

Projected Climate Change in Jordan: A Case Study of Jerash Region

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Abstract

This study analyzes the projected impacts of climate change on Jerash region of Jordan on temperature, precipitation, and groundwater recharge using the Statistical DownScaling Model (SDSM). Historical climate data from five meteorological stations were downscaled applying three IPCC Representative Concentration Pathways (RCP 2.6, 4.5, and 8.5) to project future trends during the period 2024-2100. The results indicate a continuous rise in the maximum and minimum temperatures, where maximum warming in the most intense emissions RCP 8.5 scenario occurs in Dibbin station with an increase of 2°C. Concurrently, there has been a gradual decrease in the annual precipitation received in all the stations, particularly in the RCP 8.5 scenario, where the loss exceeded 65% at Burma station. Such climatic conditions were empirically linked with the extensive loss in climate-induced groundwater recharge by up to 60%, by the year 2100, according to the results. The study indicates the need for adaptive measures in water management in order to mitigate the impacts from climate variability on semi-arid regions' societies and agriculture dependent on groundwater recharge from the Jerash area.

Keywords: Climate Change, SDSM, Precipitation, Temperature Trends, Groundwater Recharge, Jerash Region.

1. Introduction

Climate change is one of the most salient global environmental problems of the 21st century with widespread implications on natural systems, human populations, and sustainable development. It is primarily fueled by the rapid accumulation of greenhouse gases—all notably carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O)—within the atmosphere, primarily through human endeavors such as fossil fuel combustion, industrial emission sources, and deforestation. The released greenhouse gases disturb the global energy balance, causing an eventual rise in global mean temperatures. The manifestations of the warming phenomenon have profound and multidimensional implications, including alterations in precipitation regimes, greater frequencies of extreme weather occurrences, polar ice cap melting, increases in sea levels, and disruptions of water flow. The consequences have particular relevance in already-stressed environments, such as deserts and semi-arid environments, where water shortage, food insecurity, as well as ecological degradation, can be anticipated to increase under future climate scenarios.

Climate change already produced measurable impacts on many of the world's environmental systems across the globe, and future projections indicate still more drastic disruptions. The global surface temperature already increased by an estimated 1.1°C above pre-industrial concentrations, as calculated by the Intergovernmental Panel on Climate Change (IPCC, 2021), and is likely to continue and range between 1.5°C and 4.4°C at the end of the 21st century depending on scenarios of emission. These changes are non-homogeneous and more intensified in some of the world's most exposed regions. According to Trenberth (2011), it is observed that the regime of precipitation is becoming more polarized—the wet regions get wetter while dry regions suffer from recurring droughts. Such weather-related episodes interrupt the global hydrological cycle and trigger more evapotranspiration, reduced soil moisture, and declining water stores.

Mehta et al. (2024) noted that Asia and Africa's semi-arid and arid regions are witnessing phenomenal declines in groundwater recharge as temperatures and rainfall continue to escalate. Similarly, Wang et al. (2024) noted that globally groundwater dependency is increasing as surface water becomes unreliable, with resultant rapid depletion of the aquifers. In Northern Africa, the Sahel, and specific Mediterranean Basin territories, scenarios indicate reduced rainfalls of up to 30% by 2100 and promise dire consequences on agriculture, hydro-ecosystems, as well as human health (Henley & Runia, 2023). Grossi's (2023) work conducted in Italy and Xekalakis et al.'s (2023) work conducted in the Mediterranean have suggested increased sensitivity of groundwater-dependent territories to decline in recharge attributable to climate, with a push for adaptation water management methods implementation. Additionally, increased

temperatures increase the risk of salinization, loss of biodiversity, as well as desertification, with resultant socio-economic effects like displacement, poverty, and competition for natural resources (Tian et al., 2023).

For the Middle East and North Africa (MENA) region, Jordan offers a clear-cut case of climate vulnerability, namely water scarcity. Jordan's water availability per capita is among the world's lowest at less than 100 cubic meters annually, much less than the agreed threshold of absolute water scarcity of 500 m³/person/year (Hadadin et al., 2010; Whitman, 2019). Climate change, increased populations, urbanization, and increasing demand by industry and agriculture have all simultaneously pushed already rare water sources under additional stress. Kloub (2023) demonstrated that rising temperatures and declining rainfall trends have left principal aquifers with reduced recharge and quarterly drying of highland perennial springs. The impacts have been extensive environmental degradation and reduced crop yields, notably in rain-fed crops.

Country-specific research have assessed the future effects of climate change on Jordan's hydrological and agriculture systems. Albatayneh (2024) employed future high- resolution climate scenarios to project that rain may decrease as much as 40% by 2100 in some regions, while mean temperatures may rise by 2.5°C++. Bashabsheh (2024) showed that principal watersheds like the Yarmouk and Zarqa river watersheds' streamflow is projected to decline by as much as 85% under the RCP 8.5 future scenario. These scenarios have significant implications on irrigation agriculture, water supply for domestic consumption, as well as on ecosystem integrity. Furthermore, Ricart et al. (2021) and Salameh (2022) point through research that Jordan's water governance systems nowadays have issues of fragmented management and shortage of site- specific information, which hamper adaptation planning and policy-making.

Agriculture sectors, particularly those in the Jordan Valley and north highlands, remains highly reliant on groundwater as well as rainwater. The figure estimated by Ray et al. (2010) is that nearly 60% of water in Jordan is absorbed by agriculture, much of it by inefficient irrigation techniques. Over-extraction of the aquifers in regions such as Azraq and Amman-Zarqa Basin was reported by Margane et al. (2008), where groundwater tables were declining at more than natural replenishment. Yin and Shang (2023) record the increasing salinity of Jordan's aquifers due to the over-pumping, threatening soil fertility, crop yields, and water for consumption. These reports highlight all the more the need for the integration of climate modelling with water resources planning, more specifically in those sectors already under ecological as well as socio-economic stress.

Within this national context, the Jerash area is of specific relevance for learning about the localized impacts of climate variability on water resources. In north Jordan, Jerash is under the influence of a Mediterranean climate with hot dry summers and cold moist winters. The area is rich in diversity of agriculture, which is critical for local livelihoods and food security. Agriculture in Jerash is supported by seasonal rain and groundwater and is therefore strongly exposed to climate variability. Springs and shallow water tables that have long supported irrigation and domestic consumption are presently under stress through reducing recharge and over-pumping. With more unpredictable climatic patterns developing, the area finds it hard to meet water demand and sustain agriculture productivity.

The environmental and socio-economic profiles of Jerash make it an ideal case study of the regional impact of climate change. It is a microcosm of the broader semi-arid regions of Jordan where water scarcity, population pressure, and agrarian dependency converge. Moreover, topographic variability as well as access to numerous meteorological stations make it an ideal platform on which localized climate modeling as well as impact estimation can be undertaken. Insights on the way the pattern of temperature as well as that of precipitation is going to be altered within Jerash can be utilized as the foundation of national adaptation policies of enhancing resilience within groundwater-dependent regions.

