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Climate Change in Jordan: A Case Study of Rajeb Basin

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ABSTRACT

Rajeb Basin is one of the most important basins in Ajloun Governorate in Jordan. This study aims to assess the effect of climate change on the Rajeb basin using the software of the climate indices (Rclimdex) model for three rainfall stations and three meteorological stations. The future impact of climate change is determined using the statistical downscaling model (SDSM) and the second-generation model for the Earth System (CanESM2) for different emission scenarios. Additionally, the study aims to predict the potential future impact of climate change on the flow of the Rajeb basin at the end of the current century using the Soil and Water Assessment Tool (SWAT) model. Regarding temperature, the results show a significant trend for 9 out of 16 extreme indices for all stations. The hot days increased by 12 days between 1982-2020, and the hot nights increased by 10 nights for the same period. The cool days decreased by 15 days between 1982-2020, and the cool nights decreased by 17 nights for the same period. The summer days (Tmax>25℃) increased by 26 days, and the tropical nights (Tmin>20℃) increased by 61 nights for the same period. It is predicted that the temperature will increase 2100 by 0.2℃, 0.57℃, and 1.4℃ based on RCP 2.6, 4.5, and 8.5 scenarios, respectively. The precipitation is predicted to decrease 2100 by 10.8%, 23%, and 43%, for the three scenarios, respectively. Regarding the expected streamflow, SWAT forecast results indicate a decrease in streamflow by 8.1%, 38%, and 69.2% between 2018- 2100 based on RCP 2.6, 4.5, and 8.5, respectively. According to the study, local organizations and decision-makers need to take into consideration the effects of climate change on the Rajeb basin. Pumping operations from the basin must be monitored to ensure the sustainability of water resources.

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التغير المناخي في الأردن: دراسة حالة لحوض راجب

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الملخص

يُعد حوض راجب أحد أهم الأحواض في محافظة عجلون في الأردن. تهدف هذه الدراسة إلى تقييم تأثير التغير المناخي على حوض راجب باستخدام نموذج مؤشرات المناخ (RClimdex) لثلاث محطات أمطار وثلاث محطات أرصاد جوية. يتم تحديد التأثير المستقبلي للتغير المناخي باستخدام نموذج التصغير الإحصائي (SDSM) ونموذج الجيل الثاني لنظام الأرض (CanESM2) لسيناريوهات انبعاثات مختلفة. بالإضافة إلى ذلك، تهدف الدراسة إلى التنبؤ بالتأثير المستقبلي المحتمل للتغير المناخي على تدفق حوض راجب في نهاية القرن الحالي باستخدام نموذج تقييم التربة والمياه.(SWAT) فيما يتعلق بدرجة الحرارة، تُظهر النتائج اتجاهاً كبيراً لتسعة من أصل 16 مؤشراً متطرفاً في جميع المحطات. زادت الأيام الحارة بمقدار 12 يوماً بين (1982-2020)، وزادت الليالي الحارة بمقدار 10 ليالٍ لنفس الفترة. انخفضت الأيام الباردة بمقدار 15 يوماً والليالي الباردة بمقدار 17 ليلة لنفس الفترة. زادت أيام الصيف (الحد الأقصى لدرجة الحرارة > 25 درجة مئوية) بمقدار 26 يوماً، وزادت الليالي الاستوائية (الحد الأدنى لدرجة الحرارة > 20 درجة مئوية) بمقدار 61 ليلة لنفس الفترة. ومن المتوقع أن ترتفع درجات الحرارة في عام 2100 بمقدار 0.2 درجة مئوية، و 0.57 درجة مئوية، و 1.4 درجة مئوية، بناءً على سيناريوهاتRCP 2.6 ، و 4.5، و 8.5 على التوالي. ويُتوقع أن تنخفض معدلات الهطول المطري في عام 2100 بنسبة 10.8%، و 23%، و 43%، للسيناريوهات الثلاثة على التوالي. بالنسبة للتدفق المتوقع للمجرى المائي، تشير نتائج توقعات نموذج (SWAT) إلى انخفاض في تدفق المجرى المائي بنسبة 8.1%، و 38%، و 69.2% بين عامي 2018 و 2100 بناءً على سيناريوهات RCP 2.6، و 4.5، و 8.5 على التوالي. ووفقاً للدراسة، يجب على المنظمات المحلية وصناع القرار أخذ تأثيرات التغير المناخي على حوض راجب بعين الاعتبار. كما يجب مراقبة عمليات الضخ من الحوض لضمان استدامة الموارد المائية.

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Introduction

Climate change is one of the global problems that receives attention at all political, scientific, and economic levels (Hansen and Sato, 2012). Climate change is a long-term change in the weather patterns that appears after millions of years. It differs from the natural distribution of the prevailing climate condition (US Environmental Protection Agency, 2014). The major greenhouse gases are water vapor, CO_2, CH_4, N_2O, and O_3. Water vapor (H_2O) with an average atmospheric concentration of 10 ppm is emitted from water bodies such as seas and oceans. Carbon dioxide (CO_2) with a long-term atmospheric concentration of 412 ppm is primarily emitted through the burning of fossil fuels and deforestation. Methane (CH_4) with an atmospheric concentration of 1860 ppb is produced during natural processes like wetland decay, as well as through human activities such as livestock farming and the extraction of fossil fuels. Nitrous oxide (N_2O), with a very low atmospheric concentration of 1332 ppb, is released from agricultural and industrial activities, combustion of fossil fuels, and natural processes in soils and oceans. Additionally, fluorinated gases, including hydrofluorocarbons (HFCs) with an atmospheric concentration of 5 ppb, perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) with an atmospheric concentration of 10 ppt, are synthetic gases used in various industrial applications (US Environmental Protection Agency, 2021). Since 1750, concentrations of greenhouse gases such as CO_2, CH_4, and N_2O have increased by 150 percent, 20 percent, and 40 percent, respectively (Intergovernmental Panel on Climate Change, 2014). This resulted from a rise in industrial activity, fuel combustion, and population growth. This has led to a change in the rate and trend of rainfall, drought, and heat waves. The contributions of greenhouse gases in climate change are 36-72%, 9-26%, 4-9%, and 2-7% for water vapor, carbon dioxide, methane, and ozone, respectively (European Environment Agency, 2020). The increase in emissions, especially carbon dioxide, has a significant impact on the atmosphere's growing temperature. The average global temperature increased significantly when compared to the base period (1901–2000). Since 1850, the average global temperature has risen by 1.1 to 1.2 °C. By 2100, the average global temperature is projected to increase by 2 °C, and 4.2 °C by the year 2400 (Malhi et al., 2021). Therefore, this change is a major reason affecting the quality and quantity of water and causes the transfer of sediment due to severe floods and depletion of water resources (Al Qatarneh et al., 2018). Additionally, Climate change is a major threat to global agriculture. Traditional farming methods are disrupted by rising temperatures, changes in precipitation patterns, and an increase in the frequency of extreme weather events. Reduced crop yields, more water scarcity, and the spread of diseases and pests are the results of these changes (Intergovernmental Panel on Climate Change, 2021). Declining agricultural productivity can lead to an increase in poverty levels, food price instability, and rural-to-urban migration. Based on the A1B scenario, which depicts a future world characterized by very rapid economic growth, low population growth, and sharp use of alternative energy, by the year 2050, 0.5 to 3.1 billion people will suffer from water scarcity because of an increase in temperature by two degrees Celsius (Gosling and Arnell, 2016).

