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Disaggregation of global climate model data by different methods and making precipitation forecasts for the future

Disaggeration of global climate model data using different methods and predicting future precipitation

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Abstract

Global climate change is increasing its impact more and more around the world every day, causing dangerous consequences. Especially heavy rains caused by climate change lead to flood disasters. These flood events can cause loss of life and material damage. Therefore, various preventive efforts are being carried out. One of these studies is the creation of Rainfall Intensity-Duration-Frequency (IDF) curves. However, since these curves are generally based on past historical data, they are not considered appropriate for future use. Therefore, in this study, different methods were used to obtain new IDF curves for the future including climate change using climate model data and disaggregated precipitation data.

Key words: Climate modelsData decompositionIDF curves

Abstract

Climate change affects the world with increasing severity, leading to dangerous consequences. Global Climate change is increasing its effects worldwide every day and causing dangerous consequences. Especially, intense rainfall events caused by climate change lead to flooding disasters. These flooding events can result in loss of life and property damage. Therefore, various preventive measures are being implemented. One of these measures is the development of Intensity-Duration-Frequency (IDF) curves. However, since these curves are usually based on past historical data, they are not considered suitable for future use. For this reason, in this study, different methods were used to derive new IDF curves for the future, which include climate change, by using climate model data and disaggregated precipitation data.

Keywords: Climate models, Data disaggregation, IDF curves

1 Introduction

Global climate change affects almost all areas directly or indirectly and significantly affects living life. Its effects can be short-term in some regions and long and permanent in others. There are many factors that cause climate change to occur. The factors are as follows in order. Fossil fuel use: The widespread use of fossil fuels (coal, oil, natural gas) in energy production, transportation and industrial activities contributes to global climate change by increasing greenhouse gas emissions. Another factor is industrialization. Activities in the industrial sector use large amounts of energy to meet energy needs and to produce. This leads to an increase in greenhouse gas emissions. Agriculture and livestock activities, which are another cause, are important source of greenhouse gas emissions. Especially the livestock sector contributes to climate change through methane gas emissions. Destruction of Forests: Deforestation or large-scale destruction of forests leads to increased levels of carbon dioxide in the atmosphere. In addition, forests contribute to climate regulation by absorbing carbon dioxide and producing oxygen. Therefore, deforestation accelerates global climate change. Industrial Processes: Industrial processes such as cement production, chemical production, iron and steel production contribute to greenhouse gas emissions. Increasing Population and Urbanization: Rapidly growing world population and urbanization increase energy demand and greenhouse gas emissions. As energy use and resource consumption increases to meet human , climate impacts grow. Transportation: Transportation sectors such as road, maritime, air and rail transport are an area where fossil fuels are used intensively. Emissions from motor vehicles and airplanes are another major driver of global climate change. Waste Management: Improper waste management and waste disposal can lead to methane gas emissions. Methane gas is a more potent greenhouse gas than carbon dioxide and contributes significantly to climate change. When these factors are evaluated and discussed collectively, it is seen that the biggest cause of climate change is human beings, as stated by most sources [1-5]. It has also been revealed that the human impact rate is around 90% [3], [4]. Since climate change is a very important issue and has a high impact area, the studies on climate change are evaluated under various sub-headings and climate change is analyzed under various sub-headings.

