Rainfall Change Projections under Different Climate Change Scenarios in UAE

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Abstract

The increase of greenhouse gases in the atmosphere due to human activities is predicted to have significant and lasting effects on the global climate throughout the 21st century. The resulting warming over the past decades has caused various hydrologic and landscape reactions, which may continue and accelerate without proper strategies to reduce greenhouse gas emissions. Climate changes due to greenhouse gases have been observed across the world, including in the United Arab Emirates (UAE) and the Arabian Gulf region. Changes in precipitation patterns can have severe consequences for natural and human systems as precipitation is a crucial part of the hydrological cycle. As the UAE is highly susceptible to climate change, it is necessary to investigate potential local impacts in-depth to develop sustainable adaptation strategies. This study assesses the future changes in precipitation patterns in the UAE under different climate change scenarios, using statistically downscaled results from global climate models (GCMs) and considering two representative concentration pathways (RCPs): RCP4.5 and RCP8.5. The study period ranges from 2021 to 2100 and compares it to the observed historical period of 1982 to 2011. The analysis examines precipitation changes at monthly and annual scales. Based on selected GCMs under the two RCPs, the average annual rainfall in the UAE is expected to change by -61% to 88%. This study emphasizes the importance of assessing potential impacts of climate change on precipitation patterns in vulnerable regions such as the UAE and the need to develop adaptation strategies to mitigate these potential impacts.

Keywords: Climate change; Precipitation; Projection; Climate models; Downscaling; RCP

1 Introduction

The 21st century is projected to witness significant, persistent shifts in the climate globally because of the substantial increases in atmospheric greenhouse gas concentrations attributable to human activities. Observations indicate that warming has already persisted for several decades, accompanied by diverse hydrologic and landscape responses, which are predicted to escalate unless greenhouse-gas emissions are effectively reduced or reversed. Climate change projection is subject to considerable uncertainty; Despite the fact that forecasting the future impact of climate change is a complex challenge, modern numerical models of the global climate can provide useful predictions to help determine potential vulnerabilities in sediment, nutrient, hydrologic and systems (Costa-Cabral et al., 2013; Samuels et al., 2010). Considering the growing apprehension regarding impending climate change, evaluations of regional and local resource systems are being conducted across the globe. In response, assessment policies and scenarios have been developed and are being employed for preliminary evaluations (Dixon et al., 2016; Gebrechorkos et al., 2019a, 2019b).

In recent decades, global climate change has had widespread effects on both natural and human systems, affecting regions across all continents and oceans (Stocker, 2014). The United Arab Emirates (UAE) and the surrounding Arabian Gulf region have also been impacted by climate change, given the country's large coastal area, numerous islands, and rapid economic growth resulting in significant urban development. The UAE is particularly vulnerable to climate change given its susceptibility to abnormal rainfall events, rising population, and changes in atmospheric CO2 and temperature.

It is anticipated that climate change will have significant effects on global precipitation patterns, resulting in both increases and decreases in rainfall across different regions. The degree of warming experienced by the Earth is a primary determinant of future precipitation patterns. Increased atmospheric temperature can hold more moisture, potentially leading to enhanced rainfall in certain areas. Conversely, in other areas, increased evaporation due to warming can lead to a decrease in precipitation. Additionally, changes in atmospheric circulation patterns, specifically in the strength and position of the jet stream, are also important factors affecting precipitation. Climate models are utilized to predict precipitation changes under varying climate scenarios, accounting for the factors mentioned above as well as other factors such as aerosol emissions and land use modifications.

Industries have been assessed for their potential susceptibility to climate change utilizing General Circulation Models (GCMs). GCMs are typically employed to predict future climates using energy and mass balance equations (Adhikari et al., 2015; Chiew et al., 2009) , and their effectiveness in accurately describing physical processes in the climate system such as the, ocean land , and atmosphere is well-established (Cooper et al., 2008). Yet, the limited resolution of current GCMs impedes their ability to factor in local features like topography and convective clouds, potentially compromising the accuracy of projections (Donat et al., 2016).

