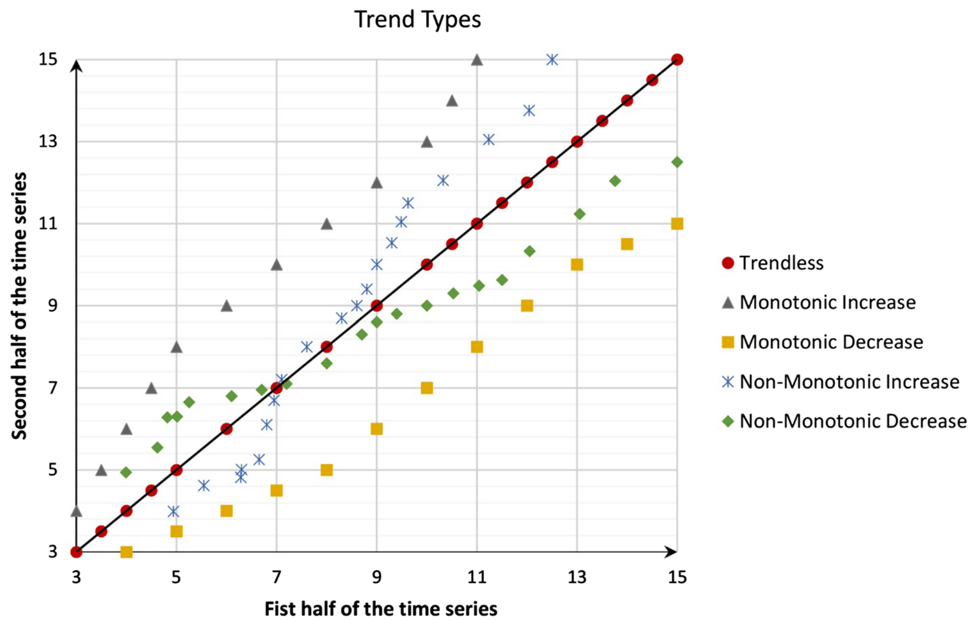

Fig. 1 ITA graph for monotonic and non-monotonic increasing, decreasing and no trends. (Dabanli et al. 2016)

line or very close to it, then there is no significant trend existence (trendless time series).

If the scatter points fall within the lower (upper) triangular area, then a decreasing (increasing) and monotonic or non-monotonic trend exists in the time series structure (Şen 2012, 2014). SST time series subjected to trend analysis can be categorized into five groups or intervals as "very cold," "cold," "warm," "warm-hot," and "hot" depending on the expert opinions. Accordingly, trend interpretations can be made plausibly for each subgroup leading to valuable information for SST record trend possibilities and future data predictions and planning.

In this study, trend envelope lines (percentage lines) are used to better interpret the existing trend pattern around the 1:1 (45°) straight line in a parallel manner and they help to classify trend behavior statistical significances at 1%, 2%, 3%, 4%, 5% and 10% levels as shown in the application and result section graphs. As a result, numerical trend assessments may be achieved more objectively by these straight-line trend envelopes.

Mann–Kendall (MK) trend method

The Mann–Kendall trend identification method is a nonparametric test for monotonic trends only in hydro-meteorological time series (Mann 1945; Kendall 1975).

Mann–Kendall test statistic (S) is followed as,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_j - X_i\right) \quad (1)$$

with

$$\operatorname{sgn}(X_j - X_i) = \begin{Bmatrix} +1; & \text{if } X_j > X_i \\ 0; & \text{if } X_j = X_i \\ -1; & \text{if } X_j < X_i \end{Bmatrix} \quad (2)$$

where X_j and X_i are the sequential rank of j-th and i-th successive measurements data in the time series and n is total number of measurements data.

For $n \geq 10$, the variance is computed by means of the following expression.

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i - 1)(2t_i + 5)}{18} \quad (3)$$

where P is the number of tied groups and t_i is the number of observation data values in the i-th cluster. The MK statistic, Z, values are calculated according to the following equation.

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{If } S > 0 \\ 0 & \text{If } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{If } S < 0 \end{Bmatrix} (4) \quad (4)$$

The standardized test statistic Z is compared with $Z_{\alpha/2}$ for a specified significant level ($\alpha = 5\%$) using a two-tailed test. If $|Z| > |Z_{\alpha/2}|$, one can reject the null hypothesis, H_0, hypothesis and the significantly decreasing or increasing trends are available; otherwise, the alternative hypothesis (H_1) hypothesis is valid, and no trend is available, in cases where $Z = \pm 1.96$ at $a = 5\%$.