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The problem has been tried to be evaluated in a wide range. These sub-headings and their contents are as follows: Climate Models and Scenarios are realized by using computer-based climate models to understand the impacts of climate change [6-8]. Based on current climate data, future climate scenarios are created and the possible impacts of climate change are evaluated. Weather and Marine Observations focus on observations using weather and marine observing stations to monitor changes in the atmosphere and seas [9-12]. These observations provide important data for detecting signs of climate change and monitoring changes. Greenhouse Gas Emissions are one of the factors most strongly associated with climate change. These studies focus on identifying greenhouse gas sources, monitoring emissions and developing mitigation strategies [13-15]. Biological Impacts of Climate Change investigates the significant impacts of climate change on natural ecosystems. These studies examine the impacts of climate change on plant and animal species, habitat loss, species migration patterns and potential threats to biodiversity [16-18]. Sea Rise and Ocean Acidification includes studies on how global climate change is causing sea level rise and ocean acidification [19-21]. These studies analyze the impacts of sea level rise, risks for coastal areas and changes in ocean ecosystems. Climate Change and Human Health explores the significant impacts of climate change on human health. These studies examine the impacts of climate change on human health, including issues such as increasing temperature, extreme weather events, epidemics, and impacts on food sources [22-24]. Climate Policies and Adaptation includes studies on the development of policies and adaptation strategies to combat climate change. These studies focus on issues such as international climate agreements, energy transition, sustainable development and improving societies' ability to cope with climate change [25-27]. In this study, under the heading of global climate models and scenarios, it was focused on the future prediction of rainfall intensity-duration-frequency (IDF) curves, which are of great importance especially in the design of water structures. IDF curves are used to calculate the design flow rates of structures such as dams, drainage systems, bridges and culverts. The main problem with this topic is that IDF curves are usually based on historical data. IDF curves based on historical data cannot provide data that includes climate change for the future. In order to solve this problem, IDF curves for the future were derived using data from global climate models and scenarios. Since global climate model data are available as daily total precipitation, they need to be decomposed into standard duration precipitation data (5, 10, 15, 30 minutes, 1-24 hours) for the generation of IDF curves. Two different methods were used in the study for decomposition. The first the equivalent quantile matching method (EQM) and the second was artificial neural networks (ANN). Artificial neural networks (ANN) and Global climate models are recognized as important research tools for the analysis of climate change and the climate system. Artificial neural networks, which are mathematical models, are inspired by biological nervous systems and have the ability to identify and learn patterns and relationships in complex data sets. Global climate models, on the other hand, are mathematical and statistical models used to simulate the complex interactions of the worldwide climate system. These models include physical, chemical and biological processes between the atmosphere, ocean, ice sheets and other components. Artificial neural networks are as a valuable tool for global climate models due to their ability identify and analyze patterns and relationships in complex climate data. In this context, artificial neural networks can be used to analyze observational data for purposes such as identifying climate change indicators, making climate predictions, and building future climate scenarios [28-29]. In addition, neural networks can also be used effectively in the development and refinement of global climate models. In line with the calculations made with equivalent quantile matching and artificial neural networks, the findings were obtained according to EQM since the equivalent quantile matching method is more advantageous than artificial neural networks, which give more appropriate results. In the calculations for Ordu province, IDF curves were derived through HadGEM-ES, MPI-ESM-MR, GFDL- ESM2M models and disaggregated precipitation data of RCP4.5 and RCP8.5 scenarios.

2 Workspace

Ordu province was selected as the study area. Ordu generally has a temperate climate. While precipitation is distributed throughout the year, it usually precipitates more intensely in the winter months. Precipitation can continue in the summer months with the effect of the Black Sea. The temperature varies in Ordu depending on the seasons. Temperatures usually hover between 25-30 degrees in the summer months, but due to the high humidity in the region, the temperature can be higher. In the winter months, the temperature usually varies between 5-15 degrees. The highest amount of precipitation is around 150 mm. The station information of Ordu province is given in Table 1 and the location map is given in Figure 1.

Table 1. Station information of the study area

Latitude	Longitude	Height (m)
40,8213	37,861	5

3 Data sets used in the study

The data used in the study were the daily total precipitation data of MPI-ESM-2M, HadGEM-ES, GFDL-ESM2M global climate models for RCP4.5 and RCP8.5 scenarios covering the years 2023-2098, the historical data set of the climate models covering the years 1971-2000, and finally the annual maximum precipitation data of Ordu province for the years 1971-2000. All data sets used were obtained from the General Directorate of Meteorology (MGM).

