An-Najah National University

Faculty of Graduate Studies

IMPACTS OF CLIMATE CHANGE ON THE WATER BUDGET IN THE FARIA CATCHMENT, PALESTINE

By

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Dedication

I dedicate this thesis to my dear parents, to my beloved brothers and sisters for their continued support.

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I would like to thank Allah for everything, for facilitating me to complete this thesis, and enabling me to achieve my ambitions successfully.

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I would also like to extend my thanks and gratitude to my wonderful and beautiful family, without whose support I would not have been able to continue my success and complete my thesis.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

IMPACTS OF CLIMATE CHANGE ON THE WATER BUDGET IN THE FARIA CATCHMENT, PALESTINE

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **Qais Mufid Ghaleb Daraghma**

Signature:

Date: **12/01/2025**

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IMPACTS OF CLIMATE CHANGE ON THE WATER BUDGET IN THE FARIA CATCHMENT, PALESTINE

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Abstract

Studying the climate change impacts on the hydrological elements in the Faria catchment is crucial, as the region is classified as semi-arid, and many its inhabitants depend on agriculture, so there is a need to understand the future of water in the region. The study includes analyzing future changes in climate elements and studying their impact on the hydrological cycle. The study uses SimClim AR6 to model the climate change and SWAT model for the hydrological modeling.

Daily climate data for the period (1990-2021) were used for building the hydrological model, and the results were calibrated and verified using SWAT-CUP to enhance its reliability.
Changes in the five elements (precipitation, minimum and maximum temperatures, relative humidity, solar radiation, and wind speed) were analyzed using 23 GCM's under the medium scenario SSP2-4.5 and the high scenario SSP5-8.5 over the time periods (2060 and 2100).

Results showed decreasing in precipitation and relative humidity, resulting a decrease in groundwater recharge by (-8.81%) in SSP2-4.5 in 2060 and (-27.43%) in SSP5-8.5 in 2100, and a decrease in the surface runoff by (-15.43%) in SSP2-4.5 in 2060 to (-43.31%) in SSP5-8.5 in 2100. The results also showed a rising in temperatures resulting in an increase in evapotranspiration rates of (3.14%) in SSP2-4.5 in 2060 and (9.64%) in SSP5-8.5 in 2100. In addition, the results showed an increase in solar radiation and a difference in wind speed.

The results showed a decrease in the water yield rates by (-14.31%) in SSP2-4.5 in 2060 and (-42.5%) in SSP5-8.5 in 2100, significantly threatening water resources, so there is an urgent need to find plans to adapt to climate change and develop water efficiency to enhance its sustainability.

The study emphasizes the importance of promoting hydrological modelling in order to understand the climate changes impacts on water resources, also the application for all catchments in Palestine. The study recommends the cooperation between decision makers and researchers be strengthened to address the expected challenges of climate change with actions that reduce its impact and developing adaptation plans.

Keywords: Climate Change, Hydrological Modelling, SWAT Model, SimClim AR6, Water Budget, Semi-Arid Zones, Faria Catchment, State of Palestine.

Chapter One

Introduction

1.1 General

Water is one of the most important components of life and the reasons for the prosperity of societies. It is an important resource that is essential to various human activities as well as human existence. With the rapidly increasing population growth and the urgent need to develop water supply, the demand for water is increasing daily owing to the evolution of living needs and human activities. Therefore, water sources and the optimal utilization of water should be preserved and all needs covered.

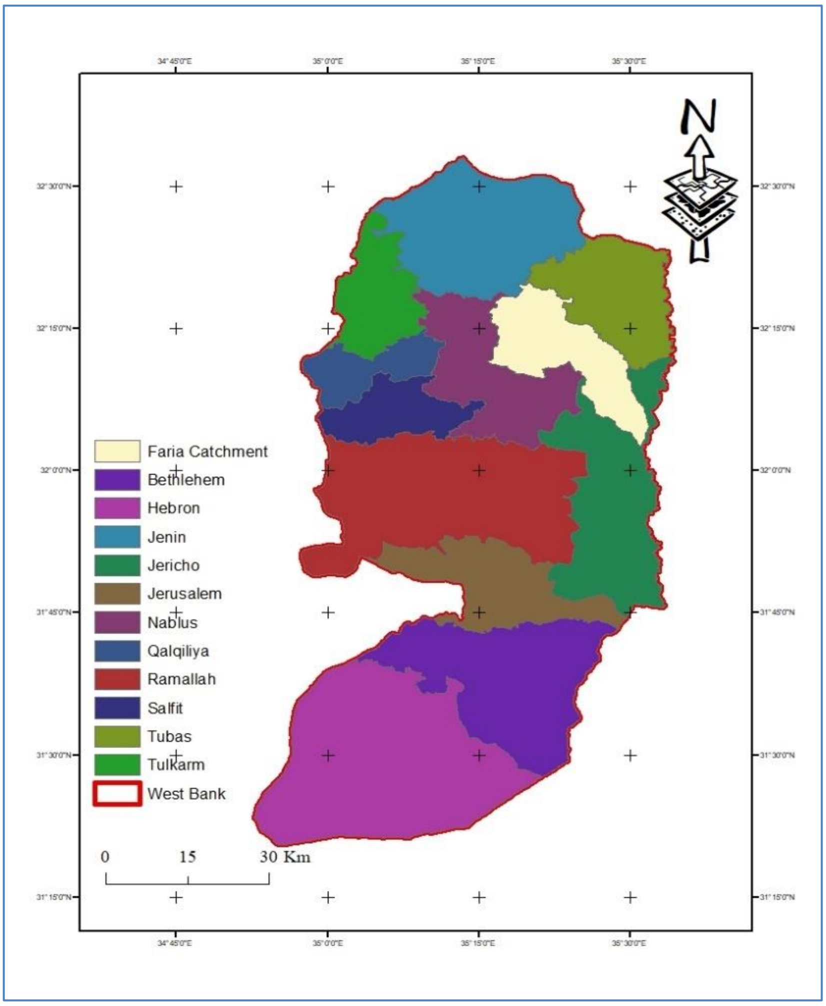
Climate is defined as average weather, as it expresses the average and volatility of relevant climatic elements over a period of time ranging from several months to millions of years. where this occurs as a result of greenhouse gas emissions and various human activities that can affect climate in general, such as industrial activities, large expansion of cities and land-use transformation (IPCC, 2008).

The Assessment Report (AR6) of the Intergovernmental Panel on Climate Change indicates that the global surface temperature was 1.09 (0.95-1.20) ºC higher in the period 2011-2020 than the period 1850- 1900, with an increase above the land surface of 1.59 (1.34-1.83) ºC, while above the surface of the ocean at 0.88 (0.68-1.01) ºC (IPCC, 2023). The potential impact of climate change is a major global concern, where it significantly affects elements of the hydrological cycle, increasing extreme hydrological phenomena such as frequent droughts, the severe storms and a decrease in the number of rainy days per year, which greatly affects the quantities of runoff from period to period. Studying the phenomenon of climate change and its potential effects is crucial for water sustainability and better water utilization.

The Faria catchment located in the north-eastern of the West Bank, has an area of approximately 320 km^2, characterized by its semi-arid climate (Abboushi, 2013). It is an area affected by climate change, with the region experiencing a clear change in rainfall amounts generally caused by global warming. Figure 1 shows the location of the Faria Catchment in the West Bank.

Figure 1

Location of the Faria Catchment in the West Bank



Changes in rainfall quantities and patterns have significant implications for the water budget of the Faria catchment, where in recent years the region has experienced storms that have become severe in the region and in short periods, significantly affecting the quantities of runoff and groundwater recharge. Groundwater sources in the Faria catchment are a major water source in the region, with the population of the region dependent on groundwater as the main source of their life and agriculture, which poses a threat to the conservation of the region's water resources and the sustainability of the aquifer.

The phenomenon of climate change has also led to changes in average minimum and maximum temperatures, relative humidity, wind speed as well as solar radiation, however, changes vary greatly from region to region, thus affecting livelihoods, agricultural and industrial human activity and others.

The region's population relies heavily on agriculture in their working lives, with the region classified as a food basket for the West Bank (Shadeed, 2008), so the water scarcity caused by climate change poses a significant risk to their economy, lifestyle and food security.

The study of climate change and its impact on the water balance in the Faria catchment helps to understand the future of the water resources and supply. It is also to develop plans and policies to improve water management practices and optimal water use in order to mitigate the expected damage to water sources caused by climate change in order to ensure water sustainability.

This thesis aims to provide modeling of climate changes over two periods of time and under two scenarios, in order to comprehensively understand the changes on the various climatic parameters including precipitation, minimum and maximum temperatures, relative humidity, wind speed and solar radiation. It models monthly, seasonally and annual climate data, in addition to hydrological modelling of the surface runoff, infiltration and evapotranspiration for Faria Catchment.

1.2 Problem Statement

Climate change is considered a global issue and Faria catchment, like many regions in the world, is affected by its consequences. It directly affects the water sector mainly as has been observed in recent years. As a result of climate change, the occurrence of many extreme phenomena that are related to the amounts of rain and the times of its rainfall during year in addition to the noticeable rise in temperatures.

Therefore, there is a need to fully understand the climatic elements as well as water budget in order to exploit them in agriculture and storage. Understanding changes in rainfall quantities and different climatic elements over the years will make better use of water and optimal water exploitation. Therefore, it is necessary to focus on the climate change impact on the different water budget elements (surface runoff, evapotranspiration and groundwater recharge) and to understand future scenarios.

Since a large percentage of the population in the catchment depend mainly on agriculture, the results of this study will help to understand the rainy season in the coming years in terms of quantities of precipitation and its variation during the seasons. Therefore, arrange their fields in terms of planting dates and type of fields to fit in with what is coming.

In addition, this study enables to comprehensively understand the issue of groundwater recharge and the potential amounts of recharge using software that fully model the hydrological cycle and work in an integrated manner with others that represent potential scenarios of climate change in the region.

1.3 Objectives of the Study

The main objectives for this research are:

1. Investigate the impact of the climate change on the climate parameters in the Faria Catchment under two durations and scenarios.
2. Modeling the Hydrological cycle in the Faria Catchment using SWAT.
3. Representing the amounts of the surface runoff, evapotranspiration, as well as the amount of groundwater recharge from the precipitation on Faria catchment under the two different periods and scenarios.

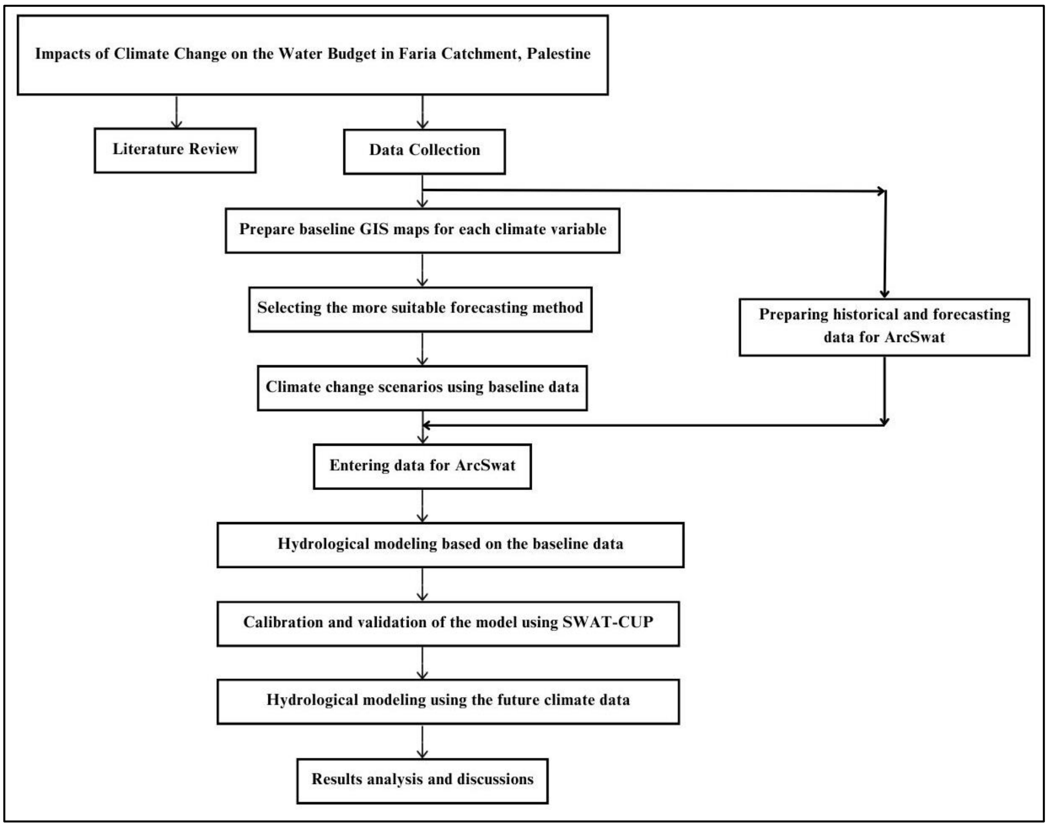
1.4 Scope of the Work and Research Methodology

In order to achieve the thesis, the main objectives will be determined. Secondly, determining the study area characteristics in terms of its area, topography, soil properties, land uses, climate properties and rainfall amounts, in addition to determining surface runoff readings and other properties. The data collected will be analyzed using Excel as well as ArcMap GIS, determine the periods of climate forecasting and scenarios under which conditions will be predicted. The climate model will then be ready to identify changes on the different climate parameters over the study periods.