The study applies three key climate variables, that is, temperature, precipitation, and groundwater recharge, in 2024–2100 under the Representative Concentration Pathways 2.6, 4.5, and 8.5 of the IPCC. The SDSM approach is adopted since it provides high-resolution climate projections based on the statistical relationship between large-scale atmospheric predictors and local weather variables. Where global climate models do not have good spatial detail at

site scales, SDSM can be applied to tailor projections at individual sites and therefore optimize the usability of outcomes for site-scale policy decision-making and planning of resources.

The research contribution lies in marrying downscaled climate scenarios with empirical estimation of groundwater recharge. Multiscalar SDSM outputs of temperature and precipitation were applied with infiltration coefficients appropriate for semi-arid Jerash, therefore offering a user-friendly method of estimating future recharge response beyond the need for highly advanced hydro-simulation software like MODFLOW. The framework is thus transferable and scalable to other regions with similar data and resource constraints. Additionally, the research bridges an important gap in the literature by offering site-specific projections under alternative futures of emissions, frequently lacking in national studies. The findings can be applied for water management planning adaptation in the region, for instance, promoting water-saving irrigation systems extension, rainwater harvesting extension, and intensified groundwater monitoring. Moreover, through linking climate projections with recharge potential, the research provides a repeatable framework for describing hydrological consequences of climate change in similar semi-arid regions of the MENA. Lastly, the work is part of growing body of research emphasizing the need for site-specific, high-resolution climate impact assessments. With the rapid progression of climate change, decision-makers require proper, interpretable information on which to inform the construction of resilient infrastructure, water use optimization, and defense of populations at risk. The results catalyzed through the work here will not only be of direct relevance to Jerash, but on a broader scale inform general discussions on climate adaptation, sustainable development, and water security in dry and semi-dry regions globally.

2. Methodology

2.1 Overview of the Methodological Framework

For the analysis of the potential effects from climate change on water resources within the Jerash region in Jordan, the present research employed a quantitative model approach reliant on the downscaled climate projections. The research approach integrates the consideration of historic climate data with the use of the Statistical DownScaling Model (SDSM) for the production of projections of future climate parameters. The two in tandem facilitate the generation of local-scale, high-resolution scenarios in the temperature and precipitation parameters central in the understanding of climate dynamics in a semi-arid and water-deficient region like Jerash.

2.2 Study Area Description

The Jerash district in northern Jordan enjoys a Mediterranean climate characterized by hot dry summers and mild rainy winters. Household consumption and agriculture greatly rely on rainfall at the seasons as well as on groundwater. Due to increasing climatic variability and growing water usage, the area serves as a great microcosm in the assessment of the influence of climate change on the accessibility of water.

2.3 Data Collection and Sources

Observational daily climatic data on rainfall and temperature from the Jordan Meteorological Department (JMD) were used for the baseline 1980–2010 period. Concurrently, the large-scale atmospheric predictor fields were assumed from the National Center for Environmental Prediction (NCEP) reanalysis dataset and formed the principal inputs for the SDSM calibration and validation.

The future climate scenarios were based on simulations from the Global Climate Model (GCM) under Representative Concentration Pathways (RCPs) 2.6, 4.5, and 8.5. These RCPs cover a range of potential future greenhouse gas concentration pathways, from a low-emission mitigation scenario (RCP 2.6) to an intermediate (RCP 4.5) and high-emission scenario (RCP 8.5). The three scenarios were chosen to cover a wide range of possible future conditions and to address uncertainty in projected climate change.

2.4 Statistical Downscaling Using SDSM

We employed the Statistical DownScaling Model (SDSM) 4.2.9 in generating future climate scenarios over Jerash. SDSM enables statistical relationships among large-scale atmospheric (predictor) and local-scale climate (predictand) parameters to be formulated in generating high-resolution regional projections of climate.

2.4.1 Model Calibration and Validation

- **Calibration Phase:** The model was trained using daily data from 1980 to 1995. Key predictors from NCEP reanalysis data were selected for their correlation with local temperature and precipitation data.
- **Validation Phase:** The remaining data from 1996 to 2010 were used to validate the model's performance by comparing the simulated outputs with observed local climate records.

The quality of model performance was assessed using statistical indicators such as the coefficient of determination (R^2), mean bias error (MBE), and root mean square error (RMSE). These metrics ensured the accuracy of projections before generating future scenarios.

2.4.2 Scenario Generation

Following successful calibration and validation, future daily climate data were generated for three time slices:

- 2024–2050 (near future),
- 2051–2075 (mid-century),
- 2076–2100 (end of century).

Projections were developed separately for the A2 and B2 emission scenarios. The resulting data series provided monthly and annual averages for both temperature and precipitation, which were then analyzed to assess long-term climate trends in Jerash.

2.5 Visualization and Analysis

The downscaled outputs were visualized through trend plots and anomaly charts, highlighting variations over time. In particular, **Figure 4.45** presents the projected annual temperature and precipitation anomalies for the Jerash region from 2024 to 2100, offering insight into climate trajectory under both emission scenarios.

These results were critically analyzed to determine the implications for water availability, particularly concerning rain-fed agriculture and groundwater recharge potential in the Jerash area.

3. Results and Discussion

This section presents the outcomes of the SDSM-based climate downscaling applied to the Jerash region, highlighting projected changes in temperature and precipitation under future emission scenarios. The implications of these changes on groundwater recharge are discussed based solely on the downscaled outputs, specifically precipitation patterns, without incorporating MODFLOW or any other external simulation tools. The projections cover the period from 2024 to 2100 and follow three IPCC emission trajectories: RCP 2.6, RCP 4.5, and RCP 8.5.

3.1 Downscaled Temperature Projections

The downscaled results indicate a consistent upward trend in both maximum (T_{max}) and minimum (T_{min}) temperatures across all five meteorological stations: Burma, Dibbin, Prince Faisal, Jerash, and Kitta.

- Under **RCP 2.6**, Tmax increases by an average of **0.1°C to 0.4°C** by 2100.
- Under **RCP 4.5**, the increase ranges from **0.2°C to 1°C**.
- Under the high-emission **RCP 8.5** scenario, the temperature is projected to rise by more than **2°C**.

The minimum temperatures exhibit a parallel upward trend, with more pronounced nighttime warming under RCP 8.5, raising concerns about reduced diurnal temperature variation, which could negatively affect crop development and soil cooling.

3.2 Downscaled Precipitation Projections

Annual precipitation projections show a gradual yet significant decrease in total rainfall across all stations throughout the century.

- Under **RCP 2.6**, average rainfall decreases by **14%–30%** by 2100.
- Under **RCP 4.5**, declines of up to **40%** are observed.
- **RCP 8.5** presents the most severe scenario, with reductions reaching **65%,43%**, particularly at the Burma and Dibbin stations respectively.