In order to investigate weather dynamics regionally and locally, global models are often downscaled using dynamical downscaling methods. This process involves using a set of coarse-resolution large-scale meteorological fields, typically derived from a GCM or global reanalysis data, to provide the preliminary, lateral, and surface boundary conditions for a regional climate model. Various approaches are used for dynamical downscaling, including GCM anomaly smoothing and interpolation, statistical modelling, machine learning, and regional dynamical climate modelling, which vary in terms of precision, resolution of the output, processing demands, and scientific resilience (Rummukainen, 2010; Tabor & Williams, 2010). The two most commonly used methods for downscaling GCMs for climate change impact research are dynamic and statistical downscaling. Bias-correction, on the other hand, involves applying statistical techniques to improve the realism and spatial resolution of climate model outputs, especially when high-resolution observations are available (Ehret et al., 2012; Hawkins et al., 2013).

Several studies have utilized GCMs to generate future climate projections under different GHG emission scenarios. For instance, Alexander and Arblaster utilized the CMIP5 models to evaluate the impacts of projected precipitation and temperature extremes in Australia (Alexander & Arblaster, 2017). They discovered that cold temperature extremes would decrease significantly while warm temperature extremes would increase significantly by the end of the century. They also found that that dry periods are projected to increase while the frequency of the most severe precipitation extremes is expected to significantly rise. Similarly, Ishida et al. investigated the impact of climate change on precipitation at the watershed scale, utilizing dynamically downscaled CMIP5 future climate projections for Northern California. However, their analysis found no major trend in the yearly accumulated precipitation amount (Ishida et al., 2017). Meanwhile, Hussain et al. (2017) projected future precipitation and air temperature values in Sarawak, Malaysia, based on CMIP5 scenarios, and projected that by 2100, the lowest air temperature would increase by 0.83°C to 2.08°C, maximum air temperatures would rise by 0.78°C to 0.94°C, and precipitation would increase by 4.5% to 10.5%, depending on the scenario (Hussain et al., 2017). Wambura et al. (2014) conducted an investigation of climate change for Tanzania utilizing 20 GCMs and the CMIP5-established RCP 8.5. Their findings indicate that temperatures are expected to rise by 0.9°C, while there will be an increase in rainfall, particularly during the month of April (Wambura et al., 2014).

However, to the best of our understanding, no research has projected future precipitation for the United Arab Emirates (UAE). Additionally, no UAE climate estimates have been produced using CMIP5, the most recent GCM platform used by the Intergovernmental Panel on Climate Change (IPCC). To address this gap, this study employs a multi-ensemble CMIP5 GCMs to provide monthly rainfall estimates for the near (2020–2050) and far (2051-2100) futures in the UAE. A trend analysis is then carried out to identify patterns in projected future precipitation for the UAE. The objective of this research is to contribute to future climate change impact studies in the UAE and to assist policymakers in developing climate change adaptation policies.

2 Study Area

UAE is located at the eastern end of the Arabian Peninsula between 22°50′ and 26° north latitude and between 51° and 56°25’ east longitude with an area coverage of 83,600 km2. The coastline of UAE spans roughly 1,318 kilometers along the Persian Gulf and the Gulf of Oman. Along the southern coast of the Persian Gulf are several saltpans that extend deep into the inland. UAE is primarily an arid area with enormous sand deserts, but it also contains sand dunes, oasis, rock mountains, valleys, marshes, mangroves, and salt plains. The majority of oasis are found in the emirate of Abu Dhabi, which is dominated by date palms. It is mainly located in a hot, arid environment with average temperatures between 26°C to 33.5°C. The UAE's rainy season normally runs from December to March, with average annual precipitation ranging from 140 to 200 millimeters and mountainous regions receiving up to 350 millimeters. The UAE is also susceptible to strong dust storms, known locally as shamal winds.

3 Methodology

3.1 Data Collection and Preparation

As shown in Figure 1, this research utilized 35 years (1985-2020) of precipitation data from 21 weather stations in different climate zones in the UAE. The data were obtained from the National Meteorology

Centre (NMC) and were collected in an appropriate format for further analysis. The completeness, accuracy, and representativeness of the data were evaluated to ensure their reliability in the study. The Normal Ratio Approach and Inverse Distance Method were employed to complete missing data.