Study area and data

The locations of 22 SST record stations on Turkey's seashore are represented in Fig. 2. Six stations (Kumköy, Inebolu, Sinop, Samsun, Ordu, and Hopa) are along the Black Sea coast and two stations (Tekirdag and Canakkale) on the Marmara Sea shoreline, other seven stations (Ayvalik, Dikili, Izmir, Kusadası, Bodrum, Marmaris, and Fethiye) are situated on the Aegean Sea and remaining six stations (Finike, Antalya, Alanya, Anamur, Mersin, and Iskenderun) are located along the Mediterranean Sea coast. The corresponding geographical coordinates of the stations are given in Table 1. SST data records from TSMS were measured at a depth of about two meters every half an hour with automated observing system instruments.

SST dataset covers the records from 1968 to 2014 with variation domain from 3.2 °C in February (Kumköy station) to 31.1 °C in August (İskenderun station). SST data for each station are obtained from Turkish State Meteorological Service (TSMS) (http://www.mgm.gov.tr/) between 1968 and 2014 inclusive.

Table 1 Geographical coordinates of seashore stations

Station name	Seashore	Latitude	Longitude
İnebolu	Black sea	41.9789	33.7636
Sinop		42.0299	35.1545
Samsun		41.3435	36.2553
Ordu		40.9838	37.8858
Hopa		41.4065	41.4330
Tekirdag	Marmara sea	40.9585	27.4965
Kumköy		41.2505	29.0384
Canakkale		40.1410	26.3993
Ayvalık	Aegean sea	39.3113	26.6861
Dikili		39.0737	26.8880
İzmir		38.3949	27.0819
Kusadası		37.8597	27.2652
Bodrum		37.0328	27.4398
Fethiye		36.6264	29.1239
Marmaris		36.8395	28.2452
Antalya	Mediterranean sea	36.9063	30.7990
Alanya		36.5507	31.9803
Anamur		36.0678	32.8588
Mersin		36.7752	34.6018
İskenderun		36.5888	36.1548
Finike		36.3022	30.1465

Application and results

In marine fauna optimal fish water temperatures can be divided into three groups as "cold," "warm," and "hot" (Chu et al. 2009). In this study, warm and cold temperatures are further split up into two subgroups to describe transition process in an innovative manner. In the implementation of trend analysis, five temperature categories are considered as "hot," "warm-hot," "warm," "cold," and "very cold," which are related to fish ecosystem.

Application of the ITA method, for monthly mean SST on the Black Sea coast at Sinop station, is presented in Fig. 3 as a significant trend. The dashed straight lines represent the trend scatter area, where positive and negative deviations