These changes suggest increased frequency and intensity of drought conditions, especially during already dry months, and will substantially impact water availability and seasonal recharge patterns.

3.3 Groundwater Recharge Trends Based on Downscaled Rainfall

Using SDSM-projected precipitation and standard infiltration coefficients tailored for the semi-arid context of Jerash, climate-driven recharge trends were estimated for each station. The recharge estimates reveal a downward trajectory aligned with precipitation reductions.

- **By 2045**, all stations experience a modest reduction in groundwater recharge (5–17%) under **RCP4.5**.
- **By 2100**, under **RCP 8.5**, some stations (e.g., Burma, Jerash) show **recharge losses exceeding 40–60%** compared to baseline levels.
- **RCP 2.6** maintains relatively stable recharge patterns, indicating the value of low-emission pathways for water sustainability.

These projections imply increasing stress on already-limited groundwater resources, threatening irrigation sustainability and domestic supply security in the region.

This figure provides a consolidated view of the expected changes in groundwater recharge across all five stations under each RCP pathway. It clearly demonstrates that the most severe decline occurs under RCP 8.5, suggesting an urgent need for adaptive water management strategies in Jerash.

3.4 Implications for Regional Water Security

The combined effects of higher temperatures and reduced rainfall—both projected by SDSM—will diminish surface water availability and exacerbate pressure on groundwater resources. Key concerns include:

- Reduced effectiveness of rain-fed agriculture, due to shorter and less intense wet seasons.
- Declining aquifer recharge rates, increasing dependency on deep wells and fossil water.

- Elevated risk of water scarcity during drought years, especially under RCP 8.5.

Without proactive adaptation measures (e.g., rainwater harvesting, drip irrigation, groundwater monitoring), Jerash may face significant hydrological imbalance and reduced climate resilience in the coming decades.

5. Discussion

The findings of this research show a clear trend of warming and precipitation decrease in the Jerash area from 2024 to 2100 for all Representative Concentration Pathways (RCPs), most notably RCP 8.5. The scenarios were generated through the Statistical DownScaling Model (SDSM) such that localized signals of climate change could be produced for high spatial resolutions. In comparison with other literature based studies done at the regional and national levels, agreements and major differences in terms of anticipated behavior of the climate and hydrological response were noticed. The current section provides a comparative discussion of the results with the literature and elucidates the novel contributions along with the differences in the approach and setting.

The research foresees the maximum temperature in Jerash rising by more than 2°C for RCP 8.5 by the end of the current century. Corresponding heating tendencies have been presented by Bashabsheh (2024), assuming a 2.5°C to 3.5°C temperature rise in northern Jordan for RCP 8.5 through the use of the PRECIS regional model. Although in the same direction, our research indicates somewhat less temperature rises, most probably owing to the variation in the model resolution and the use of statistical calibration of the SDSM for the local observational series, in attempt to diminish the overestimation.

Similarly, Albatayneh (2024), employing the HadGEM2 model, presented the national mean warming of 1.7°C to 2.9°C, also in close agreement with our estimates, especially for RCP 4.5. But the current study stands out in highlighting micro-scale station-level differences—for example, the maximum temperature increase was registered in the Dibbin station, a level of geographic specificity commonly absent in larger-scale studies. This level of detail is critical for municipal and agricultural planning but commonly neglected in the estimation of the whole nation.

Our result of diminished diurnal temperature variability, particularly for T_{min} , in RCP 8.5, has also been reported in research conducted by Tian et al. (2023) in the arid parts of China. This is a trend that would negatively impact plant physiology, enhancing the losses in evapotranspiration during nights, and thus, Jerash might face thermal stress in addition to temperature increase alone.

Our study shows a 14%–65% decrease in precipitation by 2100, with the Burma station experiencing the largest decline under RCP 8.5. This aligns with Trenberth (2011) and Hakami-Kermani et al. (2024), who confirmed a drying trend in Mediterranean climates due to shifting storm tracks and enhanced warming. In Jordan specifically, Ray et al. (2010) reported a 20%–40% drop in rainfall in the northern highlands over the past three decades—a historical trend that our model projects will intensify.

However, some discrepancies arise when comparing to Ricart et al. (2021), whose study using RCLimDex and MODIS-derived precipitation suggested only modest declines (~10%–25%) in northern Jordan under moderate scenarios. The likely reason for this variance is the coarser spatial resolution and focus on annual rather than seasonal precipitation in Ricart's work, while our SDSM approach accounts for monthly-scale variations and seasonal drought intensity, especially relevant for recharge dynamics.

Notably, our findings project greater precipitation variability and seasonal concentration, in agreement with the result of Xekalakis et al. (2023) for the semi-arid Mediterranean regions. Only limited research, however, has performed station-level examination within Jerash, thus our work is novel in presenting accurate, site-level estimates used for localised planning for droughts.

Estimates of groundwater recharge using SDSM-calculated precipitation and empirical infiltration values show recharge losses of 40–60% for RCP 8.5 in 2100. This is in line with Henley & Runia (2023) and Senent-Aparicio et

al. (2024), who pointed out the sensitivity of aquifer recharge in arid regions, presenting recharge losses of 30%–70% for the same conditions of climate.

In Jordan, Margane et al. (2008) and Kloub (2023) documented significant depletion in the Azraq Basin and northern springs, noting that climate change-induced recharge decline plays a critical role alongside anthropogenic over-extraction. While those studies relied on long-term monitoring data or groundwater modeling tools such as MODFLOW, our approach uniquely estimates recharge changes directly from precipitation anomalies and land-specific coefficients—offering a more accessible and adaptable framework for regional water planners.

What is novel in our study is the combination of downscaling precipitation with empirical estimates of recharge, such that the results directly relate projected climate anomalies to water sustainability in Jerash. Unlike Mehta et al. (2024), our approach is also based on local station records and regional hydrological coefficients, rather than calibrated hydrological simulation models for all of South Asia, and so is more transferable for the semi-arid terrains of Jordan.

Compared to earlier works on Jordan’s climate and hydrology, this study presents several novel contributions:

Reference	Study area	Main findings
Bashabsheh and Alzboon (2024)	Yarmouk river basin	Temperature will increase 1.52°C, Precipitation will decrease 43%
Kloub (2023)	Amman -Azraq Basin	Temperature will increase 3°C, Precipitation will decrease 34%
Fayez Abdulla · Tamer Eshtawi · Hamed Assaf (2008)	Zarqa River Watershed	Temperature will increase 3.5°C
Albatayneh (2024)	Jordan	Temperature will increase 1.7°C to 2.9°C
Ricart et al. (2021)	Northern Jordan	Precipitation will decrease 10%-25%

This methodological framework allows water authorities and local planners to understand **not just how climate variables change**, but **how these changes affect water security and agriculture** at a sub-regional scale—something few other models or studies in Jordan have prioritized.