Jordan receives an average of 7,200 million cubic meters (MCM) per year of rainfall, decreasing to 6,000 MCM in dry years and doubling in wet years. About 1.3% of Jordan received more than 500 mm of rainfall, 1.8% received between 300 and 500 mm, 3.8% received about 200 to 300 mm of rainfall, and between 100 and 200 mm of rainfall accounts for 12.5%; the remaining regions received less than 100 mm (Salameh, 2018). Jordan suffers from a water shortage, and this shortage has become a major challenge due to the abnormal increase in the population, due to immigration, as well as climate change. The available water resources in Jordan decreased from 3600 m^3/c.y in the mid-1950s to 125 m^3/c.y in 2016 (Ministry of Water and Irrigation, 2016). It also continued to decrease to 35 m^3/c.y in 2020 (UNHCR, 2020). This is below the water poverty index of 1000m^3/c.y (Al-Tabbal and Alzboon, 2012). Numerous studies demonstrated the substantial effects of climate change in Jordan. Al-Dahmsha et al. (2018) utilized the RClimdex program to analyze temperature and precipitation trends across six climate stations in various regions. Their findings revealed a notable decline on the account of cold days, amounting to an 11.7% reduction. Abdullah (2020) employed the SDSM model and historical meteorological data from 1961 to 2014 from eight stations in Jordan to forecast the future impacts of climate change on temperatures and rainfall. Projections indicated a 17% decrease in precipitation, and the temperature will rise, ranging from 2.5 to 5°C by the end of the century. Al Smadi (2006) analyzed T_{min} and T_{max} trends using data from Jordanian meteorological stations from 1922 to 2005, revealed a temperature increase of 0.03°C/year.

In Ajloun Governorate, the Rajeb basin is recognized as one of the most crucial sources of water resources. This basin supports the region economically and is considered one of the agricultural and tourist basins. Water resources in this basin have undergone a significant change over the past few decades. Therefore, this study aims to identify this effect to provide the decision-makers with scientific data on this issue and to address climate change in water resources strategies. To the best of the author's knowledge, this is the first study related to climate change in the Rajeb basin. Using the RClimdex program, the study will analyze data from three meteorological stations and three rainfall stations. Furthermore, using the results of the statistical downscaling model (SSD) and the second-generation Earth System Model

(CanESM2), the Soil and Water Assessment Tool (SWAT) model will be used to forecast future effects on water resources.

Methodology

The Study Area

Rajeb Basin is one of the most important basins in Ajloun Governorate. Its area is about 16% of the total area of the governorate. Rajeb basin is a perennial flow fed by numerous valleys, the most significant one among them is Al-Suq Valley, which begins with the spring of Umm Al-Jaloud in the east and then travels to the south. It represents a significant water source for the nearby agricultural plains (Gharaibeh, 2023). As shown in Figure (1), Rajeb basin is positioned astronomically in northern Jordan, south of Ajloun Governorate, between the longitudes of 32° 13' and 32°19' E and latitudes 35°40' - 35°49' N. The basin has a Mediterranean climate defined by dryness, hot summers, cold winters, and rainy autumns (Alshraifat, 2021). Its length and width are 15.8 km and 3.76 km respectively (Jalabneh and Ananzeh, 2022).

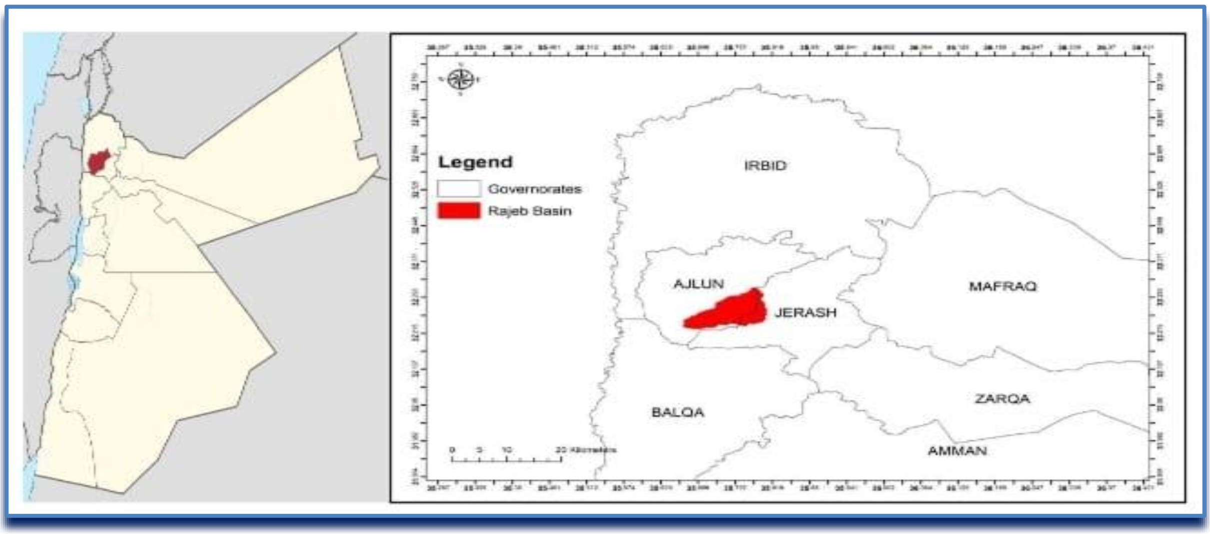

Fig. 1. Location Map of the Study Area

Data Used 1. Topography

The delineated process is carried out using a digital elevation model (DEM) downloaded from the USGS (http://earthexplorer.usgs.gov/) with a 30 m resolution (Fig. 2). The highest point of the basin is more than 1,200 meters above sea level, and the lowest point is located at the basin's outlet, at a height of about 84 meters above sea level.

2. Land use and soil

Land use maps are freely available from several space agencies, such as the European Space Agency and the National Aeronautics and Space Administration (NASA) (Wulder et al., 2018). Land use of the study area is classified as forest, crops, urban, bare ground, and rangeland, as shown in Figure 3 and Table 1. The Land cover (use) maps in this research were downloaded from the Sentinel-2 10 m land cover time series of the world from 2017–2021, produced by Microsoft, Esri, and Impact Observatory (https://www.arcgis.com/home/item.html?id= d3da5dd386d140cf93fc9ecbf8da5e31). The Digital Soil Map of the World, version 3.6, which was produced by the Food and Agriculture Organization of the United Nations (FAO/UNESCO), is shown in Figure 4 and Table 2. The research region's soil is mostly loam, but there is also clay soil that covers the eastern part (http://www.fao.org/geonetwork/srv/en/metadata. show?id=14116).