The data utilized in this study were gathered from various weather locations situated throughout the United Arab Emirates (UAE). Furthermore, the future GCMs datasets were procured from the CMIP5 platform, which is accessible through the Earth System Grid Federation (https://esgf-node.llnl.gov/search/esgf-llnl/). The study includes three distinct scenario periods: historical, near future (2021-2050), and far future (2050-2100). Each GCM generates data for four representative concentration pathways (RCPs) scenarios, which were developed in the CMIP5 project. The RCPs in question include RCP2.6, RCP4.5, RCP6, and RCP8.5 where RCP2.6 represents the scenario with the lowest GHG emissions, while RCP8.5 indicates the scenario with the highest greenhouse gas emissions. In this study, a multi-model ensemble comprising 19 GCM models was employed. The precipitation scenarios of the selected models under two RCPs, namely RCP 4.5 and RCP 8.5, were utilized.

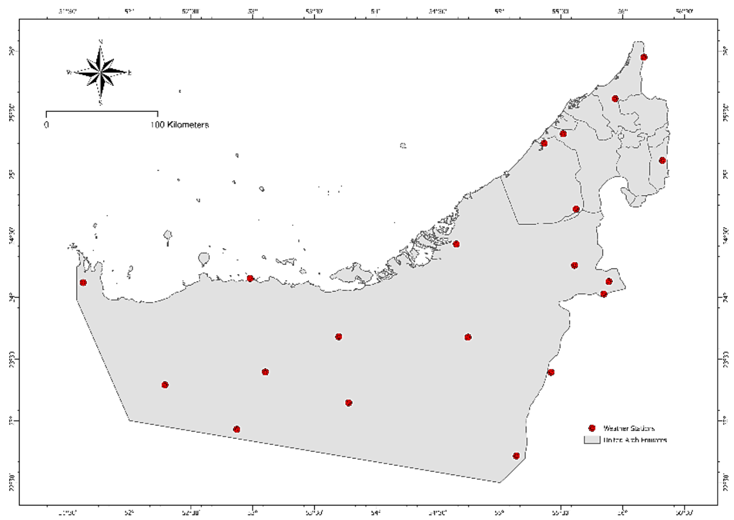


Fig. 1: Distribution of the weather stations in UAE

3.2 Bias Correction

The climate models have data that is available as a function of latitude and longitude along predetermined grid lines to cover every area on Earth. Scaling down data for UAE weather stations required interpolation or extrapolation for each model. Interpolation is the process of predicting data from a dataset using the available data. Extrapolation is the process of making predictions that go beyond the data set. Three different forms of interpolation are used to clarify the precise rainfall or temperature for each area in accordance with the station's placement within the grids of each model. When a station was between two points, interpolation between those two points was needed, and when it was in the middle of a square between four points, interpolation between those four points was required. In this study, bias correction using delta approach was used. The delta change approach is a technique that makes the output of GCMs usable for hydrological modelling and watershed scale study (which means that the GCM outputs are used indirectly). The average monthly precipitation and temperature are determined based on 35 years of records (1985 to 2020) is used to calculate the delta correction factors in this study. All data from various RCPs (RCP 4.5 and RCP 8.5) are corrected using delta approach. The delta factor can be calculated using the following equation:

$$\Delta\, month\ i = \frac{\text{Future average monthly precipitation for month i (from model used)}}{\text{Historical average monthly precipitation for month i (from a model used)}} \qquad (1)$$

3.3 Trend Analysis

The examination of trends in climatological data records at selected stations is a critical component of climate change research. To unveil trends, unfiltered data is subjected to analysis using a simple linear regression method. However, it is worth noting that the authentic trend may not manifest as a linear relationship and could be obscured by the data's noise. In the present study, the precipitation data from 20 stations were utilized to illustrate trend analysis.

