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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Forecasting sea surface temperature with feed-forward artificial networks in combating the global climate change: The sample of Rize, Türkiye

Küresel iklim değişikliğiyle mücadelede deniz yüzeyi sıcaklığının ileri beslemeli yapay sinir ağları ile tahminlenmesi: Rize örneği, Türkiye

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Abstract: The increase of the world population, especially in the global competition, together with the increasing use of fossil fuel resources to meet energy needs, leads to more greenhouse gases (more than one CO_2, methane etc.) emissions and the global climate crisis. In this process, changes in meteorological events such as temperature, precipitation, and wind, attract attention moreover but when considered as a whole, we know that these negative changes in the ecosystem negatively affect many living groups. Sea Surface Temperature (SST) as measured meteorologically is the most important environmental parameter where these changes are monitored and observed. It draws attention to the fact that changes in SST are not limited to living organisms as habitats, but also catalyze many chain reactions, especially socio-economic impacts. Therefore, much of the work is devoted to forecasting studies to adapt to changing habitats and take the necessary precautions against potential risks. Feed-forward artificial neural networks have been commonly used to address these emerging needs. Artificial neural networks, which are a simple imitation of the human neurological system, have been used as an artificial intelligence method in forecasting problems due to their superior performance and not having the limitations of classical time series. In this study, the forecasting of the time series of monthly mean SST temperature obtained from Rize station between the years 2010 and 2020 is performed by using feed-forward artificial neural networks, and the forecasting performance of the corresponding time series is compared with many forecasting methods with different characteristics. The comparison of the methods used the mean square error and mean absolute percentage error criteria, which are commonly used in the forecasting literature. The analysis results showed that the analysis results obtained with the feed-forward artificial neural networks have the best prediction performance. As a result, it can be stated that the sea surface temperature can be forecasted with a very high accuracy using the feed-forward artificial neural networks.

Keywords: Artificial neural network, sea surface temperature, global climate change, Rize

Öz: Küresel rekabet başta olmak üzere dünya nüfusundaki artış beraberinde enerji gereksinimlerini karşılamak adına fosil yakıt kaynaklarının kullanımının artmasına bu durum da sera gazlarının daha fazla salınmasına (daha fazla CO_2, metan, vb.) ve küresel iklim değişikliğine neden olmaktadır. Bu süreçte başta sıcaklık, yağış ve rüzgâr gibi meteorolojik olaylarda yaşanan değişikler dikkat çekmekle birlikte, bir bütün olarak değerlendirildiğinde ekosistemde meydana gelen bu olumsuz değişimlerin pek çok canlı grubunu da olumsuz etkilediği bilinmektedir. Deniz suyu sıcaklığı bu değişikliğin izlendiği ve gözlemlendiği en önemli çevresel parametre olup, deniz suyunda meydana gelen değişimlerin sadece habitat olarak yaşam faaliyetlerini sürdüren canlılarla sınırlı kalmayıp, aynı zamanda sosyoekonomik etkileri başta olmak üzere zincirleme birçok reaksiyonu katalize etmesiyle de dikkat çekmektedir. Dolayısıyla değişen yaşam koşullarına adaptasyon sağlamada ve olası risklere karşı gereken önlemin alınması noktasında öngörü çalışmalarına büyük iş düşmektedir. Son zamanlarda meydana gelen bu gereksinimleri karşılamak adına ileri beslemeli yapay sinir ağlarından sıkça faydalanılmaktadır. İnsan nörolojik sisteminin basit bir taklidi olan yapay sinir ağları, klasik zaman serisi yöntemlerinin sahip olduğu kısıtlamalara sahip olmaması ve üstün performansı ile öngörü problemlerinde araştırmacılar tarafından sıklıkla kullanılan bir yapay zekâ yöntemi olarak kullanılmaktadır. Bu çalışmada Rize istasyonundan 2010-2020 yılları arasında elde edilen aylık ortalama deniz suyu sıcaklığına ait zaman serisinin tahmini ileri beslemeli yapay sinir ağları ile birlikte gerçekleştirilmiş olup ilgili zaman serisinin tahmin performansı farklı özelliklere sahip birçok öngörü yöntemi ile de karşılaştırılmıştır. Yöntemlerin karşılaştırılmasında öngörü literatüründe sıklıkla kullanılan hata kareler ortalaması karekök ve ortalama mutlak yüzdelik hata kriterleri kullanılmış olup elde edilen analiz sonuçlarına göre ileri beslemeli yapay sinir ağları ile elde edilen analiz sonuçlarının en uygun öngörü performansına sahip olduğu görülmüştür. Sonuç olarak; ileri beslemeli yapay sinir ağları yönteminden faydalanılarak deniz suyu yüzey sıcaklığının çok yüksek doğruluk oranı ile tahmin edilebileceği ifade edilmektedir.