Then processing the necessary data for input to the hydrological modeling and processing all the necessary maps for each characteristic of the study area. The calibration of the model will be done to ascertain its validity, as will the sensitivity analysis. Many statistical processes are employed to evaluate the model. Future climate parameters and data will be entered to determine the proportion of each of the different hydrological elements. Figure 2 comprehensively shows a detailed outline of the research methodology.

Figure 2

Outline of the research methodology



1.5 Thesis Outline

This thesis is organized as follows

Chapter 1 includes an introduction to the research, its relevance, main objectives, the scope of the work, and at the end of the chapter, the literature review of previous studies about the water balance and how it is expressed and calculated is reviewed, studies on climate forecasts using climate modelling tools and prediction over different periods and scenarios, as well as a brief understanding of hydrological modeling for several objectives such as identifying the elements of the hydrological cycle under these conditions as case studies in different regions.

Chapter 2 includes the research methodology, where the illustration of the different characteristics of the study area, data collected and analyzed, periods of study and general climate models as well as different scenarios, the preparation of the hydrological modeling model, as well as the operation of the model and the calibration phase. Chapter 3 presents the results of both climate forecasting and hydrological modelling, the analysis of the results, evaluating the model according to the results of the calibration phase and various statistical calculations, and clarifying the water balance in the Faria Catchment, and Chapter 4 presents the conclusions reached and recommendations for future studies according to the results obtained.

1.6 Literature Review

1.6.1 General

Studying the elements of the water budget and their impact on climate change factors is very important and valuable, so there are many studies that have been conducted to understand the water budget in the current situation in many regions of the world. Other studies have covered the subject in the long term and with the presence of many possible scenarios for emissions and studying the impact on the elements of the water budget, in order to better understand the subject of water and understand what is coming under each possible scenario.

1.6.2 Water Balance

Water is considered to be one of the most important natural sources especially in dry and semi-dry areas, as it suffers from a significant increase in population, as well as the scarcity of fresh water as well as variability high in rainfall amounts as well as significant changes in land uses, which increases the occurrence of hazards such as droughts and erosion.

So managing water sources is very important at the catchment level, which is by studying the interactions that link the different climatic factors, human activities that are land uses, as well as the surface of the land, that are soil types. The term water balance expresses consideration of all inputs and outputs of the hydrological system, so that the net output difference is the change in water storage.

A hydrological model has been developed to represent the water balance in all its components together and to understand the change in water storage WetSpass model, Water and Energy transfer between Soil, Plants and Atmosphere under steady state. This model is used to estimate water balance elements annually and seasonally (surface runoff, evapotranspiration and the groundwater recharge) and works in collaboration with the GIS program. GIS is used to process and prepare spatially distributed data for all parties to the water balance for use in hydrological models.

This model was applied in the study of water balance elements in Dura sub-catchment in northern Ethiopia, where its area is about 1240 ha, and the region is also characterized by a high variability in its topography with elevations ranging from (2060 to 2644) m AMSL, as well as slopes ranging from (0% to 76%).

This area is classified as semi- arid climate where the value of aridity index is 0.455, a measure that expresses the ratio of rainfall to potential evapotranspiration, and monthly temperature rate values are 19 ºC and the rates are higher in months (May-June).

Rainfall data were used for 35 consecutive years (1982-2016), with an annual rainfall rate of 734.6 mm and divided by two seasons during the year, the first with a small rainfall ratio and located in the months of March-April, and the other with the majority of rains extending from months (June-September).

The necessary data for the model (rainfall, temperatures, wind speed, sunshine hours and groundwater depth) and in addition to the data represented by soil classes, land uses, elevations and slopes were introduced for the model.

The water balance of each cell is calculated in the model, where the values of hydrological elements (Surface runoff, Evapotranspiration and Groundwater recharge) are calculated in equations that take into account the dedicated part to include (vegetated, bare soil, open water and impervious area) according to the maps introduced to the model.

An assessment of the model was made to ensure its effectiveness in use, where a comparison was made between the results of the model and measured values and estimated values, as well as a calculation of the coefficient of determination of R^2, where the results indicated a significant convergence between measured values and model outputs where the difference ratio was less than (5%).

The results indicated that the region's runoff values ranged from (5-222) mm/year with a mean of 100.5 mm/year and at (13.7%) of the annual rainfall, while the values of evapotranspiration were between (417 – 1618) mm/year at a (78.4%) of the annual rainfall, groundwater recharge values ranged from (0-266) mm/year with a mean of 58.2 mm/year and at (7.9%) of the annual rainfall.(Gebru & Tesfahunegn, 2020).

WetSpass model is good for estimating surface runoff, evapotranspiration and groundwater recharge rates. An estimation of the monthly surface runoff, evapotranspiration and groundwater recharge rates in Low Folded Zone in Iraq made using this model in addition to using ArcMap GIS. This area constitutes about (13%) of the area of Iraq and consists of 13 governorates.

The data were collected including meteorological data (precipitation, temperature and wind speed), land use, soil texture and groundwater depth. Maps of these data were prepared using GIS as inputs for the model.

The effectiveness of the model was confirmed by using the SCS-CN method to estimate surface runoff in order to compare the two results. Several calculations such as R^2, RMSE and RSE were also performed to evaluate the performance of the model, where it was found that the use of this model is very good.

The results indicated that surface runoff constitutes (21%) of the average monthly rainfall, while evapotranspiration constitutes (40%) and groundwater recharge constitutes (39%). It was indicated that changes in the soil type, topography, and land use of the region, in addition to meteorological data, are responsible for the change in the elements of water balance (Sabri & Khayyun, 2023).

Another estimation for the water budget elements for the year 2013 in the Gaza Strip using the WetSpass model and ArcMap GIS, where the necessary climatic elements such as rainfall, temperature, topography, etc. were analyzed and prepared in the form of GIS grids to be inputs for the model, which in turn analyzes these elements together and produces long term average annual digital maps for the surface runoff, evapotranspiration and groundwater recharge according to the equation of long term average seasonal water balance.

The results indicated that the values of evapotranspiration ranged from 100 to 300 mm with an average of 206 mm, which constitutes (77%) of the total annual precipitation, while the values of surface runoff ranged from 0 to 184 mm with an average of 29 mm which constitutes (11%) and the values of groundwater recharge ranged from 0 to 148 mm with an average of 33 mm which constitutes (12%) of the total annual precipitation (Aish, 2014).

It is also very important to determine the temporal and spatial change during one year for the elements of the water balance. this were determined for the Sulaymaniyah Governorate - Iraq as a case study in order to determine the possibility of expanding irrigated agricultural lands in the future. Six monitoring stations representing the governorate were used and their climate records were relied upon.

The Thornthwaite and Ivanov equations were used to calculate evaporation and transpiration for each station, which depends on monthly temperature and relative humidity rates. The situation was summarized in tables for the water and climate balance for each station separately in order to determine the values of the water surplus and deficit. The results indicated that the potential evaporation and transpiration rates decrease in winter compared to summer due to lower temperatures and shorter daylight hours in winter. It also showed that these rates are higher in summer compared to winter due to higher relative humidity rates in summer.

In addition to the above, the study identified the months of water deficit and surplus in the region. Based on the results of the study, it was found that the region enjoys a long rainy season (about six months). Given the terrain of the region, which is characterized by the presence of a large percentage of seasonal valleys, it is good to invest in this number of waterfalls by placing contour dams in order to delay the water as much as possible in order to increase the percentage of groundwater recharge and also to invest in these areas as a tourist destination (Taleb & Al-Balani, 2008).

1.6.3 Overview of Soil and Water Assessment Tool (SWAT)

Hydrological modeling of basins is extremely important because it shows us the interaction between the elements of the hydrological cycle and the effects obtained. The SWAT (Soil and Water Assessment Tool) model is one of these models that helps us for studying the basin hydrologically. It takes into account all the characteristics of the basin such as soil types, land uses, elevations, slopes and various daily weather data for the study period, so it enables a good understanding of the basin and where the precipitation water goes.

A study of the Lake Tana basin, which is the water source of the Blue Nile River, has an area of about 15,000 Km^2 and is about 4,000 m AMSL, and an average annual rainfall about 1300 mm.

Hydrological modelling of the basin was done using SWAT software, where the necessary data were collected such as the DEM obtained from ASTER Global Digital Elevation Model which is a digital model of elevations developed by National Aeronautics and Space Administration (NASA) and in cooperation with the Japan Aerospace Exploration Agency (JAXA).

Also, the soil map downloaded from Food and Agriculture Organization website (FAO), various weather data (Precipitation, Temperature, Relative Humidity, Wind speed and Solar radiation) have been processed for years from 1978-2014 and obtained from Climate System Reanalysis (CFSR).

In addition, the data of observed discharge data for the years 1992-1996 were processed for calibration and for the years 2004-2005 for validation.

The SWAT model have a Hydraulic Response Unit (HRU) which is used which aims to divide the basin for subbasins according to the type of soil and land uses and slopes uses that is, it is divided into similar places in terms of outflow of the basin within the same subbasin.

The calibration of the model was done using SWAT- CUP software (SWAT-Calibration and Uncertainty Program) which contains 2 algorithms Generalized Likelihood Uncertainty Estimation (GLUE) and Sequential Uncertainty Fitting version 2 (SUFI-2) for calibration and validation as the R^2 and NSE are calculated to compare the results with the observed data and the results were acceptable.

The results indicated that the evapotranspiration was about (85%) of the precipitation, while the basin outflow was about 4.47 billion cubic meters and the surface runoff about (25%) of the basin outflow (Mohamed et al., 2022).

In another study of water balance in semi-arid basins, it was studied in Bouregreg basin the north-central of Morocco, which is located near the capital of Rabat. The basin has an area of about 9570 km^2 and is characterized by a marked variation between surface heights, where elevations range from 46 m AMSL which is located at the outlet of the basin where there is a dam known as Sidi Mohamed Ben Abdellah (SMBA) dam reaches an elevation of about 1,630 m AMSL for the south-eastern mountains the basin, and average annual rainfall about 400 mm, while temperature rates range from (11-22) ºC.

This study aims to do hydrological modeling of the basin, water balance as well as an estimate of the monthly volume of inflow at the dam. ArcSWAT has been used for basin modeling, as this model is very important and helpful especially in developing countries that are characterized by unavailability or scarcity of climate and hydrological data. The necessary data for the model is processed from its different sources and equipped with the appropriate format and file type so that it is ready to be entered into the model, Where DEM data from ASTER GDEM has been obtained which features spatial resolution up to 30 meters, Land use data obtained from Landsat Image TM and with spatial accuracy up to 30 meters where there were 6 types of land use, As for soil data, they were downloaded from the FAO website.

In addition, weather data for the period (1985-2005) were processed through 9 rain gauge stations, 8 streamflow gauge stations, and for temperatures they were downloaded from UK Climate Research Unit (CRU) for the period (1901-2010).

The model was calibrated using the monthly rates of streamflow for the period 1989-1997. The model validation was also done to assess the model's performance over a period of time other than that used for calibration, where data were used for the period 1998-2005.

The ratio of the average annual evapotranspiration was ranging between (0.7-0.82) from the annual precipitation, while ratio of the average annual surface runoff was ranging between (0.14-0.2) of the annual precipitation (Fadil et al., 2011). Another study examined the hydrological cycle of the Wadi Mina Upstream Watershed basin in the north-east of Algeria.