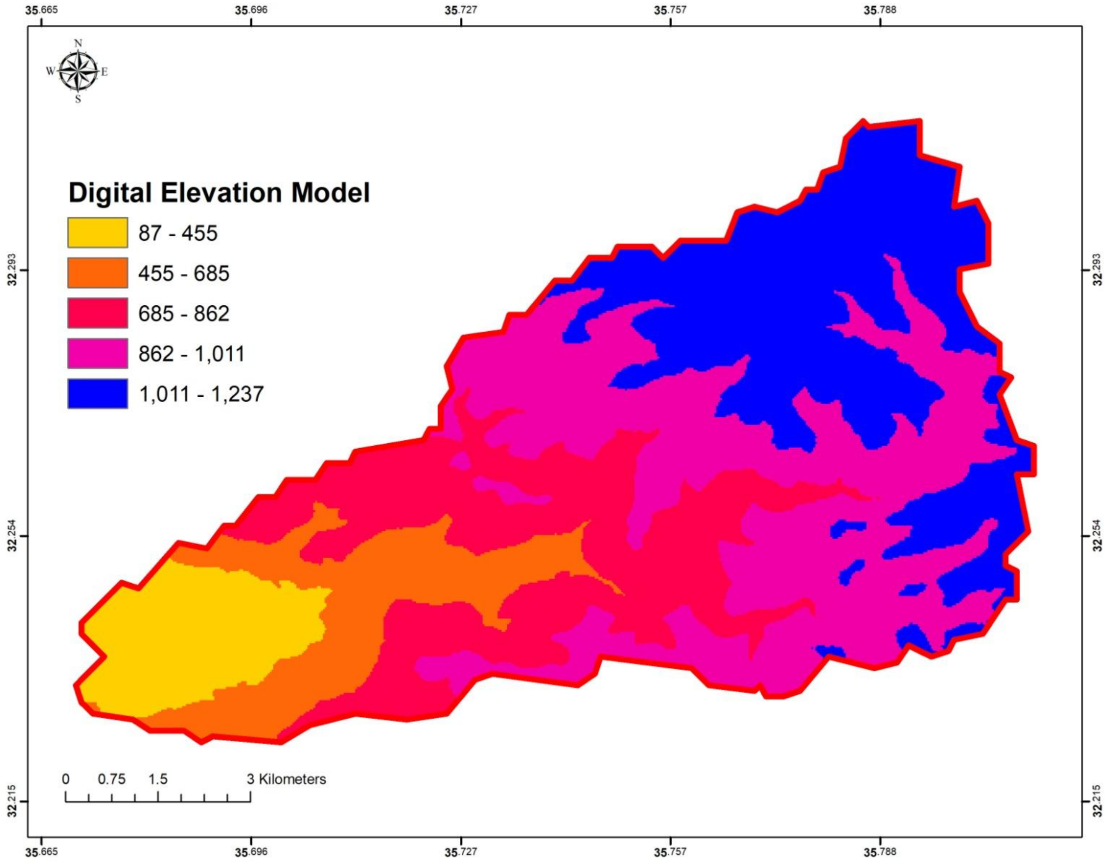

Fig. 2. Topography of the study area using Digital Elevation Model (m above sea level).

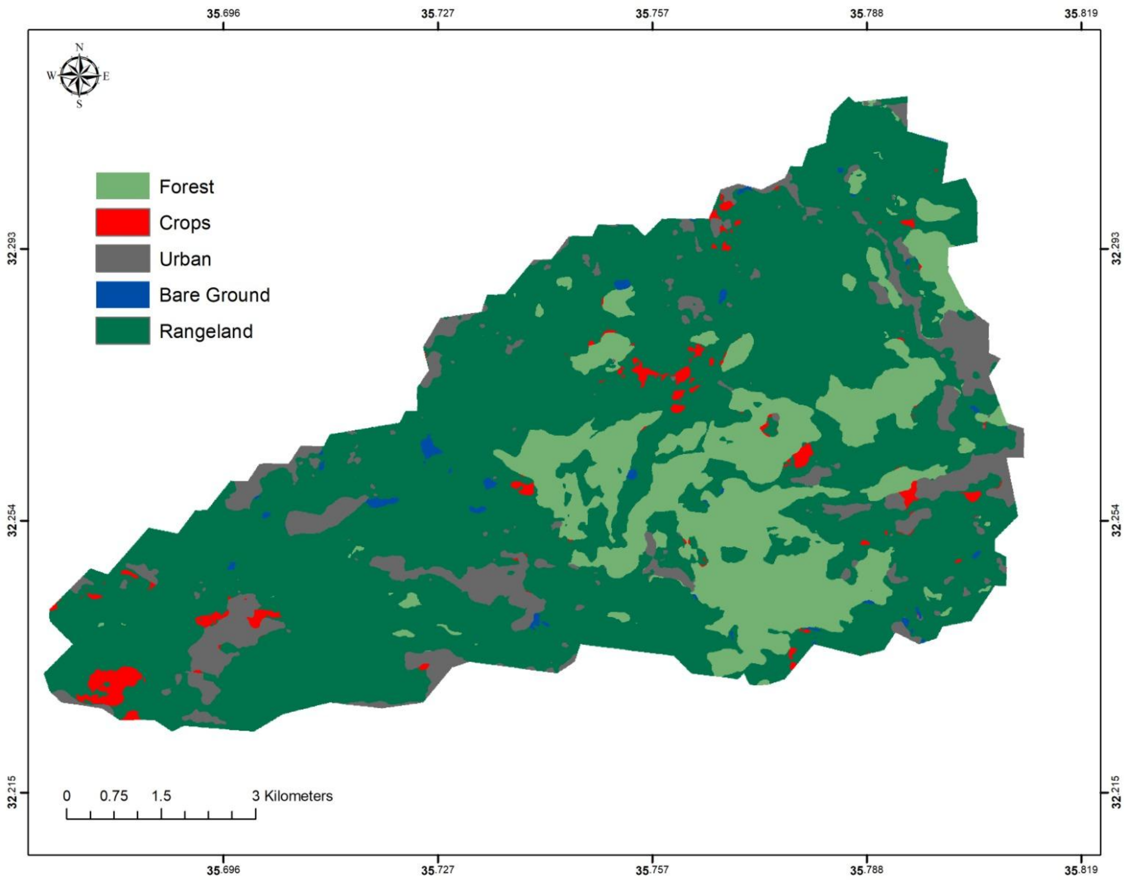

Fig. 3. Land use map of the study area.

Table 1: Classification of the land use in the study area.

Class Name	Land Use (%)
Rangeland	65.7
Forest	19.3
Urban	7.8
Crops	5.8
Bare Ground	1.4

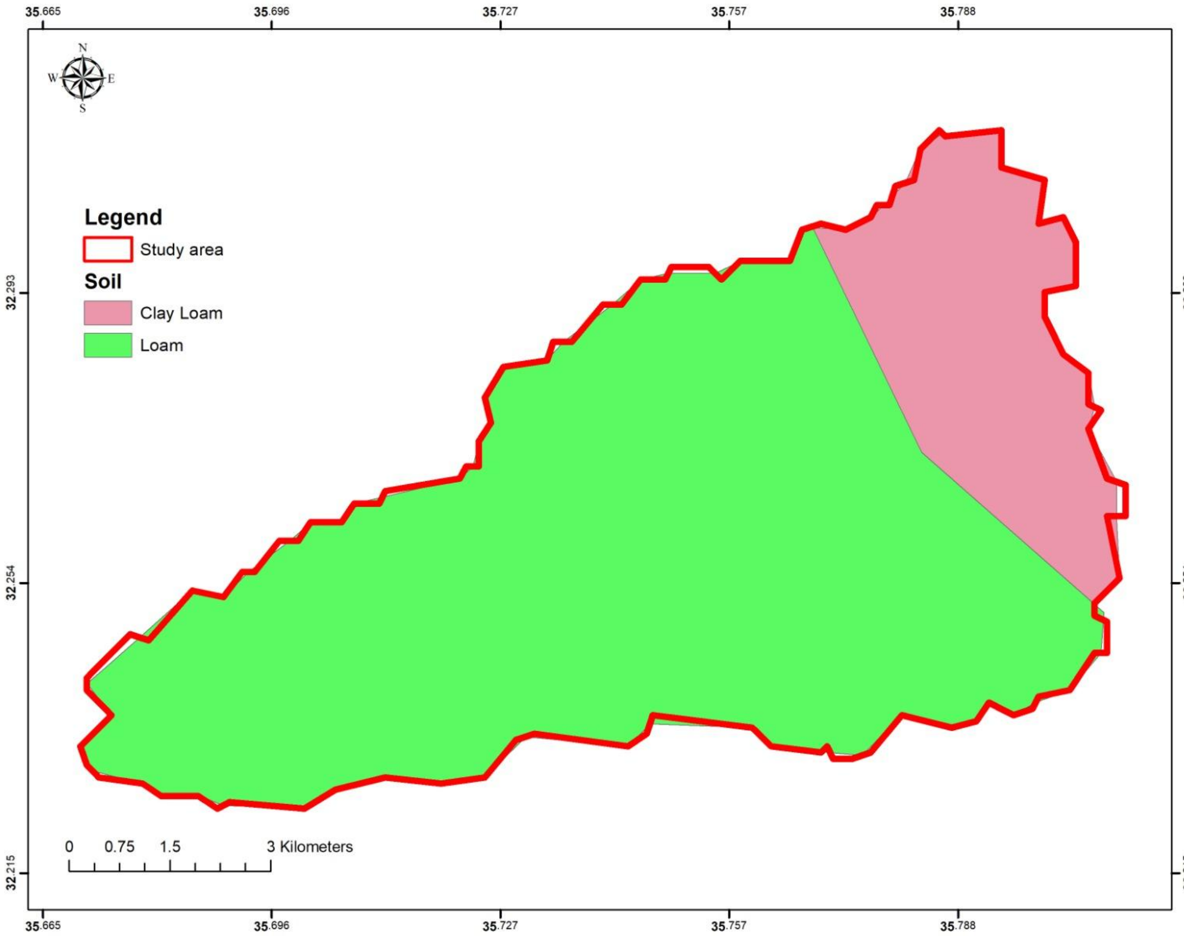

Fig. 4. Soil Map of the Study Area.

