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-Araştırma Makalesi-

Antalya İstasyonu II Deniz Seviyesi Değişiminin Değerlendirilmesi

Halid AKDEMİR[1]

Öz

Antalya, Türkiye kıyıları dış dinamiklere çok duyarlı olduğundan dolayı Antalya kıyılarındaki deniz seviyesi değişim sürecini daha yakından açıklamaya ihtiyaç vardır. Bu amaç doğrultusunda bu çalışmada Antalya kıyılarındaki deniz seviyesi değişimi istatistiksel ve analitik bir yaklaşımla aylık ve yıllık olarak incelenmiş ve değerlendirilmiştir. Buna göre Güney Salınımı (SOI), Arktik Salınımı (AO), Antarktika Salınımı (AAO), Kuzey Atlantik Salınımı (NAO), El Nino Güney Salınımı (NINO 3.4) gibi bazı endekslerin korelasyonları ve arktik buz erimesi, Antalya hava sıcaklığı, küresel hava sıcaklığı, küresel okyanus sıcaklığı, Akdeniz denizi yüzey sıcaklığı (SST) gibi parametreler Antalya İstasyonu II'nin deniz seviyesi değişimi sorununa açıklık getirmek amacıyla incelenmiştir. Endekslerle yapılan korelasyon çalışması, Antalya İstasyonu II'deki deniz seviyesi değişimi ile endeksler arasında anlamlı bir ilişki olmadığını ortaya koymuştur. Çalışılan değişkenlerden arktik buzullarının erimesi ve Antalya hava sıcaklığı aylık bazda yapılan çalışmada sırasıyla 0.6959 ve 0.6412 korelasyon değerleri gibi nispeten yüksek korelasyon değerlerine sahiptir. Akdeniz denizi yüzey sıcaklığı yıllık bazda yapılan çalışmada ise 0.93 korelasyon değeri ile deniz seviyesi değişimi ile en yüksek korelasyona sahip görünmektedir. Ek olarak ve korelasyon çalışmasının da katkısıyla, deniz seviyesindeki değişimin neden olduğu düşünülen parametrelerle ilişkisini incelemek için analitik bir çalışma yapılmıştır. Antalya İstasyonu II'de gözlenen deniz seviyesi değişiminin nedeni olarak Akdeniz denizi sıcaklığı, buzulların erimesi ve erozyon gibi diğer faktörler olmak üzere üç etkili parametre belirlenmiş ve incelenmiştir. Bu analitik çalışma, Antalya İstasyonu II'de deniz seviyesinin değişimine katkının en çok %82 ile deniz sıcaklığı artışı, %14 ile buzulların erimesi ve %4 ile erozyon gibi diğer faktörlerle ilişkili olduğunu göstermiştir.

Anahtar Kelimeler: Deniz Seviyesi Değişimi, Antalya İstasyonu, Akdeniz, Sıcaklık Değişimi, Buzul Erimesi.

Evaluation of Sea Level Change at Antalya Station II

Abstract

Antalya, Turkey, coasts are very sensitive to external dynamics so there is a need to explain the sea level change process on the shores of Antalya more closely. In line with this purpose, the sea level change on the Antalya coast has been examined and evaluated monthly and annually with a statistical and analytical approach in this study. Accordingly, the correlations of some indexes such as Southern Oscillation (SOI), Arctic Oscillation (AO), Antarctic Oscillation (AAO), North Atlantic Oscillation (NAO), El Nino Southern Oscillation (NINO 3.4), and the parameters of arctic ice melt, Antalya air temperature, global air temperature, global ocean temperature, Mediterranean Sea surface temperature (SST) with the sea level change at Antalya Station II were examined to clarify the problem. The correlation study with the

[1] Antalya Bilim University, Civil Engineering Department, Antalya Bilim University, Antalya, Turkey
Corresponding author: halid.akdemir@antalya.edu.tr
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indexes revealed that there is no significant relationship between the indexes and the sea level change at Antalya Station II. Among the studied variables, the arctic ice melt, and the Antalya air temperature have relatively high correlation coefficients of 0.6959 and 0.6412 respectively in the monthly analysis. The Mediterranean SST seems to have the highest correlation with the sea level change with a correlation value of 0.93 in the annual analysis. Accordingly, analytical research was carried out to examine the correlation of the change of the sea level with the parameters that are thought to be the cause. Three effective parameters are identified and examined as the cause of sea level change observed at Antalya Station II, which are Mediterranean Sea temperature, ice melt, and other factors such as erosion. The result of this analytical study shows that the contribution to sea level change at Antalya Station II is mostly related to the temperature increase with a contribution of 82%, to ice melt with a contribution of 14%, and the other factors such as erosion with a contribution of 4%.