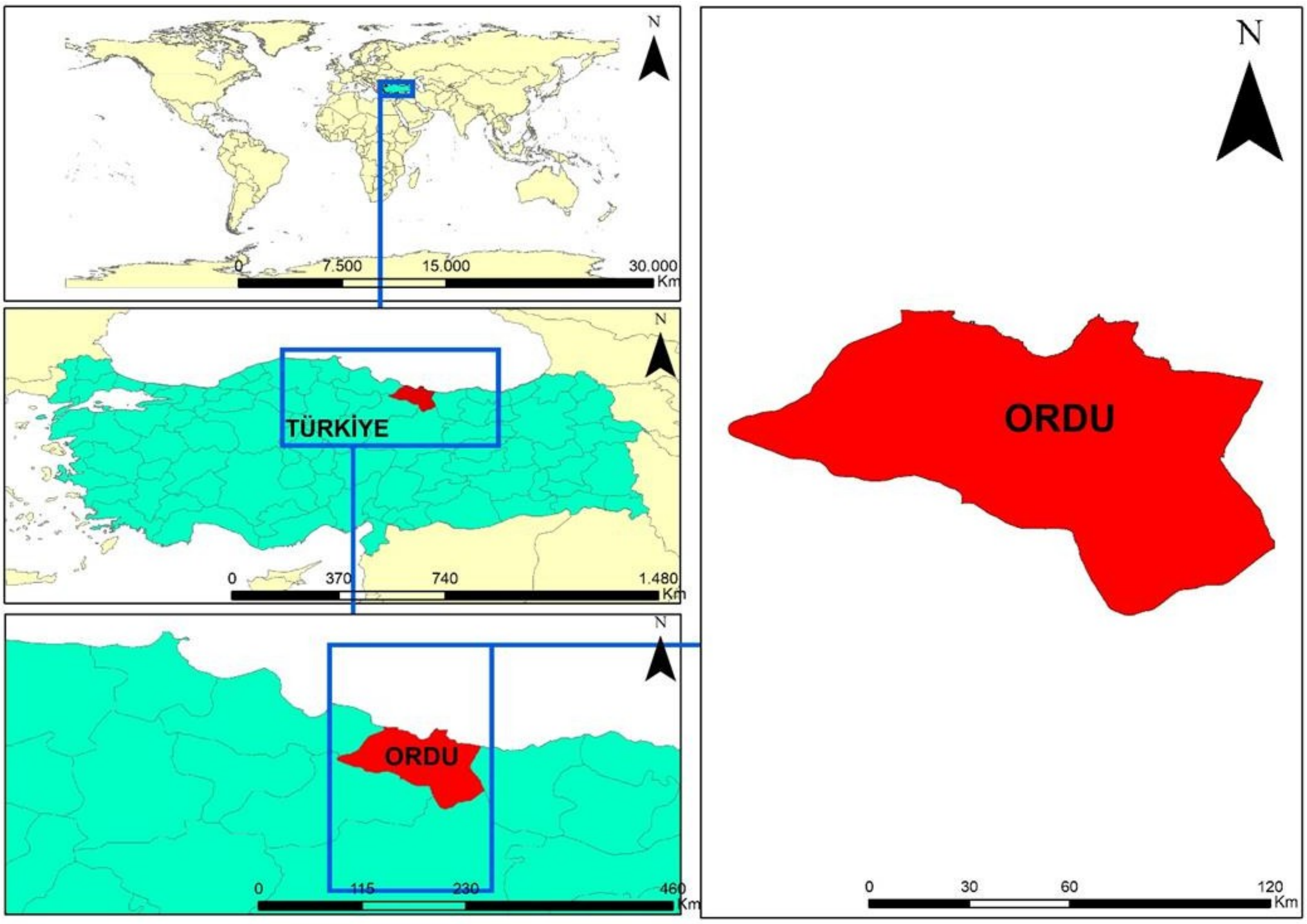

Figure 1. Location map of the study area

The HadGEM-ES climate model was developed by the UK's Hadley Centre for Climate Prediction and Research. It simulates the interaction of various components, including the atmosphere, oceans, glaciers and biosphere. The GFDL-ESM2M climate model was developed by the Geophysical Fluid Dynamics Laboratory (GFDL) of the USA. GFDL-ESM2M is an Earth climate model that includes the interaction of the atmosphere, ocean, ice and land systems. The MPI-ESM-MR climate model was developed by the Max Planck Institute in Germany.

MPI-ESM-MR is a climate model that simulates the complex interactions of atmosphere, ocean, ice and land systems. Since the original global climate models have high resolution, it is difficult and meaningless to conduct city or regional scale studies with these data. Therefore, these data were downscaled from 115-220 m resolution to 20 m by RegCEM4.3.4 regional downscaling process by MGM. There are many climate models other than the climate models used in the study. However, as a result of the studies conducted by MGM, the most suitable models for Turkey's climate dynamics and climate types were determined as the models used in the study. The data used in the study were data with a resolution of 20 m.