The basin has an area of about 1173 km^2, ranging from 1267 m to 247 m at the outlet. The region is classified as semi-arid climate with a cold winter and a hot summer, with temperatures ranging from 7 °C in January to the highest of 39 °C in July.

Average annual rainfall about 370 mm, with rainy months of (October-April) while dry months are (May- September) and relative humidity values range from (62% to 78%).

Topographic data, land uses, soil types and necessary weather data were collected and processed from their different sources, the basin was divided into 23 sub-basins and 387 HRU's.

The model's calibration and validation were done using the observed monthly flow data at the outlet, where data from (January 2012 - August 2013) were used for calibration purposes, while data between (September 2013 - December 2014) were used for validation purposes.

The R^2 has also been calculated as an indicator of the relationship between modal results and observed data, NSE to evaluate the accuracy of the model and PBIAS where the inclination of simulated data is measured as being higher or lower than the observed data.

The results indicated a significant convergence between modal results and observed data and noted that the model tended to be overestimated especially in the heavy events of rainfall.

The results of the southern part had the highest values of monthly rain, with values ranging between (55-66) mm, for northern part between (50-55) mm while values for the eastern part ranging between (45-55) mm, regarding the values of evapotranspiration the results indicated a gradual decrease of upstream values ranging between (39-41) mm until the downstream reaches values ranging between (22-28) mm. In terms of runoff values, values in the southern part ranging between (13-33) mm while in the northern part between (0-13) mm, where this depends on the region's topography, land uses and soil type (Mebarki et al., 2024).

1.6.4 General Circulation Models (GCM's) and Climate Modeling

Climate change is a global issue and affects everyone. Its study and subsequent impacts on various elements of weather are highly valuable and critical. Climate change studies rely on projections of climatic elements with precise spatial resolution, General Circulation Models (GCM's), which are complex mathematical models that simulate the climate system under several scenarios whether they relate to greenhouse gas emission or socio-economic scenarios on a coarse scale, thus, it is necessary to reduce the output of these models to be finer spatial resolution.

Many models have been developed to predict the effects of climate change on climate components over the next several years and using different General Circulation Models (GCM's).

Many studies have been carried out in many regions of the world to predict and understand the potential future impacts of climate change, especially in areas that are scarce in freshwater and rely mainly on rain, so it is necessary to understand the changes that occur in order to best adapt to the next situation and to encourage a better handling of the climate issue to understand its impacts.

Climate changes in the Gaza Strip were identified in the form of spatially distributed maps of temperature and precipitation, fossil energy intensive was used with a high-sensitivity emission scenario and the medium assembly approach was used to obtain representative results from general circulation models (GCM’s) outputs, all models were taken into account, as one cannot be taken and another left because no models can be judged more suitable for the Gaza Strip, and the program takes median into account ,not the mean so this method is the most appropriate.

The analysis was based on the basic values of temperature and precipitation for the years 1972 to 2002 and the values were predicted for 3 periods (2020, 2050 and 2080) of the SimClim climate model prediction process.

The expected rainfall results for 2020, 2050 and 2080 were 294.68 mm per year, 243.70 mm per year and 170.82 mm per year respectively, as indicated by changes in rates from baseline to -7.48, -23.98 and -46.37 mm/year respectively. The results of the study also showed that changes in temperature rates for 2020, 2050 and 2080 were 20.66 °C, 22.48 °C and 25.08 °C, respectively, and changes in annual rates from baseline 0.85 °C, 2.67 °C and 5.28 °C, respectively (Western et al., 2015;Gharbia et al., 2015).

The process of linking potential future climate changes with the changes in hydrological elements is very important as it helps decision makers in developing effective plans to adapt to the upcoming situation to ensure environmental sustainability in the region.

In a study of the impact of climate change on the water balance in the Akaki Basin in Ethiopia, which has an area of 1,468 square kilometers and consists of 29 sub-basins. The coordinated regional climate experiment (CORDEX) and soil and water assessment tool (SWAT) were used, taking into account two emission scenarios, the first one is the medium emission scenario RCP 4.5 and the other is the high emission scenario RCP 8.5 for the periods (2026-2055) and (2056-2085).

The changes that occurred in the amounts of precipitation during the two scenarios, the two study periods and the months of the year were also determined, as the region witnessed changes represented for the RCP 4.5 scenario were (-0.6% to 57.3%) and (-120.9% to 73.54%) during the years 2040s and 2060s respectively while the changes during the RCP 8.5 scenario were (-35.69% to 87.62%) and (-87.62% to 68.48%) during the years 2040s and 2060s respectively.

The results also indicated a potential increase in the average minimum and maximum temperatures in all months in the catchment, while it witnessed a higher change in RCP 8.5 than RCP 4.5, as the hydrological elements are likely to be affected more in the higher emissions scenario, and the results indicated a decrease in the potential surface runoff values for both scenarios (Guyasa et al., 2024).

In another study, the expected minimum and maximum temperatures were predicted, as well as the change in precipitation amounts from (2021-2100) for the middle and west regions of Iraq, represented by the main cities (Karbala, Najaf and Anbar) over three time periods (2021-2040), (2051-2070) and (2081-2100), where the study relied on data for 4 stations (Karbala, Najaf, Hadithah and Rutba) for 30 consecutive years (1990-2020). Long Ashton Research Weather Generator (LARS-WG) and 5 GCM's were used based on two emissions scenarios RCP 4.5 and RCP 8.5.

The results indicated an expected increase in temperatures at all stations at a rate ranging between (0.94-4.98)ºC at the study period end 2100, where the value is higher the further north we go, as this increase is considered large and will have a significant impact on the agricultural sector in general, and it is also expected that it will accelerate the desertification process in the region and will affect soil properties and land uses and the most important is the impact on water resources as this increase will increase evaporation rates in the region.

The results also indicated the possibility of an increase in the amount of rainfall, as this increase ranges between (6.09% to 14.31%) for the RCP 4.5 scenario and (11.25% to 20.97%) for the RCP 8.5 scenario compared to the baseline data, and an increase in the amount and intensity of rain is expected and thus a possible increase in the occurrence of floods, which will greatly affect the infrastructure in the region, and on the other hand this increase will be beneficial in terms of investment in agriculture, especially since there is a significant shortage of water in the summer (Hassan et al., 2023).

Another method of downscaling was used in Shannon River catchment - Ireland using the GIS based python algorithm method.

The basin has an area of about 18,000 km^2, constituting about (20%) of Ireland's island area, and is characterized by a large agricultural activity, with agricultural areas constitutes for about (73%) while the wetlands constitute about (12%).

5 GCM's have been used over 3 periods of time 2020, 2050 and 2080 and using 2 RCP's (RCP 4.5 and RCP 8.5), working on the median and (75%) quartile account, being recommended for use in literature review as they offer us non-climate risk optimum minimum uncertainty.

Climatic data (precipitation, temperatures, relative humidity, wind speed as well as solar radiation) were collected for the period (1961-2014), where the period between (1961-2000) was used as baseline data while the data was used between (2000-2014) for calibration purposes.

Taylor's diagram was used to evaluate performance, in addition to using statistical relationships to assess results reached using GCM's in the study area.

Delta change method was used for downscaling of temperature and precipitation, as the multiple regression models were used for wind speed, relative humidity and solar radiation.

Results showed that the highest temperature increase was 1.8 ºC in the 2080 period under RCP 8.5 scenario (75%), as well as for precipitation where the highest amounts of were under the same scenario, with regard to solar radiation, the results indicated a clear increase initially from RCP 4.5 (50%), RCP 4.5 (75%), RCP 8.5 (50%) until we reach RCP 8.5 (75%), respectively and in the same way as relative humidity, quite the opposite were wind speed results where gradually decreasing from the RCP 8.5 (75%) scenario to RCP 4.5 (50%).

The study emphasized that the most important source for uncertainty is GCM selection, so the study suggests the importance of using multiple GCM's especially when working in a hydrological study (Gharbia et al., 2016).

Studying the impact of climate change on different climate elements is crucial as it directly affects our lives and affects our different activities in the present and future.

The impact of climate change on Pakistan's minimum and maximum temperature rates on south-west Asia has been studied, with the region's climate characterized as arid to semi -arid climate with cold winter and hot summer.

The change in minimum and maximum temperatures was studied during periods 2030 and 2060 monthly, seasonally and annually, with 40 GCM's used under RCP 6.0 scenario and using data for 39 stations, where historical data for the years from (1996-2015) were obtained from NASA's website.

SimClim downscaling tool was used to develop and evaluate the climate changes using multiple GCM's and using appropriate study scenarios. CLIMsystem data package is provided to each region in order to predict various climate elements using multiple GCM's.

The results indicated a rising in the minimum and maximum temperatures, as the highest increase was in maximum temperature in December, while the highest increase in lower temperature was in July, where there was a variability by location in temperature changes.

The results also indicated that there was a decrease in the rate of minimum and maximum temperatures in Azaad Kashmir and Khyber Pakhtunkhwa) in the winter months, spring and autumn, while values increased in the summer for these areas.

The study recommended the importance of these studies to assess climate risks in different sectors in the present and in the future (Amin et al., 2018).

Studies that are interested in studying potential future climate forecasts and their impact on the hydrological cycle and its components have varied, as these studies help in strategic planning under all possible climate conditions.

The study examined the impact of climate change on Swat River basin flows in northern Pakistan, where the basin has an area about 14,039 km^2. This basin is characterized by geographical and climate diversity, which significantly affects precipitation amounts and patterns as well as water flows.

The study included prediction of climatic elements through analysis of data under the effect of the RCP 4.5 and RCP 8.5 scenarios and using 6 GCM's on 3 time periods (2020-2040), (2041-2070) and (2071-2100) and then hydrological modelling using the SWAT model.

The basin was divided into 6 sub-basins and 14 HRU's according to the characteristics of the topographic region, soil type and the land use. The model was calibrated to verify its accuracy using SWAT-CUP where RSE, RSD and PBIAS indicators were used.

The results showed that high flows, which occur in periods of heavy rainfall, will increase continuously over all periods. Medium flows will increase continuously over all periods, either with regard to low flows, which flow to the river in droughts or when there is little rain, they are expected to see a marked increase in their rates.

The study also recommended the need to develop strategies for water sustainability to meet various future climate challenges and under all possible conditions (Anjum et al., 2019).

The world is an unprecedented climate challenge, but in Palestine it is a special issue because it suffers from complex political and geographical conditions and conditions, exacerbating these impacts. The Palestinian Environment Quality Authority's first national report on climate change highlighted the current and potential future impacts of climate change in Palestine, focusing on analysis of greenhouse gas emissions from different sectors, as well as assessment of adaptability and review of possible scenarios based on the fifth report of the IPCC (AR5).

The report focused particularly on possible scenarios according to the AR5 based on temperatures and precipitation as well as extreme weather events. The report included 3 possible scenarios, the first was the most likely scenario if such emissions did not increase the average global temperature by more than 2 °C, a scenario that conforms to the IPCC's requirements for the erosion of severe climate change impacts, assuming an increase of about 1 °C, 1.5 °C and 2 °C by 2025. 2055 and 2090 respectively, and it is assumed that rainfall does not change or may increase slightly until 2035 and with little likelihood of severe rainfall accidents.

The second most likely scenario is continuing to increase emissions with some declines from previous levels, but without increasing the average global temperature by 2 °C. It is supposed to increase the prediction of temperatures at a rate of about 1 °C, 2 °C and 3 °C by 2025, 2055 and 2090 respectively, in addition to a projected decrease in precipitation of about (10%), (15%) and (20%) by 2025, 2055 and 2090 respectively, as well as the likelihood of a slight change to increase flood risk and the likelihood of frequent droughts. Finally, the third scenario presupposes an increase in emissions at earlier rates without adhering to specific rules and strategies to avoid climate change. Where this scenario assumes a potential temperature increase of about 1.5 °C, 2.5 °C and 4.5 °C by 2025, 2055 and 2090, as well as a possible drop in rainfall of about (20%), (30%) by 2055 and 2090, as well as a decrease in the number of wet days and increase for droughts (EQA, 2016).

Chapter Two

Materials and Methods

2.1 The Study Area

2.1.1 Location and Geography

Faria catchment locates in the north-eastern of the West Bank. It is one of the 33 catchments throughout the West Bank, with an area of approximately 320 km^2, which constitutes about (6%) of the West Bank area.