Table 2: Soil characteristics in the study area.

Soil Class	Soil ratio (%)	FAO Soil Class	Ks*(mm/hr)	Bulk Density (g/m³)	Hydrology group	Clay (%)	Silt (%)	Sand (%)
Clay Loam	24.6	Be36-3bc-5154	12.49	1.2	C	36	37	27
Loam	75.4	Ao55-2bc-5125	11.23	1.3	C	23	28	49

*Ks is the saturated hydraulic conductivity (mm/h).

3. Climate Data

Two data types are used: hydrological (rainfall and streamflow) and meteorological (maximum and minimum temperatures, relative humidity, and wind speed). Data were obtained from two sources: the Ministry of Water and Irrigation (MWI) and the Data Access Viewer website (DAV)(Larc.NASA, 2023) (https://power.larc.nasa.gov/data-access-viewer/). The effects of global warming on temperature, rainfall, and streamflow were investigated using three meteorological stations, three rainfall stations, and one streamflow gauge station. In this study, data on maximum temperature, minimum temperature, precipitation, wind speed, relative humidity, and discharge will be used to determine the impact of climate change in the study area.

4. Data quality control

Homogeneity tests are employed to assess whether a dataset exhibits uniformity in distribution and maintains consistent statistical characteristics. In climate studies, the utilization of dependable data is essential to ensure the elimination of erroneous trends or fluctuations. One method to ascertain data reliability involves comparing a climatic series with adjacent stations, which are used as the foundational principle for all relative homogeneity tests. In this study, Pettitt's test, the standard normal homogeneity test (SNHT), and von Neumann's test are utilized to assess the homogeneity of meteorological and hydrological data, with analysis conducted using the XLSTAT program (Al Qatarneh et al., 2018).

Models used

1. RClimdex Program

Numerous researchers in different countries used Rclimdex to calculate climate change indices (Al-Dahamsheh et al., 2018; Bashabsheh and Alzboon, 2024). It was created by Byron Gleason at the National Climate Data Centre (NCDC) in the United States (Zhang and Yang, 2004). Daily rainfall data and daily maximum and minimum temperatures were used in the Rclimdex program to calculate the basic climatic indices.

Before computing the core indices, the data should be homogeneous. In addition, Rclimdex performs data quality control by replacing invalid values and missing data with (-99.9), such as daily precipitation levels below zero and daily maximum temperatures below daily minimum temperatures (Zhang and Yang, 2004). The significant trend is tested with a p-value and a comparison of the estimated slope with the error slope. A significant trend will be recognized if the p-value < α and the estimated slope is larger than the slope error value (Berhane et al., 2020). The core indices that are displayed with their definitions and units in Table (3) are necessary to assess potential climate change during the study period.

Table 3: Climate Indices Terms and Definitions (Zhang and Yang, 2004; Alzboon et. al., 2021).

ID	Indicator name	Definitions	Units
FD0	Frost days	Annual count when TN (daily minimum) < 0°C	Days
SU25	Summer days	Annual count when TX (daily maximum) > 25°C	Days
ID0	Ice days	Annual count when TX (daily maximum) < 0°C	Days
TR20	Tropical nights	Annual count when TN (daily minimum) > 20°C	Days
GSL	Growing season length	Annual (1st Jan–31st Dec in NH, 1st July–30th June in SH) count between first span ≥6 days with TG>5°C and first span after July 1 with TG<5°C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
RX1day	Max 1-day precipitation	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by number of wet days (PR ≥1.0mm)	mm/day
R10	Number of heavy precipitation days	Annual count of days when PR ≥10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PR ≥20mm	Days
Rnn	Number of days above nn mm	Annual count of days when PR ≥ nn mm (user defined)	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR <1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥1mm	Days

2. Statistical Downscaling Model (SDSM)

SDSM was used successfully in many international studies to predict future climate change. In this research, the daily precipitation, maximum, and minimum temperature data for Ajloun, Kufranja, and Wadi Al-Rayyan stations from 2000 to 2018 are used for this purpose. The historical climatic data are divided into two time periods: the calibration period from 2000 to 2015, and the validation period from 2015 to 2018. The SDSM applies the multiple regression method to analyze the relation between the daily climate data at local locations and the large-scale predictors supplied by GCM simulations. Three RCPs (RCP2.6, RCP4.5, and RCP8.5) are considered in this study. Representative Concentration Pathways (RCPs) are the concentrations of greenhouse gases that the IPCC adopted in 2014 for its Fifth Assessment Report (AR5). In general, RCP 8.5 calls for an enormous rise in the use of fossil fuels for energy by the end of the century and no mitigation to keep CO_2 concentrations under control, while RCP 4.5 predicts an increase in energy use until 2040, then decline, and by 2050, renewable energy resources will have grown significantly (Intergovernmental Panel on Climate Change, 2014). The second generation of the Earth System Model (CanESM2) is a tool for evaluating how the climate will change. It generates climate change scenarios using different RCPs. The rainfall, maximum, and minimum temperatures for the period (2018–2100) were predicted using the SDSM, climatic data for the base period (2000–2018), and the outputs of the CanESM2 model based on three scenarios (RCP 2.6, RCP 4.5, and RCP 8.5).

3. SWAT Model

The SWAT model is used in the hydrological model to determine the impact of climate change on the streamflow of the Rajeb basin. The model outputs show a good similarity with the observed data (1981 to 2018), with a coefficient of determination (R^2) exceeding 0.6.

Streamflow is simulated up to the year 2100 to forecast changes in streamflow based on average maximum and minimum temperatures and precipitation under three emission scenarios (RCP2.6, RCP4.5, and RCP8.5). RCPs delineate the trajectory of pollutant concentration up to the year 2100, with RCP2.6, RCP4.5, and RCP8.5 corresponding to radiative forcing pathways of 2.6, 4.5, and 8.5W/m^2 in 2100, respectively. The Arc SWAT-ArcGIS interface is employed in this study. The SWAT is developed to forecast the effects of land management techniques on water, sediment, and agricultural chemical yields in large, complex watersheds with different types of soils, land use, and management situations over extended periods. Based on the characteristics of land use and soil, each watershed is first classified into subbasins, and then into hydrologic response units (HRUs). SWAT can calculate the amount of sediment carried by surface runoff from soil particles and other chemical and chemical mixtures (Arnold et al., 2013). In this study, the runoff curve number (CN) method is used for estimating direct runoff.

4. XLSTAT Program

XLSTAT is a powerful statistical analysis software add-in for Microsoft Excel. In this research, Pettitt's test, SNHT, and von Neumann's tests are used to evaluate the homogeneity of meteorological and hydrological data. Any substantial change or break in a time series can be found using the Von Neumann test, which also shows when the change did not occur. Pettitt's test is used to determine significant changes or breaks in a time series. On the other hand, SNHT is employed to evaluate if there is a considerable shift in the mean between different years. Von Neumann, Pettit, and SNHT tests are performed using the XLSTAT program for time series with a significance level of 0.05. The test hypotheses are:

-Ho indicates homogeneous data.