Keywords: Sea Level Change, Antalya Station, Mediterranean Sea, Temperature Change, Ice Melt.

1. Introduction

Antalya is a city of Turkey located in the Mediterranean with its tourist attraction. However, it has been facing coastal problems for a long time (Alpar, 2009). One of these problems is the rapid rise in sea level. Researchers have been studying these sea level rise effects and causes for a long time (Gomis et al., 2012; Sezen & Baybura, 2010). These studies have been conducted in the global and local sense (Dangendorf et al., 2017). Many studies have also been conducted on sea level rise in Antalya and the Mediterranean region (Adloff et al., 2018; Lichter et al., 2010; Mahdi & Hebib, 2020; Ozturk et al., 2018). Many different methods have been adapted to these studies (Baart et al, 2012; Visser et al., 2015; Yılmaz, 2019).

Globally, sea level rise poses many direct and indirect dangers for many regions (Enríquez et al., 2017). For this reason, projections of global sea level increase have been made so that measures can be taken (Gregory & Lowc, 2000). In some developed countries around the world, efforts to take measures according to these projections have started and have been continuing rapidly. The main factors affecting the change in global sea level are temperature increase and ice melt (Forsberg et al., 2017; Shukla et al., 2017). Apart from these, there may be different local or teleconnection reasons for regions (Simav et al., 2012; Vecchio et al., 2019; Volkov et al., 2019).

Antalya coasts are geologically sensitive additionally exposed to high human mobility due to its tourism attraction (Leventeli, 2011). Additionally, Antalya has been confronted great climate change challenge for a time which increases seasonal extremes and contributes to coastal destructions (Şen et al., 2015). Therefore, it is necessary to carry out studies on it. Although Antalya coasts are not exposed to high energy waves, they are morphologically prone to erosion (Koşun et al., 2019). The erosion of the coasts means destruction of tourist areas, which means devastation for such a popular touristic city (Dipova, 2019). This strong impact of erosion is even milder than the devastating effect of sea level rise in there. The rise of sea level both increases erosion and destroys living spaces by causing floods in coastal areas (Hinkel et al., 2013). Such extremes cause Antalya to lose its appeal. The worst part of the rise in sea level is that it is happening too fast and the measures cannot keep up.

Most of the world's population lives in coastal areas, which shows how important the management of coastal areas is (Barragán & de Andrés, 2015; Neumann et al., 2015; Pethick, 2001). Climatic processes and coastal dynamics are very complex and obscure events but identifying problems is an important stage in order to take precautions. Therefore, these issues

need to be examined and thus clarified. Antalya coasts are very sensitive to external dynamics as well so there is a need to explain the sea level change process on the shores of Antalya more closely. Thus, the process can be managed better. In line with this purpose, the sea level change on the Antalya coast has been examined and evaluated with a statistical and analytical approach in this study and some approaches have been developed for this purpose. The methods and data sets used for this study are explained in Section 2. The relationship of some indexes and some parameters with the sea level change in Antalya coasts was analyzed and interpreted by statistical approach in Section 3. After the correlation study, the sea level change was evaluated analytically in Section 4. Conclusion part can be found in Section 5 which announces that, the contribution to sea level rise at Antalya Station II is mostly related to the temperature increase with a contribution of 82%, to ice melt with a contribution of 14%, and the other factors such as erosion with a contribution of 4%.