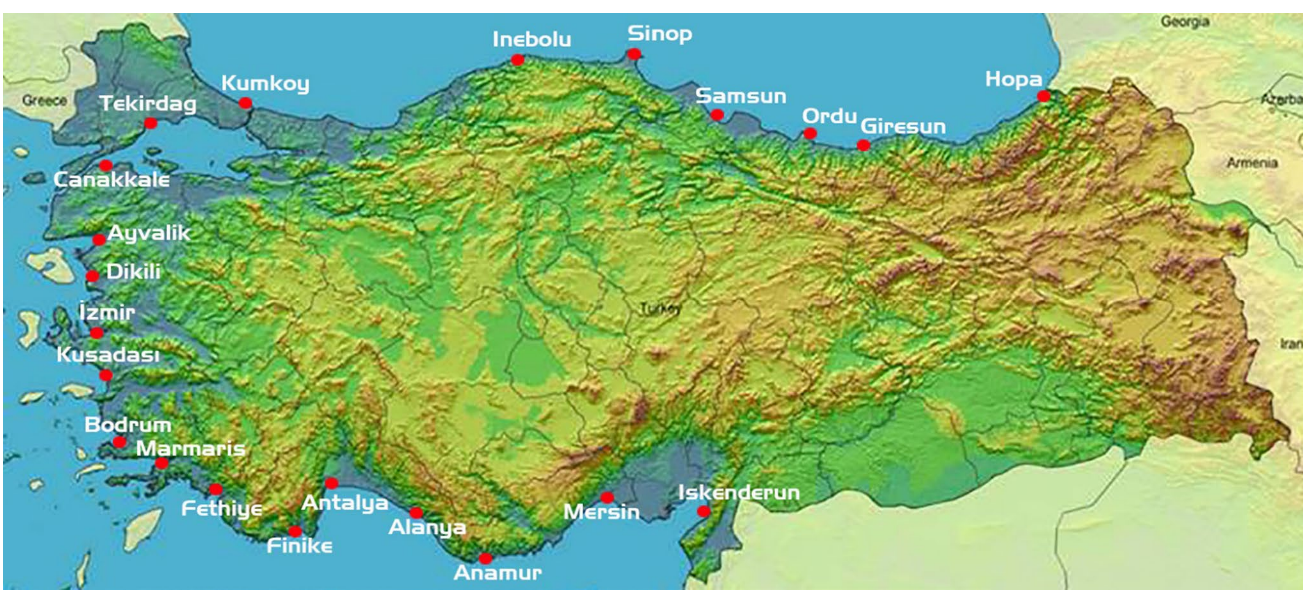

Fig. 2 Geographical location of seashore stations over Turkey mainland

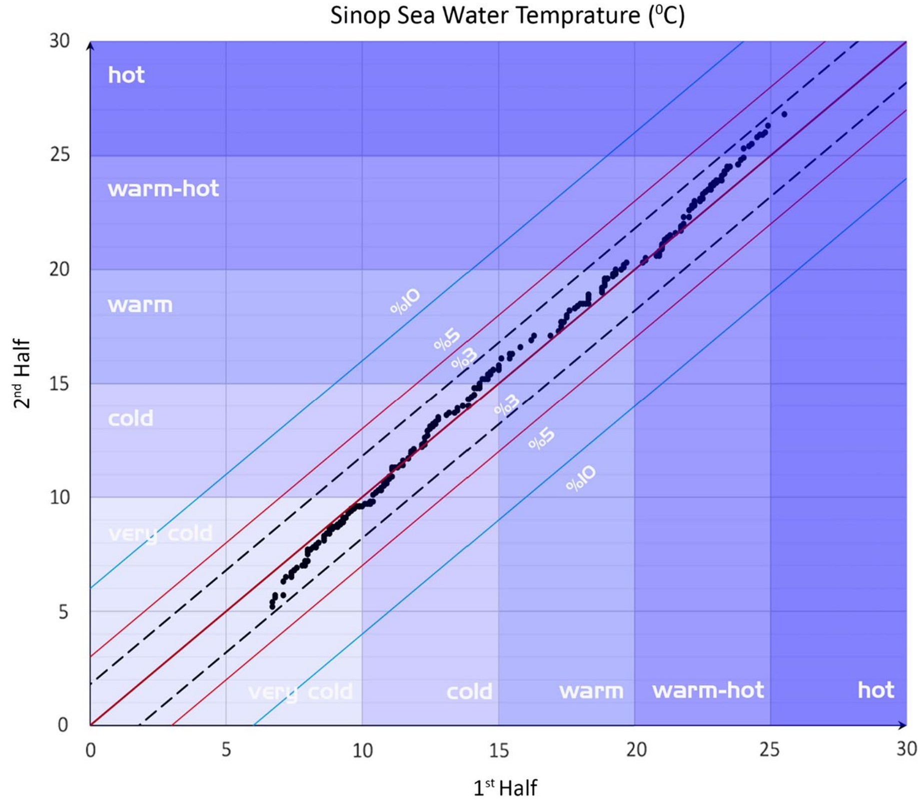

Fig. 3 ITA results on monthly mean SST data series at Sinop station

appear from the 1:1 straight line. Data points on the graph illustrate an increasing (decreasing) trend existence based on the above (below) position with respect to the 1:1 (45°) straight line. From this figure, one can see that trend behavior at Sinop coastal area has SST fluctuations between ± 3% limits. Especially, “warm-hot” and “hot” temperatures increase rapidly by + 3% in the form of positive trend. Another interpretation of the graph is that winter season SST measurements have descending trends. This behavior can be interpreted such that extreme events in winter season are more frequent than past cases on the Black Sea coasts.

Another station on the Marmara Sea coast is Tekirdag, and its categorical trends are illustrated in Fig. 4. This station SST has an increasing trend for all categories except a small group of data for the “warm” class. Especially, in “warm-hot” and “hot” temperatures increasing trends are approximately close to the + 4% parallel line, which implies that the mean temperature shifts from 26 to 27.04 °C in hot waters. It is understood from the same figure that negative -1% weak trend exists in “warm” temperature interval.