Anahtar kelimeler: Yapay sinir ağları, deniz yüzey sıcaklığı, küresel iklim değişikliği, Rize

INTRODUCTION

The unique feature of water, which is the dominant compound of the chemical structure and is the basis of life on Earth; is its atomic structure, bonds, and bonding abilities in different phases of water molecules. One of the most important

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environmental factors determining the behaviour of not only biological life, but also the water in the biosphere is temperature. Especially in aquatic ecosystems, water temperature is important as it causes direct and/or indirect changes in many physical and chemical variables of seawater (Akbari et al., 2017). It is known that sudden and large-scale changes in temperature in marine ecosystems, regardless of their origin, can cause stresses that may result in death in biological life. Likewise, in species of economic importance such as fish; It has been found to have a direct effect on forage finding and utilization, metabolism and vitality, changes in migration routes, and spawning (Houlihan et al., 2001). On the other hand, especially within the scope of combating the global climate crisis, the Intergovernmental Panel on Climate Change (IPCC) states that the definition of seawater temperatures is one of the most important environmental parameters in studies on climate change (Houghton, 1996).

Marine areas are affected by many factors such as water temperature, atmospheric oscillations, precipitation, density changes, and current systems. In this direction, water temperature is among the most important variables monitored in many studies so far, especially in the sea, in different habitats such as rivers (Daigle et al., 2017) and lakes (Sharma et al., 2015). The data for detailed analysis of trends in the seawater temperature; climate change-induced negative or opportunities for the evaluation of different fields and sectors is important for hydrology, meteorology, agriculture, livestock, tourism, etc. Moreover, in the studies where the changes and trends in seawater temperatures were evaluated in detail, deficiencies were found by Şişman (2019). This study, it is aimed to estimate the seawater temperature by using foresight methods. This provides a great advantage both in the creation of action plans that contribute significantly to national and international institutions/organizations in the long-term struggle, especially in the global climate crisis scenarios, and in the determination of possible changes in biological life. For this purpose, the time series of the monthly average seawater temperature obtained from the Rize station between 2010 and 2020 is analysed. In the analysis phase, first of all, the structure of the relevant time series is examined and, other analysis methods suitable for the data structure are determined. The analytical performance of these determined analysis methods and the feed-forward artificial neural network method is compared with some error criteria frequently used in the forecasting literature.

MATERIAL AND METHODS

Study Area

In this study, long-term seawater surface temperature data measured by the Rize meteorological observation station located on the Black Sea coast are used. All data have been obtained from the Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, Turkish State Meteorological Service.

The surface area of Rize, which is located in the Eastern Black Sea Region, is 3920 km² and the length of the coastline is 80 km (Ay and Duman, 2015). There are many rivers in this region due to the slope and flat areas, and these rivers carry their waters to the Black Sea (Tecer and Cerit, 2009).