4 Results and Discussion

Figure 2 presents the annual precipitation time series for the different weather zones analyzed in the investigation, which involved a comprehensive evaluation of the annual and monthly precipitation data to identify discernible trends. The results indicated a modest declining trend in annual precipitation, as evidenced by the negative slope of the regression line and a correlation coefficient of approximately 0.3.

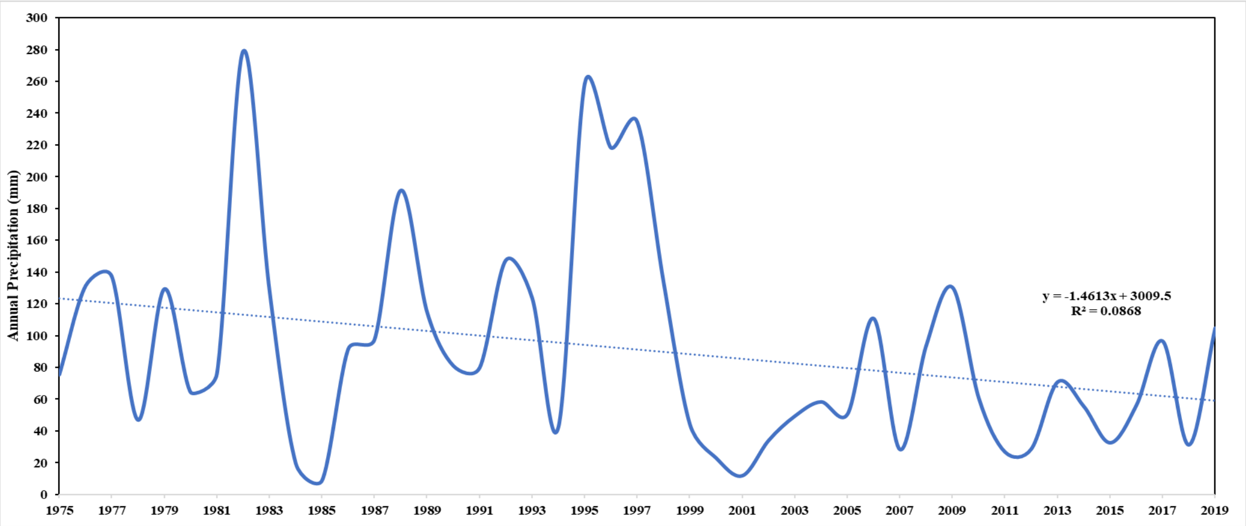
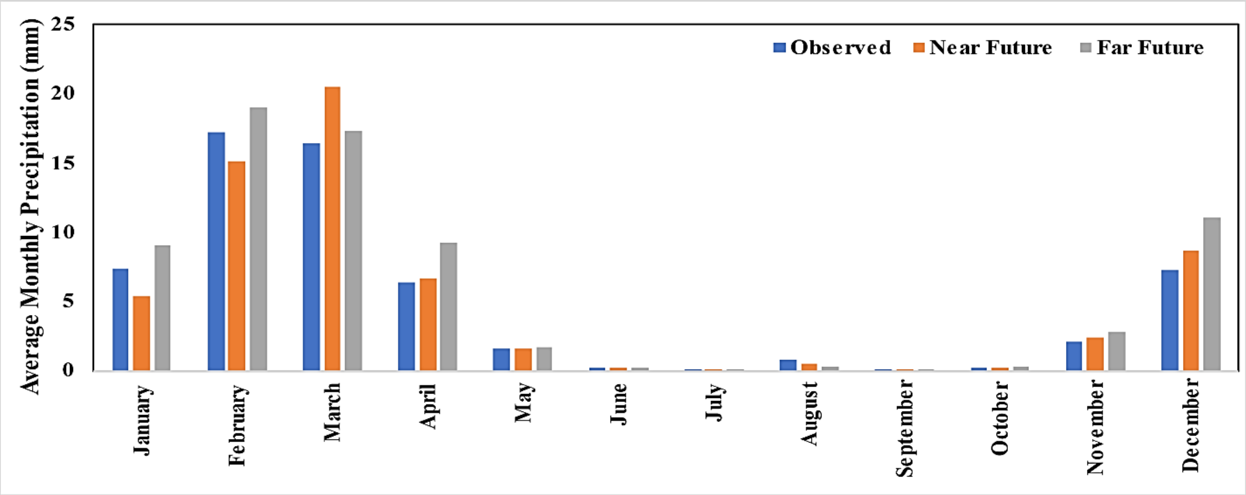