Figure 5 represents the categorical ITA scatter points for Aegean Sea station SST records at Dikili shores. It is obvious that monthly average SST is “cold” in winter season. Unexpectedly, “cold” sea water temperatures show a strong decreasing trend close to -4% trend line. However, “warm,” “warm-hot” and “hot” temperatures imply an increasing trend. In these sub-categories, increasing trend reaches + 4% in “hot” waters, because long summer season may trigger this process.

Finally, Fig. 6 presents the categorical innovative trend pattern from the Mediterranean Sea coast at Antalya station. General climate behavior at this station is hot because its location is on the south coast of Turkey, which is closer to the tropical climate zone of the world. The figure suggests that annual SST is above the 15°, and therefore, it is not possible to refer to cold waters. The trend envelope lines remain between − 2% and + 2%. A close inspection of the scatter points indicates ascending trend behavior, especially in the hot waters.

The results of these analyses suggest that recently average SST values increase along the whole coastal areas of Turkey, which is clearly seen from the detailed information presented in Table 2.

On the other hand, all SST datasets are also examined with MK trend test to compare the results with ITA method results. MK test gives only unique result as whether positive or negative trends. Positive trends are detected at six stations only (Kusadasi, Marmaris, Finike, Anamur, Mersin, and Iskenderun), and remaining stations’ results do not imply any trend. However, as it is obvious from the same table, ITA (Innovative-Şen) test presents detailed trend behavior for each sub-category.

ITA and MK analyses show that it is not possible to have a common result for trend behavior in four shores. One can

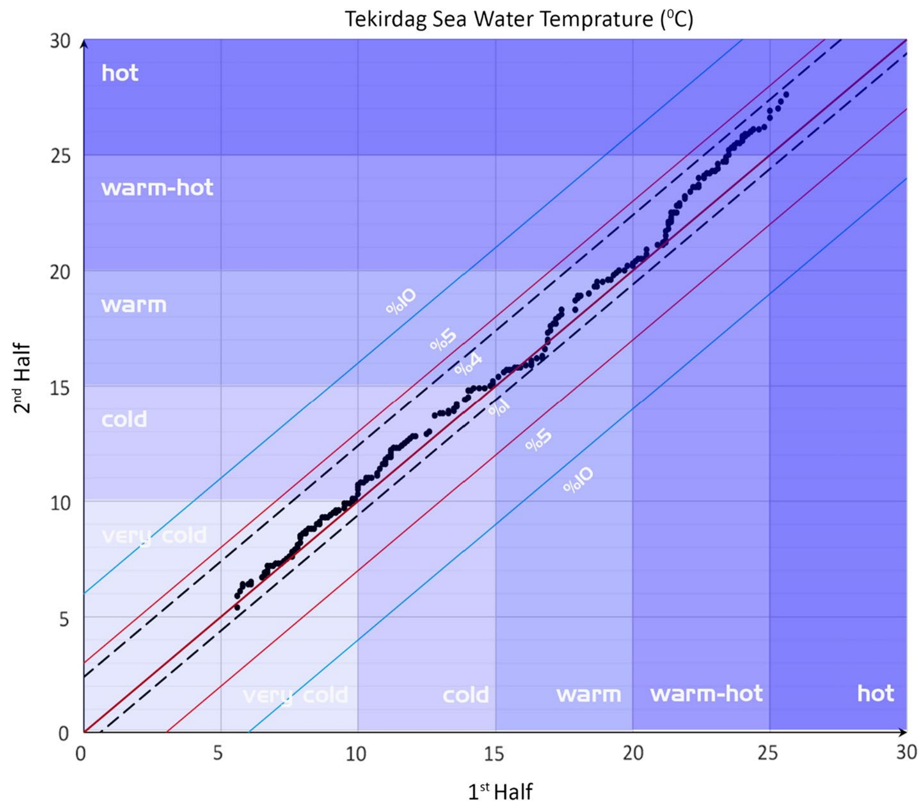

Fig. 4 Illustration of ITA results on monthly mean SST data series at Tekirdag station