Methods

The methods used in this paper are Seasonal Naive, ETS (error, trend, seasonal), SARIMA (autoregressive integrated moving average), and feed-forward artificial neural network methods. In the analysis phase, some functions in the "forecast" package in R software prepared by Hyndman and Khandakar (2008) and Hyndman et al. (2021) are used.

The Seasonal Naive Method

The logic of the seasonal naive method is similar to the naive method, but with the seasonal naive method, the forecast is taken as the last observed value of the same season of the year. The seasonal naive method is used in the analysis of time series containing seasonality. A forecast for the seasonal naive method can be obtained by Equation (1).

$$\hat{x}_{t+h} = x_{t+h-s(k+1)} \qquad (1)$$

In Equation (1), s is the seasonal period, k is the full part of $(h-1)/s$, and h is the number of forecast steps.

ETS Method

ETS (Error, Trend, Seasonal) method is a univariate analysis method used in the analysis of time series containing trend and/or seasonal components. The first letter of the ETS method indicates the error type ("A", "M" or "Z"); the second letter is the trend type (“N”,” A”,”M” or “Z”); the third letter represents the seasonality type (“N”,” A”,”M” or “Z”). From these expressions, “N” =none, “A” =addition, “M” =multiplicative and “Z” =auto. The ETS method automatically selects the best method among different combinations of error, trend, and seasonality types.

SARIMA

The SARIMA method, known as the seasonal ARIMA method, is used in the analysis of time series containing seasonality. The automatic SARIMA method proposed by Hyndman and Khandakar (2008) is an automatic analysis method whose purpose is to find the best model of the SARIMA model.

Feed Forward Artificial Neural Networks

Feed-forward artificial neural network (FF-ANN) is one of the most commonly used artificial neural network models. FF-ANN is a feed-forward artificial neural network that produces a series of outputs from a series of inputs. In FF-ANN, information is transferred from the input layer to the output layer through hidden layers. Each unit in a layer is linked to all units in the previous layer. Each link can have different weights. Although obtaining the weights in the network structure is known as an optimization problem, this process is called the

training of the network. Rumelhart et al. (1986) used the backpropagation algorithm to update the weights. The data passes from layer to layer in the network until it reaches the output layer, and there is no feedback between the layers. For this reason, these artificial neural networks are called feed-forward neural networks.

The architecture of FF-ANN with two hidden layers with m inputs is given in Figure 1. In Figure 1, the first layer is called the input layer, and the last layer is called the output layer. The layers between these two layers are also hidden layers.

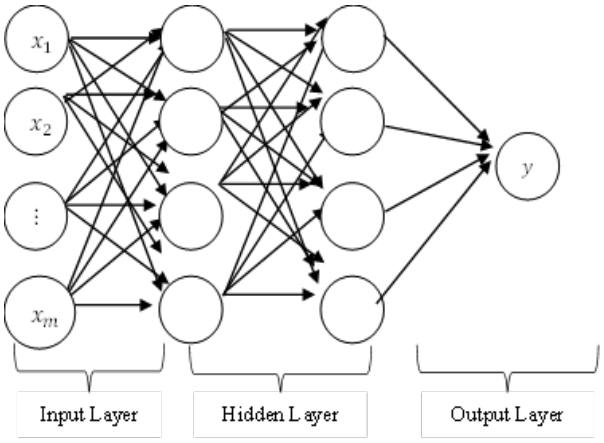

Figure 1. A two hidden layer architecture with m inputs

RESULTS

In this study, the time series of mean seawater temperature (RIAODSS) obtained monthly from Rize station between the years 2010 and 2020 are forecasted. The graph of the relevant time series is given in Figure 2.