2. Methodology

Accordingly, the correlations of some parameters such as Southern Oscillation Index (SOI), Arctic Oscillation (AO), Antarctic Oscillation (AAO), North Atlantic Oscillation (NAO), El Nino Southern Oscillation (NINO 3.4) and arctic ice melt, Antalya air temperature, global air temperature, global ocean temperature and Mediterranean Sea surface temperature (SST) with the sea level rise at Antalya Station II were examined to clarify the problem. Then, with the help of the correlation study and the research study conducted, the effective parameters were revealed. Finally, an analytical study was carried out to clarify the sea level rise at Antalya Station II. The all parameters whose relationship with the sea level change investigated were taken from World Meteorological Organization. Correlation coefficient parameter was used for the correlation analyses.

2.1. Location and sea level data

The study was carried out for Antalya Station II. The reasons of sea level change at Antalya Station II were explained and interpreted. Antalya is a popular seaside town in the south of Turkey. Antalya has faced various coastal problems like erosion and sea level rise for a long time. For this reason, it is necessary to examine and conduct research on it. Antalya Station II is located at the coordinates of 36.8969° N, 30.7133° E, in the northeastern Mediterranean region. Antalya Station II sea level data was taken from Permanent Service for Mean Sea Level (PSMSL) and the data set includes monthly average sea level measurements covering the years between 1985 and 2009. The completeness rate of the data is 85% and id and code of Antalya Station II are 1681 and 52 respectively. The monthly average sea level measurements were carried out at the Antalya Konyaaltı port at the location shown in Figure 1 and its study has been conducted by scientists of PSMSL with quality checks to detect and identify suspicious values (Ozturk et al., 2018).

Figure 1. The location of Antalya Station II and the view of Antalya city

Figure 2 shows the relevant data set, the equation given on the figure is the expression of the trend. The variable t gives the number of data and the variable d gives the depth corresponding to the number. For example, the data set starts with the date of 01.11.1985, which corresponds to the first data. This means that t value in the trend equation on Figure 2 equals 1 and d value corresponding to this is the depth, which is 6905,5 mm for this example.

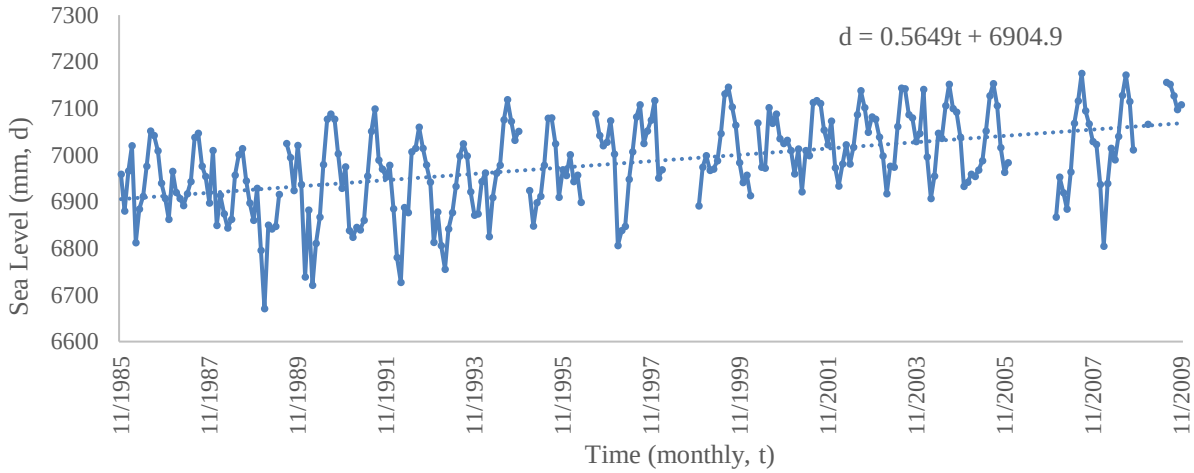

Figure 2. Sea level data set of Antalya Station II

At first glance, when examined more closely, the sea level tends to rise in the summer months, while it tends to decrease in the winter months. It is clear that there is a linear increase in sea level in the dataset.

Figure 3 named regulated data was formed from actual data by removing trend. It only reflects the oscillations. It was created so that it can be subjected to correlation analysis with oscillating indexes.