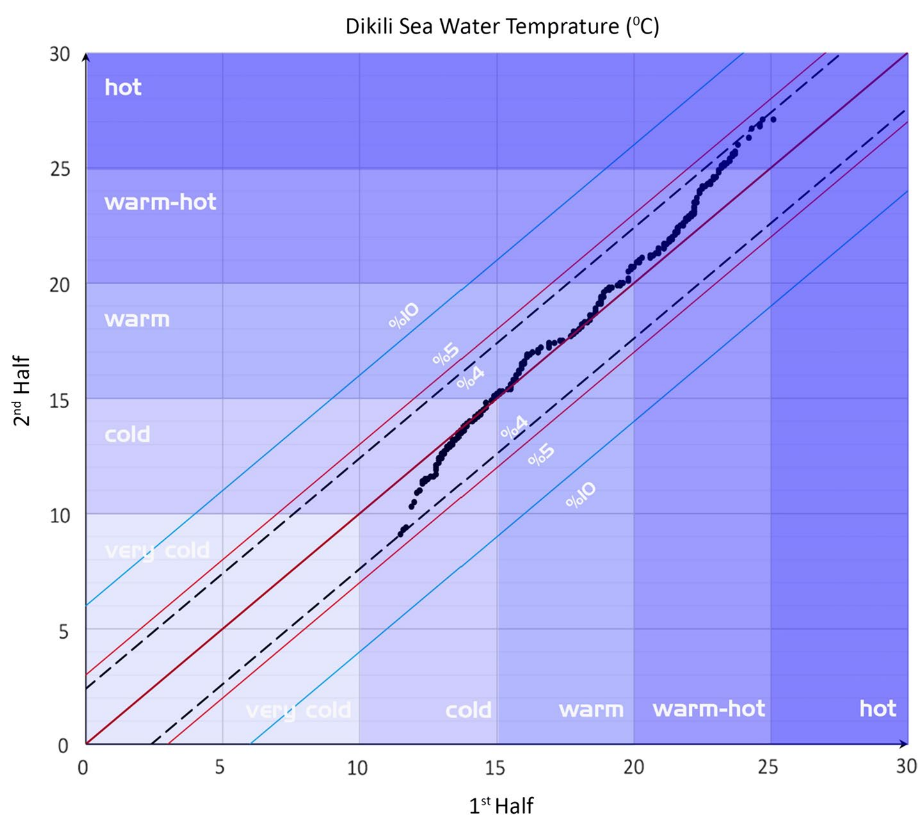

Fig. 5 Illustration of ITA results on monthly mean SST data series at Dikili station