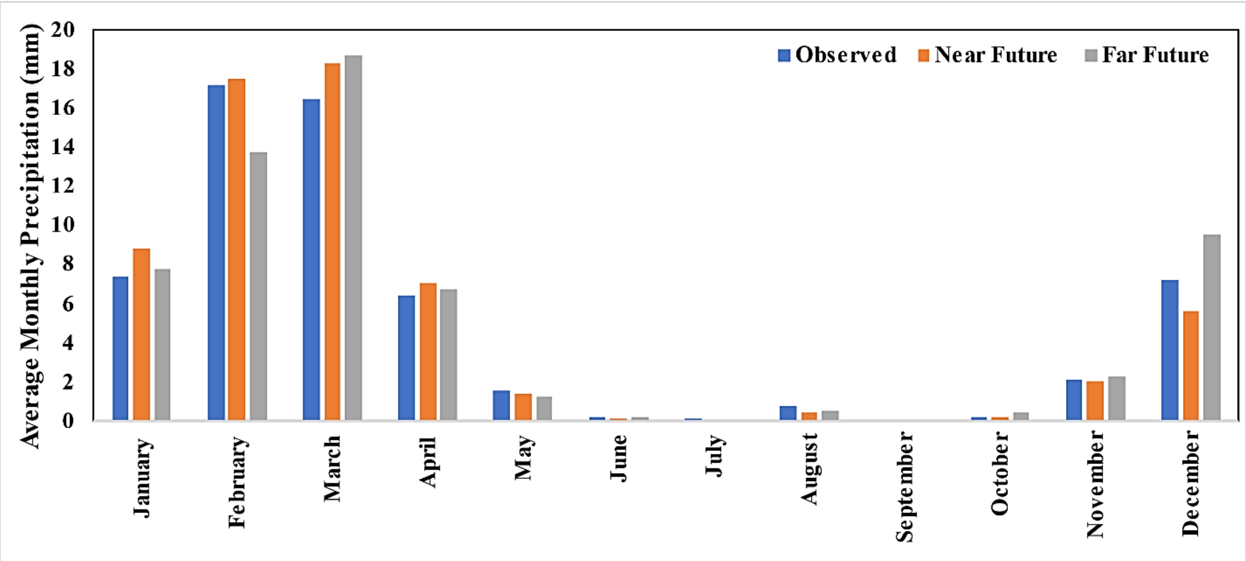
Fig. 2: Historical Annual Precipitation

Fig. 3 shows the average monthly precipitation for the near and far futures under RCP 4.5 and RCP 8.5 scenarios for UAE, respectively. There will be mainly a decrease in precipitation in almost all the months except for March, April, and December in the near future compared to the observed precipitation for RCP 4.5. However, all the months have an increase in precipitation except for July and August. In general, there will be a change in precipitation from -30% to 25% and -61% to 52% depend on the month in near and future, respectively, for RCP 4.5. Moreover, precipitation is expected to decrease in the near future for RCP 8.5 compared to the observed precipitation in almost all months except winter months (from January to April). On the other hand, the far future RCP 8.5 demonstrated mixed results where half of the months showed an increase (January, March, April, June, October, November, and December) and the other half had a decrease. Precipitation changes are expected to range from -41% to 20% and -34% to 88% depending on the month in the near future and the far future for RCP 8.5, respectively. Overall, Highest average precipitation value for RCP 4.5 and RCP 8.5 are 20.5 mm (March) and 18.3 mm (March), respectively, for the near future. In the far future, the highest values are 19 mm (February) and 18.7 mm (March) for RCP 4.5 and RCP 8.5, respectively. **Fig. 4** and **Fig. 5** show the heat maps for change in precipitation every 10 years for RCP 4.5 and RCP 8.5, respectively.