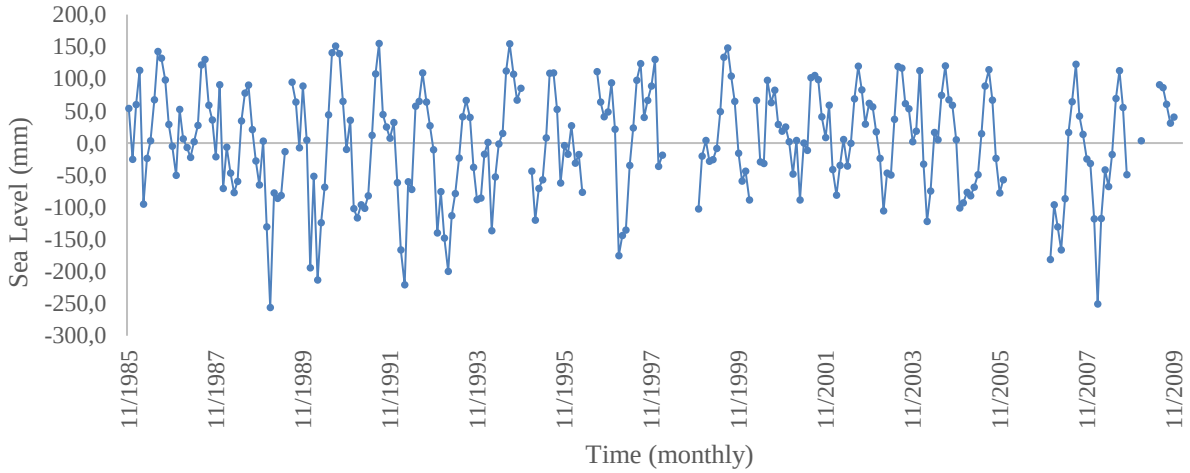

Figure 3. Regulated sea level data set of Antalya Station II

2.2. Climate oscillations

SOI and NINO 3.4 can be explained in the same framework because the both originally indicate the oscillation of two different parameters of the same meteorological event. SOI show the variation of sea surface pressure differences, while NINO 3.4 explain the variation of sea temperature differences in Equatorial Pacific. See more detailed and comprehensive explanation (Trenberth & Stepaniak, 2001; Troup, 1965).

AO refers to an atmospheric circulation pattern over the mid-to-high latitudes of the Northern Hemisphere. The most obvious reflection pf the phase of this oscillation is the north to south location of the storm-steering, mid-latitude jet stream. This index depicts the variation of the air pressure difference between the Arctic region and the Pacific region. See more detailed and comprehensive explanation (Thompson & Wallace, 1998).

AAO is an index that is the dominant pattern of non-seasonal tropospheric circulation variations South 20S, which demonstrate the pressure differential change of two regions similar to the arctic oscillation. See more detailed and comprehensive explanation (Gong & Wang, 1999).
NAO is a weather phenomenon in the North Atlantic Ocean of fluctuations in the difference of atmospheric pressure at sea level between Icelandic Low and Azores High. See more detailed and comprehensive explanation (Wanner et al., 2001).

3. Statistical Evaluation Of Sea Level Change

In this section, data analysis has been made on monthly average values. The data includes the period from 1985 to 2009. The reason for this data range and analysis on a monthly scale is the data consistency and the purpose of increasing the number of data as much as possible in order to get more accurate results. For the correlation study of the oscillations and the change in sea level, the upward trend was deducted from the actual sea level change at Antalya Station II and the correlation analysis has been done considering the oscillation in sea level. However, the correlation analysis has been made on the raw data of temperature change and ice melt with sea level change to take into account the trends.

3.1. Teleconnections of oscillations with sea level change

The relationship between Southern Oscillation Index (SOI), Arctic Oscillation (AO), Antarctic Oscillation (AAO), North Atlantic Oscillation (NAO) and El Nino Southern Oscillation (NINO 3.4) oscillators and the sea level change at Antalya Station II has been revealed by the correlation study.

Table 1 which is formed with correlation analysis in this paper indicates that there is no significant correlation between the examined indexes and the sea level oscillation.

