JAES
Journal of Anatolian Environmental and Animal Sciences
(*Anadolu Çevre ve Hayvancılık Bilimleri Dergisi*)
DOI: https://doi.org/10.35229/jaes.1533333
Year: 9, No: 4, 2024 (785-794)
AÇEH
Yıl: 9, Sayı: 4, 2024 (785-794)
ARAŞTIRMA MAKALESİ RESEARCH PAPER

Monitoring Sea Level Changes Along the Coast of Rize, Turkey Throughout the Year

Veli SÜME[1] **Hasan Oğulcan MARANGOZ**[1]*
[1]*Recep Tayyip Erdogan University, 53100, Rize, Türkiye*

Received: *14.08.2024* ***Accepted:*** *23.12.2024* ***Published:*** *31.12.2024*
How to cite: **Süme, V. & Marangoz, H.O. (2024).** Monitoring sea level changes along the coast of Rize, Turkey throughout the year. *J. Anatolian Env. and Anim. Sciences*, ***9***(4), 785-794. https://doi.org/10.35229/jaes.1533333
Atıf yapmak için: **Süme, V. & Marangoz, H.O. (2024).** Rize, Türkiye Kıyılarında Deniz Seviyesi Değişimlerinin Yıl Boyunca İzlenmesi. *Anadolu Çev. ve Hay. Dergisi*, ***9***(4), 785-794. https://doi.org/10.35229/jaes.1533333

*: https://orcid.org/0000-0003-0215-6159
: https://orcid.org/0000-0001-8251-2461

***Corresponding author's:**
Hasan Oğulcan MARANGOZ
Recep Tayyip Erdogan University, 53100, Rize, Türkiye
: hasanogulcan.marangoz@erdogan.edu.tr

Abstract: Global climate change is leading to significant environmental challenges, with sea level rise being one of the most critical. This study focuses on monitoring sea level changes along the Rize coastline in Turkey, a region particularly vulnerable due to its high rainfall and strategic location along the Black Sea. Data from mareograph stations located at İyidere, Çayeli, and Riport Port were collected throughout 2020, providing a detailed analysis of sea level fluctuations. The study used time-series analysis to interpret these changes and identify their relationships with local meteorological factors such as rainfall and atmospheric pressure. The findings reveal short-term fluctuations in sea level that correspond with periods of heavy rain, posing risks to coastal infrastructure and economic activities. While the data is limited to a single year, the study underscores the need for continuous monitoring and adaptive planning in response to local meteorological events and broader climate change trends. This research offers valuable insights for infrastructure planning and disaster management strategies in coastal areas like Rize, where the impacts of sea level rise are becoming increasingly pronounced.
Sea level rise, Climate change, Rize, Tide gauge, Coastal management, Meteorology

Keywords: Sea level rise, climate change, Rize, tide gauge, coastal management, meteorology.

Rize, Türkiye Kıyılarında Deniz Seviyesi Değişimlerinin Yıl Boyunca İzlenmesi

Öz: Küresel iklim değişikliği, deniz seviyesindeki yükselme gibi ciddi çevresel sorunlara yol açmaktadır. Bu çalışma, Karadeniz kıyısında yer alan Rize sahil şeridi boyunca deniz seviyesindeki değişimlerin izlenmesine odaklanmaktadır. Yoğun yağış alan bu bölge, coğrafi konumu nedeniyle iklim değişikliklerine karşı savunmasızdır. İyidere, Çayeli ve Riport Limanı'nda bulunan mareograf istasyonlarından 2020 yılı boyunca elde edilen veriler kullanılmış ve deniz seviyesindeki dalgalanmalar ayrıntılı olarak analiz edilmiştir. Bu değişimler, yerel meteorolojik faktörler (yağış, atmosfer basıncı gibi) ile ilişkilendirilmiş ve zaman serisi analizi kullanılarak yorumlanmıştır. Bulgular, yoğun yağış dönemlerinde deniz seviyesinin kısa vadeli dalgalanmalar gösterdiğini ve bunun kıyı altyapısı ile ekonomik faaliyetler için riskler oluşturduğunu ortaya koymaktadır. Verilerin yalnızca bir yıl ile sınırlı olmasına rağmen, çalışma yerel meteorolojik olaylar ve daha geniş iklim değişikliği eğilimlerine yanıt olarak sürekli izleme ve uyumlu planlama gerekliliğini vurgulamaktadır. Bu araştırma, deniz seviyesindeki yükselmelerin etkilerinin giderek daha belirgin hale geldiği Rize gibi kıyı bölgelerinde altyapı planlaması ve afet yönetim stratejileri için önemli bulgular sunmaktadır.

***Sorumlu yazar:**
Hasan Oğulcan MARANGOZ
Recep Tayyip Erdoğan University, 53100, Rize, Türkiye
: hasanogulcan.marangoz@erdogan.edu.tr

Anahtar kelimeler: Deniz seviyesi yükselmesi, iklim değişikliği, Rize, mareograf, kıyı yönetimi, meteoroloji.

INTRODUCTION

Global climate change has become an increasingly significant concern worldwide in recent years and has emerged as one of the most critical environmental issues (IPCC, 2021). This change is largely due to the increase in greenhouse gases in the atmosphere. In particular, the rise in concentrations of gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) is causing global temperatures to rise (NASA, 2020; NOAA, 2021). This situation is leading to the rapid melting of glaciers in polar regions, consequently resulting in a rise in sea levels (Greenland Ice Sheet Project, 2018; Antarctic Ice Sheet Study, 2019).