4 Methods

4.1 Equivalent quantile matching method

Figure 2 shows the process steps of the first method used. the process steps is given below.

- First, annual maximum precipitation data are obtained from the historical data set of global models, future data set and observed precipitation data sets of Ordu province.
- In the second stage, for each data set, the distribution parameters that best fit the Gumbel distribution are calculated. These parameters are the features that describe the statistical distribution of the data set.
- A statistical relationship is established between the daily maximum data of global climate models and the observed standard time maximum data series. This relationship is obtained using the quantile matching principle. A statistical relationship is established by equating the cumulative probability distribution of the global climate model with the cumulative probability distribution of the standard time series (Equation 1, Equation 2).

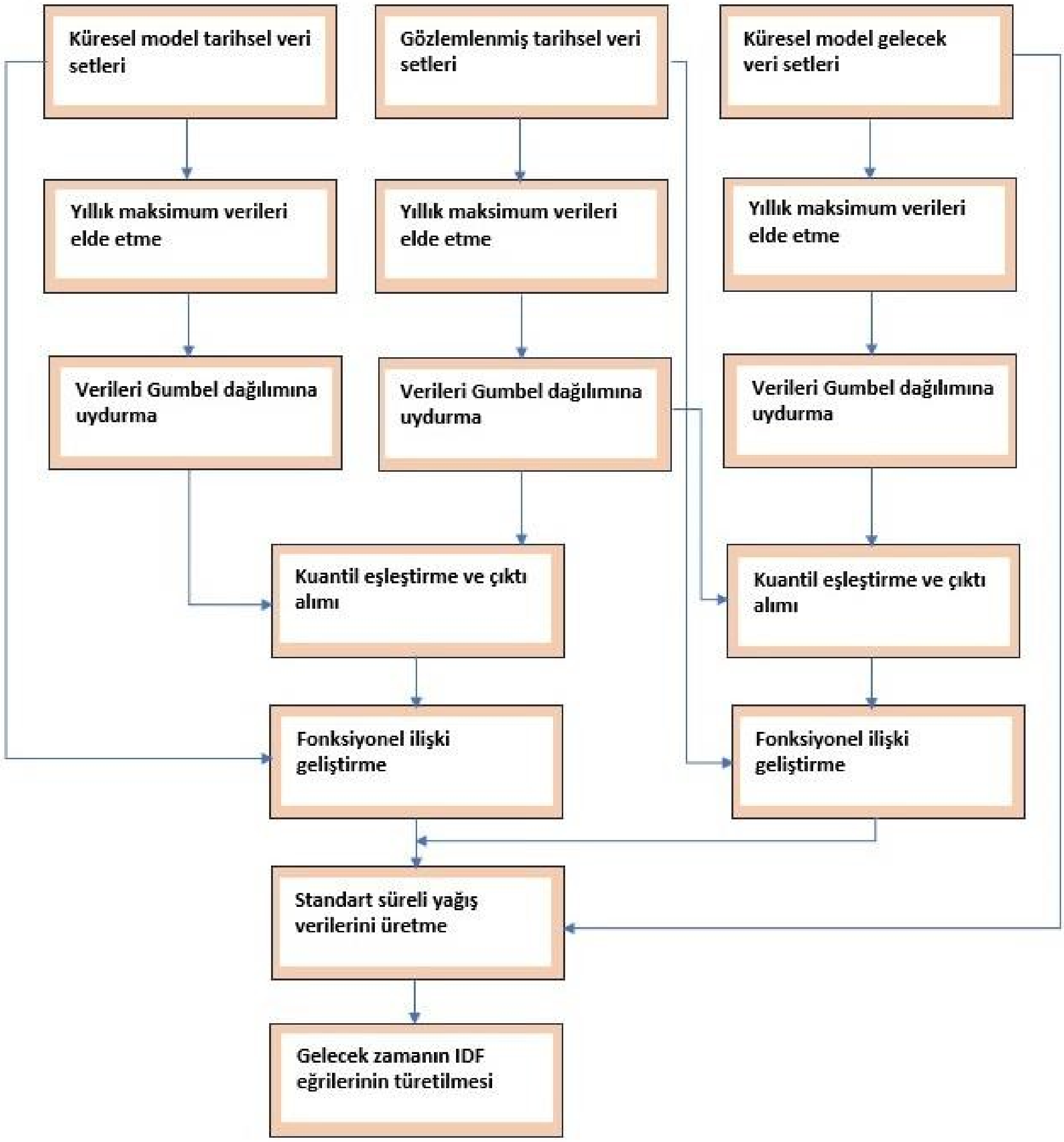

Figure 2. Process steps of the equivalent quantile matching method [30]