Table 1. Correlations of the oscillations with the regulated sea level change

Relation	Correlations (R)
SOI	-0.1157
AO	-0.1892
AAO	-0.0797
NINO 3.4	0.1544
NAO	-0.2035

However, the index having the highest relationship with the sea level change among all indexes is NAO. There is a negative correlation between the sea level change with the all but NINO 3.4. The lowest correlation of sea level change is with AAO, which is quite explainable since AAO is located in the southern hemisphere. There is some difference between the R values of SOI and NINO 3.4, which measure the oscillation of 2 different parameters in the same area. In fact, this is because the temperature change in the sea is more effective than the change in air pressure on the sea level change.

3.2. Correlations of climatic parameters with sea level change

Apart from oscillations, ice melt and temperature increase parameters, which are among the most effective parameters of sea level change, were also examined. Some other factors affecting the change in sea level include land sinking, slowing of gulf stream and coastal erosion. Changes in sea level of regions may be related to local changes or may also result from global influences or neighboring regions effects.

In this section, specifically, the correlation of arctic ice melt, Antalya air temperature, global air temperature and global ocean temperature with the sea level change at Antalya Station II was examined.

Table 2 is created by performing correlation analysis. According to the results in Table 2, the highest relation of the sea level change is the arctic ice melt first and then the Antalya air temperature. The change in global ocean temperature has the higher relationship than the change in global air temperature has. Among the studied variables, the arctic ice melt and the Antalya air temperature have relatively high correlation coefficients of 0.6959 and 0.6412 respectively.

Table 2. Correlations of the variables with the sea level change

Relation	Correlations (R)
Arctic ice melt	0.6959
Antalya air temperature	0.6412
Global air temperature	0.1989
Global ocean temperature	0.3081

According to the correlation study, oscillations, global air temperature and global ocean temperature do not have a significant relationship with the sea level change at Antalya Station II. The reason that the arctic ice melt and Antalya temperature have a high relationship with

sea level change is that the melting ice causes additional water mass and the temperature increase causes thermal expansion. However, here it becomes necessary to examine the effect of ocean temperature and ice melt closely, which is examined in Section 4 statistically and analytically.

4. Analytical Evaluation of Sea Level Change

According to the previous correlation study, the ocean temperature, the Antalya air temperature and the ice melt are relatively main indicators of the sea level change at Antalya Station II. Therefore, these variables have been studied more closely here. All the data studied here cover annually and the period between 1991 and 2007 due to data consistency and adequacy.

In this section, a simple approach has been created that analytically describes the change in sea level. What is meant by the analytical analysis in this study is that the causes of the change in sea level are associated with some effective variables determined in previous section. For this reason, the annual sea level change data which is longer term then the monthly data were studied. Primarily, the correlation study between Mediterranean SST, Antalya air temperature and arctic glacial melting with sea level change at Antalya Station II has been done and demonstrated. Then, some assumptions were made and the approximate sea level change was calculated analytically. The weights of the causes for sea level change at Antalya Station II were also examined.

Table 3 represents that the correlation of the change in sea level and the studied variables on an annual basis is quite high. The Mediterranean SST seems to have the highest correlation with the sea level change with a correlation value of 0.93.

Table 3. Correlations of the variables with the sea level change

Relation	Correlations (R)
Mediterranean SST	0.933
Antalya air temperature	0.857
Arctic ice melt	0.667

There are two main factors affecting the sea level change at Antalya Station II. These are the increase in water mass due to ice melt and thermal expansion due to temperature increase. In addition, erosion of Antalya coasts has an effect on sea level rise locally. In summary, there are three effective parameters, which are Mediterranean Sea temperature, ice melt and the other factors like mainly erosion to be examined for sea level change at Antalya Station II.

In the light of the interpretive results obtained from the correlation study and the research study, the effect of the parameters on the sea level rise at Antalya Station II was analyzed analytically.

- Firstly, the contribution of the volume of melted ice on the ocean in depth was calculated with the assumption of evenly distributed.
- Secondly, the thermal expansion was calculated by determining the change of the temperature of the Mediterranean Sea with the assumption of incompressibility and evenly distributed.
- Finally, the measured sea level change and the calculated sea level change were compared with each other, thus revealing the weights of the temperature rise, the ice melt, the other unaccounted for effects on the sea level rise.