Turkey, a country surrounded by seas on three sides, is among the nations directly experiencing the effects of these changes (Turkish State Meteorological Service, 2020). The rise in sea levels poses serious threats, especially for the population living in coastal areas, and negatively impacts economic activities in these regions (Turoğlu, 2017; Çakıcı, 2015). Coastal areas, characterized by high population density and intense economic activities, are significantly affected by such environmental changes (Demir, 2002; Yıldız, 2005). Structures in these regions, including residential areas, tourism facilities, agricultural lands, fishing harbors, and ports, are directly impacted by sea level changes, which could potentially lead to even greater problems in the future (Gürdal, 1998; Sezen, 2006).

Therefore, monitoring sea level changes and taking necessary precautions have become critical requirements for infrastructure and settlement projects in coastal areas (Simav, 2012; Süme, 2011). Particularly in regions with heavy rainfall, like Rize, it is crucial to closely monitor sea level changes (Baltacı, 2010; Polat & Sunkar, 2017). Monitoring and evaluating these changes in Rize is extremely important for both the sustainability of the local economy and the preservation of the community's quality of life (Dağ, 2007; Yalçın & Bulut, 2007).

Some recent studies have investigated the impacts of sea level changes in Turkey, particularly in its vulnerable coastal regions. Similarly, a study by Uludağ et al. (2021) focused on the Mediterranean coast, where rising sea levels and more frequent storm surges threaten key tourist areas like Antalya and agricultural regions. Çelik and Güler (2019) highlighted the Marmara Sea, particularly Istanbul, suggesting that sea level rise, combined with rapid urbanization, puts critical infrastructure at risk, including transportation networks and residential areas. Moreover, Yalçın et al. (2022) explored the Aegean coastline, where coastal erosion and saltwater intrusion are becoming more common, impacting agricultural lands and freshwater resources. These recent studies emphasize the growing need for Turkey to adopt adaptive strategies such as constructing coastal defenses and revising urban planning to mitigate the potential damage caused by sea level rise.

In this study, data obtained from mareograph stations established at İyidere Port on the Rize-Trabzon highway, Çayeli Port on the Rize-Artvin highway, and Riport Port in Rize Center were analyzed (Süme, 2007; TUDES, 2021). The data from these stations aim to reveal the trends in sea level changes over time and their relationship with meteorological events (Simav & Türkezer, 2011; Sezen, 2006). These analyses indicate that sea level changes are closely related not only to regional but also to global climate change (IPCC, 2019; Pugh, 2004)

***Factors Affecting Sea Level Changes*:** Sea level changes are caused by many different factors, which can be effective both globally and locally (Pugh, 2004; IPCC, 2021). On a global scale, factors such as climate change, tidal events, tectonic movements, and ocean currents lead to fluctuations in sea level, while local conditions can also significantly affect these changes (Pugh, 2004; Simav, 2012).

Water level changes are influenced by a complex interplay of global and local factors. On a global scale, climate change is a major driver, as the warming of the planet due to increased greenhouse gases leads to the melting of glaciers and ice caps, contributing to a rise in sea levels (IPCC, 2021). This is further compounded by thermal expansion, where warming water expands and raises sea levels (NASA, 2020). Tidal events, caused by the gravitational forces of the moon and the sun, generate predictable fluctuations in water levels (Pugh, 2004), while tectonic activities, such as undersea earthquakes or land subsidence, can cause sudden shifts, either raising or lowering sea levels (Simav, 2012).

Oceanographic factors also play a significant role. Ocean currents, variations in water temperature, and changes in salinity can lead to regional differences in water levels (Pugh, 2004). Warmer water expands, contributing to higher sea levels, and variations in salinity, due to freshwater input from melting ice or changes in evaporation, can affect water density and sea levels (Geymen & Dirican, 2016).

On a more local scale, meteorological factors such as atmospheric pressure, wind patterns, and precipitation are critical. Low atmospheric pressure systems, such as those associated with storms, can cause temporary sea level rises, known as storm surges (Polat & Sunkar, 2017). Wind can drive water towards coastlines, elevating local sea levels, while heavy rainfall can increase water volumes in rivers and coastal areas, leading to localized flooding (Simav, 2012). Additionally, human activities, including coastal development, land reclamation, and the construction of dams or sea walls, can alter natural water levels, either by directly modifying coastlines or disrupting natural water flow patterns (Sezen, 2006).

Tides are periodic events that cause the sea level to regularly rise and fall, and the gravitational forces of the moon and the sun form the basis of this process (Pugh, 2004; Turoğlu, 2017). The movement of the moon around the earth pulls the seas, causing the sea level to rise; when the moon moves away, the sea level drops again (Yıldız, 2005). While these events are particularly noticeable on ocean coasts, these effects can also be observed in countries surrounded by seas, like Turkey (Sezen, 2006; Gürdal, 1998).

Meteorological conditions are also among the significant factors affecting sea level (Polat & Sunkar, 2017). Changes in atmospheric pressure, the strength and direction of the wind, can cause temporary fluctuations in sea level (Simav, 2012). For instance, low atmospheric pressure causes the sea level to rise, while high pressure leads to a drop in this level (Pugh, 2004). The force exerted by the wind over the sea can cause water to accumulate, especially in shallow areas, leading to coastal flooding (Demir, 2002).

Tectonic movements can cause sudden changes in sea level due to changes in the earth's crust (Simav, 2012). Undersea earthquakes can lead to the rapid rise or fall of sea levels (Demir, 2002). Countries like Turkey, located on active fault lines, are at greater risk of being affected by such tectonic events (TUDES, 2021). Additionally, vertical movements such as the uplifting or sinking of land masses can also trigger changes in sea level (Yıldız, 2005).