The key differences between our results and those of earlier studies arise from:

- **Model Type:** Statistical downscaling (SDSM) vs. dynamic modeling (PRECIS, RCLimDex).
- **Data Resolution:** Use of daily, station-level data in this study vs. interpolated or national datasets in others.
- **Scope:** Focused on Jerash alone with five distinct stations vs. generalized projections over the northern region.
- **Recharge Estimation:** Use of infiltration coefficients for empirical estimation vs. physical simulation models.

These choices make our study more **locally relevant and application-ready**, especially in settings with **limited computational capacity** or lack of detailed hydrological datasets.

6. Conclusion

This study employed the Statistical DownScaling Model (SDSM) in the projection of future trends in the climate—temperature and precipitation—of the Jerash region in Jordan under the Representative Concentration Pathways

(RCPs) 2.6, 4.5, and 8.5. The outcome from the downscaled simulations provided a clear image on the potential role climate change may play in regional hydrological dynamics up until the end of the 21st century.

Each station exhibited a precise and continuous increase in maximum and minimum temperatures. The warming tendency is highest under RCP 8.5 where the projected increase will exceed 3°C by the year 2100. Such thermal shifts are expected to intensify evapotranspiration rates, disrupt seasonal crop cycles, and increase the demand for irrigation water.

In parallel, **annual precipitation is projected to decline steadily**, especially under the moderate and high-emission scenarios. The decline in rainfall directly correlates with a **reduction in climate-driven groundwater recharge**, as estimated using empirical infiltration ratios based on SDSM outputs. Recharge levels under RCP 8.5 may fall by up to 60%, posing a critical risk to water security in a region already marked by water scarcity.

The findings underscore an urgent need for adaptive water resource management strategies in Jerash, including:

- **Enhanced groundwater monitoring** and recharge modeling based on updated climate projections.
- **Promotion of water-saving irrigation techniques** (e.g., drip systems, deficit irrigation).
- **Expansion of rainwater harvesting infrastructure** to buffer against reduced seasonal rainfall.
- **Climate-resilient agricultural planning**, aligning crop selection and timing with shifting climate patterns.
- **Scenario-based water policy development**, using SDSM projections as planning tools.

By integrating climate modeling into water governance and agricultural decision-making, local authorities and stakeholders in Jerash can proactively address the looming threats of climate variability and ensure long-term sustainability of water resources.

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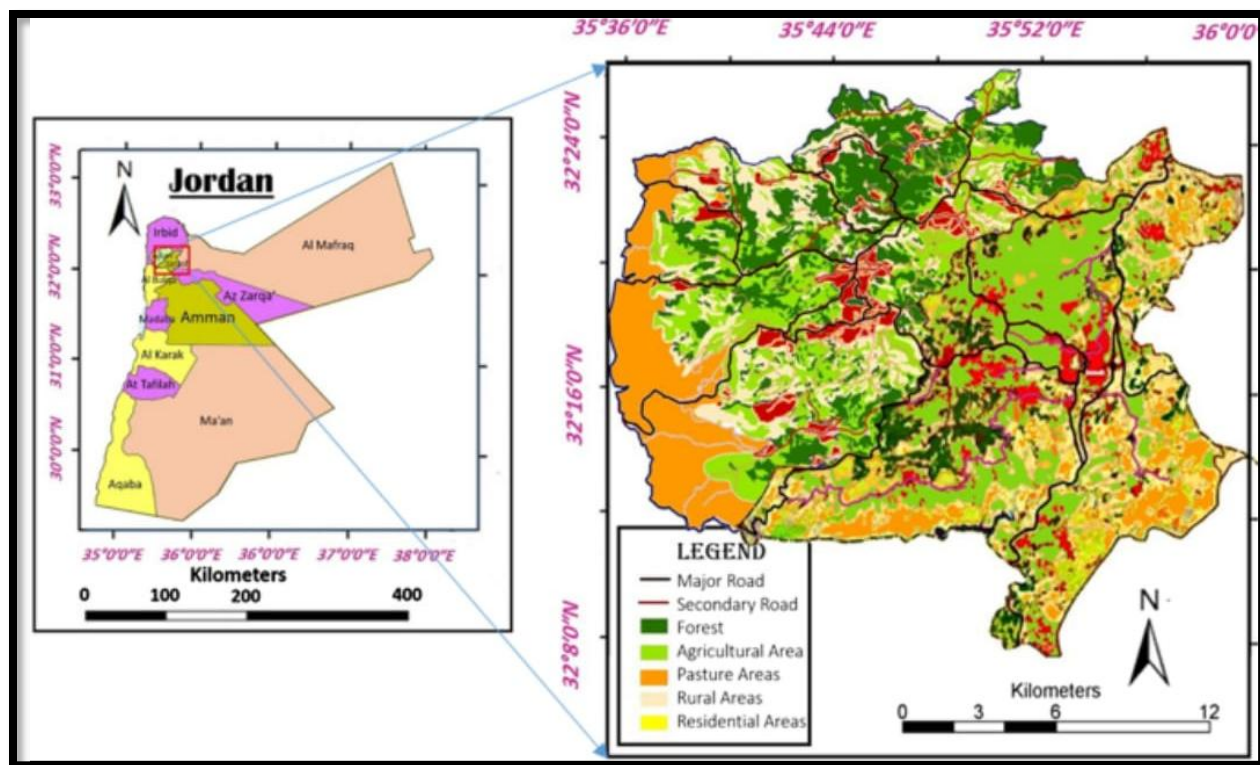