$$Y^{STN}_{max,j} = f\left(X^{GCM}_{max}\right) \quad (1)$$

$$Y^{STN}_{max,j} = a_1 * X^{GCM}_{max} + b_1 \quad (2)$$

- Cumulative probability of maximum data of historical datasets of global climate models and future maximum precipitation data of global climate models a similar quantile matching-based statistical relationship is established between the distributions (Equation 3, Equation 4).

$$Y^{GCM,FUT}_{max} = f\left(X^{GCM}_{max}\right) \quad (3)$$

$$Y^{GCM,FUT}_{max} = a_2 * X^{GCM}_{max} + b_2 \quad (4)$$

- In the next step, Equation (3) and Equation (4) is combined to obtain the following equation (Equation 5).

$$X^{STN,FUT}_{max} = a_1 * \left[\frac{X^{GCM,FUT}_{max} - b_2}{a_2}\right] + b_1 \quad (5)$$

- In the last step, future IDF curves are drawn according to the gumbel distribution with the disaggregated data obtained from Equation (5) [30].

5 Decomposition with artificial neural networks (ANN)

Artificial neural networks are based on the natural biological from the provisions inspired by created mathematical models. These models are used to solve complex problems and to recognize patterns. Artificial neural networks are made up of many layers and each layer contains neural cells. These neural cells process data and transmit it to the next layer, producing the final output. Neural networks are trained through a learning process and improve their performance by extracting knowledge from experience. These networks well in many tasks such as classification, regression, pattern recognition and prediction. Neural networks play an important role in computer science and artificial intelligence research and are considered a powerful tool for solving complex problems. The second method used in this study is the artificial neural network, which uses 1, 6, 12, 24 hours of observed precipitation data as input. The standard durations to be predicted 5, 10, 15, 30 minutes. A two-layer feed-forward model with Sigmoid transfer function was used for the model. Lavenberg-Marquardt back-propagation algorithm was used to develop the model. The ann structure used is shown in Figure 3.

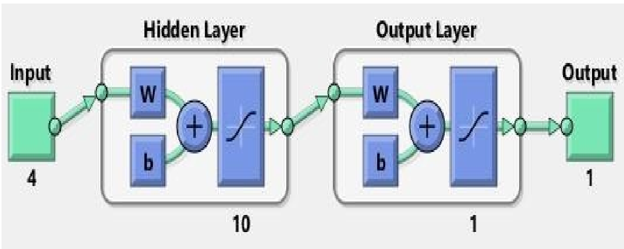

Figure 3. ANN structure

6 Findings and discussion

In the study, firstly, the observed historical data sets between 1971-2000 and the historical data of the climate models for the same period were used to determine the suitability of the equivalent quantile matching method used to update the IDF curves by reducing the daily precipitation data of the climate models to shorter duration precipitation data. As a second step, the maximum data of 161224 hours observed with artificial neural networks
precipitation data for 5, 10, 15, 30 minutes were to be estimated. The success of both methods in deriving the precipitation data required to obtain future IDF curves was tested to determine which method is better in precipitation data parsing and the advantages and disadvantages of using the methods.

As seen in Figure 4, it is seen that the precipitation data decomposed by the equivalent quantile matching method are in high agreement with the observed precipitation data. For this reason, it was understood that it is appropriate to use EQM in the generation of future IDF curves. One advantage of the EQM method is that it does not require data transformation. It offers the opportunity to perform statistical analysis only by matching without changing the initial data set. This ensures that data integrity is preserved and facilitates the analysis process. The EQM method reduces the effect of sample size on distribution matching. This that effective results can be obtained even with small samples. Thanks to this feature, the EQE method can be used with limited samples due to data limitations. for researchers working in the field of distribution matching. In summary, the EQM method is useful for distribution matching because it matches the distribution between two variables, does not require data transformation and is sensitive to sample size.