Oceanographic factors are among the other important causes of sea level changes. Ocean currents and changes in the physical properties of seawater, particularly fluctuations in temperature and salinity, can lead to significant changes in sea level (Pugh, 2004; Sezen, 2006). For example, an increase in seawater temperature can cause the water to expand, leading to a rise in sea level (Geymen & Dirican, 2016).

Global warming leads to the rise in global temperatures due to the increase in greenhouse gases accumulated in the atmosphere (IPCC, 2021; NASA, 2020). This situation causes glaciers in polar regions to melt, and the flow of melted glaciers into the seas contributes to rising sea levels (Greenland Ice Sheet Project, 2018; Antarctic Ice Sheet Study, 2019). Additionally, climate change can create short-term fluctuations in precipitation patterns and temperatures, leading to temporary changes in sea level (Turoğlu, 2017). For instance, excessive rainfall can temporarily raise sea levels, while drought periods can lead to a drop in sea levels (Polat & Sunkar, 2017).

Finally, human activities, particularly in coastal areas, can be a direct cause of changes in sea level (Gürdal, 1998). Filling works, port constructions, dams, and other structures in coastal areas can disrupt the natural balance of sea levels (Sezen, 2006). Furthermore, human activities such as fossil fuel use and deforestation increase greenhouse gas emissions, accelerating global warming and consequently contributing to the rise in sea levels (IPCC, 2021; NASA, 2020). The dominant factor influencing water level changes varies depending on the specific geographical context, but in general, climate change is considered the most significant overarching driver. However, several specific factors contribute to water level changes, and their dominance can differ by region.

Global climate change is inextricably linked to human activities, particularly since the Industrial Revolution. The burning of fossil fuels, deforestation, and industrial processes have significantly increased the concentration of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere (IPCC, 2021). These activities, primarily driven by energy production, transportation, agriculture, and manufacturing, have altered the Earth’s natural climate systems, leading to rising global temperatures, shifts in weather patterns, and an increase in the frequency and intensity of extreme weather events (NASA, 2020). Human-induced climate change has far-reaching consequences for ecosystems, sea levels, food security, and public health. The acceleration of melting polar ice caps and glaciers, the warming of oceans, and more acidic seas are direct outcomes of human influence (IPCC, 2021). Additionally, shifts in precipitation patterns and the increasing prevalence of droughts and floods are putting pressure on water resources, agriculture, and infrastructure (WMO, 2022).

Introduction of the Study Area: The Rize coastline, particularly the area between the districts of İyidere and Çayeli, was selected as the study area, and the impact of sea level changes on this region was examined in detail. This coastline is situated in a geography that is directly exposed to the temperate and variable climatic conditions of the Black Sea and hosts various structures due to its geographical and strategic importance. Along this coastal strip, 25 T-groins have been constructed to prevent the sea from eroding the land and to control coastal erosion. These engineering structures contribute to the preservation of the shoreline by dissipating wave energy while also protecting other structures along the coast. Figure 1 presents a scaled map of the study area, showing the locations of the mareograph stations and district centers.

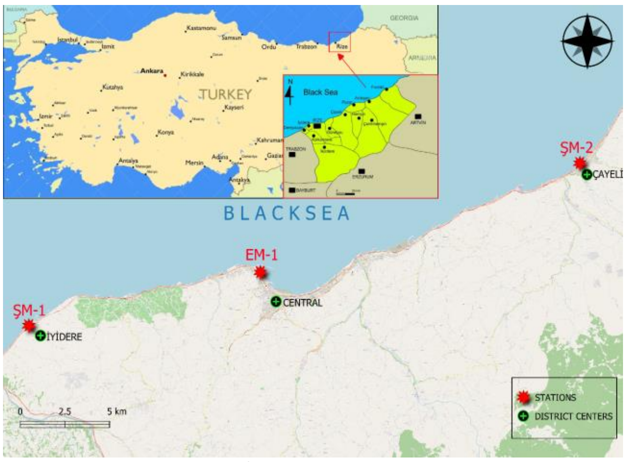

Figure 1. The appearance of the stations and district centers in the study area (ŞM-1, EM-1, and ŞM-2 represent the Iyidere, Central and Çayeli stations).

One of the significant features of the region is its extensive logistics fill areas. These fill areas allow for the revitalization of trade in the region and the concentration of various economic activities. These logistics areas are particularly critical for port operations and enhance the economic vitality of the region. The tourism sector also plays an important role along this coastline. The tourist facilities built along the coast serve visitors who wish to experience the natural beauty of Rize, thus increasing the tourism potential of the region.

Additionally, major ports are among the important elements of this region. In particular, Rize Port and Ünye Cement Port serve as central hubs for both local and international trade, contributing significantly to the region's economy. These ports enable the concentration of commercial activities in the region while also providing critical logistical support for other structures in the area. This coastline also features fishing shelters for those engaged in fishing, which plays a vital role in sustaining the fishing activities that are a significant livelihood for the local population. Furthermore, social facilities belonging to Recep Tayyip Erdoğan University are located in this region, contributing to the cultural and social life of the area by hosting academic and social events. All these structures are directly impacted by changes in sea level, making the monitoring and assessment of sea level changes crucial for the protection and sustainability of the structures in this region.

In this context, the Rize coastline has become the focal point of this study, creating a complex and dynamic environment with its natural and structural features. The coastal structures and economic activities in the region are sensitive to changes in sea level, providing critical data for future planning of structures in the area.

MATERIAL AND METHOD

This study utilized sea level data recorded from mareograph stations located at İyidere, Çayeli, and Riport Port in Rize, Turkey. These stations provide continuous measurements of sea level fluctuations at high temporal resolution. The dataset spans from beginning of the 2020 to end of the 2020, providing detailed information on short-term and long-term sea level changes. The sea level data are represented as a time series SL(t), where t denotes the time (e.g., daily or hourly intervals).