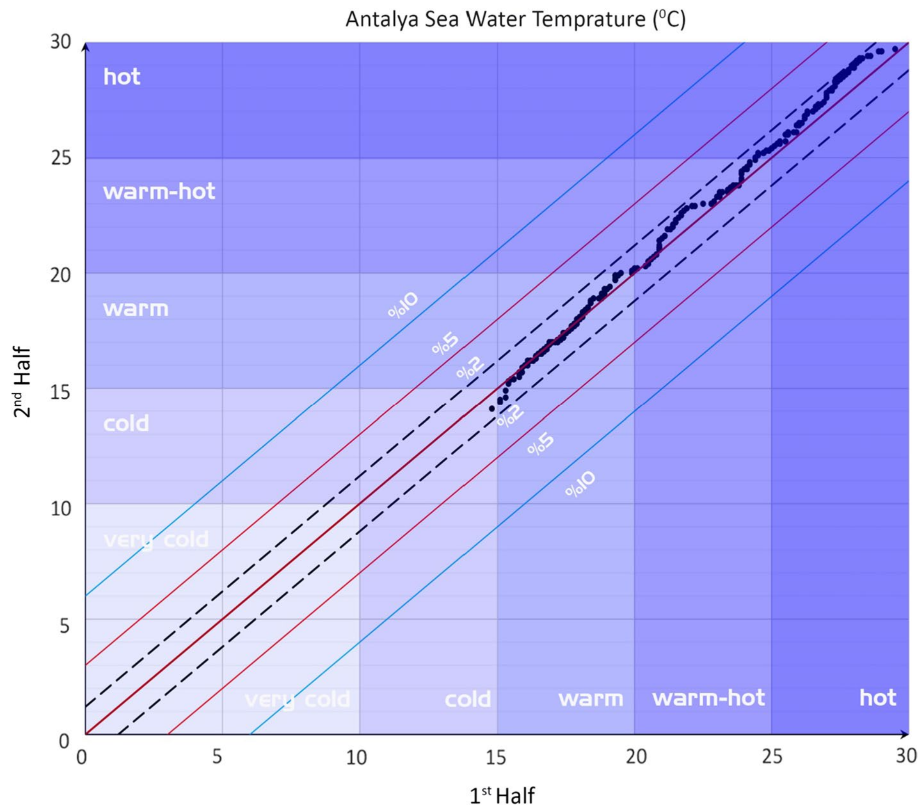

Fig. 6 ITA results on monthly mean SST data series at Antalya station

say that even if MK test does not present any trend in considered stations, ITA test presents trend or characteristic each five classification. It can be said that all warm water temperatures tend to increase in all regions according to ITA. These outputs may relate to frequency increase in the hot and long summer season due to the global warming and consequent climate change impact. MK test result shows trend for Aegean and Mediterranean shores only. All trends in these stations have positive tendency. The ITA and MK trend results are consistent in the Mediterranean region.

One can have general scientific ideas about relationship between the fish recruitment and SST values in different seasons. Fish population needs optimal water temperature range for laying, growing, and feeding activities. If temperature tolerance is exceeded for any fish population, it is necessary that recruitments must adjust for sustainable temperature. Especially in hot seasons, water temperature tends to increase according to the ITA analysis on each region and this is why one expects to shift cold water fish population to cooler regions. Without analysis, it is hard to claim consistency between SST temperature and fish recruitment or fish population behavior, but it is clear that when the optimal temperature range changes, fish population may try to move toward convenient destination for food availability. Otherwise, fish population size is bound to decrease gradually.

Furthermore, higher temperatures accelerate metabolic activities in fish, and hence, food demand increases in warmer waters (Meekan et al. 2003; Sponaugle et al. 2006). When the balance between main food sources in seas (phytoplankton and zooplankton) is considered, the SST temperature changes take place, especially in higher temperatures, and therefore start to disrupt this balance. Possibly, a seasonal increase in phytoplankton due to recruitment may lead to increase in zooplankton and a consequential decrease in phytoplankton. Decreasing phytoplankton is followed by a declining zooplankton and initiation of the cycle again (Robitzch and Berumen 2020).

Conclusion

Trend analysis is one of the fundamental ways to identify possible average changes in any hydro-meteorological time series like SST records. The innovative trend analysis (ITA) methodology provides linguistically qualitative, graphically objective, and visible trends without any assumptions. In this paper, the ITA method is applied by considering five categorizations ("hot," "warm-hot," "warm," "cold," and "very cold") for SST records in Turkey seashores. The basis of this categorization depends on optimal water temperatures for marine life. On the other hand, Mann–Kendal (MK) trend test is also applied for each time series at each station to compare its results with the ITA results. The suggested trend envelope lines in the ITA provide scientific basis for