Arctic glacial melting trend is approximately 278 Gt per year. This value is 140 Gt per year for Antarctica. Considering that these two glacial masses are major, a total of approximately 418 Gt of water per year enters the system. Assuming that 1 km^3 water equals 1 Gt of water, 418 km^3 volume of water is mixed into the oceans per year. The ocean's surface area is approximately 361.8 million km^2.

$$VIM/SA = SLR \quad (1)$$

VIM stands for total volume of ice melt while SA means ocean surface area. SLR represents sea level rise.

Assuming that the melted ice mass is evenly distributed, we can derive the annual sea level trend from Equation 1. Thus, it can be said that the 1.15 mm increase trend globally is due to the ice melt.

SST data are available for the Mediterranean Sea but there is no any temperature change data on the basis of depths of the Mediterranean Sea. It is necessary to reveal the change in the sea temperature of the Mediterranean in the calculation of volumetric expansion due to the thermal change. Since there is only SST change data of the Mediterranean Sea, it was statistically obtained how the temperature change changes as goes down to the depths. Globally, there are SST data such as average sea temperature data up to 100 meters depth, average sea temperature data up to 700 meters depth and average sea temperature data up to 2000 meters. Equation 2 in Figure 4 which was formed with the curve fitting method has been obtained by establishing a relationship between these data and using the curve fitting method.

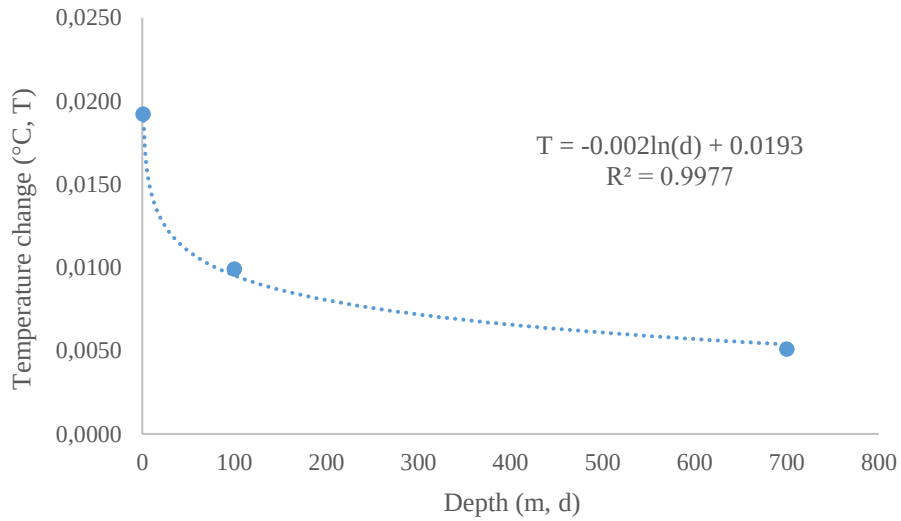

Figure 4. Curve fitting to obtain the change of temperature change with depth (data of global ocean temperature)

$$T = -0.0021\ln(d) + SST \quad (2)$$

T states the average temperature change and d is the depth, so the average temperature changes up to the desired depth can be calculated with this equation. It has been calculated how the change in the Mediterranean SST causes a change in average temperature of the sea as go deeper.

The annual change trend of the Mediterranean Sea surface temperature is 0.0356 degrees Celsius. The average depth of the Mediterranean is 1500 meters and the trend of change in average sea temperature between 0 and 1500 meters' depth of the Mediterranean Sea is found as 0.0210 degrees Celsius per year by using Equation 2. The volumetric expansion caused by the temperature increase can be found approximately from the thermal expansion equation in Equation 3.

$$dL = \Phi L dT \quad (3)$$

dL denotes the change in length while Φ, L, dT are the coefficient of thermal expansion, the length and the change in temperature, respectively.