To monitor sea level changes and understand their impacts, mareograph stations have been established at strategic coastal points in Rize. These mareograph stations, located at İyidere Port, Çayeli Port, and Riport Port in Rize Center, are equipped with advanced technology devices that continuously monitor and record changes in sea level. While these devices record both short- and long-term trends in sea level changes in detail, the data is stored for regular analysis. The mareograph stations not only collect sea level measurements but also analyze the connection between these changes and weather events. This allows for a clearer understanding of how sea level changes are related to seasonal variations, storms, sudden weather changes, and other meteorological events. The rainfall-induced changes in sea level are illustrated in Figure 2 below.

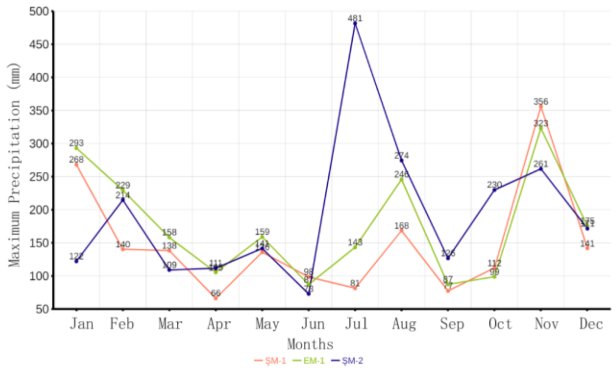

Figure 2. Annual Maximum Rainfall Data Considered in Level Measurements (for all station areas) (ŞM-1, EM-1 and ŞM-2 represent the Iyidere, Central and Çayeli stations).

In this context, monitoring sea level changes along the Rize coastline and systematically analyzing these data are crucial for enhancing the resilience of coastal structures and infrastructure against future environmental risks in the region. The complex and often unpredictable climate of the Black Sea can lead to sudden and unexpected changes in sea level. Such changes can result in serious environmental issues like coastal erosion, floods, and seawater intrusion. Monitoring these environmental changes is also critically important for the sustainability of economic activities in the region. For instance, economic activities such as agriculture, tourism facilities, and fishing are directly affected by sea level changes, and the regular monitoring of these changes plays a vital role in ensuring the continuity and safety of these activities.

The data obtained from mareograph stations help us understand the short-term fluctuations, seasonal trends, and long-term patterns in sea level changes, thereby clarifying the relationship between sea level and meteorological events. Particularly in regions with heavy rainfall, like Rize, sudden increases in sea level can pose significant flood risks along the coastal areas. These risks can create serious threats to both the natural ecosystems and human life in the region. In this context, the data from mareograph stations provide critical information not only for scientific research but also for local governments in their disaster management and risk reduction strategies.

Mareograph data also play a crucial role in developing predictive models to forecast future sea level changes and assess their potential impacts. By integrating historical records with advanced statistical techniques, such as time series decomposition and multiple regression analyses, it is possible to identify patterns and trends that may not be immediately apparent. These predictive models can simulate various scenarios, including extreme weather events and long-term climate shifts, enabling authorities to prepare more effective adaptation strategies. Moreover, combining mareograph data with meteorological inputs, such as wind patterns and atmospheric pressure variations, enhances the accuracy of these predictions, providing a more comprehensive understanding of the factors influencing sea level dynamics. This integrated approach supports proactive decision-making and helps mitigate the adverse effects of sea level fluctuations on both natural and human systems.

Continuous monitoring of sea level changes and the use of this data in long-term planning processes are vital for enhancing the safety of infrastructure projects in the region. For example, considering the data obtained from mareograph stations while constructing coastal protection structures against sea level rise can increase the effectiveness of these structures and provide protection against potential environmental disasters. Additionally, the use of this data can help better understand the impacts of sea level changes on agricultural lands, allowing for more informed planning of agricultural activities.

Determination of the Sea Level Changes: Coastal regions are highly sensitive to fluctuations in sea levels, especially in areas characterized by intense rainfall and variable climatic conditions. Rize, located along Turkey's Black Sea coast, is a prime example of such a region where heavy rainfall and seasonal changes significantly influence sea level dynamics. Understanding these variations is crucial for assessing flood risks, protecting infrastructure, and planning sustainable development. This study focuses on analyzing sea level changes along the Rize coastline, highlighting the impact of seasonal rainfall patterns on fluctuations observed in the data. By utilizing measurements from mareograph stations, the research aims to evaluate the extent of sea level changes and their implications for flood management and disaster mitigation strategies.

Research has found that sea level changes along the Rize coastline are particularly noticeable during rainy seasons. During these periods, intense rainfall has led to sudden and significant rises in sea level, considerably increasing the risk of flooding in coastal areas. The research has shown that increases in rainfall, particularly in July, August, and November, have led to notable rises in sea levels. This indicates that the high-rainfall climatic conditions of Rize have a direct and significant impact on sea level fluctuations.

Figures 3, 4, and 5 show the maximum, minimum, mean-maximum, and average sea level values obtained from the mareograph stations. According to these figures, the scales at all stations showed minimum levels in November and maximum levels in July.

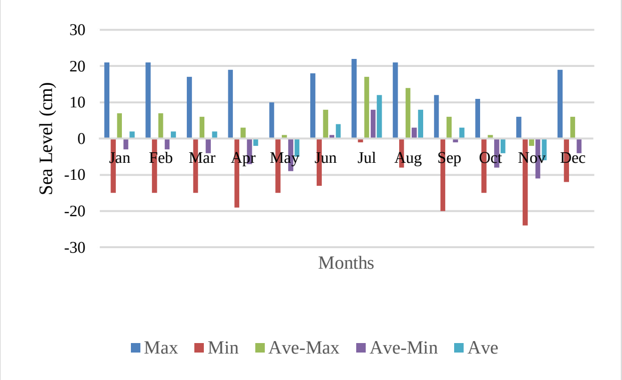

Figure 3. Data Graph of the SM-2(Çayeli) Mechanical Float Mareograph Station for the Year 2020.