Figure 1: Study area location and land use

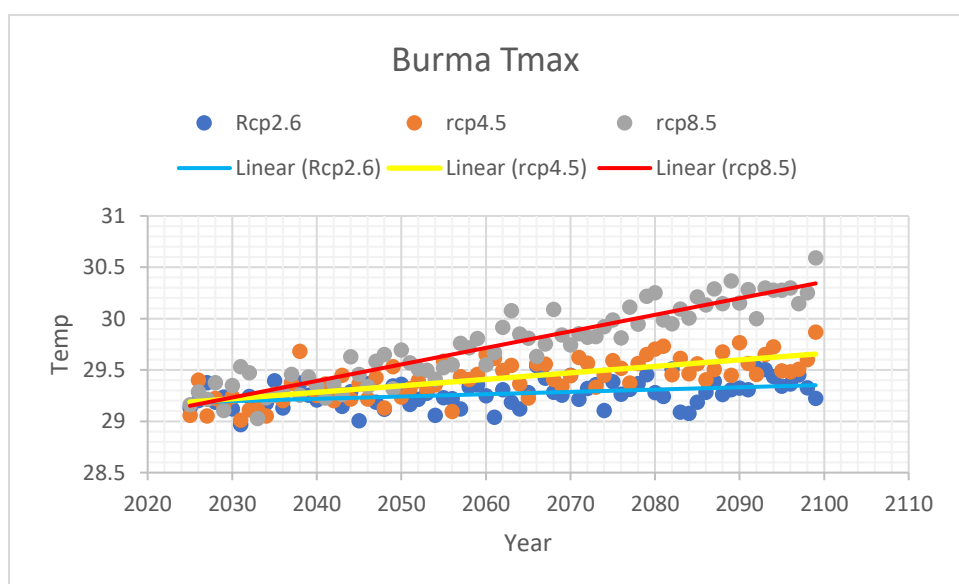


Figure 2: Projected Annual Maximum Temperatures for Burma Station under RCPs

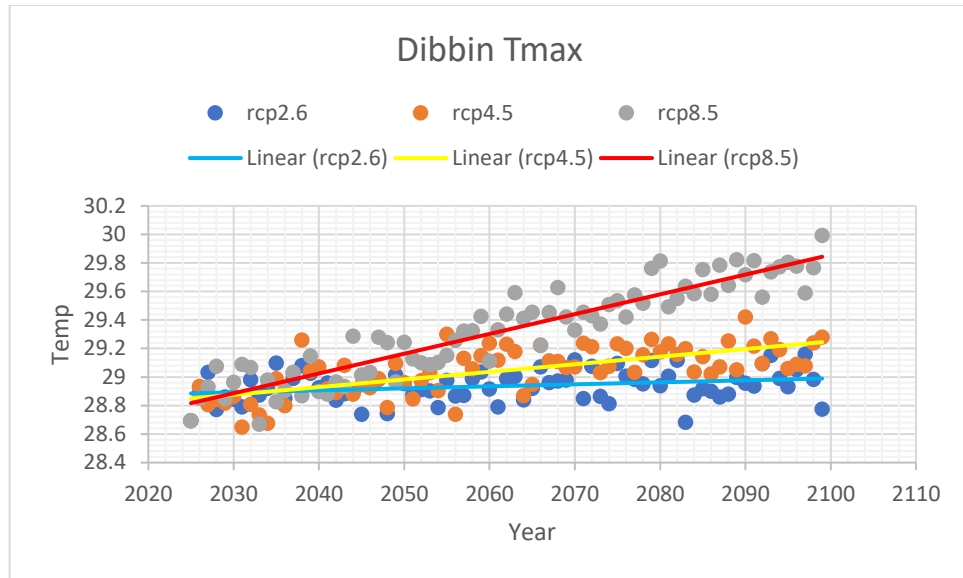


Figure 3: Projected Annual Maximum Temperatures for Dibbin Station under RCPs

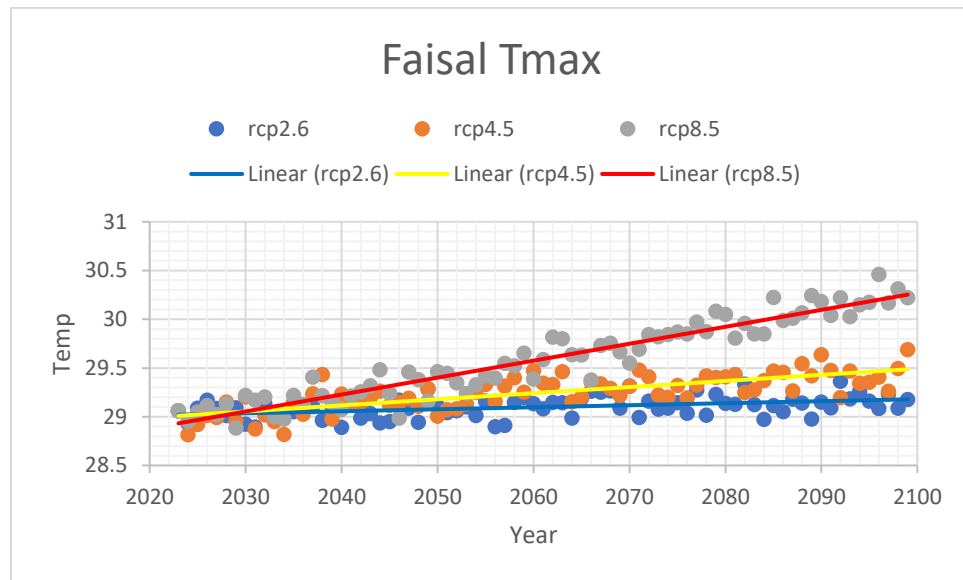


Figure 4: Projected Annual Maximum Temperatures for Faisal Station under RCPs

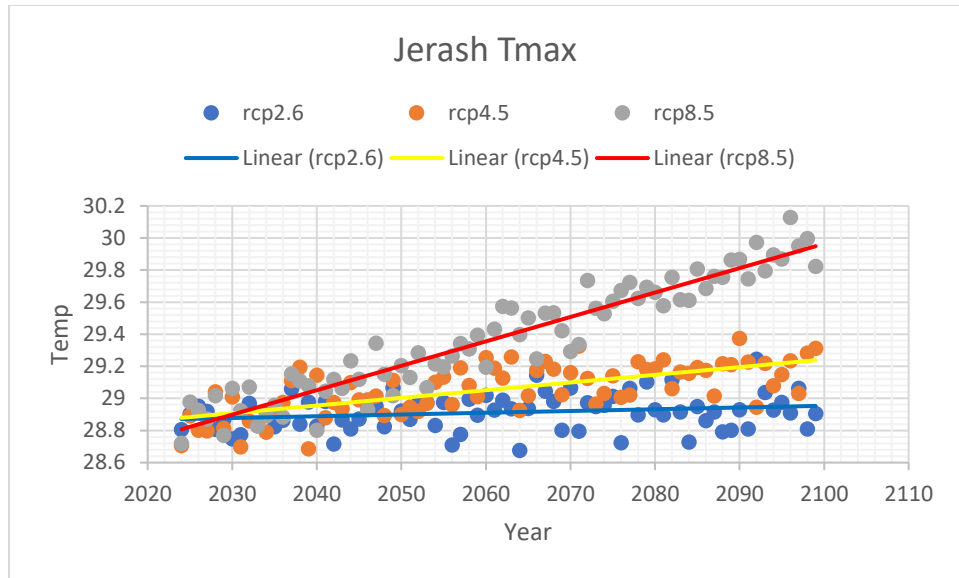