The thermal expansion coefficient is considered as $2.1 * 10^{-4}$ 1/ºC. The annual sea level increase trend due to the temperature increase in the Mediterranean region is calculated as 6.61 millimeter with Equation 3. Considering the ice melt mass and the expansion caused by temperature together, the annual change trend of the Mediterranean Sea level was calculated as 7.76 mm in average. The amount of deviation from this value explains the intensity of local effects such as land sinking, erosion or effects of climatic variables etc. The trend of change in sea level at Antalya Station II between the years examined was calculated to be 8.08 mm per year. According to these calculations, a difference of 4% occurs. This difference can be said to be an increase in sea level at Antalya Station II caused by mostly erosion and many other effects. In summary, it can be roughly said that the contribution to sea level rise at Antalya Station II is caused by mostly temperature increase with 82%, ice melt with 14%, erosion and the other effects with 4%, which can be seen in Figure 5. This result roughly gives an idea about the weights of the causes of sea level rise at Antalya Station II. There are many studies on the causes and their contributions of global sea level rise in the literatüre (Cazenave & Nerem, 2004). (Church et al., 2001) have presented that the contribution to global sea level rise is caused by temperature increase with 30%, ice melt with 30%, and the other effects with 30%. In the study of (Frederikse et al., 2020), these values has been found to be 35.5%, 49% and 15.5%, respectively.

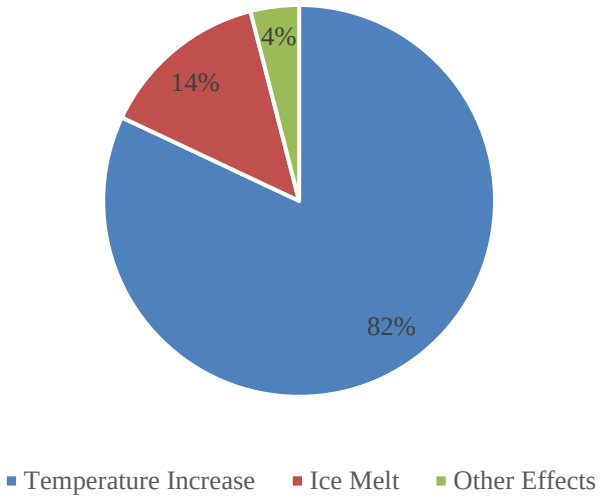

Figure 5. Contributors of the sea level rise at Antalya Station II

According to the monthly average sea level measurements at Antalya Station II, there is an annual upward trend of 8.08 mm per year which is at a level that threatens touristic coastal cities such as Antalya. All the data studied here cover annually and the period between 1991

and 2007 due to data consistency and adequacy. For this reason, the annual upward trend of 8.08 mm per year is also the value calculated between these years. In the literature, it was determined that there is an annual upward trend of 9.6 mm per year at Antalya Station II by (Demirkesen et al., 2008) using the data covering the years 1984 and 2002. Another study was conducted by (Anzidei et al., 2011) and this value was determined as 6.83 mm per year at Antalya Station II using the data covering the years 1985 and 2005.

Figure 6 represents the elevation map of Antalya central settlements, accordingly, some coastal areas are at altitudes close to sea level. The horizontal legend shown in the figure gives the scale, while the vertical legend gives the elevation of the region.