The impact of rainfall on sea levels in these regions is also related to the geographical and climatic characteristics of the area. Rize, which has a coastline along the Black Sea, is one of the provinces in Turkey with the highest annual average rainfall. This intense rainfall, particularly during the summer and autumn months, causes the sea level to rise rapidly. These seasonal rises increase the risk of flooding for economically significant structures such as settlements, agricultural lands, and tourism facilities located along the coastline. In this context, the risks posed by sea level changes in coastal areas are critical factors that must be considered in infrastructure projects carried out in these regions. Floods resulting from rising sea levels can pose a serious threat to economic activities and residential areas in coastal regions, leading to both economic losses and social problems.

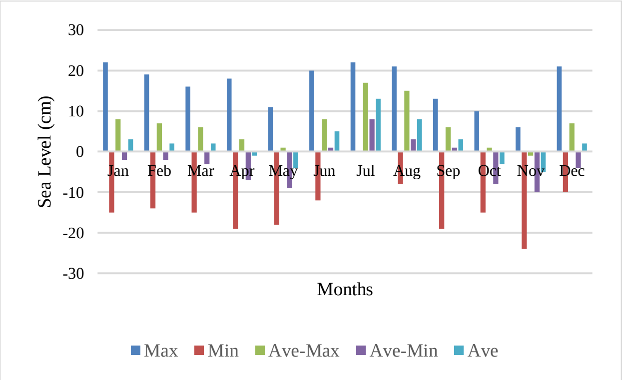

Figure 4. Data Graph of the EM-1(Central) Electronic Float Mareograph Station for the Year 2020.

Sectors that are particularly dependent on the coast, such as tourism and fishing, are directly affected by sea level rises, which in turn create negative impacts on the regional economy. Moreover, failure to consider these changes in sea level during the planning and implementation of coastal infrastructure projects could lead to greater environmental problems and costs in the future. Therefore, in regions with rainy climate conditions like Rize, it is crucial to continuously monitor sea level changes and to develop strategic plans accordingly. This is vital not only for the safety of the local population but also for the economic sustainability of the region.

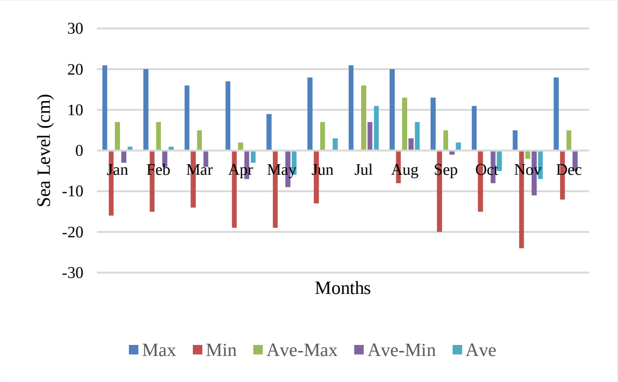

Figure 5. Data Graph of the SM-1(Iyidere) Mechanical Float Mareograph Station for the Year 2020

These findings indicate that the changes in sea level in the region are not merely temporary events but also serve as an important data source for long-term planning. Therefore, monitoring sea level changes and developing infrastructure projects based on this data will contribute to making the region more resilient to future natural disasters. This is an indispensable requirement for ensuring sustainable development in sensitive coastal areas like Rize.

In addition to sea level data, meteorological data, including rainfall R(t)), wind speed W(t), and atmospheric pressure P(t), were collected from [local meteorological sources]. The meteorological variables provide insight into local climatic conditions that may influence sea level.

To compare local trends with global phenomena, global sea level data GSL(t) were obtained from global sources such as [e.g., NOAA, NASA]. These datasets offer a global baseline for assessing long-term climate change impacts on sea levels.

Data Preprocessing

Data Cleaning: Outliers in the sea level data, resulting from sensor errors or environmental noise, were removed using statistical filtering techniques. Anomalies were detected by calculating the Z-score for each observation is showed on Equation 1:

$$Z = \frac{SL(t) - \mu}{\sigma} \quad (1)$$

where μ is the mean sea level over the period and σ is the standard deviation. Any values of SL(t) with |Z|>3 were flagged as potential outliers and removed from the dataset. The equation was used to standardize sea level data and ensure comparability in the analyses. The term SL(t) represents the sea level value at a specific time, while μ denotes the average sea level value, and σ represents the standard deviation. In our study, the average sea level value (μ) was taken in the range of 5–13 cm, based on long-term observational data and considering the region's hydrodynamic characteristics. The standard deviation (σ) was used to explain variations in the measurements, providing a better representation of fluctuations in sea levels. This approach allowed the modeling of sea level changes in response to temporal and atmospheric influences, thereby enhancing the reliability of the obtained results

Gap Filling: During the one-year period of sea level measurements, certain gaps emerged in the dataset due to occasional instrument malfunctions, sensor errors, and unintentional operational mistakes. These interruptions resulted in incomplete data records, which posed challenges for continuity and analysis. To address these gaps and ensure the integrity of the dataset, interpolation techniques were employed, as demonstrated in Equations 2 and 3 below. These methods allowed for the estimation of missing values by utilizing the trends and patterns observed in the surrounding data points, thereby restoring the completeness of the dataset. By filling in the gaps with interpolated values, the data was made more consistent and suitable for further analysis, enabling a more accurate assessment of sea level variations and long-term trends. For short gaps (e.g., one or two missing values), linear interpolation was applied in equation 2 and 3:

$$SL(t) = SL(t-1) + \frac{SL(t+1) - SL(t-1)}{2} \quad (2)$$

For longer gaps, cubic spline interpolation or autoregressive integrated moving average (ARIMA) models were employed to estimate missing values:

$$SL(t) = \sum_{i=1}^{p} \phi_i SL(t-i) + \sum_{j=1}^{q} \phi_j \epsilon(t-j) + \epsilon(t) \quad (3)$$

where p is the autoregressive order, q is the moving average order, ϕ and θ are model coefficients, and ϵ(t) is the error term at time t.