Figure 5: Projected Annual Maximum Temperatures for Jerash Station under RCPs

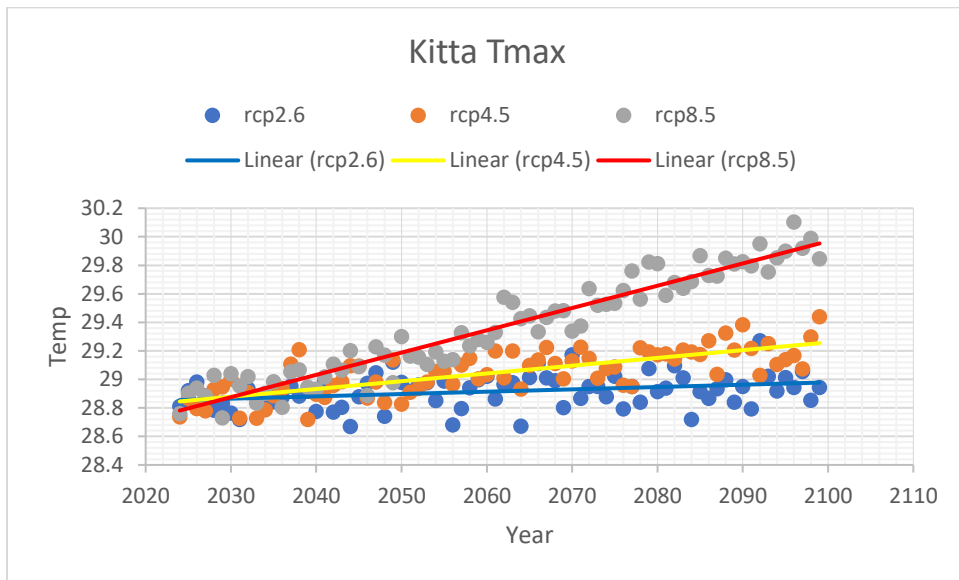


Figure 6: Projected Annual Maximum Temperatures for Kitta Station under RCPs

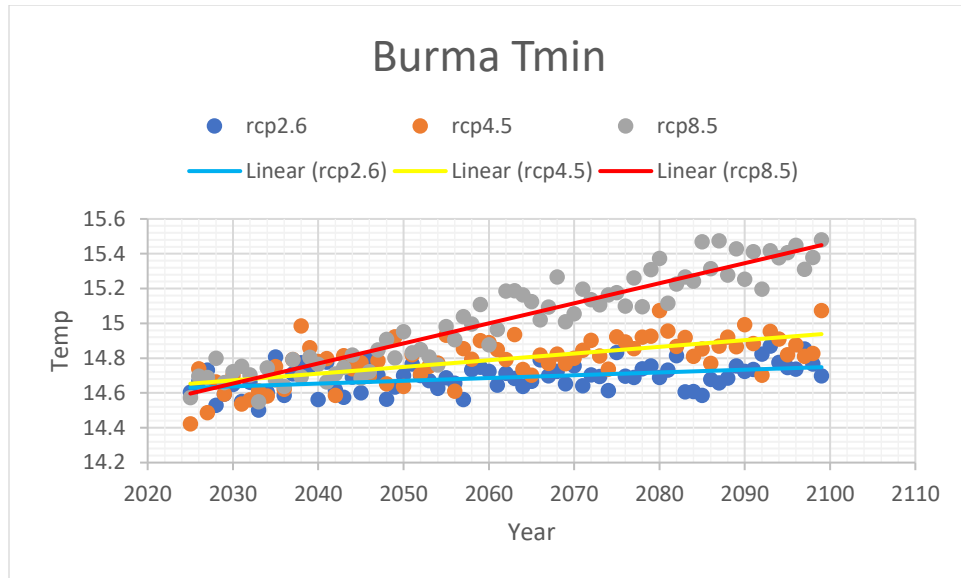


Figure 7: Projected Annual Minimum Temperatures for Burma Station under RCPs

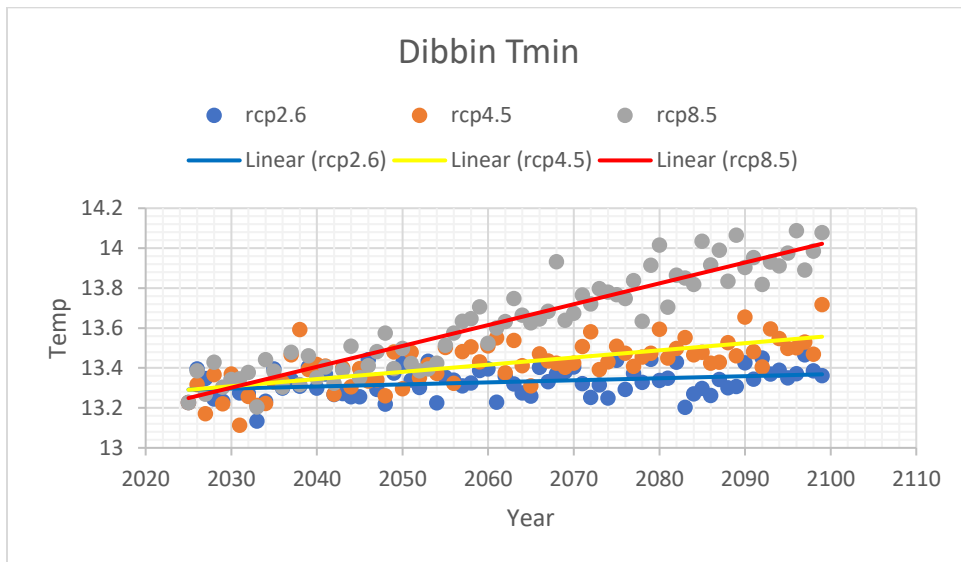


Figure 8: Projected Annual Minimum Temperatures for Dibbin Station under RCPs

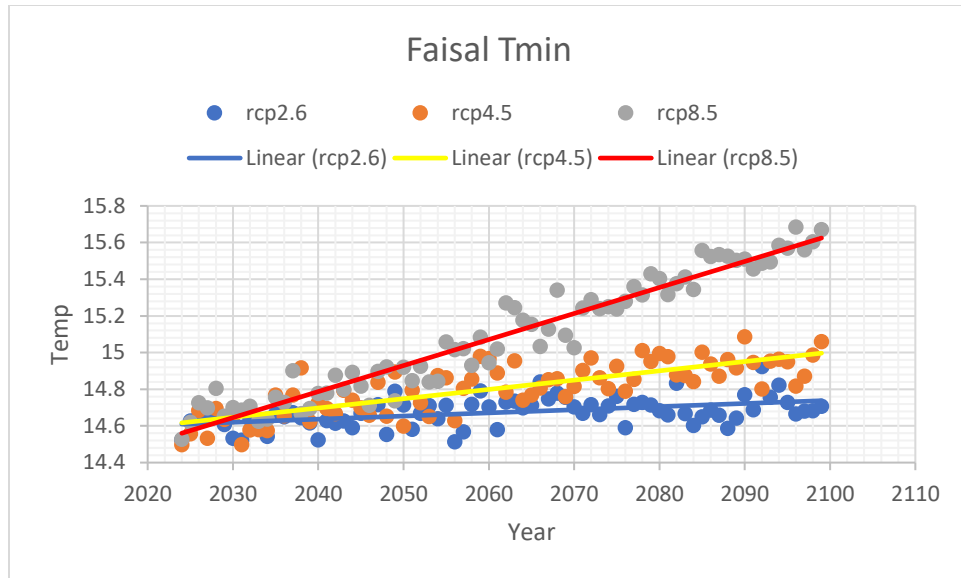