Faria catchment extends over a part of the territories of 4 governorates of 11 governorates of the West Bank governorates, the first one is Tubas governorate which constitutes about (15.52%) of the governorate's territory, Nablus governorate about (28.68%), Jenin governorate about (0.79%) and Jericho governorate about (14.57%).

The Faria catchment is characterized as agricultural, where its land majority is agricultural land, as this is due to the quality of arable soil as well as the availability of water, where many underground wells are observed in the catchment, which increases agricultural activity in the area.

The catchment contains 23 communities within its borders, 10 of these are located around the main stream of the catchment, which is called Al-Faria Wadi. These are Ras Al- Faria, Al-Faria refugee camp and Wadi Al-Faria, Badan, Beit Hasan, Al-Nassariyya, Al-Aqrabania, Froush Beit Dajan, Ein Shibli and Al-Jiftlik.

2.1.2 Topography

The topography of the Faria catchment characterized by high variability of elevations throughout a small area, ranging from about 901 m AMSL in the Nablus Mountains in the north (Yasid Mountains) to about 350 m BMSL at the outlet for catchment in the Jordan River region (See Figure B.1).

2.1.3 Soil and Geology

Six types of the soil in the Faria catchment (see Table 1), varies in their characteristics and areas where the largest proportion of the catchment are for the types (terra rossas, brown rendzinas and pale renzinas) which constitutes about (65%) of the catchment area, these types are characterized as clay texture which means that large amounts of filtration are not allowed through them. There are different types of the soil in the catchment such as dolomites and limestones, which is characterized by allowing water to infiltrate through it, then reducing the amount of runoff water. Soil types in the Faria catchment are represented and distributed spatially (see Figure B.3).

Table 1

Types of soil in the Faria catchment

Soil Type	Soil Texture	Area (Km^2)	Area (%)
Brown lithosols and Loessial arid brown soils	Loamy	16.398	5.12
Brown rendzinas and pale renzinas	Clay loam	76.983	24.01
Grumusols	Clay	46.049	14.36
Loeessial serozems	Sandy loam	19.873	6.20
Regosols	Clay loam	29.989	9.35
Terra rossas, brown rendzinas and pale renzinas	Clay	131.286	40.95

The geological nature of the Faria catchment is also characterized by being a structurally complex system with Faria Anticline as it extends from the northeast to the southwest parts and represents the main feature of control, additionally there are a series of joints and faults that are perpendicular to this Anticline (Shadeed, 2008). This significantly affects the quantities of water drained according the catchment. catchment formations consist mainly of limestone marl and dolomite (Abu Hijleh, 2014).

2.1.4 Climate

Faria catchment is characterized by its mediterranean semi-arid climate, which has a rainy and relatively cold winter and a hot and dry summer. The rainfall period extends for 6 months from October to April of the year and most of the rainfall falls in this period, for the remaining 6 months, it is a relatively dry summer.

The catchment is characterized by high variability in the climate despite its small size, but the topography of the area and the large difference in elevations has the greatest impact, where the climate varies as we go from the higher elevations in the northwest where elevations reach 901 m AMSL to the southeast of the catchment where elevations reach 350 m BMSL.

The annual temperature in the catchment ranges from about 18 ºC at the northwestern side to about 24 ºC at the south-eastern side at the outlet near the Jordan River.

There are only two climate monitoring stations in the catchment, one at the top is the Nablus Climate Monitoring Station (570 m in elevation) and another at the bottom of the catchment which is Al-Faria Climate Monitoring Station located in the Al-Jiftlik community (-237 m in elevation).

The relative humidity rates in the catchment ranging from about (61%) in the western part to about (58%) in the eastern part of the catchment (Shadeed, 2008).

As for the evaporation and thus evapotranspiration where values vary greatly throughout the year, where the values of the potential evapotranspiration at Nablus station during the months (November - March) and at the Faria station in the months (December and January) are lower than the values of precipitation, so there is rainfall surplus, and in the rest of the months the values of potential evapotranspiration are higher than the precipitation (Abu Hijleh, 2014).

The region has both northwestern and southwestern winds, with annual wind speeds at 2 m above the earth's surface ranging from its highest value at the Nablus station at the top of the catchment about 2.2 m/s until its values reach about 1.3 m/s at the Al-Faria station at the bottom of the catchment (Shadeed, 2008).

The amount of rainfall in the catchment varies considerably, as this is due to the large disparity in the topography, which significantly affects the climate. The amount of rainfall in the Faria catchment ranging from about 650 mm at the top of the catchment to about 150 mm at the bottom (the outlet) near the Jordan River. Quantities vary as we go from west to east as well as north to south (Abu Hijleh, 2014).

High-elevation areas are characterized by a rich rainy season and somewhat frequent snow precipitation, while the southern part is characterized by little rainwater.

2.1.5 Land Use and Land Cover

Land uses are varied in the Faria catchment, where there are 8 land uses spatially distributed throughout the catchment. The largest use is the agricultural area since it’s representing the most prominent and largest economic activity in the region. In addition to other uses, (Bare rocks, olive plantations, scattered olive plantations, natural grassed hill slopes, natural forests, built up areas, and sparsely vegetated hill slopes), different areas are shown in Table 2. Land use classifications in the Faria catchment are represented and distributed spatially (see Figure B.4).

Table 2

Land use classifications in the Faria catchment

Land Use Classification	Area (Km^2)	Area (%)
Agricultural	70.96	22.13
Olive plantations	9.11	6.37
Bare rocks	15.11	2.84
Built up	2.83	4.71
Scattered olive plantations	90.79	8.18
Natural forests	20.42	0.88
Natural grassed hill slopes	26.23	28.31
Sparsely vegetated hill slopes	85.22	26.58

2.1.6 Water Resources

Water sources in the Faria catchment are classified either surface water or groundwater, and the area is classified as being mainly within the Eastern ground Basin.

There are about 71 groundwater wells in the region, most of these are classified for agricultural purposes, where the depth ranging from 10 m to 190 m, as the total use of groundwater wells ranges from (4.4-11.5) MCM annually.

Another source of water is springs, where they are the only natural outlet for drainage of groundwater in the catchment. There are 11 springs in the upper and middle parts of the catchment. The values of the discharge for these springs range from about (1.4 - 40) MCM.(Shadeed, 2008).

In addition, surface water is considered to be moving from the north to southeast of the catchment. The surface flow of water by catchment includes runoff from the eastern regions of Nablus and areas within the catchment in Tubas and Tammun, as well as from the Faria refugee camp at the top of the catchment and areas along the catchment. It also includes water discharged from springs and passing through the valley, which contributes to the valley not being allowed to dry in the summer, there is also untreated sewage from the eastern part of Nablus and the Al-Faria refugee camp (Qasim Sulaiman, 2017).

2.2 Software Used

2.2.1 SimClim AR6

SimClim AR6 is a tool used to manage climate data, helping us access climate data that helps assess and adapt to the risks of climate change.

Covers all over the world spatially, where the program has been used in many countries for making a statistical downscaling for GCM's for climate data, including precipitation, temperature, relative humidity, wind speed as well as solar radiation as future predictions, 49 GCM's has been used for the program under several scenarios involving Representative Concentration Pathways (RCP’s) and Shared Socio-economic Pathways (SSP’s).

2.2.2 ArcMap GIS 10.5

ArcMap GIS is a computer software used to analyze and connect geospatial data, as well as used to analyze and produce maps and many other targets. It is used in many areas such as water, environment, agriculture, urban planning, transport etc., so as to be flexible in handling and analysis. In this thesis the ArcMap 10.5 version will be used.

2.2.3 ArcSWAT 2012

In order to identify and evaluate the effects of land practices on water and agricultural chemical yields in a specific catchment where land and soil use vary over extended periods of time, this tool integrates GIS with SWAT (Soil and Water Assessment Tool).

The software needs complete climate data for the area in addition to all spatial data related to the catchment, such as land use, soil type, and DEM. The coordinates system to be used is the global projected coordinates system WGS_1984_UTM_Zone_36N.

2.2.4 SWAT-CUP

Soil and Water Assessment Tool Calibration and Uncertainty Program is used to analyze and calibrate the results of the SWAT model, as it serves as a supplementary tool to improve the forecast and results of the satellite model during calibration based on hydrological parameters, soil, weather and climate, plant and land use, groundwater, water quality as well as canals.

2.3 Data Collection

2.3.1 Introduction

The accuracy and efficiency of any model depend on the input data accuracy, so the study model's efficiency depends on the accuracy of the hydrological input and climate data.

The quality of hydrological input data depends on spatial coverage, which is the geographical location or area represented by the data, and also on time coverage, the time period during which the data is collected. Quality is also associated with accuracy of data, such as cell size in spatial datasets.

Runoff and Rainfall data remaining very limited in the arid and semi-arid regions, often due to the volatile climate nature and extreme events occurring irregularly, resulting in a lack of modelling tools and available data compared to other regions. The watershed in the Faria catchment faces similar challenges, as hydrological data are very limited and generally unavailable. Accordingly, many satellite-monitored data records were used to complete the data required for the models used in the study.

Also, at a minimum, building a hydrological model using SWAT requires a set of basic data, which are land cover/ land use data, digital elevation model (DEM), soil data, as well as climate data. These data are used to estimate surface runoff properties and calculate the model's various hydrological parameters. The following sections outline methodologies for the use of ArcMap GIS and SWAT tools for the preparation and processing of such data for the operation of the hydrological model and the analysis of results.

2.3.2 Weather Data

Climate data sources and accuracy are extremely important for any study, being the basis for modeling in both stages of the study in both the climate outlook as well as hydrological modeling, where in the climate forecasting phase (SimClim AR6 model) it is preferable to rely on long-lasting historical data to see changes in climate parameters (precipitation, temperature, relative humidity, wind speed and solar radiation) over the past decades.

The available data for the State of Palestine will be used during the model, where the baseline data has been generated from the region's global data set, where it has been generated on ultra-accurate data from WorldClim (where the resolution reaches about 1 km) plus and coarse-resolution data from CRUTS4.03, where WorlClim data covers the period between 1971 and 2000, while CRU data covers the period from 1901 to 2023.

As for the climate data required for hydrological modelling (ArcSWAT model) for Faria catchment, available data for rainfall will be used from 6 rainfall stations which are (Nablus, Talluza, Tammun, Al-Faria, Tubas, and Beit Dajan) stations. The data will include daily rainfall readings for catchment stations from 1990 to 2021 that obtained from the Palestinian Meteorological Department of the Ministry of Transportation and Communications. Table 3 represent the available data for the stations in addition to the elevations.

Table 3

Available data from the stations

Rainfall station	Elevation (m)	Period for daily data	Average Annually Rainfall (mm)
Al-Faria Station	-237	1969-1978	198.6
Nablus Station	570	1975-2021	642.6
Tubas Station	375	1967-2010 and 2011-2021	415.2
Tammun Station	340	1967-1987 and 1990-2021	322.3
Talluza Station	500	1968-2021	630.5
Beit Dajan Station	520	1967- 2005 and 2004 and 2015-2021	379.1

As for the other climate parameters needed for ArcSWAT model, they will be downloaded from The National Aeronautics and Space Administration (NASA) website for the period 1990 -2021 for all stations.

2.3.3 Rainfall Stations

The number of stations used to represent rainfall is important for the accuracy of work in the calculation of the rainfall for a given area in order to be well represented and spread over the entire area, where the optimal number of stations required is calculated by the following formula (Shadeed, 2008):

$$N = (\frac{C_v}{E_p})^2 \quad (1)$$

Where:

N: is the optimal number of stations.

Cv: is the coefficient of variation of the rainfall from the existing stations in percentage.

Ep: is the allowable percentage of error in the estimation of the aerial mean rainfall.

To calculate the coefficient of variation (C_v), the following steps were applied:

Mean Rainfall Calculation

The average rainfall (P_{avg}) was computed using the formula:

$$P_{av} = \frac{1}{n} \sum P_i \quad (2)$$

Standard Deviation Calculation

The standard deviation was determined as follows:

$$\sigma_{n-1} = \frac{1}{(n-1)} \sum (P_i - P_{av})^2 \quad (3)$$

Coefficient of Variation Calculation

The coefficient of variation was then calculated by:

$$C_v = \frac{\sigma_{n-1} X\ 100}{P_{av}} \quad (4)$$

Six current stations' rainfall data were used to generate the previous statistical parameters; the values were:

P_{av} = 417.5 mm

$\sigma_{n-1} = 175.9$

C_v = 42.13

The allowable percentage of error was assumed to be (11%), then the optimal number of Stations N = 15.