Separation of Local Meteorological Factors from Global Climate Effects: To separate the local effects from global influences on sea level changes, a combination of correlation analysis, regression modeling, and time series decomposition was employed.

Correlation Analysis: To quantify the relationship between sea level SL(t) and local meteorological variables R(t), W(t), P(t), Pearson's correlation coefficient (r) was calculated for each pair of variables showed in equation 4:

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 (Y_i - \bar{Y})^2}} \quad (4)$$

Where X_i and Yi represent the values of two variables (e.g., SL(t) and R(t), and $\bar{X}$ and $\bar{Y}$ are their respective means.

This analysis revealed the extent to which sea level changes were influenced by local meteorological factors, particularly during heavy rainfall periods and storm events.

Multiple Linear Regression: In order to maintain continuity in the formulation and account for certain unknown terms and parameters, multiple linear regression was utilized. This method allowed for the estimation of missing or uncertain values by establishing relationships between the dependent variable and multiple independent variables. By leveraging observed patterns and correlations within the dataset, multiple linear regression provided a systematic approach to predict unknown parameters and refine the formulation. This approach not only improved the reliability and accuracy of the model but also ensured that the equations used in the analysis could effectively represent the underlying processes and variations observed in the data. To further quantify the contributions of local meteorological factors and global climate change to sea level variations, multiple regression models were constructed. The model takes the form in equation 5;

$$SL(t) = \beta_0 + \beta_1(t) + \beta_2 W(t) + \beta_3 P(t) + \beta_4 GSL(t) + \epsilon(t) \quad (5)$$

where:

- β_0 is the intercept,
- β_1,β_2,β_3 are coefficients for the local meteorological variables (rainfall, wind speed, and pressure),
- β_4 is the coefficient for the global sea level trend, and
- $\epsilon(t)$ is the error term.

The values of β_1,β_2,β_3 indicate the strength of local effects, while β_4 represents the impact of global sea level rise on the observed changes in Rize. β parameters used to model sea level changes were carefully selected based on the region's climatic, hydrological, and meteorological characteristics, and reasonable values were determined for each parameter. The intercept (β_0) represents the initial conditions and the baseline value of sea level in the model. This parameter, based on the region's average sea level data, was selected in the range of 20–50 cm to initiate the model with reference to sea level variations. The temporal trend (β_1) represents long-term changes in sea level over time and typically takes positive values as a result of global warming effects. Considering Rize's location along the Black Sea coast and observed annual increases, a value in the range of 1.5–3.0 mm/year was selected. Wind speed (β_2) represents the effect of prevailing wind conditions on water surges and surface currents. Taking into account the influence of northerly winds in the Black Sea, this parameter was determined to be in the range of 0.2–0.5 cm/(m/s). Atmospheric pressure (β_3) explains the impact of changes in air pressure on sea level as a negative parameter, where low pressures increase and high pressures decrease sea levels. Based on meteorological data from Rize, this parameter was assigned a value in the range of -0.4–-0.7 cm/hPa. Global sea level change (β_4) accounts for the influence of global trends on local sea level and is a critical factor in long-term variations. Assuming that the region exhibits changes aligned with global trends, this parameter was selected in the range of 0.8–1.2 cm/cm. All these parameters were validated through detailed statistical analyses considering the hydrological and meteorological conditions of Rize and optimized to enhance the reliability of the model. Particularly in modeling the effects of frequent storms and heavy rainfall observed along the Black Sea coast, selecting the parameters in this manner has enabled the model to more accurately reflect real-world conditions.

Time Series Decomposition: Seasonal-Trend Decomposition (STL) was used to analyze the sea level data collected over a one-year period in the Rize region. This method was applied to separate the data into three main components—trend, seasonality, and residual—allowing for a more detailed examination of long-term changes and short-term variations. To further distinguish between long-term trends and short-term local influences, the sea level data were decomposed using Seasonal-Trend Decomposition (STL) in equation 6:

$$SL(t) = T(t) + S(t) + R(t) \quad (6)$$

where:

- T(t) is the long-term trend component,
- S(t) is the seasonal component, and
- R(t) is the residual (noise) component.

The trend component (T(t)) captures gradual changes in sea level, such as the effects of climate change or tectonic shifts, and was modeled based on observed long-term patterns, showing a steady increase of 1.5–3.0 mm/year. The seasonal component (S(t)) reflects periodic fluctuations caused by factors such as tides, temperature, and atmospheric pressure changes, and was analyzed with monthly and seasonal cycles, highlighting variations of 5–15 cm depending on the time of year. The residual component (R(t)) represents irregular variations and noise, accounting for short-term anomalies that cannot be attributed to trends or seasonal influences. By decomposing the data, this approach ensured that the effects of each component were isolated and analyzed separately, providing a clearer understanding of sea level dynamics in the region. This method also allowed for the identification of missing values, anomalies, and trends, improving the overall reliability and accuracy of the dataset used for further modeling and forecasting.