- Ha indicates nonhomogeneous data.

The Ho hypothesis is accepted if P is greater than 0.05. Conversely, the Ha hypothesis is accepted at (P < 0.05). Additionally, if the data passes two out of the three checks, it is considered acceptable.

Results and Discussions

Quality Control and Data Analysis

The Ho hypothesis is accepted if P is greater than 0.05. Conversely, the Ha hypothesis is rejected if P < 0.05. Additionally, if the data passes two out of the three checks, it is considered acceptable. All stations in this research passed the homogeneity tests as shown in Tables 4, 5, and 6. Therefore, the data are considered homogenous, and no further fitting process is required. The data series are acceptable and can be utilized in trend analysis and modeling.

Table 4: Results of the homogeneity test for annual rainfall data.

Station Name	Station ID	Pettitt's Test			standard normal homogeneity test (SNHT)			Von Neumann's Test		
		α	P	Check	α	P	Check	A	P	Check
Ajloun	AJ0001	0.05	0.277	Ok	0.05	0.965	Ok	0.05	0.871	Ok
Kufranja	AJ0002	0.05	0.523	Ok	0.05	0.906	Ok	0.05	0.909	Ok
Wadi Al-Rayyan	AH0002	0.05	0.349	Ok	0.05	.337	Ok	0.05	0.247	Ok

Table 5: Results of the homogeneity test for mean annual temperature data.

Station ID	Pettitt's Test			standard normal homogeneity test (SNHT)			Von Neumann's Test		
	α	P	check	A	P	Check	A	P	check
Ajloun	0.05	0.246	Ok	0.05	0.362	Ok	0.05	0.772	Ok
Kufranja	0.05	0.239	Ok	0.05	0.361	Ok	0.05	0.769	Ok
Wadi Al-Rayyan	0.05	0.240	Ok	0.05	0.366	Ok	0.05	0.775	Ok

Table 6: Results of the homogeneity test for stream data Series.

Station ID	Pettitt's Test			(standard normal homogeneity test) SNHT			Von Neumann's Test		
	A	P	Check	A	P	Check	A	P	Check
AH0002	0.05	0.016	Not.ok.	0.05	0.433	Ok	0.05	0.131	Ok

Climate Change Trend Analysis

Rclimdex is used to calculate 27 core indices (16 temperature indices and 11 rainfall indices) to determine climate change trends in the study area, as displayed in Tables 7 and 8.

1. Temperature Trend Analysis

Table 7 presents the results of significant tests for temperature indices. The test is conducted with a 95% confidence interval and α = 0.05. All stations exhibit a significant decreasing trend in the cold days (TX10p) index, with slopes of 0.33, 0.33, and 0.401/year for Ajloun, Kufranja, and Wadi Al-Rayyan stations, respectively. This indicates a reduction in the number of cold days by 13, 13, and 15 days, respectively, during the study period (1982-2020). Similarly, there is a significant decrease in the number of cold nights (TN10p) across all stations with a slope of 0.44/year, indicating a reduction of approximately 17 nights during the study period.

The warm days and warm nights (TX90p and TN90p) exhibit a significant positive trend, indicating an increase in the number of hot days by 9-11 days and hot nights by 12-13 nights. Additionally, the monthly maximum value of the daily maximum temperature (TXx) index demonstrates a statistically significant increasing trend in Wadi Al-Rayyan with a slope of 0.057, corresponding to an increase of 2.17°C. Similarly, the monthly minimum value of the daily maximum temperature index (TNx) shows a statistically significant increasing trend in all stations with an average slope of 0.05, implying an increase of 1.9°C.

Regarding the extreme climate indices, there has been a significant increase in the number of summer days with a daily maximum temperature exceeding 25°C (SU25) and tropical nights with a minimum temperature exceeding 20°C (TR20), reaching up to 28 days and 69 nights for SU25 and TR20, respectively. This trend indicates a notable tendency towards warmer temperatures, with a more pronounced increase observed for hot nights compared to hot days. Al Qatarneh et al. (2018) showed a positive trend in TR20 in the Azraq basin, with temperature analyses revealing increases ranging between 0.847 and 0.424°C per year. Similarly, Abdullah (2020) noted that temperatures in Jordan exhibited an upward trend during the period 1961 – 2014, with the minimum temperature experiencing a more significant increase compared to the maximum temperature.

The annual count of days with at least six consecutive days with TX> 90^{th} percentile (WSDI) reflects the increasing frequency and intensity of heat waves. WSDI is an indicator of hot days with a daily maximum temperature greater than 90^{th}, and represents the warm days over 6 consecutive days. The results of this research show a significant increase in Ajloun and Kufranja stations with an average slope of 0.254/year, indicating a rise in the number of days with at least 6 consecutive days with Tx>90^{th} percentile (Table 7).

Table 7: Results of the significant tests for extreme temperature indices.

Indices	Ajloun			Kufranja			Wadi Al-Rayyan		
	A	P-value	Slope	α	P-value	Slope	α	P-value	Slope
SU25	0.05*	0.001*	0.676	0.05*	0.001*	0.668	0.05*	0.001*	0.715
TR20	0.05*	0*	1.493	0.05*	0*	1.477	0.05*	0.00049*	1.831
FD0	0.05	0.338	-0.03	0.05	0.129	-0.049	0.05	0.143	-0.042
GSL	0.05	0.285	0.015	0.05	0.457	0.009	0.05	0.418	0.012
TXx	0.05	0.081	0.05	0.05	0.081	0.05	0.05*	0.019*	0.057
TXn	0.05	0.417	0.02	0.05	0.417	0.024	0.05	0.392	0.024
TNx	0.05*	0.006*	0.055	0.05*	0.006*	0.055	0.05*	0.006*	0.05
TNn	0.05	0.214	0.036	0.05	0.214	0.036	0.05	0.186	0.038
TX10p	0.05*	0.0003*	-0.33	0.05*	0.0005*	-0.338	0.05*	0.0004*	-0.425
TX90p	0.05*	0.0002*	0.242	0.05*	0.0009*	0.237	0.05*	0.00049*	0.284
TN10p	0.05*	0.003*	-0.44	0.05*	0.0004*	-0.441	0.05*	0.0003*	-0.44
TN90p	0.05*	0.006*	0.335	0.05*	0.0004*	0.333	0.05*	0.0005*	0.311
WSDI	0.05*	0.045*	0.261	0.05*	0.02*	0.299	0.05	0.114	0.201
CSDI	0.05*	0.001*	-0.34	0.05*	0.002*	-0.33	0.05*	0*	-0.478
DTR	0.05	0.307	0.006	0.05	0.307	0.006	0.05	0.293	0.013

*Significant at P≤0.5

2. Rainfall Trend Analysis

The PRCPTOT index (annual total precipitation in wet days) represents the total accumulated precipitation from "wet days" (days with precipitation greater than or equal to 1 mm) within a specific period. The PRCPTOT index shows a significant trend (P=0.021) in Wadi Al-Rayyan station with a negative slope (-2.968), indicating that total precipitation decreased by 112 mm during the study period, while the other stations show an insignificant trend. Days with heavy precipitation (R10mm) show a significant increasing trend in Wadi Al-Rayyan with a slope equal to 0.103 during the study period.

As shown in Table 8, there are no significant changes in any of the indicators at Kufranja station. However, the CDD indicator shows a significant decrease in the Ajloun station, which expresses successive dry days in which the amount of precipitation is less than 1 mm, with a slope of 0.821 per year and a decrease of 31 days during the study period. The results also show that (R10mm and PRCPTOT) had significant changes for the Wadi Al-Rayan station. R10mm index, which indicates days with heavy precipitation, shows a significant increasing trend in Wadi Al-Rayyan with a slope equal to 0.103 and a decrease by 4 days

Models Calibration and Validation

1. Statistical Downscaling Model (SDSM)

The historical climatic data are divided into two time periods: the calibration period from 2000 to 2015 and the validation period from 2015 to 2018, as shown in Table 9. The model's performance is considered acceptable if R^2 is greater than 0.65. The values of R^2 for the maximum and minimum temperature and precipitation are greater than 0.82 for all stations, so the model's performance is considered acceptable. All stations show higher R^2 for temperatures than for precipitation, which could be related to the annual variability in precipitation.