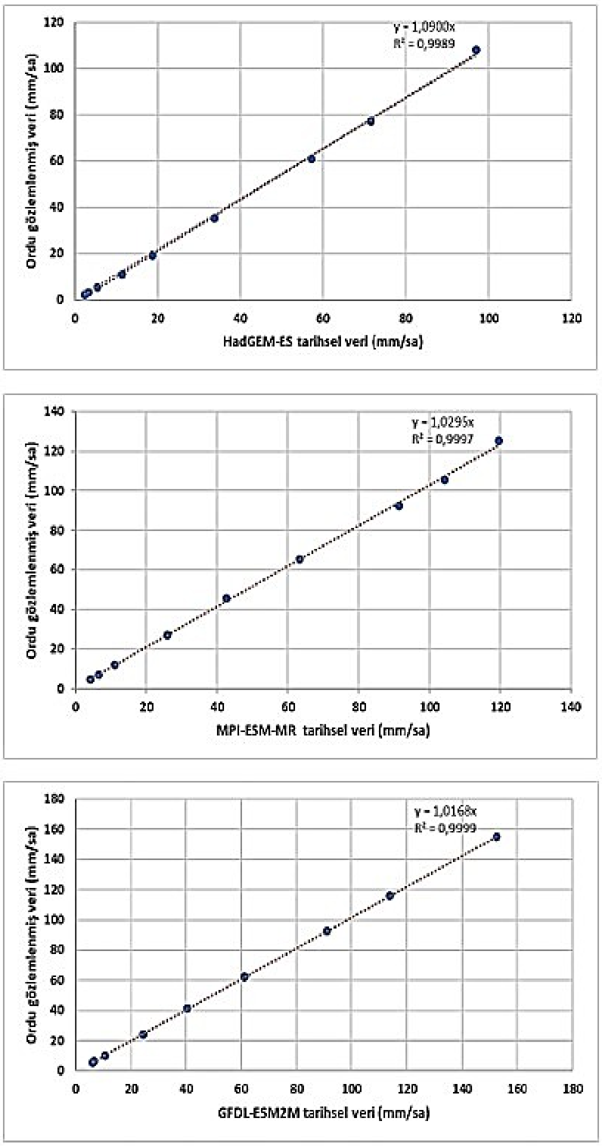

Figure 4. Comparison of HadGEM-ES, MPI-ESM-MR, GFDL-ESM2M models' disaggregated T=10 year period precipitation data and observed data of Ordu province, from top to bottom, respectively

As a result of the analysis performed with artificial neural networks the prediction of 1, 6, 12, 24 hours of observed data and 30 minutes of precipitation data, good results obtained (Figure 5). However, in the data obtained with artificial neural networks, the similar high success obtained with EQM could not be achieved. Artificial neural networks change their results according to the learning and the amount of data they use. With this feature, it is disadvantaged from EQM. Since EQM is more advantageous than artificial neural networks, all findings in the study were obtained with EQM in terms of practicality.

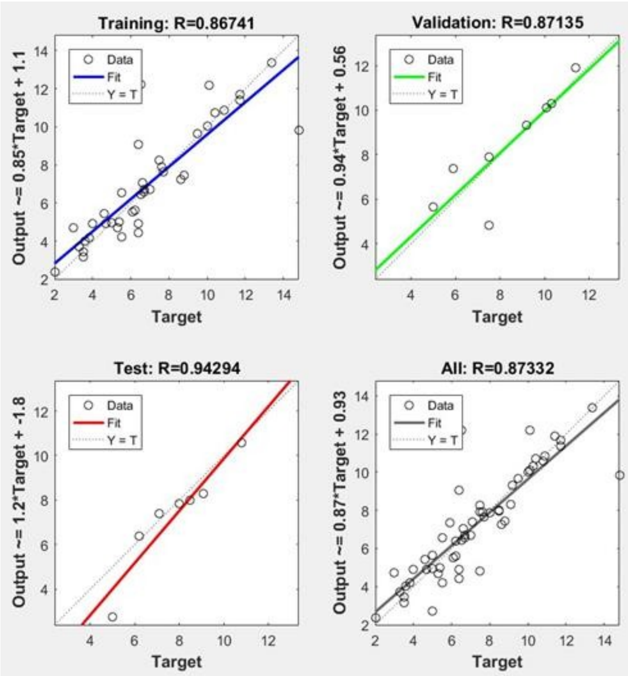

Figure 5. Test results of obtaining 30 min rainfall data with artificial neural networks