Comparative Analysis with Other Regions: To contextualize the Rize findings, comparisons were made with sea level data from other Turkish coastal regions, such as the Aegean and Mediterranean coasts. Sea level trends from these regions were modeled using the same approach, and the results were compared to Rize's trends. Additionally, global comparisons were made with similar coastal regions affected by climate change, such as other Black Sea coasts and European coastal cities.

Limitations and Uncertainty: Several limitations and uncertainties were identified in this study:

Measurement Errors: The presence of sensor noise or malfunctions during extreme weather events can introduce biases in the sea level measurements. These errors were modeled as random noise ϵ_{meas} added to the true sea level in equation 7:

$$SL_{observed}(t) = SL_{true}(t) + \epsilon_{meas}(t) \quad (7)$$

This approach was used to quantify the uncertainty introduced by environmental factors, sensor limitations, and operational issues during data collection. The random noise component $\epsilon_{meas}(t)$ was estimated by analyzing deviations from expected values, based on statistical measures such as standard deviation and variance. In this study, noise levels were modeled with a mean value of zero and a standard deviation in the range of 1–5 cm, reflecting realistic variations observed in the field. Incorporating measurement errors into the analysis allowed for a more robust interpretation of the data, ensuring that biases did not distort trend analysis or parameter estimation. This method also enhanced the reliability of the model by accounting for uncertainties, enabling more accurate predictions and evaluations of sea level changes in the Rize region.

Gaps in Data: Despite interpolation techniques, long gaps in the dataset introduce uncertainty in the overall trend. The uncertainty U due to missing data was estimated as in the equation 8:

$$U = \frac{(Interpolaed - Actual)^2}{n} \quad (8)$$

Where n is the number of interpolated points.

The multiple regression models assume linear relationships between variables, which may not capture all the nonlinear effects of meteorological factors on sea level. Future studies could improve this by applying nonlinear models such as generalized additive models (GAMs). While multiple regression models effectively capture linear relationships, they may fail to account for the nonlinear and complex interactions between meteorological factors and sea level variations. For instance, phenomena such as storm surges, rapid pressure drops, and wind-driven currents often exhibit nonlinear behaviors that cannot be fully represented by linear models. As a result, future studies could enhance the accuracy and reliability of predictions by incorporating nonlinear approaches such as generalized additive models (GAMs) or machine learning techniques. These advanced methods allow for more flexible modeling of relationships, capturing intricate patterns and dependencies in the data. Additionally, integrating higher-resolution meteorological inputs and real-time observations could further reduce uncertainty and improve the performance of predictive models, making them more applicable for long-term sea level monitoring and management strategies.

DISCUSSION AND CONCLUSION

The results of this study underscore the direct relationship between climate-induced sea level changes and their impact on the Rize coastline. Periods of heavy rainfall, particularly during July, August, and November, lead to significant sea level rises, which exacerbate risks to coastal infrastructures, agricultural lands, and tourism facilities. These findings align with previous research that highlights the vulnerability of the Black Sea region, particularly Rize, to drastic sea level fluctuations due to its unique meteorological and oceanographic conditions.

Factors such as rainfall intensity, climate changing, tidal variations, and atmospheric pressure were found to contribute to these sea level changes, as evidenced by data from mareograph stations along the coastline. The role of climate change is particularly pronounced, not only influencing long-term coastal stability but also posing immediate threats to human life and property. Sea level rise in Rize mirrors the broader global challenge, indicating that this region serves as a microcosm for other coastal areas facing similar risks. Given these findings, a proactive approach to managing sea level changes is crucial. Continuous and real-time monitoring of sea levels, alongside infrastructure planning that integrates these data, will be essential in mitigating future risks. Moreover, disaster management strategies should incorporate these insights to better prepare for potential flooding events. Local governments must also take preventive measures, such as reinforcing coastal protection structures and implementing comprehensive early-warning systems. The evidence suggests that sea level rises in Rize are not merely temporary but are likely to persist as global climate change accelerates. Therefore, adapting infrastructure to accommodate both current and projected sea level changes is vital. This includes integrating continuous data collection and analysis into long-term urban and regional planning processes to ensure the sustainability of both natural and man-made environments.

In conclusion, this study provides essential insights into the significant impacts of global climate change on sea levels, specifically along Turkey's Rize coastline. It lays a foundation for future research and regional policy development aimed at addressing climate-induced sea level changes. By enhancing our understanding and monitoring of these variations, we can develop more resilient coastal infrastructures, ultimately protecting communities, their economies, and the environment from the growing threat of rising sea levels.

ACKNOWLEDGEMENTS

This study was financially supported by the Recep Tayyip Erdoğan University Scientific Research Committee under project number FYL-2020-1061.

REFERENCES

Baltacı, H. (2010). *Examination of Landslide-Rainfall Relationships and Determination of Minimum Threshold Values in the Eastern Black Sea Region (Rize, Trabzon, Giresun).* Master's Thesis, Istanbul Technical University, Istanbul.

Batan, N., Atamov, V., Ekşi, S. & Erata, H. (2018). Contrubition to the bryophyte flora of the İkizdere district (Rize, Turkey). *Phytologia Balcanica*, ***24***(1), 9-15.

Çakıcı, A. (2015). *Identification of Behaviors in Mareograph Stations Using Time Series Analysis: The Case of TUDES Mareograph Stations.* Master's Thesis, Aksaray University, Aksaray.

Dağ, S. (2007). *Landslide Susceptibility Analysis of Çayeli (Rize) and Its Surroundings Using Statistical Methods.* PhD Thesis, Karadeniz Technical University, Trabzon.

Demir, C. & Yıldız, H. (2002). Investigation of Vertical Crustal Movements Using Sea Level and Geodetic Measurements at Erdek Mareograph Station and Its Surroundings. *Mapping Journal*, ***127***, 9-18.