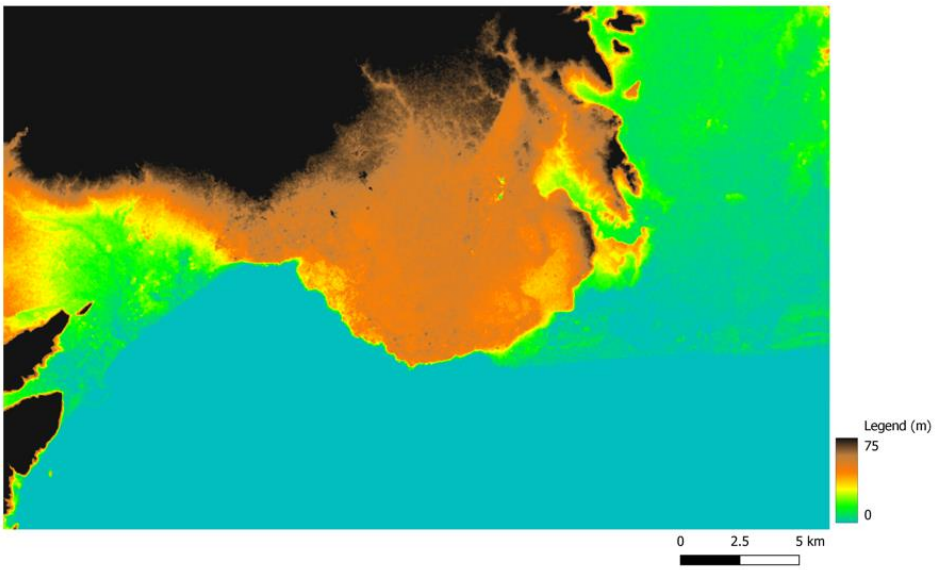

Figure 6. Digital elevation model of the city center

In case of the sea level rises by 50 cm, the blue areas in the settlements shown in Figure 7 indicate that they will be flooded. In the scenario of based on the 8.08mm sea rise every year, the scenario in Figure 7 will take place in approximately 62 years.

Figure 7. Settlement whose elevation will remain below sea level in case the sea level rise of 0.5 meters

2 meters rise in the sea level threatens the vast settlements shown in Figure 8. In the scenario of based on the 8.08mm sea rise every year, the scenario in Figure 8 will take place in approximately 248 years. Although the average water level rises at these values, it is inevitable that the inland areas relative to the coast will be exposed to flooding when the periodic rises and waves are taken into account.

Figure 8. Settlement whose elevation will remain below sea level in case the sea level rise of 2 meters

Figures 6, 7 and 8 were created with QGIS software and the DEM data of the region were obtained from the NASA's Earth Observing System Data and Information System (EOSDIS).

5. Conclusion

In this study, the sea level change at Antalya Station II was analyzed statistically and analytically. First of all, the correlation study was made between the oscillations and the regulated sea level change data. These oscillations are SOI, AO, AAO, NINO 3.4, and NAO. The correlation study with the indexes revealed that there is no significant relationship between the indexes and the sea level change at Antalya Station II.

The correlation of the arctic ice melt, Antalya air temperature, global air temperature and global ocean temperature with the sea level change at Antalya Station II was examined. Among these variables, the arctic ice melt and the Antalya air temperature have relatively high correlation coefficients of 0.6959 and 0.6412 respectively while the global air temperature and the global ocean temperature have low correlation coefficients in the monthly study.

The simple approach has been formed that analytically describes the sea level rise at Antalya Station II in Section 4. Primarily, the correlation study between Mediterranean SST, Antalya air temperature and arctic glacial melting with the sea level change at Antalya Station II has been done and demonstrated. (see Table 3) According to this correlation analysis, the Mediterranean SST seems to have the highest correlation with the sea level change with a correlation value of 0.93 in the annual study. The causes of sea level change at Antalya Station II were evaluated, and with the correlation study carried out in this study and the literature research, the reasons such as sea temperature, glacial melting and erosion were revealed. According to the analytical and statistical study, the annual average sea level change of Mediterranean Sea was calculated.

In summary, the indexes do not have a significant effect on sea level change in Antalya. The sea level change is related to the sea temperature rise, the ice melt and the other effects like the erosion, respectively. As a result of the analytical study conducted in this paper explains that, the contribution to sea level rise at Antalya Station II is mostly related to the temperature increase with a contribution of 82%, ice melt with a contribution of 14%, and the other factors such as erosion with a contribution of 4%.

Figures 6 and 7 show the settlements that would be submerged in the case of a sea rise of 50 cm and 200 cm, respectively. Considering that there is an annual upward trend of 8.08 mm per year, the coastal areas and some residential areas in the city center faces with the risk of flooding in the near future. According to the conclusion in this paper, it is seen that the rise in sea level is mostly caused by the increase in temperature, and the fact that the Mediterranean region is one of the regions most affected by global warming reveals the gravity of the situation which is that the vast settlement areas faces with the flood risk.
The weights of the causes for sea level rise at Antalya Station II can be calculated by including it in other stations in the Mediterranean for future studies.

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