Existing Stations (n) = 6, then the additional required stations = N-n = 9.

The amounts of precipitation in the Faria catchment are affected by the elevations, as the amount of precipitation increases with the increase in elevation. A spatial relationship was developed to estimate the average annual rainfall for the stations by (Abedel-Kareem, 2005), where multiple linear regression was used for five stations within the catchment (Nablus, Talluza, Beit Dajan, Tubas and Tammun), which depends on the spatial coordinates (Palestinian coordinates) of the station as well as the elevation as:

$$R = 8285 – 39.41X - 2.46Y - 0.34Z \quad (5)$$

Where:

R is the annual average rainfall of the station (mm), X and Y is the geographic Palestinian coordinates (Km) and Z is the elevation (m).

The sixth station (Al-Faria station) was used to verify the relationship. The additional 9 stations were added so that they are well spatially distributed throughout the catchment and are representative also the mean annual rainfall for the these stations were calculated using equation 5. Figure 3 shows the distribution of the stations in the Faria catchment. The characteristics of the suggested stations are shown in table 4.

Table 4

The characteristics of the suggested stations

No	Station	X Coordinate (m)	Y Coordinate (m)	Elevation (m)	Mean Annual (mm)
7	S7	181174	179701	499.00	533.21
8	S8	181743	190250	287.00	556.92
9	S9	183751	185414	100.00	553.26
10	S10	188196	182186	-50.00	437.03
11	S11	192429	178694	-131.00	306.32
12	S12	193646	174461	-157.00	277.61
13	S13	196345	167476	-162.00	190.14
14	S14	198864	163845	-306.00	148.76
15	S15	192262.82	170367.64	68.00	265.70

2.1.1 Filling Missing Rainfall Data

Filling the missing rainfall data is essential to complete all the necessary rainfall data and thus the success of the model. The estimate for each day of missing reading at a particular station is based on the data observed on that day for the Faria catchment stations and on the average for each station. There is no day for which there are no known values.

Equation 1 was used to calculate missing values

$$P_x^y = \left(\frac{P_{av-x}}{n}\right)\sum_{i=1}^{n}\left(\frac{P_i^y}{P_{av-i}}\right) \quad (6)$$

where:

P_x^y is the missing rainfall at station x at time step y (mm).

P_{av-x} is the long-term annual average of station x (mm).

P_i^y is rainfall at station i at time step y (mm).

P_{av-i} is the long-term annual average of station i.

n is the number of stations in the catchment.

2.3.4 Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) data of the Faria catchment has been obtained from the Geomolg website, an official website in Palestine dedicated to geospatial information, which was developed by the Palestinian Ministry of Local Government in cooperation with the German International Cooperation Foundation (GIZ), with a data resolution of 25m × 25m.

2.3.5 Land Use and Land Cover

Land use data for the Faria catchment were obtained from the Geomolg website, Land uses were defined according to the SWAT database, and land use lookup tables were prepared for input into SWAT (See Figure 3).

2.3.6 Soil Data

Soil data in the Faria catchment were obtained from the Geomolg website, also the soil data for Palestine were also obtained from the world soil dataset provided by the Food and Agriculture Organization of the United Nations (FAO), which provides data for 6998 soil classes according to the latest update, with a spatial resolution scale of 1:5000000. FAO data includes chemical and physical properties of soil such as the available water capacity (AWC), hydraulic conductivity (K), and others for each soil class, FAO data were used because it gives each soil class a specific code according to the different properties in the FAO soil database, this database was added to the SWAT database, and lookup tables were prepared for soil classifications in SWAT. Table 5 shows the general characteristics of soil classifications by SWAT classification. Showing the soil map that was applied in the SWAT and includes soil classes according to the FAO classification (See Figure 3).

Table 5

SWAT soil classifications

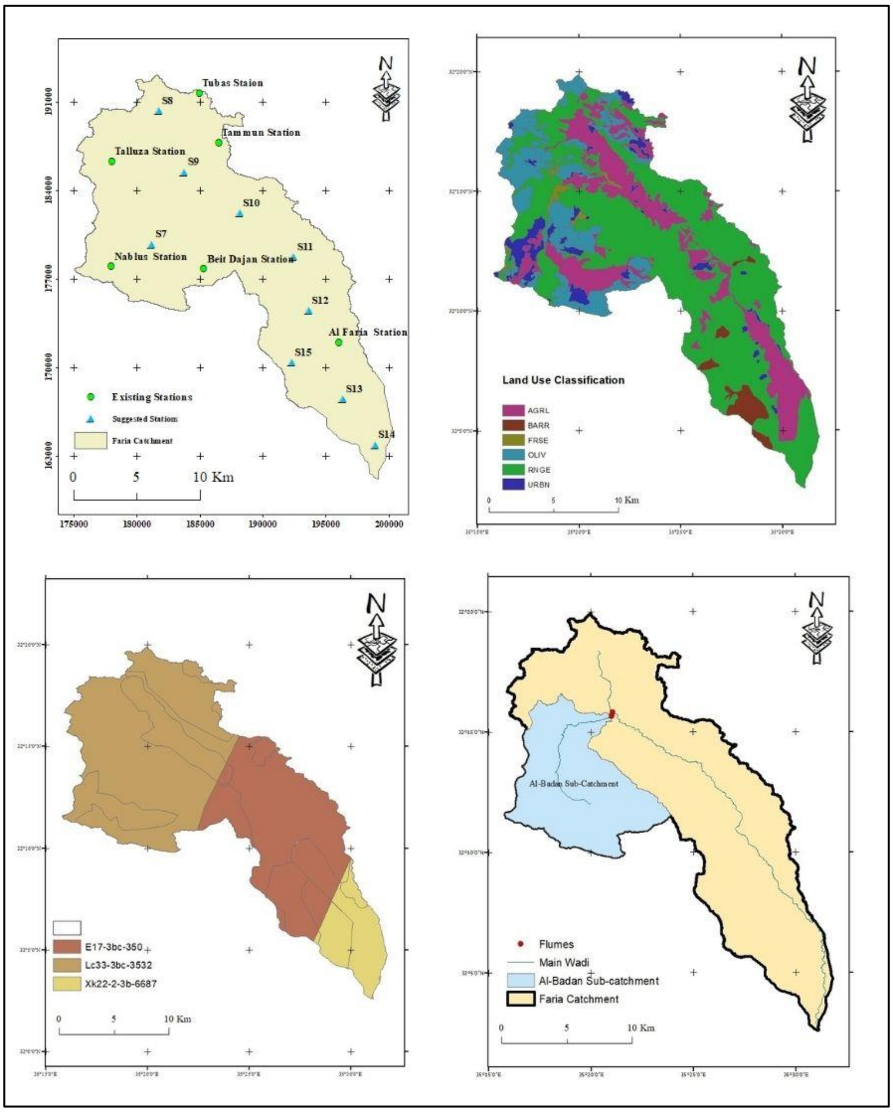
Soil Code	Lc33-3bc-3532	Xk22-2-3b-6687	E17-3bc-3502
Texture	CLAY	SANDY-CLAY-LOAM	CLAY
Depth of the First Soil Layer (mm)	300	300	300
Available Water Content (AWC) (cm/cm)	0.085	0.158	0.056
Saturated Hydraulic Conductivity (K) (mm/hr)	4.55	6.3	4.39
Hydrological group	D	D	D

2.3.7 Observed Runoff

For any hydrological model to be useful in a particular location, measured field readings are a must. This is because the model can be calibrated by comparing the serial results between the modal result and the observed reading. the observed data from a previous reading for the badan sub-catchment using Parshall flumes used for the calibration and validation purposes, which were collected at the sub-catchment outflow during the period (2005-2007), for the calibration (1/11/2004 to 9/3/2005 and 1/10/2005 to 16/3/2006) and for the validation (15/11/2006 to 28/3/2007) (See Figures B.5, B.6 and B.7). Figure 3 shows the location badan sub-catchment, Parshall flumes and the main wadi in the catchment.

Figure 3

Stations, Land use map for SWAT model, SWAT soil classifications and Badan sub-catchment



2.4 Data Analysis

2.4.1 General Circulation Models (GCMs)

Future climate projections based on global climate models (GCMs) are an important basis for studying the impacts of climate change. Many of these climate models have also developed by many of the world's research centers, some of which are characterized by higher accuracy in certain geographical areas, where the level of accuracy depends on the size of the cells used to simulate the atmosphere, the surface of the earth and the oceans, where the smaller size of the cells the higher accuracy of the climate system.

The process of selecting the most suitable model according to two main criteria: the first is its common use in global research, according to literature, ensuring reliance on reliable and widely accepted models. The second criterion is due to the accuracy of the model, where high-resolution models are preferred for their ability to more accurately represent regional climatic patterns, including the effects of terrain and local weather events.

Thus, researchers focus on the particular importance of choosing the most suitable models for the most used and accurate models, to ensure accurate and detailed climate forecasts, thereby enhancing their understanding of potential climate changes and their regional impacts.

For this thesis in Faria catchment - West Bank, where taking only one model is not logical, since this is the first time that future projections are applied in the region, where it's not accurate to take a model instead of the other, and we can't judge a model that's better than another, so the best fit for the region is to take different GCMs, When we use the median (50th percentile) approach for the outputs of these models and not the average, The use of this principle eliminates the outcomes of the extreme modal, using all models is the most appropriate solution for the region for climate forecasting over the 2060 and 2100 periods, as the SimClim AR6 software can do so. The 23 identifiable models within SimClim AR6 with all the climate variables needed for study (precipitation, temperature, relative humidity, wind speed and solar radiation) will be selected and illustrated in Table 6.

Table 6

GCM's selected in the SimClim AR6

No.	Institution	Model name (in SimClim)
1	Australian Research Council Centre of Excellence for Climate System Science, Australia	ACCESS-CM2
2	Australian Research Council Centre of Excellence for Climate System Science, Australia	ACCESS-ESM1-5
3	Canadian Centre for Climate Modelling and Analysis, Canada	CanESM5
4	Canadian Centre for Climate Modelling and Analysis, Canada	CanESM5 -CanOE
5	Chinese Academy of Sciences, China	CAS-ESM2-0
6	Euro-Mediterranean Center on Climate Change, Italy	CMCC-ESM2
7	National Center for Meteorological Research, France	CNRM-CM6-1
8	National Center for Meteorological Research, France	CNRM-CM6-1-HR
9	National Center for Meteorological Research, France	CNRM-ESM2-1
10	Swedish Meteorological and Hydrological Institute, Sweden	EC-Earth3- AerChem
11	Swedish Meteorological and Hydrological Institute, Sweden	EC-Earth3- Veg-LR
12	National Aeronautics and Space Administration, USA	GISS-E2- 1-G
13	The UK Meteorological Office, UK	HadGEM3 -GC31-LL
14	The UK Meteorological Office, UK	HadGEM3 -GC31- MM
15	Russian Academy of Science, Russia	INM-CM4-8
16	Russian Academy of Science, Russia	INM-CM5-0
17	Institute Pierre Simon Laplace, France	IPSL-CM6A-LR
18	Japan Agency for Marine-Earth Science and Technology, Japan	MIROC6
19	Japan Agency for Marine-Earth Science and Technology, Japan	MIROC-ES2L
20	Max Planck Institute for meteorology, Germany	MPI-ESM1-2- HR
21	Max Planck Institute for meteorology, Germany	MPI-ESM1-2- LR
22	Meteorological Research Institute, Japan	MRI-ESM2-0
23	The UK Meteorological Office, UK	UKESM1- 0-LL

2.4.2 Shared Socioeconomic Pathways (SSPs)

Climate scenarios are used to assess the impacts of climate change on different projects, adopting Coupled Model Intercomparison Project (CMIP 5) on Representative Concertation Pathways (RCP's), RCP’s are a method for capturing those assumptions within a set of scenarios. The conditions of each scenario are used in the process of modelling possible future climate evolution. RCP’s include the following scenarios (RCP 2.6, RCP 4.0, RCP 6.0 and RCP 8.5) where the number refers to Radiative forcing (W/m^2) in 2100, RCP 2.6 refers to a significantly reduced emission scenario while RCP 8.5 refers to a high emission scenario.