Table 2 Innovative trend analysis and MK trend method results

Sea coast	Station	ITA test							MK test		
		Very Cold 0–10 °C	Cold 10–15 °C	Warm 15–20 °C	Warm-hot 20–25 °C	Hot 25–31 °C	MK test statistic	Calculated Z value	*Critical Z value* α = *5%*	H0 hypothesis	Trend (±)
Black Sea	Hopa	%(− 2,0) Decrease	%(− 1,0) Decrease	%(− 2,0) Decrease	%(0, + 2) Increase	%(+ 1, + 2) Increase	2474	0.6345	± 1.96	Accept	No
	Ordu	%(− 3,0) Decrease	%(0, + 2) Increase	%(− 1,0) Decrease	%(− 1,0) Decrease	–	3083	0.4765	± 1.96	Accept	No
	Giresun	%(− 2,0) Decrease	%(0, + 1) Increase	%(− 2,0) Decrease	%(− 1, + 1) No	%(0, + 1) Increase	3166	0.5653	± 1.96	Accept	No
	Samsun	%(− 1,0) Decrease	%(− 1,0) Decrease	%(− 1,0) Decrease	%(− 1, + 1) No	%(0, + 1) Increase	− 63	0.991	± 1.96	Accept	No
	Sinop	%(− 3,0) Decrease	%(0, + 1) Increase	%(0, + 2) Increase	%(0, + 2) Increase	%(+ 1, + 3) Increase	6892	0.1853	± 1.96	Accept	No
	Inebolu	%(0, + 1) Increase	%(0, + 2) Increase	%(0, + 3) Increase	%(+ 1, + 2) Increase	–	7919	0.0861	± 1.96	Accept	No
	Kumköy	%(+ 1, + 2) Increase	%(0, + 2) Increase	%(0, + 2) Increase	%(+ 1, + 3) Increase	%(+ 2, + 3) Increase	9577	0.0819	± 1.96	Accept	No
Marmara Sea	Tekirdag	%(0, + 1) Increase	%(0, + 2) Increase	%(0, + 2) Increase	%(0, + 3) Increase	%(+ 2, + 4) Increase	8563	0.0635	± 1.96	Accept	No
	Canakkale	%(0, + 1) Increase	%(0, + 2) Increase	%(0, + 3) Increase	%(0, + 4) Increase	%(+ 2, + 4) Increase	10,268	0.0622	± 1.96	Accept	No
Aegean Sea	Ayvalik	%(− 3,0) Decrease	%(0, + 2) Increase	%(0, + 2) Increase	%(0, + 3) Increase	%(+ 1, + 3) Increase	4852	0.2931	± 1.96	Accept	No
	Dikili	–	%(− 3,0) Decrease	%(0, + 2) Increase	%(+ 1, + 4) Increase	%(+ 3, + 4) Increase	6517	0.2104	± 1.96	Accept	No
	Izmir	%(− 1, + 1) No	%(0, + 1) Increase	%(0, + 1) Increase	%(0, + 1) Increase	%(0, + 2) Increase	3883	0.4807	± 1.96	Accept	No
	Kusadasi	–	%(− 1,0) Decrease	%(0, + 2) Increase	%(+ 1, + 3) Increase	%(+ 2, + 4) Increase	10,453	0.0158	± 1.96	Reject	Yes (+)
	Bodrum	–	%(− 2,0) Decrease	%(− 1, + 1) No	%(0, + 3) Increase	%(+ 2, + 4) Increase	8527	0.1214	± 1.96	Accept	No
	Marmaris	–	–	%(0, + 1) Increase	%(0, + 2) Increase	%(+ 1, + 2) Increase	10,152	0.0278	± 1.96	Reject	Yes (+)
	Fethiye	–	–	%(0, + 1) Increase	%(0, + 2) Increase	%(0, + 2) Increase	7580	0.1686	± 1.96	Accept	No

Table 2 (continued)

Sea coast	Station	ITA test							MK test		
		Very Cold 0–10 °C	Cold 10–15 °C	Warm 15–20 °C	Warm-hot 20–25 °C	Hot 25–31 °C	MK test statistic	Calculated Z value	*Critical Z value* α = *5%*	H0 hypothesis	Trend (±)
Mediterranean Sea	Finike	–	–	%(0, +2) Increase	%(0, +3) Increase	%(+1, +3) Increase	11,633	0.0072	±1.96	Reject	Yes (+)
	Antalya	–	–	%(0, +1) Increase	%(0, +2) Increase	%(0, +2) Increase	5327	0.3059	±1.96	Accept	No
	Alanya	–	–	%(0, +2) Increase	%(0, +2) Increase	%(+1, +3) Increase	8946	0.0855	±1.96	Accept	No
	Anamur	–	–	%(0, +2) Increase	%(+1, +2) Increase	%(+1, +3) Increase	12,010	0.0055	±1.96	Reject	Yes (+)
	Mersin	–	%(+2, +4) Increase	%(+1, +3) Increase	%(+1, +4) Increase	%(+1, +3) Increase	16,521	0.0001355	±1.96	Reject	Yes (+)
	Iskenderun	–	–	%(0, +2) Increase	%(0, +2) Increase	%(0, +2) Increase	12,959	0.0186	±1.96	Reject	Yes (+)

(+): increasing trend; (−): decreasing trend; (+,–): no trend; (–): no Data detailed interpretations. The results are discussed based on the ITA graphs and tables for various situations with comparison to MK trend test results. The ITA method helps to determine the trend behaviors for each category in detail. Based on this study, it is documented that climate change has noticeable effects on the SST records at Turkey seashores. Besides, during the extremely cold winter seasons "very cold" temperatures have frequently decreasing trends. This also shows that climate change triggers extreme events even in cold seasons. These trends may cause to shift in the marine life and fish specious in coastal areas. Consequently, these results support that the study area is expected to be more vulnerable to hot seasons and extremely short but cold seasons in the future.

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Compliance with ethical standards

Conflict of interest Not Applicable.

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