The study reports that under the RCP 4.5 scenario, the UAE is expected to experience a decrease in precipitation in most months of the year, except for March, April, and December, in the near future. On the other hand, all months are expected to see an increase in precipitation except for July and August. Similarly, under the RCP 8.5 scenario, the UAE is expected to experience a decrease in precipitation in most months, except for the winter months (from January to April) in the near and far future. In contrast, the future RCP 8.5 scenario demonstrated mixed results where half of the months showed an increase, and the other half had a decrease in precipitation.



(a)



(b)

Fig. 3: Precipitation for UAE for the near and far futures under
(a) RCP 4.5 and **(b)** RCP 8.5 scenarios

Under scenario RCP 4.5, the potential change in precipitation varies from less than -1.23 mm to about 0.62 mm between 2020 and 2050, whereas the potential change in precipitation varies from –1.62 mm to 1.54 mm between 2051 and 2100. Under scenario RCP 8.5, the possible precipitation varies from less than -0.57 mm to about 0.42 mm between 2020 and 2050, whereas the potential precipitation changes ranges from -1.17 mm to 0.97 mm between 2051 and 2100.

The potential changes in precipitation between 2020 and 2050 are relatively small compared to the changes expected between 2051 and 2100. This suggests that the changes in precipitation patterns will become more pronounced as we move further into the future, and the impact of climate change on precipitation patterns in the UAE will be more significant in the long term. It is also interesting to note that the range of potential changes in precipitation is broader under the RCP 8.5 scenario than under the RCP 4.5 scenario. This is likely because the RCP 8.5 scenario represents a more severe emissions scenario than the RCP 4.5 scenario, leading to more significant changes in climate variables such as precipitation.