As for CMIP 6 where it relied on Shared Socio-economic Pathways (SSP's), where these scenarios are considered to be more comprehensive because they include social and economic factors as well as greenhouse gas emissions, where scenarios range between (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5), where SSP2-4.5 represents a scenario that is expected to continue with current trends in terms of social and economic growth, while SSP5-8.5 represents a scenario of increase in rapid innovation and technological progress but with intense reliance on fossil fuels, thus increasing greenhouse gas emissions.

This study will include two scenarios, SSP2-4.5 and SSP5-8.5, which are included in the SimClim AR6 software for several GCM's, where the medium scenario was chosen as the most likely for the current situation, while the high scenario was selected to understand the potential prospects for the worst future situation and for two periods of time (2060 and 2100) (See Figure B.2).

2.4.3 SWAT models Setup

Using an extension of ESRI ArcView 10.5 GIS, the ArcSWAT 2012 hydrological model was utilized for runoff modeling.

Prior to commencing any processing, ArcSWAT requires that all spatial data have the same coordinate system. Spatial datasets for the project were processed by redropping them to the global projected coordinates system WGS_1984_UTM_Zone_36 . These datasets included the Digital Elevation Model (DEM), the Land Use map, and the soil map based on FAO classifications. Maps were clipped using ArcGIS's Clip tool to identify the research area.

2.4.3.1 Watershed Delineation

The first step to doing hydrological modeling is to identify watersheds as well as sub-basins within the Faria catchment, so that after the SWAT project was established, the watershed was set by a set of steps, the first step is to add the DEM for the basin and select the unit so that it is in meter, definition of flow direction of water according to DEM, identification of inlets and outlets for discharge of sub-basins, calculate the areas of sub-basins which have been divided according to DEM and in addition calculate the parameters of sub-basins.

The model automatically identifies flow directions as well as flow accumulations over the entire basin area, as well as determining the network of streams, dividing the basin into sub-basins, identifying topographic parameters such as elevations, slopes, the length of the main path of runoff, etc. The number of sub-basins during modeling were 33 sub-basins and the number of outlets were 33 (See Figure B.8).

2.4.3.2 Definition of Hydrological Response Unit (HRU)

The Hydrological Response Unit (HRU) is the smallest element in the hydrological modeling of SWAT, where it is characterized by each unit having a unique composition that combines soil types, land use and slope within each sub-basin. These models enable the hydrological model to represent all the differences in hydrological processes such as evaporation and infiltration.

After the watershed identification process has been completed, the slope analysis carried out according to the Digital Elevation Model (DEM) for the catchment, in addition to soil varieties and land cover is added to SWAT, where these different data are used to identify HRUs, each of which has similar soil type properties, land use and slope.

In terms of slope analysis, it has been categorized into these categories ((0% to 10 %10.01) ,(% to 20 %), (20.01% to 30%30.01) ,(% to 40 %), and more than (40 %)). To ensure the compatibility of the virtual SWAT database, land use was reclassified using the HRU window, where land use in the catchment was linked to the classifications in the SWAT database for land use classifications, and specialized lookup tables were equipped that link the data to the model database.

For soil data, the FAO database was used in the model, where the data was entered containing FAO classifications to the SWAT database, where it was also linked using lookup tables and specially designed to comply with SWAT entries.

After defining the previous data, it is overlayed to obtain a map showing HRU's, as these units are characterized by accurate data that reflects the nature within each sub-basin, and thus the hydrological processes are accurately represented, as 597 units were defined according to the data.

2.4.3.3 Model Run

The simulation process was conducted to analyze the runoff and all hydrological processes of the watershed by integrating into three main methods. First, the runoff curve method (CN) has been used to estimate the amount of runoff resulting from all forms of rainfall, as it depends mainly on land uses, soil characteristics and the rainfall amount to determine the amount that turns into surface runoff compared to the quantities that leak into soil and evaporation.

Second, the amount of possible evapotranspiration is certified on the Penman-Monteith method to calculate the amount of water that can evaporate from the ground or sweat from plants under possible conditions. Third, the variable storage method has been used to simulate how water moves within currents and rivers, helping to clearly understand how water travels through the stream path in the water catchment. The default parameters of the SWAT model were relied on without being modified, meaning that the software was used with its general initial settings. When analyzing available data, there has been a lack of data recorded in some days for the catchment stations especially for rainfall records, and there are doubts about the accuracy of data recorded in some years, affecting the quality of simulation and analysis.

In general, these methods and models helped to estimate the runoff, evapotranspiration and water trajectory, but the accuracy of the results was largely dependent on the quality of available data, which was marred by some shortcomings and uncertainty in some periods, so a calibration of results will be done based on the values measured in the field in order to reach a better representation of the results.

2.4.4 Calibration and Validation for SWAT Model (Performance Evaluation)

The SWAT evaluation process is crucial to ensure its performance and thus to ascertain and rely on its outputs, using 2 key parameters for evaluating its performance that are present within the Sequential Uncertainty Fitting Algorithm (SUFI-2), which is the coefficient of determination (R^2) and the Nash Sutcliff Efficiency (NSE).

These parameters are the most common and comprehensive in assessing the SWAT model for calibration and verification phases. R^2 is a measurement of the compatibility of the modal's results and measured values. Equation 2 shows the R^2 formula:

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(Q_{obs}\,(i)-\overline{Q_{obs}}\right)\left(Q_{sim}\,(i)-\overline{Q_{sim}}\right)\right]^2}{\sum_{i=1}^{n}\left(Q_{obs}\,(i)-\overline{Q_{obs}}\right)^2 \sum_{i=1}^{n}\left(Q_{sim}\,(i)-\overline{Q_{sim}}\right)^2} \qquad (7)$$

Where Q_{obs} indicates for the observed flow values, Q_{sim} for the simulated values, $\overline{Q_{obs}}$ is the average observed flow and the $\overline{Q_{sim}}$ is the average of the simulated flow. R^2 values range from 0 to 1, so that the higher the value, the better the model's representation and indicates a .perfect correlation between the results and the observed values

The NSE refers to goodness's assessment of the modal from the convergence of simulation with observed values, and its values range from $-\infty$ to 1, whereas the values ≤ 0 indicates that the model is not reliable and when the values close to 1, this indicates the convergence of the simulated and observed values, where Equation 3 shows the NSE formula:

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs}\,(i)-Q_{sim}\,(i)\right)^2}{\sum_{i=1}^{n}\left(Q_{obs}\,(i)-\overline{Q_{obs}}\right)^2} \qquad (8)$$

Table 7 indicates the model's performance ratings according to the parameters in its evaluation:

Table 7

Model's performance ratings

Classification	NSE	R^2
Very Good	$0.75 < NSE \leq 1.00$	$0.75 < R^2 \leq 1.00$
Good	$0.60 < NSE \leq 0.75$	$0.60 < R^2 \leq 0.75$
Satisfactory	$0.50 < NSE \leq 0.60$	$0.50 < R^2 \leq 0.60$
Unsatisfactory	$NSE \leq 0.50$	$R^2 \leq 0.50$

Chapter Three

Results and Analysis

3.1 SimClim AR6 Results and Analysis

SimClim AR6 has been used to forecast the climate change on different climate parameters in the Faria catchment for periods 2060 and 2100, where it follows IPCC guidelines, where work was done under two scenarios, which are SSP2-4.5 and SSP 5-8.5 for the two periods according to baseline datasets for Palestine, clip has been working on output maps according to the borders of the Faria catchment, with the aim of identifying climate changes across the entire area of the catchment.

3.1.1 Precipitation

The results indicated significant changes in the annual precipitation of the Faria catchment, where changes in precipitation in 2060 were under the SSP2-4.5 scenario and the SSP5-8.5 scenario ranged between (-6.81% to -5.83%) and (-9.84% to -8.43%) respectively, while changes in 2100 under SSP2-4.5 and SSP5-8.5 ranged from (-10.15% to -8.69%) and (-20.82% to -17.85%) respectively.

For changes at the catchment stations, where the highest changes in the 2060 and 2100 years were S14 station, where the change in 2060 were (-6.81%) and (-9.84%) under SSP2-4.5 and SSP5-8.5 scenarios respectively, while the change in 2100 were (-10.15%) and (-20.82%) under SSP2-4.5 and SSP5-8.5 respectively. To clarify the spatial distribution of changes in precipitation in the Faria catchment (See Figure B.9).

3.1.2 Temperature

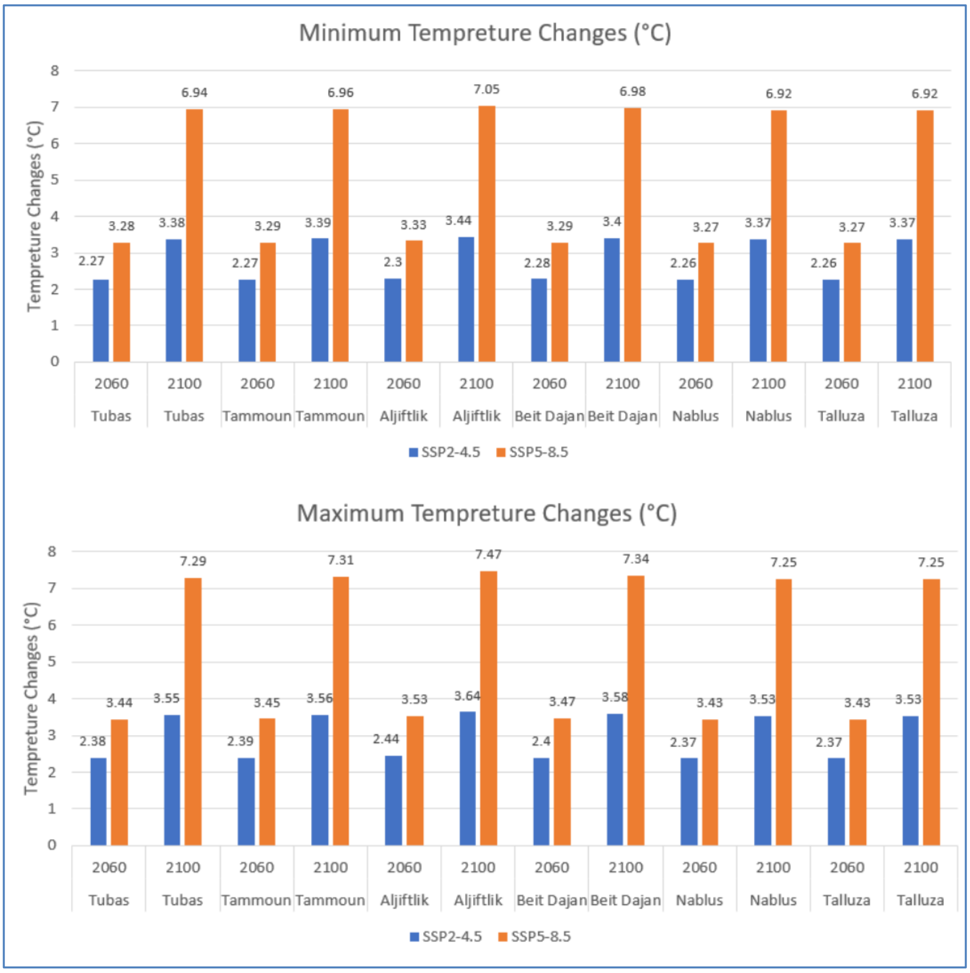
The results indicated a varying increase in the minimum and maximum temperatures in the Faria catchment under two study periods scenarios, changes in the minimum temperatures in 2060 ranged from (2.26-2.32) °C and (3.26-3.36) °C under the SSP2-4.5 and the SSP5-8.5 scenarios respectively, where are the changes in 2100 ranged from (3.36-3.47)°C and (6.90-7.11)°C under the SSP2-4.5 and SSP5-8.5 scenario respectively.

For the maximum temperature changes, the results in 2060 indicated changes ranged from (2.36-2.47) °C to (3.41-3.57)°C under SSP2-4.5 and SSP5-8.5 respectively, while changes in 2100 ranged from (3.52-3.69)°C and (7.22-7.57)°C under SSP2-4.5 respectively SSP5-8.5.

For higher and lower temperature changes at catchment stations, where the highest changes in 2060 and 2100 were at S14 Station, with minimum temperature variability in 2060 reaching 2.32 °C and 3.36 °C under SSP2-4.5 and SSP5-8.5 scenarios respectively, while in 2100 the variability was 3.47 °C and 7.11 °C under SSP2-4.5 and SSP5-8.5 scenarios respectively. While changes in the station's maximum temperatures in 2060 were 2.47 °C and 3.56 °C under the SSP2-4.5 and SSP5-8.5 scenario respectively, the change in 2100 was 3.68 °C and 7.55 °C under the SSP2-4.5 and the SSP5-8.5 scenarios respectively. Figure 4 represents the changes in the minimum and maximum temperatures.