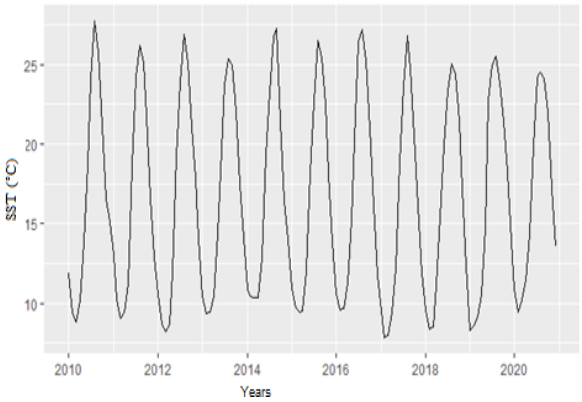

Figure 2. Average seawater temperature (SST) obtained monthly from Rize station between the years 2010-2020

When the time graph of "RIAODSS" given in Figure 2 is examined, at first glance, it is seen that there is seasonality in the data. To confirm the accuracy of this situation, the autocorrelation and partial autocorrelation graphs created for the "RIAODSS" time series are as in Figure 3 and Figure 4.

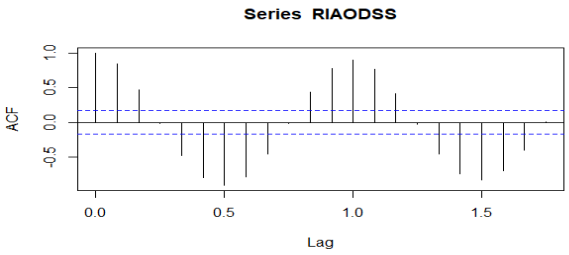

Figure 3. Autocorrelation plot for RIAODSS time series

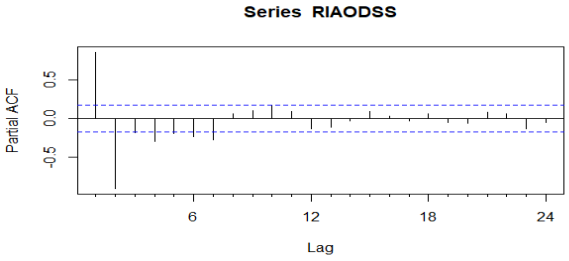

Figure 4. Partial autocorrelation plot for RIAODSS time series

When Figures 3 and 4 are examined, it can be stated that the RIAODSS time series has a dominant seasonal component. When the seasonality graph given in Figure 5 of the RIAODSS time series is examined, it is revealed that the relevant series has seasonality.

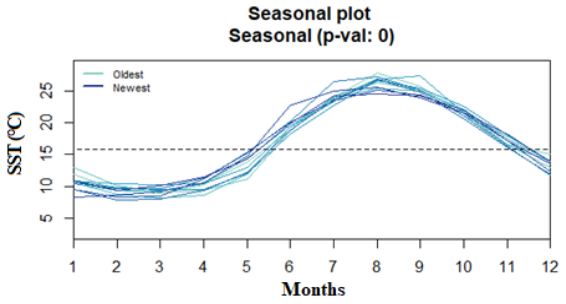

Figure 5. Seasonality graph of the RIAODSS time series

In this study, the RIAODSS time series is analyzed by Seasonal Naive, ETS, and SARIMA methods apart from the FF-ANN method. In the analysis phase, the last 12 observations (last one year) of the "RIAODSS" time series are taken as the test set. In the analysis of the RIAODSS time series with the FF-ANN method, the number of hidden layers is 1, the number of hidden layer elements is 2, the maximum number of iterations is 1000, and the training algorithm is the "Quickprop" algorithm. Two lagged variables (x_{t-1}, x_{t-12}) are used as the input of the network. The results for the root mean square error (RMSE) and mean absolute percentage error (MAPE) criteria values of the test set obtained from all methods are given in Table 1. The values of RMSE and MAPE error criteria are calculated by Equation (2) and Equation (3).

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(x_t - \hat{x}_t)^2}{n}} \quad (2)$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{x_t - \hat{x}_t}{x_t}\right| \quad (3)$$

In Equation (2) and Equation (3), n, x_t and $\hat{x}_t$ are the number of learning samples, observed values, and predictive values respectively.