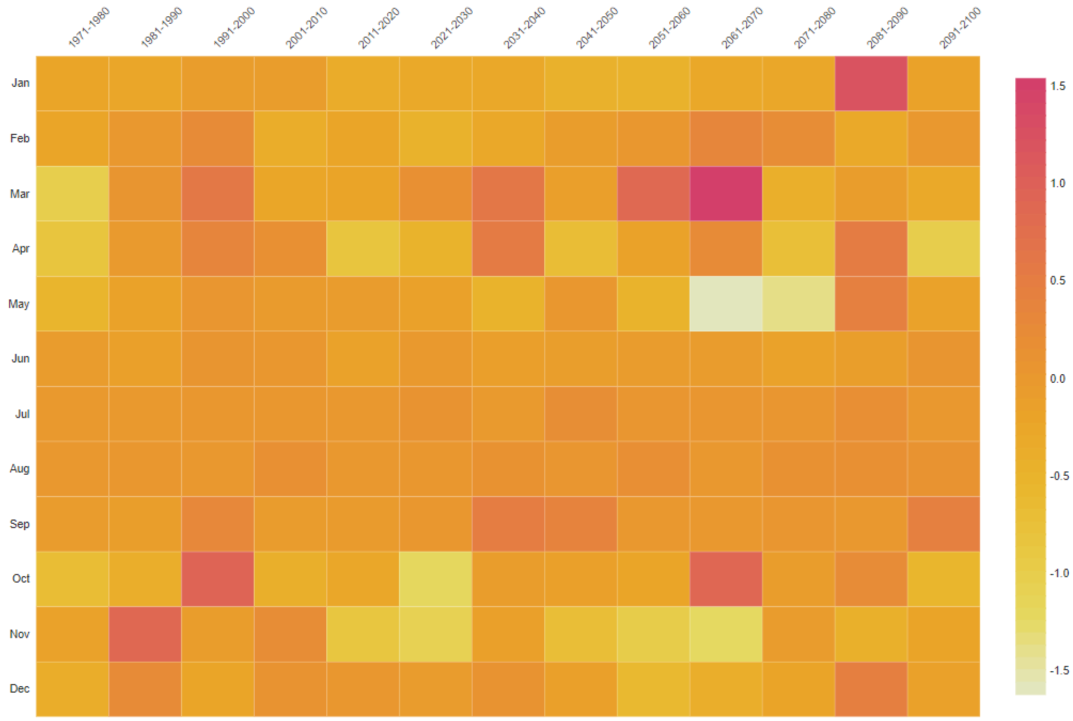


Fig. 4: Projected precipitation anomaly under RCP 4.5

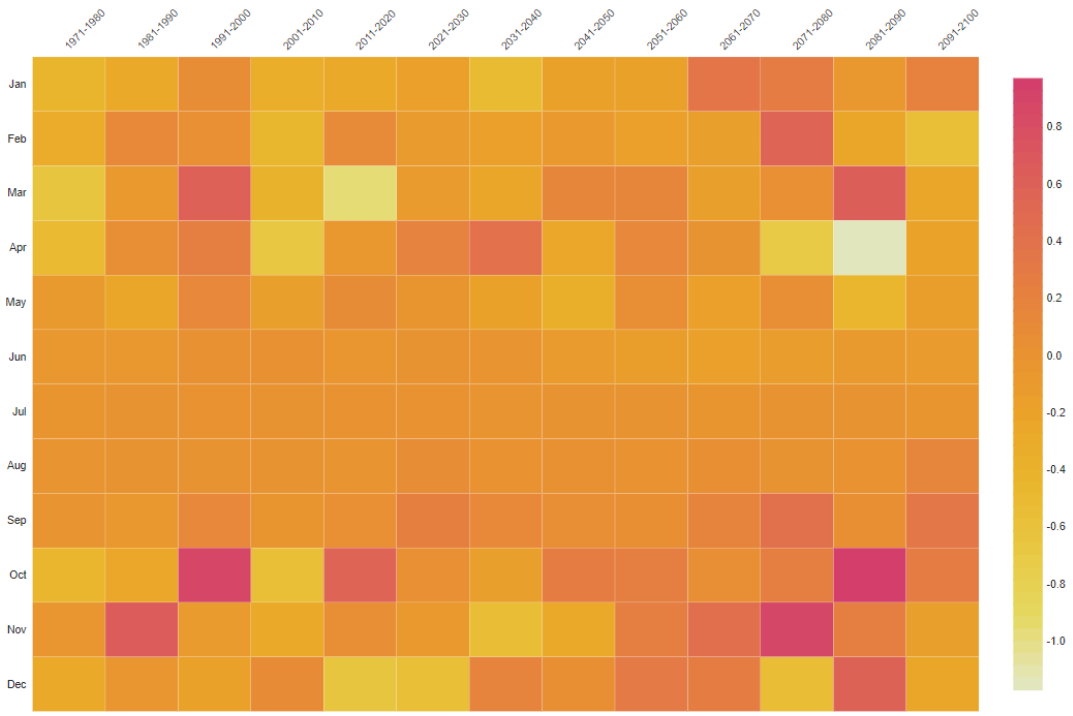


Fig. 5: Projected precipitation anomaly under RCP 8.5

5 Conclusion

In this research, a combination of 19 GCM models were utilized to produce future precipitation projections at 20 meteorological stations in UAE under RCP 4.5 and RCP 8.5 scenarios for both near and far future periods. The principal findings of this study were that the UAE has experienced a reduction in precipitation over the years, according to historical data. Furthermore, based on the GCM models and RCPs selected, it is anticipated that average annual precipitation in the UAE will vary between-61% and 88% by the end of the century. Analyses also revealed that the most significant decreases in precipitation occurred in January and February for RCP 4.5 and RCP 8.5, respectively, while the greatest increases were observed in March and October under the respective RCPs. This research suggests that the UAE is likely to continue experiencing a decline in precipitation, similar to other climate change studies conducted in the region. Given the UAE's location in a water-scarce region, continued drought could have severe consequences for the country. As such, it is crucial to conduct impact assessments of climate change using the projected precipitation values from this study, as well as those from other climate change projection studies in the UAE, and to develop and implement adaptation policies based on the results of hydrological impact studies.

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