Gürdal, M.A. (1998). *Sea Level Measurements and Mareograph Stations Operated by the Mapping General Command. Mapping Journal*, ***119***, 1-14.

IPCC. (2019). *Special Report on the Ocean and Cryosphere in a Changing Climate.* Intergovernmental Panel on Climate Change.

IPCC. (2021). *Climate Change 2021: The Physical Science Basis.* Intergovernmental Panel on Climate Change.

NASA. (2020). *Global Climate Change: Vital Signs of the Planet.* Retrieved from https://climate.nasa.gov/

NOAA. (2021). *National Oceanic and Atmospheric Administration Annual Climate Report.* Retrieved from https://www.noaa.gov/

Polat, P. & Sunkar, M. (2017). Climate Characteristics of Rize and Trend Analyses of Long-Term Temperature and Precipitation Data in the Rize Region. *Fırat University Journal of Social Sciences*, ***27***(1), 1-23.

Pugh, D. (2004). *Changing Sea Levels: Effects of Tides, Weather, and Climate.* Cambridge University Press.

Sezen, E. (2006). *Investigation of Sea Level Changes at Antalya-1 (1935-1977) and Antalya-2 (1985-2005) Mareograph Stations.* Master's Thesis, Afyon Kocatepe University, Afyonkarahisar.

Simav, M. (2012). *Investigation of the Possible Effects of Sea Level Rise on Coastal Areas in Istanbul.* PhD Thesis, Istanbul Technical University.

Simav, M. & Türkezer, A. (2011). Data Quality Control and Management System of the Turkish National Sea Level Monitoring Network. *Mapping Journal*, ***145***, 15-28.

Süme, V. (2007). Examination of "T" Groins for Coastal Protection Between İyidere and Çayeli in Rize. *6th National Coastal Engineering Symposium*, Izmir.

Süme, V. (2011). *Sea Level Change in Rize.* Recep Tayyip Erdoğan University, Scientific Research Project, Rize.

Turoğlu, H. (2017). *Coastlines in Legal and Scientific Dimensions.* Publication of the Geomorphology Association, Istanbul.

Yalçın, A. & Bulut, F. (2007). Landslide Susceptibility Mapping Using GIS and Digital Photogrammetric Techniques: A Case Study from Ardeşen (NE-Turkey). *Natural Hazards*, ***41***(1), 201-226.

Yıldız, H. (2005). *Investigation of Long-Term Absolute Sea Level Changes Using Mareograph and Fixed GPS Time Series Analysis.* PhD Thesis, Istanbul Technical University.

Demir, C. & Yıldız, H. (2002). Investigation of Vertical Crustal Movements Using Sea Level and Geodetic Measurements at Erdek Mareograph Station and Its Surroundings. *Mapping Journal*, ***127***, 9-18.

Geymen, A. & Dirican, A.Y. (2016). Analysis of Sea Level Changes Due to Climate Change Using Geographic Information Systems. *Electronic Journal of Mapping Technologies*, ***8***(2), 65-74.

Greenland Ice Sheet Project. (2018). *Global Climate Change and the Greenland Ice Sheet.* Retrieved from https://greenland-ice-sheet-project.org/

Gürdal, M.A. (1998). Sea Level Measurements and Mareograph Stations Operated by the Mapping General Command. *Mapping Journal*, ***119***, 1-14.

IPCC. (2021). *Climate Change 2021: The Physical Science Basis.* Intergovernmental Panel on Climate Change.

NASA. (2020). *Global Climate Change: Vital Signs of the Planet.* Retrieved from https://climate.nasa.gov/

Polat, P. & Sunkar, M. (2017). Climate Characteristics of Rize and Trend Analyses of Long-term Temperature and Precipitation Data in the Rize Region. *Fırat University Journal of Social Sciences*, ***27***(1), 1-23.

Pugh, D. (2004). *Changing Sea Levels: Effects of Tides, Weather, and Climate.* Cambridge University Press.

Sezen, E. (2006). *Investigation of Sea Level Changes at Antalya-1 (1935-1977) and Antalya-2 (1985-2005) Mareograph Stations.* Master's Thesis, Afyon Kocatepe University, Afyonkarahisar.

Simav, M. (2012). *Investigation of the Possible Effects of Sea Level Rise on Coastal Areas in Istanbul.* PhD Thesis, Istanbul Technical University.

TUDES. (2021). *Turkish National Sea Level Monitoring System (TUDES).* Retrieved from https://tudes.harita.gov.tr/

Turoğlu, H. (2017). *Coastlines in Legal and Scientific Dimensions.* Publication of the Geomorphology Association, Istanbul.

Yıldız, H. (2005). *Investigation of Long-Term Absolute Sea Level Changes Using Mareograph and Fixed GPS Time Series Analysis.* PhD Thesis, Istanbul Technical University.

World Meteorological Organization. (2022). State of the global climate 2021. https://public.wmo.int/en/our-mandate/climate

Uludağ, S., Demir, A. & Şahin, F. (2021). Sea level rise impacts on the Mediterranean coast of Turkey. *Environmental Science and Policy*, ***114***, 98-107. DOI: 10.1016/j.envsci.2021.05.004

Çelik, M. & Güler, H. (2019). The risks of sea level rise on Istanbul's coastal infrastructure. *Marine Geodesy*, ***42***(3), 213-227. DOI: 10.1080/01490419.2019.1612787

Yalçın, E., Erdem, E. & Korkmaz, M. (2022). Coastal erosion and saltwater intrusion along Turkey's Aegean coastline. *Ocean & Coastal Management*, *212*, 105789. DOI: 10.1016/j.ocecoaman.2022.105789