Figure 9: Projected Annual Minimum Temperatures for Faisal Station under RCPs

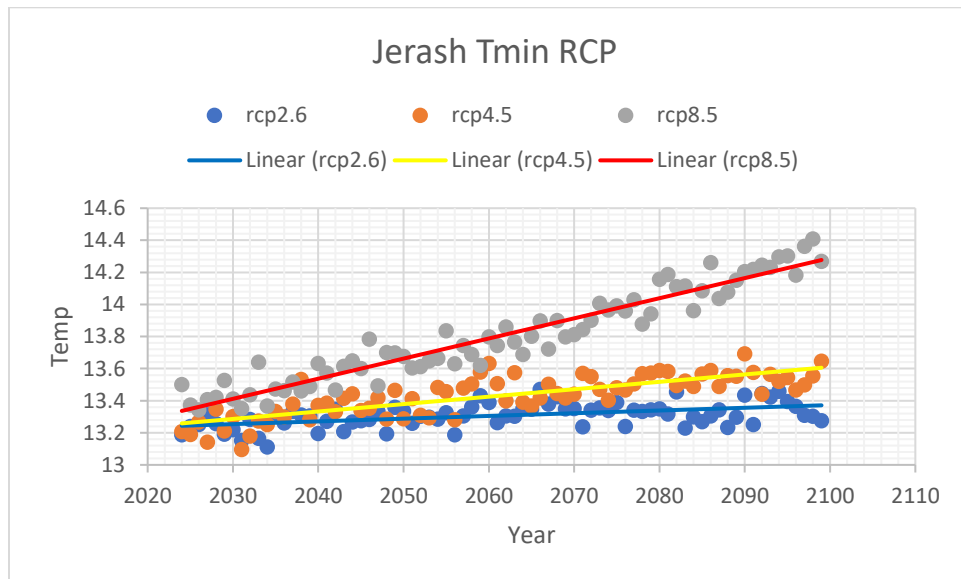


Figure 10: Projected Annual Minimum Temperatures for Jerash Station under RCPs

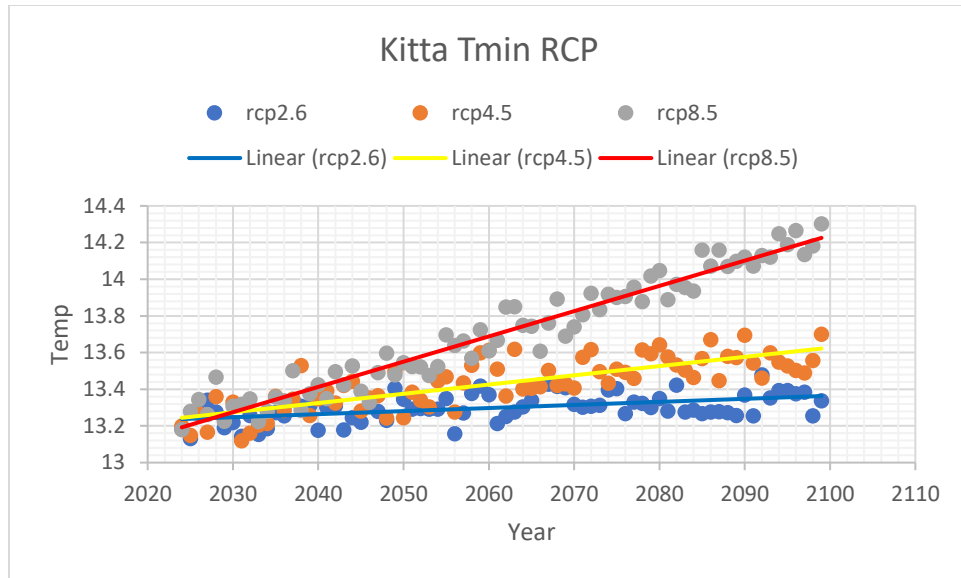


Figure 11: Projected Annual Minimum Temperatures for Kitta Station under RCPs

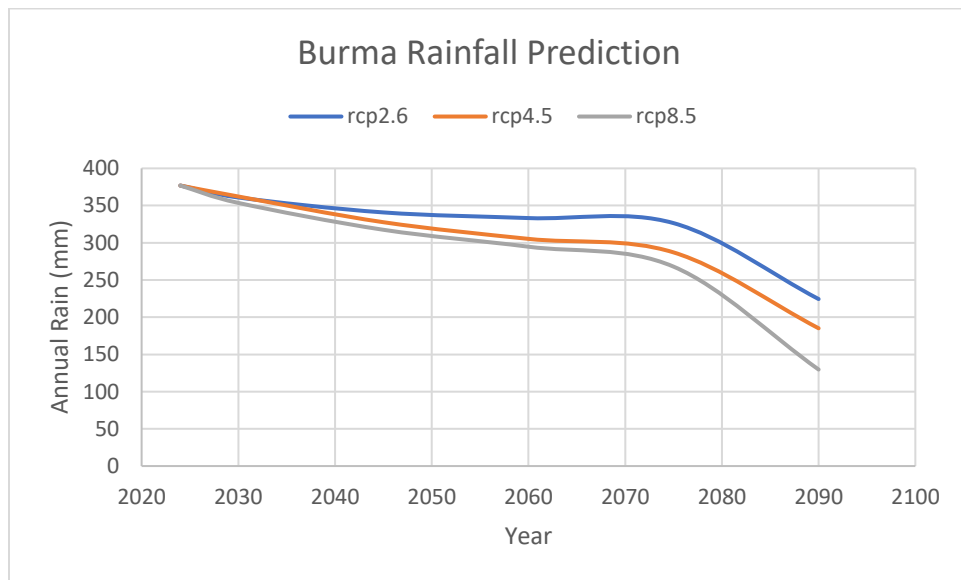


Figure 12: Projected Annual Precipitation Totals under RCP Scenarios for Burma station