Regarding the limitations of SDSM, the spatial resolution of SDSM may not be sufficient to capture local-scale variations in climate within the study area, leading to potential biases in local-scale predictions. Additionally, SDSM relies mainly on historical relationships between large-scale climate variables and local observations. Changes in these relationships due to climate change can limit the model's accuracy in future projections. Emission scenarios (RCPs) are based on assumptions about the future, including technological change, energy use patterns, and population growth. These assumptions are uncertain and can significantly impact future greenhouse gas emissions and climate change projections.

Table 8: Results of the significant tests for extreme precipitation indices.

Indices	Ajloun			Kufranja			Wadi Al-Rayyan		
	A	P-value	Slope	α	P-value	Slope	α	P-value	Slope
RX1day	0.05	0.89	0.02	0.05	0.44	-0.11	0.05	0.21	-0.25
RX5day	0.05	0.67	-0.15	0.05	0.20	-0.38	0.05	0.06	-0.69
SDII	0.05	0.69	0.01	0.05	0.89	0.00	0.05	0.44	-0.02
R10mm	0.05	0.43	-0.06	0.05	0.12	-0.08	0.05*	0.05*	-0.10
R20mm	0.05	0.56	-0.02	0.05	0.56	-0.02	0.05	0.17	-0.03
R25mm	0.05	0.33	0.02	0.05	0.61	0.01	0.05	0.69	0.01
CDD	0.05*	0.046*	-0.88	0.05	0.12	-0.78	0.05	0.10	-0.80
CWD	0.05	0.19	-0.03	0.05	0.55	-0.01	0.05	0.16	-0.03
R95p	0.05	0.82	0.19	0.05	0.64	-0.30	0.05	0.22	-0.85
R99p	0.05	0.64	0.23	0.05	0.94	0.35	0.05	0.14	-0.73
PRCPTOT	0.05	0.45	-1.17	0.05	0.13	-1.82	0.05*	0.021*	-2.97

*Significant

Table 9: SDSM performance during the calibration and validation stages.

Model	Parameter	Calibration			Validation		
		Ajloun	Kufranja	Wadi Al-Rayyan	Ajloun	Kufranja	Wadi Al-Rayyan
		R^2			R^2		
SDSM	T max	0.97	0.96	0.95	0.97	0.95	0.94
	T min	0.97	0.93	0.96	0.96	0.96	0.96
	Precipitation	0.92	0.93	0.84	0.93	0.87	0.82

2. SWAT Model

The results of the hydrological model (SWAT) are not accurate but give a clear indication of the current and future status of water resources in the Rajeb Basin. It is difficult to identify the outputs of the SWAT model because the model requires wide-ranging inputs such as meteorological data, soil properties, and land use. Many parameters in SWAT are uncertain and have a significant impact on model results. Sensitivity analyses are used in this study to assess the impact of parameter uncertainty on model results. A total of thirty-six years of streamflow data are utilized for calibration (1985-2000) and validation purposes (2011-2018).

Table 10 lists the most sensitive parameters used in model calibration. These parameters and their values are determined via a sensitivity analysis based on relevant literature (Arnold et al., 2012; Feyereisen et al., 2007).

According to Santhi et al. (2001), the model is considered acceptable when its R^2 value is greater than 0.6, and its Nash–Sutcliffe model efficiency coefficient (NSE) value is greater than 0.5. The values of R^2 and NSE for the calibration period are 0.95 and 0.88, respectively, and 0.9 and 0.83 for the validation period. This indicates that the model is calibrated and can be used for future projection of streamflow (Fig. 5).

Table 10: SWAT model calibration parameters.

Parameter	Calibrated value	Estimated value	Range	Unit	Definition
CN2	77	83	0-100	----	Curve number
Gw_Delay	420	300	----	days	Groundwater delay time
Sol_Awc	0.13	0.1	----	mm/ mm	Soil effective Water content
Sol_K1	12.5	3.5	0-100	mm/hr.	Hydraulic conductivity parameter
Sol_Z2	1300	300	0-2000	mm/hr.	Soil depth parameter

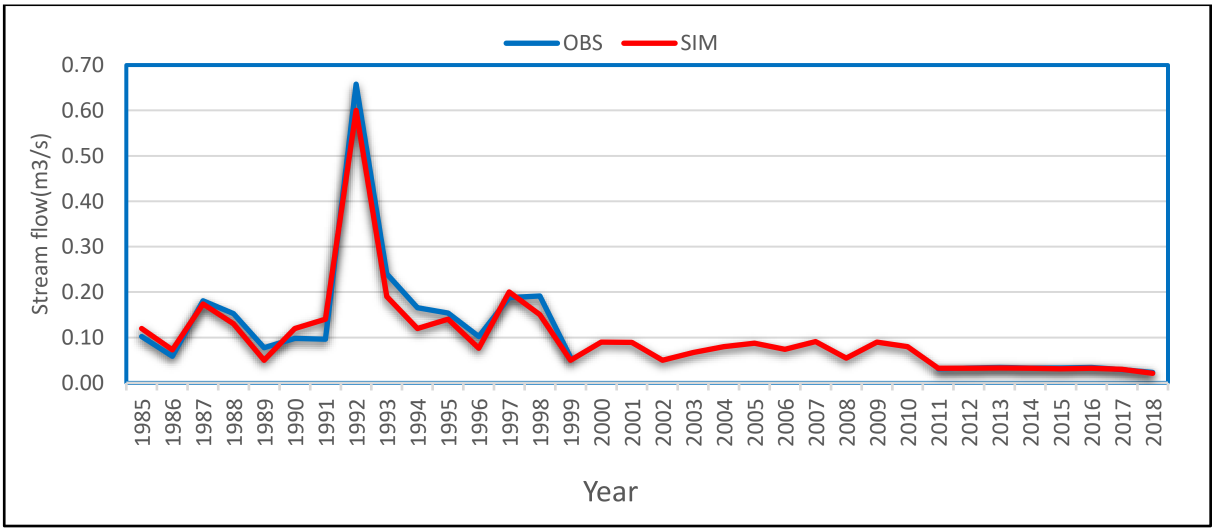

Fig. 5. Observed Streamflow (OBS) versus Simulated Streamflow (SIM) in the basin.

Models Prediction

1. Future Climate Prediction (SDSM)

As shown in Figure 6, the model predicts an increase in the maximum temperature of Ajloun station for the RCP 2.6 scenario by 0.33°C, 0.34°C, and 0.32°C for years 2050, 2075, and 2100, respectively. Similarly, the increase in Kufranja station will be 0.3°C, 0.3°C, and 0.29°C for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the maximum temperature will increase by 0.31°C, 0.33°C, and 0.3°C for the same periods. For the RCP 4.5 scenario, the maximum temperature of Ajloun station will increase by 0.45°C, 0.52°C, and 0.56°C for the years 2050, 2075, and 2100, respectively. The increase in Kufranja station will be 0.4°C, 0.54°C, and 0.6°C for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the maximum temperature will increase by 0.41°C, 0.57°C, and 0.64°C for the same years. For the RCP 8.5 scenario, the maximum temperature of Ajloun station will increase by 0.6°C, 0.89°C, and 1.48°C for years 2050, 2075, and 2100, respectively. The increase in kufranja station will be 0.62°C, 0.98°C, and 1.46°C for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the maximum temperature will increase by 0.64°C, 1.1°C, and 1.56°C for the same years, respectively.