Figure 4

Changes in the minimum and maximum temperatures



3.1.3 Relative Humidity

The results indicated a general decrease in relative humidity during the two study periods and varying spatially within the Faria catchment, where the percentage of changes from the baseline value in 2060 as follows, (-1.40% to -0.96%) and (-2.02% to -1.39%) under the SSP2-4.5 and the SSP5-8.5 scenarios, respectively, while the results indicated that the percentage of changes in 2100 was (-2.09% to -1.44%) and (-4.28% to -2.95%) under the SSP2-4.5 and the SSP5-8.5 scenarios, respectively.

For changes in relative humidity at the catchment stations, where the highest changes were in the S14 station, where the percentage changes in in 2060 were (-1.40%) and (-2.02%) in the SSP2-4.5 and SSP5-8.5 scenarios respectively, while in 2100 the percentage of changes were (-2.09%) and (-4.28%) in the SSP2-4.5 and SSP5-8.5 scenarios respectively.

While the lowest changes in relative humidity averages were at Nablus station, the changes ranged from (-0.96% to -1.39%) in the SSP2-4.5 and SSP5-8.5 scenarios respectively, while the results indicated a change of (-1.44%) and (-2.95%) in the SSP2-4.5 and SSP5-8.5 scenarios respectively in 2100.

3.1.4 Wind Speed

The results showed the percentages of change in the wind speed in the catchment, where the results indicated an expected increase in wind speed in some areas, also decrease in others.

Changes in 2060 ranged from (-0.22% to 0.36%) and (-0.32% to 0.52%) under the SSP2-4.5 and the SSP5-8.5 scenarios respectively, while changes in 2100 ranged from (-0.33% to 0.54%) and (-0.68% to 1.09%) under the SSP2-4.5 and the SSP5-8.5 scenarios respectively.

The most decreasing stations for wind speed were S8 station, where the percentage changes in 2060 were (-0.22%) and (-0.32%) in the SSP2-4.5 and SSP5-8.5 scenarios respectively, while in 2100 the percentage of changes were (-0.33%) and (-0.68%) in the SSP2-4.5 and the SSP5-8.5 scenarios respectively.

While the results indicated that the most increased stations in wind speed were at Beit Dajan station, the changes ranged from (0.36% to 0.52%) in the SSP2-4.5 and the SSP5-8.5 scenarios respectively, while the results indicated a change of (0.54%) and (1.09%) in the SSP2-4.5 and the SSP5-8.5 scenarios respectively 2100.

3.1.5 Solar Radiation

There is an expected increase in solar radiation values in the Faria catchment in general, the results showed that the projected increase in 2060 ranges from (1.16% to 1.30%) and (1.68% to 1.88%) under SSP2-4.5 and SSP5-8.5 scenarios respectively, while the percentages in 2100 ranged from (1.76% to 1.94%) and (3.55% to 3.98%) under the SSP2-4.5 and the SSP5-8.5 scenarios respectively.

For changes at Faria catchment stations, the most increased solar radiation station was S8 station, where in 2060 the percentage of increase was (1.30%) and (1.88%), while in 2100 it was (1.94%) and (3.98%) under SSP2-4.5 and SSP5-8.5 scenarios, respectively.

3.2 Swat Analysis and Results

3.2.1 Evaluation of Runoff Modelling

The SUFI-2 has been used for the calibration process, where SWAT results are brought to SWAT-CUP, where this method is good because it can handle a large number of parameters as it can handle observed values for more than subbasin outlets at the same time, and several simulations can be implemented in each iteration so that we can reach the best values in calibration.

The sensitivity analysis on flow parameters is based on daily time steps of SWAT Model results with observed values at the subbasin outlet (9) known as Badan sub-catchment, where this work was done to identify the most influential parameters of flow in each iteration.

The calibration was started with 25 parameters, where filtration and several iterations were made in order to reach the most sensitive parameters of flow, thus finding the best calibration, as it was reduced to 15 parameters.

Selected parameters include the following ones: SCS runoff curve number (CN2), Baseflow alpha factor (ALPHA_BF), Moist bulk density (Sol_BD), Plant uptake compensation factor (EPCO), Soil evaporation compensation factor (ESCO), Available water capacity of the soil layer (SOL_AWC), Saturated hydraulic conductivity (SOL_K), Average slope steepness (HRU_slp), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) (mm), Groundwater delay (GW_Delay) (days), Deep aquifer percolation fraction (RCHRG_DP), threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN) (mm), Average slope of main channel (CH_S2), Manning's "n" value for overland flow (OV_N) and Average slope length (SLSUBBSN) (m). Table 8 represents the sensitivity analysis for selected parameters:

Table 8

Sensitivity analysis for SWAT-CUP parameters

Rank	Parameter Name	t-Stat	P-Value
15	R__OV_N.hru	-0.28	0.79
14	V__GWQMN.gw	0.30	0.78
13	R__SOL_AWC(..).sol	0.42	0.69
12	R__SOL_K(..).sol	0.80	0.47
11	V__EPCO.bsn	0.80	0.47
10	V__ESCO.bsn	-0.94	0.40
9	V__REVAPMN.gw	-0.95	0.39
8	R__ALPHA_BF.gw	-1.00	0.37
7	V__GW_DELAY.gw	-1.39	0.24
6	R__SLSUBBSN.hru	-1.84	0.14
5	R__SOL_BD(..).sol	2.21	0.09
4	R__HRU_SLP.hru	-2.56	0.06
3	R__CH_S2.rte	-3.97	0.02
2	R__RCHRG_DP.gw	4.64	0.01
1	V__CN2.mgt	-7.18	0.00

Where t-stat and P- value are tools for determining the importance of the Parmeter in the model and its influencing on the flow, where whenever the value of t-stat is large and the value of P-value is low, the Parmeter is of great effect and importance, therefore it must be paid attention when adjusting its value, here CN2 Parmeter is the most sensitive and most influential in the flow.

The (V__) also indicates that the process will be done on this Parmeter by replacing the original value during simulations in each iteration in the calibration process, while the (R__) indicates that the value selected when the calibration is performed will be calculated as relative of the original value. hru, gw, sol, bsn, rte and mgt refer to classifications of the parameters that represent a particular part of the ecosystem or hydrological system, which represent Hydrological Response Unit, Groundwater, Soil, Basin, Reach/Stream Routing and Land and crop management parameters respectively.

Parametrization was done by several iterations and worked with at least 50 simulations in each iteration in order to reach to the best values for R^2 and NSE and thus reach the best calibration of the model. Table 9 indicates the selected parameters and their respective values at the subbasin outlet No. 9.

Table 9

Fitted values for the parameters

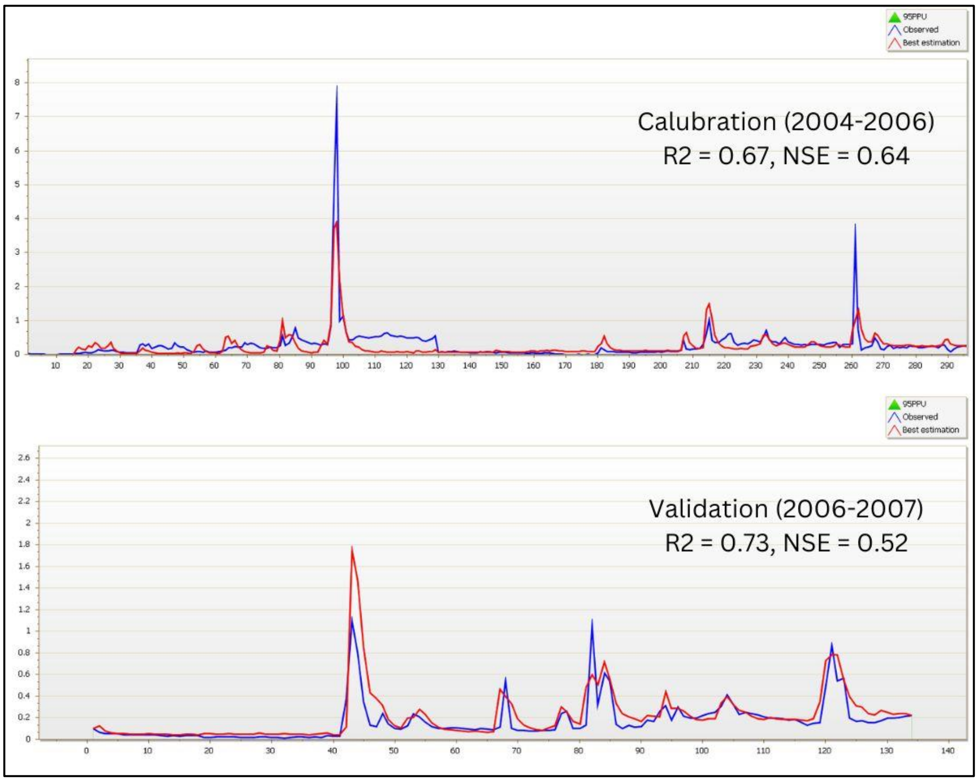
Parameter	Fitted Value	Absolute Range	
		min	max
V__CN2.mgt	56	35	98
R__SOL_BD ().sol	0.396	-0.1	1
R__ALPHA_BF.gw	0.951	0	1
R__HRU_SLP.hru	0.234	0	1
R__SOL_K(..).sol	-0.146	-0.2	0.1
V__EPCO.bsn	0.7025	0	1
V__ESCO.bsn	0.9382	0	1
R__SOL_AWC(..).sol	0.085	-0.1	0.1
V__GWQMN.gw	3182.5	0	4000
V__GW_DELAY.gw	204.796	0	450
R__RCHRG_DP.gw	0.0741	0	0.1
V__REVAPMN.gw	237.5	0	500
R__CH_S2.rte	4.453	-0.001	10
R__OV_N.hru	27.4	0.01	30
V__SLSUBBSN.hru	62.5	0	150

The values obtained at the calibration stage using observed data for the period (2004-2006), R^2 = 0.67 and NSE = 0.64, while the values for the validation phase using data for the period (2006-2007) were R^2 = 0.73 and NSE = 0.52.

It is according to these values that performance is good. Figure 5 represents the comparison between the observed and simulated data values for the calibration and the validation phases.

Figure 5

Comparison between observed and simulated values for calibration and validation stage



3.1.1 Water Balance

Water balance in the Faria catchment is affected spatially and temporally with climate changes, which significantly affects precipitation amounts and in addition to different climatic elements, Changes in water balance elements that include surface runoff (SRO), evapotranspiration (ET), water yield (WY) and the groundwater recharge at the sub-basin level and also during the months of one year in future periods 2060 and 2100 under the SSP2-4.5 and SSP5-8.5 scenario. The impact of climate change in the basin has been assessed according to the results of baseline, where spatial distribution of land uses, plant cover and soil properties are expected to remain constant. For representing the hydrological cycle components for the catchment by SWAT (See Figure B.10).