As can be seen in Figure 6, Figure 7 and Figure 8, there is an increase in precipitation according to HadGEM- ES model, while there is a decrease according to GFDL-ESM2M and MPI-ESM-2M models, and the decrease according to MPI model is higher than GFDL.

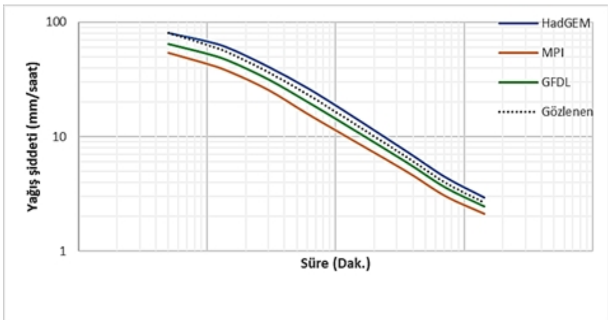

Figure 6. Comparison of precipitation estimates obtained according to RCP8.5 scenario with observation values for the period T=2 years

According to the findings obtained, it is seen that precipitation increased in the range of 5-15% according to the HadGEM model, decreased in the range of 33-50% according to the MPI model, and decreased in the range of 8-22% according to the GFDL model in the T=2 year period (Figure 9). In the T=5 year period, precipitation increased by 16-24% according to HadGEM model, decreased by 20-38% according to MPI model, and decreased by 16-34% according to GFDL model (Figure 10). In the period of T=10 years, it is observed that precipitation increases in the range of 20-30% according to HadGEM model, decreases in the range of 14-37% according to MPI model and decreases in the range of 20-43% according to MPI model (Figure 11). Considering the recent years, Ordu

It was observed that many flood events occurred in the province. On July 7, 2023, it was observed that floods occurred in Bülbül Stream due to excessive rainfall and serious damages occurred due to flooding [31]. On July 18, 2022, workplaces and most houses were flooded after the flood in Ilıcalı Stream in Fatsa district of Ordu [32]. Considering these floods that occurred in Ordu province in recent years, it was seen that the precipitation situation of Ordu province was more compatible with the HadGEM-ES model. When the findings obtained in the study were analyzed, it was seen that similar results were obtained to the studies in the literature [33-35].

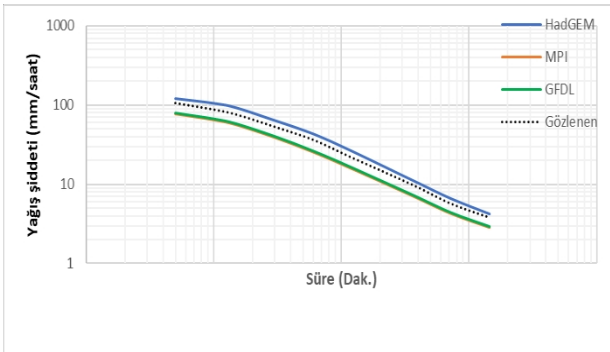

Figure 7. Comparison of precipitation estimates obtained according to RCP8.5 scenario with observation values for the period T=5 years

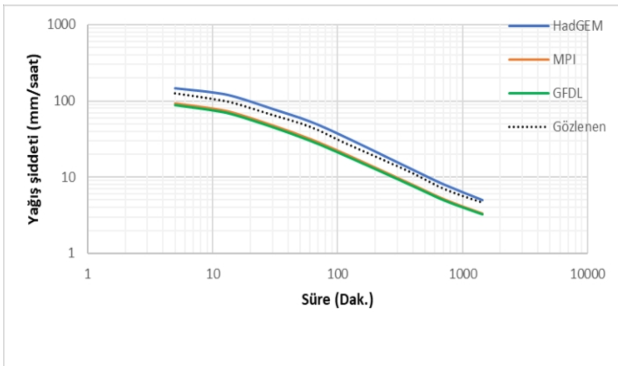

Figure 8. Comparison of precipitation estimates obtained according to RCP8.5 scenario with observation values for a period of T=10 years