As shown in Figure 7, the minimum temperature for Ajloun station based on the RCP 2.6 scenario will increase to 0.27°C, 0.29°C, and 0.28°C for years 2050, 2075, and 2100, respectively. The increase in Kufranja station will be 0.25°C, 0.24°C, and 0.25°C for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the minimum temperature will increase by 0.25°C, 0.23°C, and 0.21°C for the same years, respectively. According to the RCP 4.5 scenario, the minimum temperature of Ajloun station will increase by 0.35°C, 0.46°C, and 0.54°C for the years 2050, 2075, and 2100, respectively. The increase in Kufranja station will be 0.37°C, 0.44°C, and 0.48°C for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the minimum temperature will increase by 0.3°C, 0.46°C, and 0.52°C for the same years, respectively. RCP 8.5 predicted that the minimum temperature of Ajloun station will increase by 0.55°C, 0.9°C, and 1.39°C for the years 2050, 2075, and 2100, respectively. The increase in Kufranja station will be 0.58°C, 0.94°C, and 1.33°C for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the maximum temperature will increase by 0.45°C, 0.92°C, and 1.37°C for the same years, respectively. The temperature rise will increase the evaporation rate, decrease the soil moisture, and increase soil salinity, leading to an extremely high rate of land degradation, which intensifies desertification and creates soils lacking in nutrients. Food and Agriculture Organization (FAO) reported that if the current trend of climate change continues, the production of wheat and rice in 2100 will decline by 5-50% and 20-30% respectively (Arora, 2019).

The future precipitation trend suggests a significant decrease. As shown in Figure 8, the model predicted a decrease in the precipitation of Ajloun station for the RCP 2.6 scenario by 8%, 10.4% and 10.5% for years 2050, 2075, and 2100, respectively. The decrease in Kufranja station will be 10%, 10.3% and 10.6% for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the precipitation will decrease by 9.8%, 10% and 10.8% for the same years. RCP 4.5 predicted that the precipitation of Ajloun station will decrease by 10.4%, 20% and 22% for years 2050, 2075, and 2100, respectively. The decrease in Kufranja station will be 11.6%, 20% and 25% for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the precipitation will decrease by 10%, 20% and 21% for the same years. In the RCP 8.5 scenario, the precipitation at Ajloun station will decrease by 16%, 33%, and 44% for the years 2050, 2075, and 2100, respectively. The decrease in Kufranja station will be 13.6%, 33% and 44% for the years 2050, 2075, and 2100, respectively. In Wadi Al-Rayyan station, the precipitation will decrease by 14%, 33% and 42% for the same years. This reduction in rainfall will cause a significant decline in streamflow in the basin up to 69.6% in 2100, as discussed before. Reduction in streamflow will cause a deficiency in the basin's water budget, affecting water supply for different purposes.

All stations exhibited increases in both maximum and minimum temperatures, with no significant variation observed among the stations. Among the emission scenarios, RCP2.6 demonstrated lower impacts compared to RCP4.5 and RCP8.5, underscoring the importance of adhering to this scenario to mitigate the adverse effects associated with high emissions. These findings are consistent with previous studies conducted in the same area or neighboring regions. For instance, a study on climate change in Ajloun Governorate utilizing Global Climate Models (GCMs) projected a rise in maximum temperature by 1.7°C, minimum temperature by 2.2°C, and a decrease in precipitation by 18.7% by 2050 (Raggad et al., 2016). Similarly, Bashabsheh and Alzboon (2023) investigated the impact of climate change in the Yarmouk River Basin using SDSM and GCMs, reporting an increase in average temperatures ranging from 0.427°C to 1.52°C by 2100 under RCP2.6 and RCP8.5 scenarios, respectively. Precipitation was forecasted to decrease by 11.4% to 43.2% by 2100 under both scenarios. Additionally, a prediction by the US Agency for International Development (USAID) (2017) suggested a 2°C increase in the annual average temperature in Jordan by 2050.

Table 11: Predicted average rainfall drops in the study area (%).

Year	RCP 2.6	RCP 4.5	RCP 8.5
2018	0	0	0
2050	-9.3	-10.8	-15.9
2075	-11.3	-19.2	-32.3
2100	-11.4	-23.4	-44.2

Table 12: Predicted average temperature increase in the study area (%).

Year	RCP 2.6	RCP 4.5	RCP 8.5
2018	0	0	0
2050	0.28	0.41	0.64
2075	0.3	0.53	0.96
2100	0.30	0.57	1.47

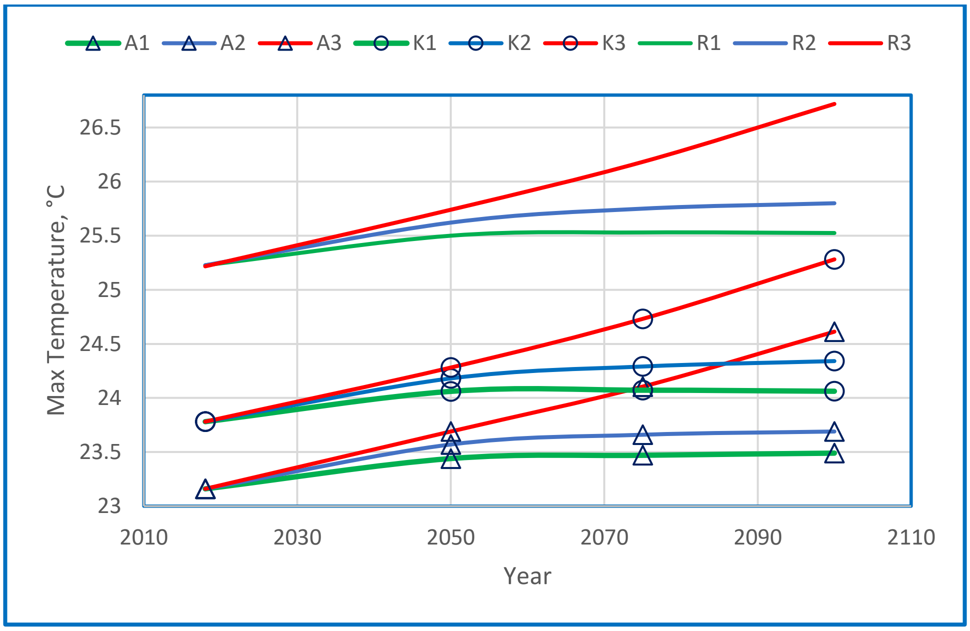

Fig. 6. Projection of the Max. temperature trend (A, K, R refers to Ajloun, Kufranja, and Wadi Al-Rayyan stations respectively; 1,2,3 refer to the RCP2.6, RCP4.5, and RCP 8.5 respectively).

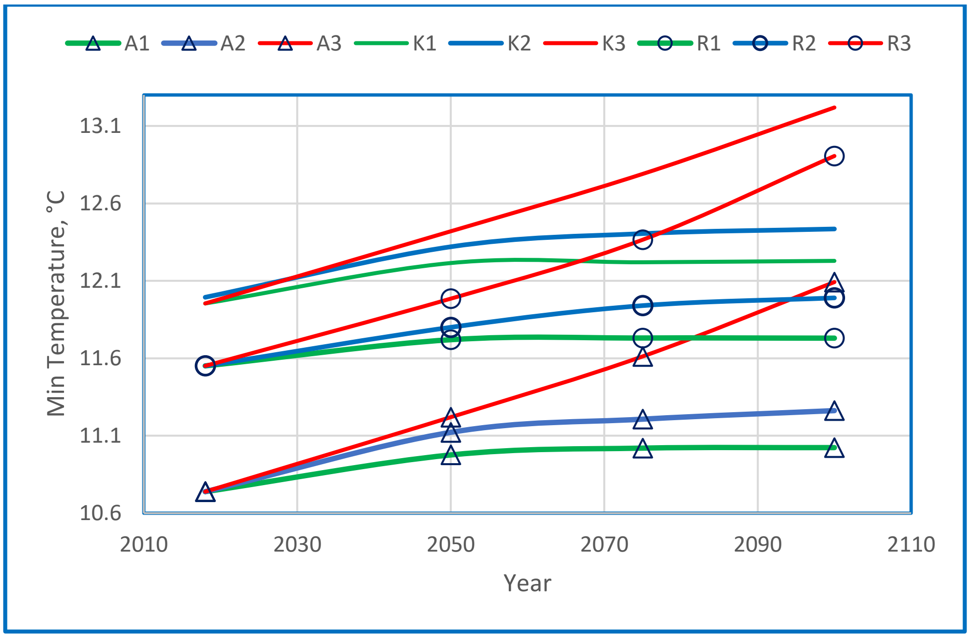

Fig. 7. Projection of the Min temperature trend (A, K, R refers to Ajloun, Kufranja, and Wadi Al-Rayyan stations respectively; 1,2,3 refer to the RCP2.6, RCP4.5, and RCP8.5 8.5 respectively).