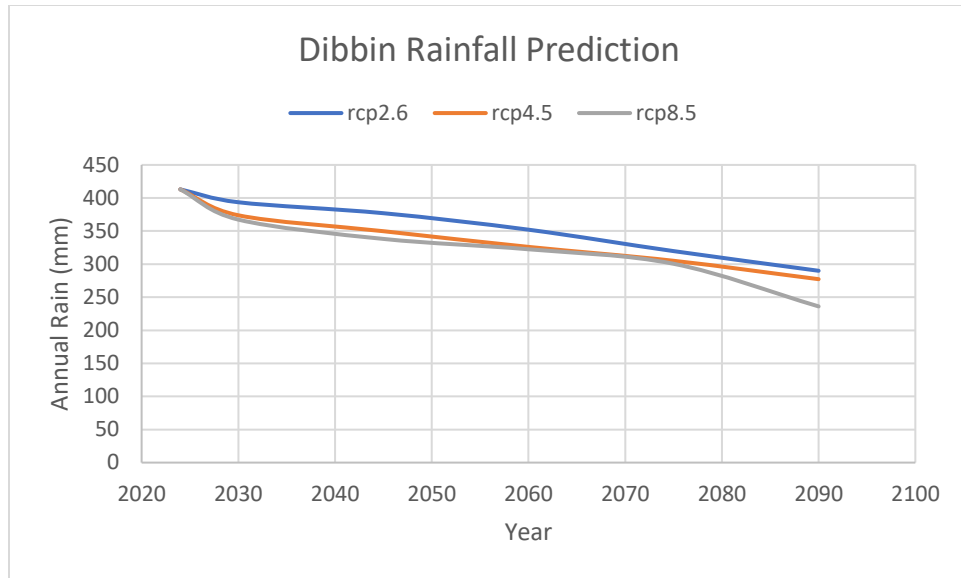


Figure 13: Projected Annual Precipitation Totals under RCP Scenarios for Dibbin station

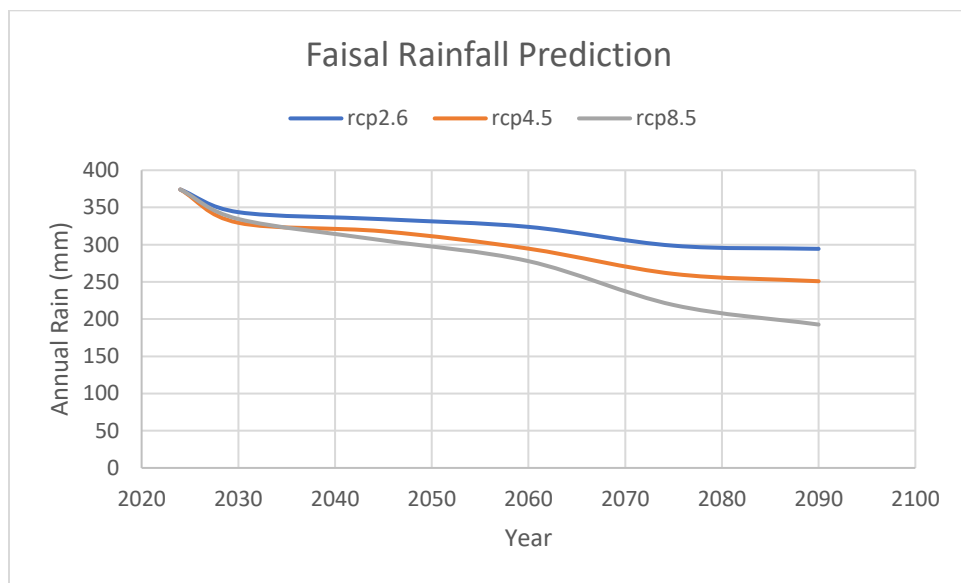


Figure 14: Projected Annual Precipitation Totals under RCP Scenarios for Faisal station

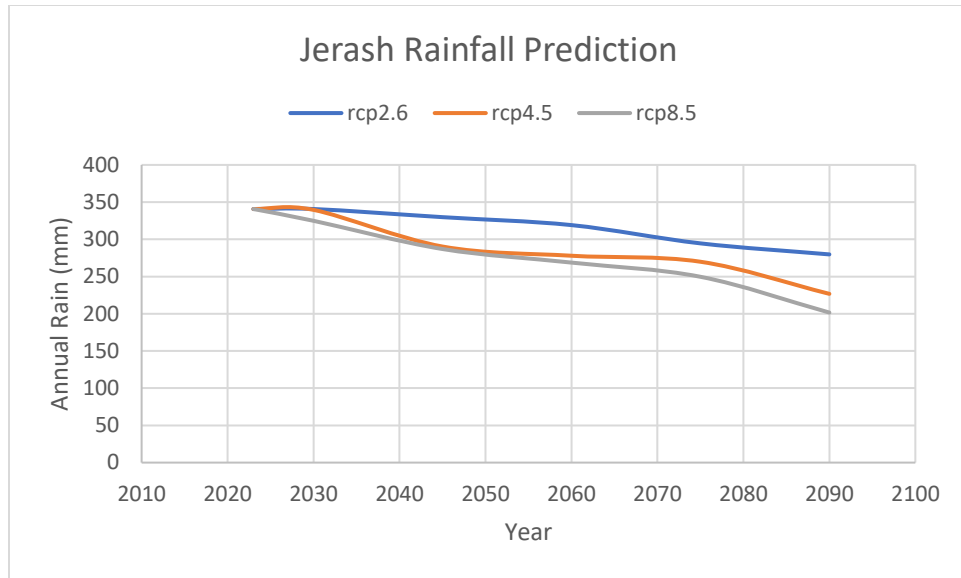


Figure 15: Projected Annual Precipitation Totals under RCP Scenarios for Jerash station

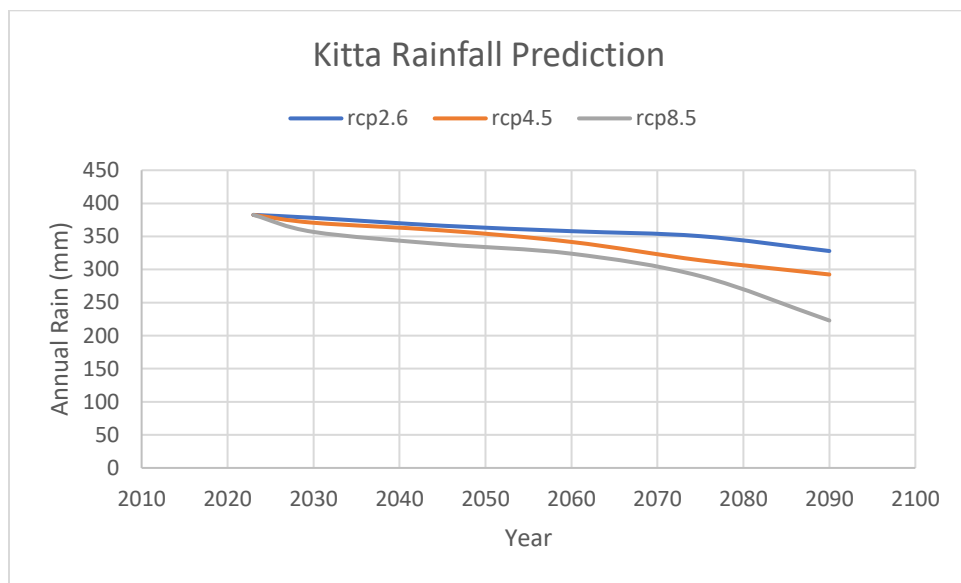


Figure 16: Projected Annual Precipitation Totals under RCP Scenarios for Kitta station