Table 1. RMSE and MAPE error criteria values obtained by all methods for the "RIAODSS" time series

Method	RMSE	MAPE
Seasonal Naive	1.29	7.01
ETS (M, N, M)	0.80	4.14
SARIMA	0.81	3.98
FF-ANN	1.21	0.90

When the analysis results given in Table 1 are examined, the best forecasts are obtained with a 0.90% error rate, especially considering the MAPE criterion, with the FF-ANN method. In addition, the graph of the test set of the RIAODSS time series and the forecasts obtained from the FF-ANN method are determined as in Figure 6.

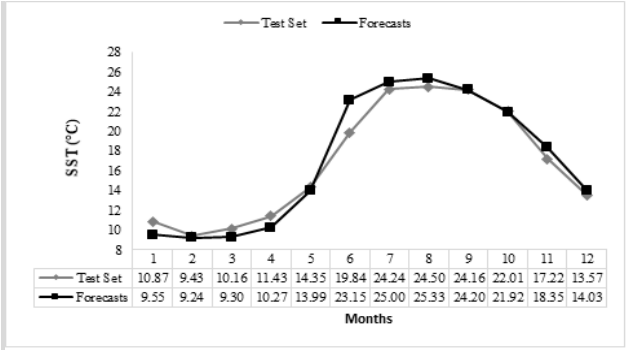

Figure 6. Graph of the test set of RIAODSS time series and the forecasts obtained from the FF-ANN method

Therefore, when the seawater temperatures in Figure 6 are examined, it has been noted that the forecasts and the observation values of the test set are quite compatible.

DISCUSSION

In this study, which is carried out for the first time in our country for the forecasting seawater surface temperatures in Rize province by the FF-ANN method, an accuracy rate of 99.10% is achieved. Although there is no similar study conducted for the current area in the literature, it has been determined that there is a general increase in seawater surface temperatures on the Black Sea coasts, and this trend has been more noticeable, especially in the last 10 years (Ağırbaş and Çakıroğlu, 2021). Similarly, it has been determined by the modeling results that seawater temperatures in the Aegean and Mediterranean coasts have been in a constant warming trend after 1970, and the most significant and significant increase has been recorded in the Iskenderun Bay from 2000 through 2009 (Şişman, 2019). Moreover, it is stated in many other studies that the average seawater temperatures in all our seas in our country tend to increase when the long-term trend is considered (Demircan et al., 2013; Dabanli et al., 2021; Kalıpcı et al., 2021).

In this study, which is carried out with quantitative data and a very high accuracy rate compared to the literature studies, it is revealed that the forecasting seawater surface temperatures in our country can be successfully performed with FF-ANN. With the results obtained in this direction, we provide an advantage in taking possible measures to the global climate crisis scenarios, and our national economic activities; A serious advantage can be gained in making plans for different fields and sectors such as agriculture, and animal husbandry and tourism, etc. Moreover, the determination and prediction of the quantitative change of variables that directly concern biological life, such as seawater temperature; will also help to understand the change of different species, especially fish of commercial importance, and therefore the change of biodiversity. Relatedly, it will provide a serious advantage in determining the dynamic change that commercial fishing activities will face in the short, medium, and long term, and in creating solutions for the problems.

CONCLUSION

As a result, with this study we have done, we can state that the determination of the seawater surface temperature (SST) with a very high accuracy rate, using the FF-ANN method, can be performed with different variables according to needs and purposes, and this will make significant contributions to future action plans.

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AUTHORSHIP CONTRIBUTIONS

All authors contributed equally.

CONFLICT OF INTEREST STATEMENT

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS APPROVAL

The author declare that all applicable guidelines for sampling, care, and experimental use of animals in this study have been followed.

DATA AVAILABILITY

The data sets generated during and/or analysed during the current study will be provided by the corresponding author upon the request of the editor or reviewers.

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