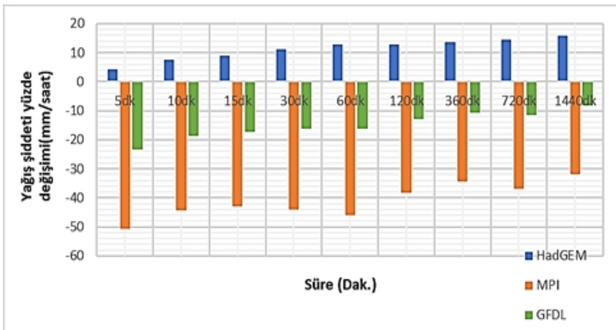

Figure 9. Comparison of precipitation estimates obtained according to RCP8.5 scenario with observation values as % change for T=2 year period

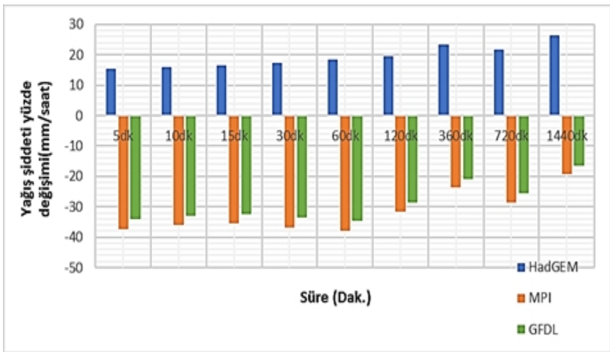

Figure 10. Comparison of precipitation estimates obtained according to RCP8.5 scenario with observation values as % change for T=5 year period

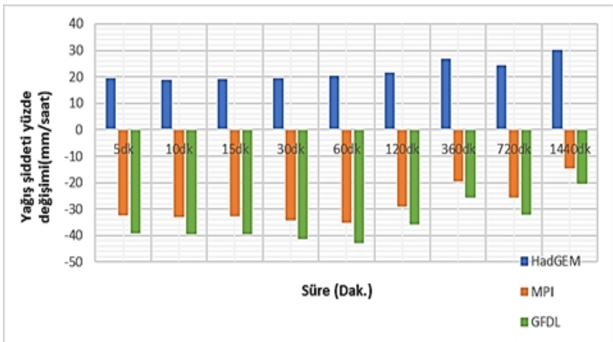

Figure 11. Comparison of precipitation estimates obtained according to RCP8.5 scenario with observation values for a period of T=10 years
Comparison as % change

7 Results

Climate change is recognized worldwide as a serious problem. Scientific evidence shows that the increase in greenhouse gases in the atmosphere is leading to an increase in global temperature and significant changes in climate systems. Therefore, combating climate change and mitigating its impacts is of paramount importance. For these reasons, a lot of work needs to be done globally to combat climate change and mitigate its impacts. In this study, IDF curves, which are of great importance especially in the design of water structures, are emphasized. The fact that IDF curves based on existing observation data are not capable of reflecting future climate change has revealed the need for updating IDF curves. In this study, future projections of IDF curves were made. As a result of the findings, it was concluded that the precipitation of Ordu province will increase according to the HadGEM-ES model, while the precipitation will decrease according to the MPI-ESM-MR and GFDL-ESM2M models. In other words, according to the HadGEM model, the water infrastructure of the city will be insufficient, while according to the other models, water infrastructure of the city is sufficient and there is no situation that will cause any flooding. Due to the floods that have occurred in Ordu in recent years, it has been seen that the HadGEM model is a more suitable model for the design of water structures in Ordu province compared to other models. Since the parameters and calculation techniques of global climate models are different It is also seen that each model gives different results. When the results obtained from the area to be studied are examined, it is recommended to carry out engineering studies according to the flood situation that may pose a danger. It is hoped that the data obtained in the study will support the application studies to be carried out by various institutions and academic studies related to this subject.

Conflict of interest

The authors that there is no conflict of interest.

Similarity rate (iThenticate): 9

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