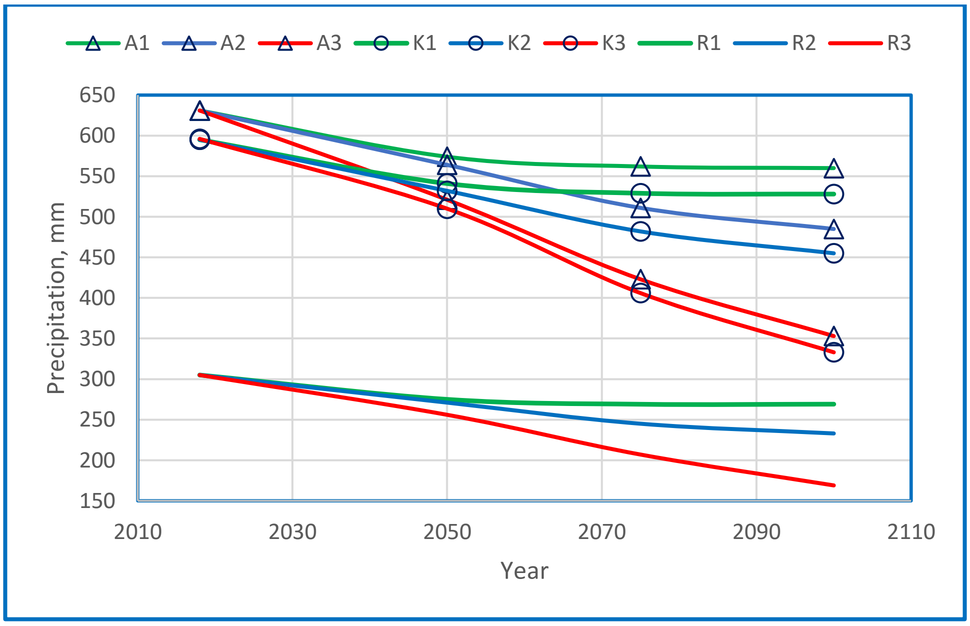

Fig. 8. Projection of precipitation trend (A, K, R refers to Ajloun, Kufranja, and Wadi-Al-Rayyan stations respectively; 1,2,3 refer to the RCP2.6, RCP4.5, and RCP8.5 8.5 respectively).

2. Prediction of Climate Change Impact on Streamflow (SWAT)

It is anticipated that the streamflow will decline across all research periods, with reductions ranging from 8.0% to 69.6% according to the SWAT forecast results. As illustrated in Figure 9, under the RCP2.6 scenario, the streamflow is projected to decrease by 8% between 2018 and 2050, 9.5% between 2051 and 2075, and 16% between 2076 and 2100. Conversely, the RCP4.5 scenario indicated a streamflow decrease of 9% between 2018 and 2050, 31% between 2051 and 2075, and 38% between 2076 and 2100. Moreover, the RCP8.5 scenario predicted a more substantial reduction in streamflow with declines of 22% between 2018 and 2050, 40% between 2051 and 2075, and 69.6% between 2076 and 2100. These findings underscore the severe impacts of climate change on basin water resources, highlighting the urgent need for mitigation measures.

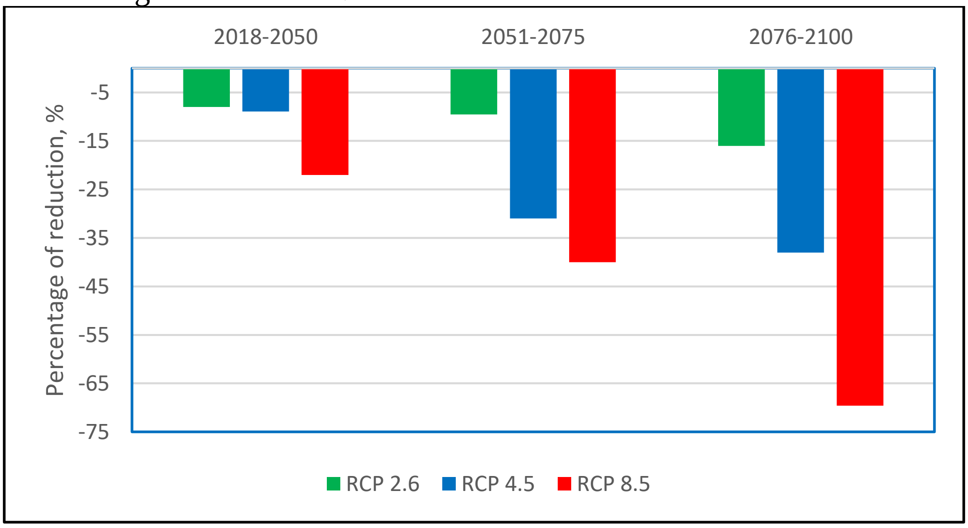

Fig. 9. Projection of changes in streamflow (%).

Conclusion and Recommendation

This study has examined the potential repercussions of climate change on an important basin within Ajloun Governorate employing RClimDex, SDSM, and SWAT models. According to the study's findings, the basin is greatly impacted by climate change, with hot days, hot nights, summer days, and tropical nights increasing dramatically between 1982 and 2000, while cool days, cool nights, and frost days fall significantly. It is predicted that the average temperatures will increase in 2100 by 0.29℃, 0.57℃, and 1.46℃ based on RCP 2.6, 4.5, and 8.5 scenarios, respectively, while precipitation will decrease in 2100 by 10.8%, 23% and 43% based on the same scenarios, respectively. The SWAT prediction results show a reduction in the streamflow during the period (2018-2100) by 8.1% to 69.2% based on RCP scenarios (2.6 and 8.5), respectively.

After conducting a study on the impact of climate change on water resources in Rajeb Basin, there is an urgent need for a set of comprehensive recommendations to address emerging challenges and protect this vital resource. These recommendations aim to develop an integrated strategy that contributes to achieving sustainability in water resource management in the basin, considering expected climate changes. The proposed strategy consists of the following pillars:

- Development of an advanced monitoring system to obtain accurate and comprehensive data on the status of water and climate resources in the basin, and track changes that occur over time.
- Researchers must have access to the climate change data they need.
- Planting of drought-resistant types.
- Using modern technology in irrigation to save water resources.
- Development of climate change-adapted crops.
- Change planting dates to avoid exposure to drought periods and take advantage of longer growing seasons.
- Modifying the crop rotation and planting types to require less water and be less sensitive to drought.
- Modifications to farming methods, such as the use of agroforestry and conservation tillage
- Promote research on climate change and water use efficiency.
- Fostering an engaging policy environment for climate change adaptation.
- The decision-makers and local organizations need to take into consideration the evident impacts of climate change on the Rajeb basin.
- Additional projects and financial support are necessary to control the impact of climate change.
- Pumping operations in the Rajeb basin require monitoring to ensure water resource sustainability.

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