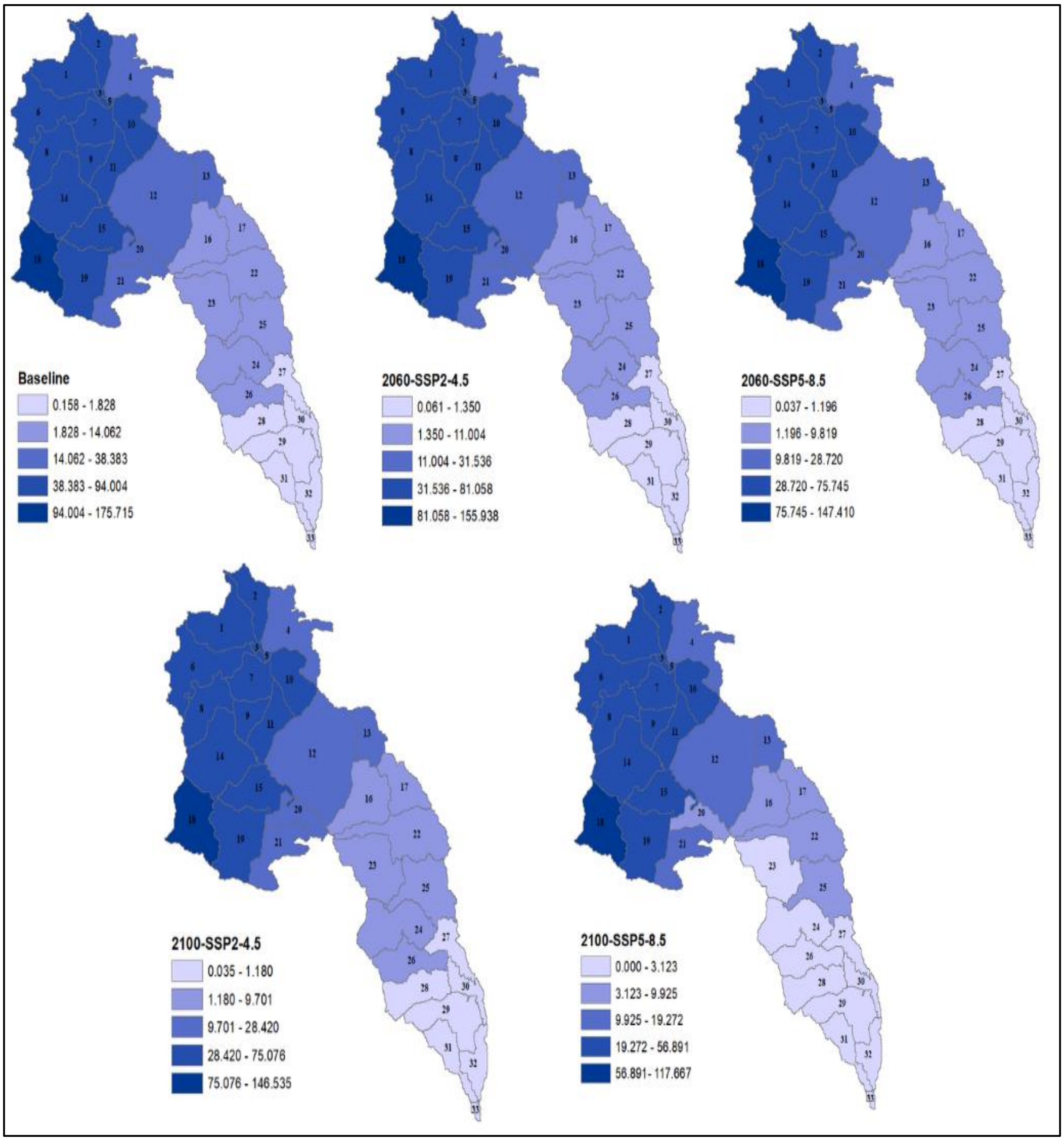
Results showed that the annual amounts of SRO in the catchment are higher in the upper parts, while it is significantly lower in the lower parts, as this is due to the rise in annual precipitation in the upper parts and conversely in the lower parts.

The results indicated a significant decrease in the SRO under the two emission scenarios, The highest amount of SRO is about 175.72mm in sub-basin 18, where it decreased by

(11.25%) and (16.11%) for the 2060, under the SSP2-4.5 and the SSP5-8.5 scenarios respectively, while decreasing by (16.61%) and (33.03%) for the 2100 period under the SSP2-4.5 and the SSP5-8.5 scenarios respectively. Figure 6 shows the spatial distribution of SRO in the Faria catchment under the scenarios of climate change for the two time periods.

Figure 6

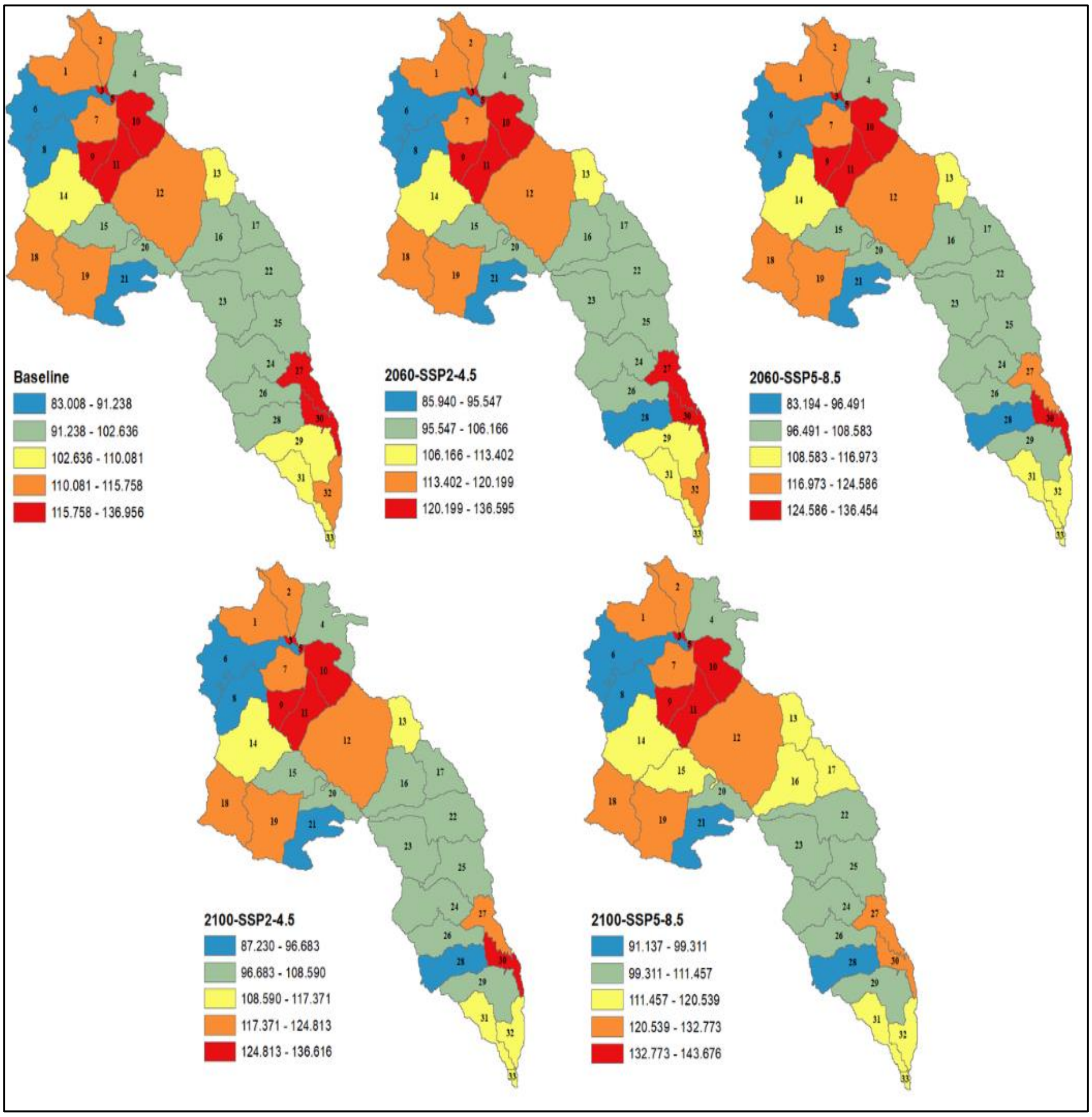
Spatial distribution of the surface runoff in the Faria catchment under the SSP2-4.5 and the SSP5-8.5 for 2060 and 2100



Evapotranspiration outcomes showed an increase over various sub-basins, where the lower value based on baseline results in sub-basin 6 was about 83.008 mm, where the value had changed by (3.53%), (0.225%), (5.08%) and (9.79%) under the scenarios of SSP2-4.5 and SSP5-8.5 for 2060 and 2100, respectively, indicating a rise in ET values overall. While the highest values reached about 143.68 mm in sub-basin 3 in a SSP5-8.5 scenario in the 2100 period, where the increase was (2.3%) over the baseline .Figure 7 refers to the spatial distribution of ET values in the basin under the SSP2-4.5 and SSP5-8.5 scenarios for the two periods.

Figure 7

Spatial distribution of the evapotranspiration in the Faria catchment under the SSP2-4.5 and the SSP5-8.5 for 2060 and 2100



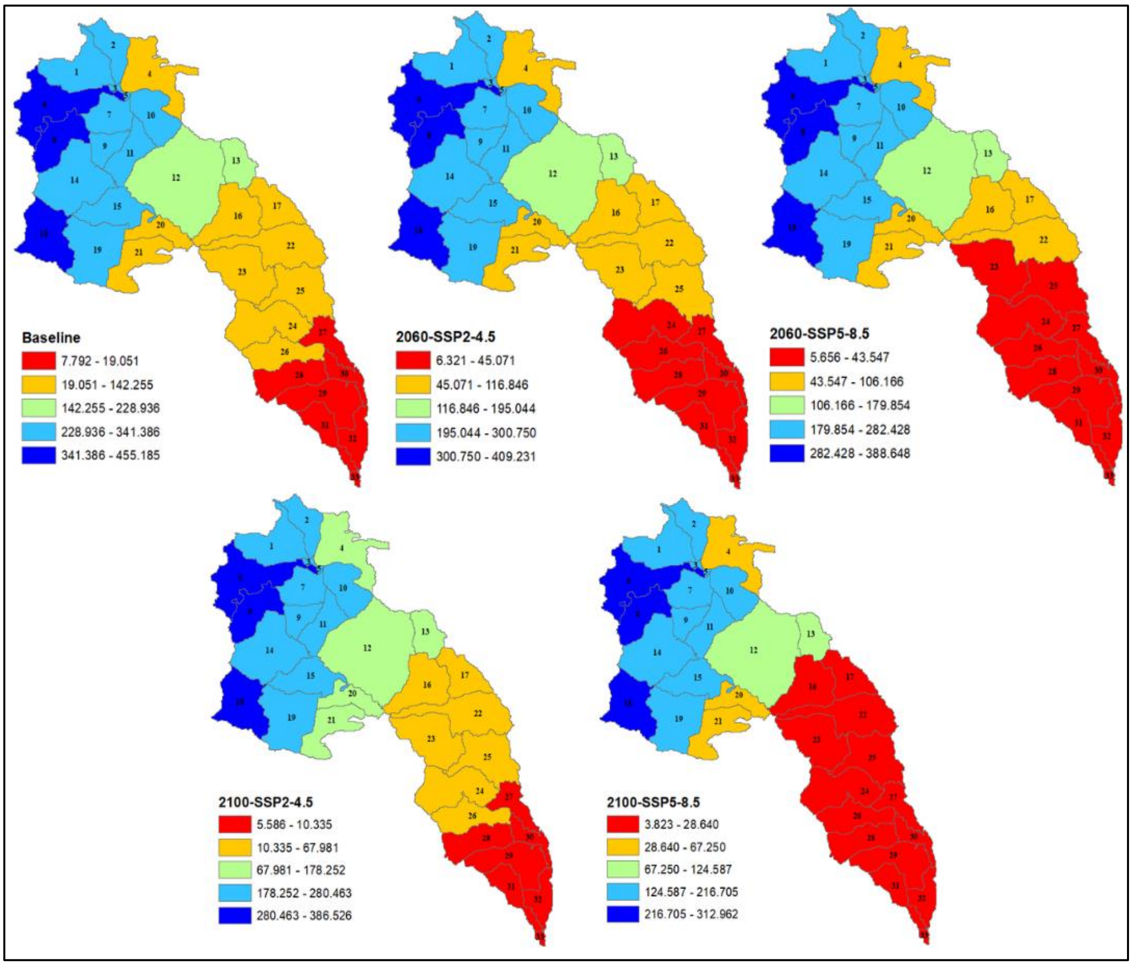
The results indicated that the water yield values are influenced by climate change, with the water yield reflecting the amount of water leaving the HRU's and entering the mainstream during the time step, as lower precipitation rates and higher minimum and maximum temperatures as well as changes in the relative humidity, solar radiation and wind speed have demonstrated their impact on WY.

WY values are higher in the above parts in the catchment, due to high precipitation rates, with the highest values were about 445.19 mm in sub-basin 18, while the value under the two emissions scenarios changed by (-8.07%), (-12.77%), (-13.17%) and (-29.7%) for 2060 and 2100, respectively.

Figure 8 shows the spatial distribution of WY and changes in the sub-basin level of the branch basin under its SSP2-4.5 scenario, SSP5-8.5 for 2060 and 2100 periods.

Figure 8

Spatial distribution of the water yield in the Faria catchment under the SSP2-4.5 and the SSP5-8.5 for 2060 and 2100

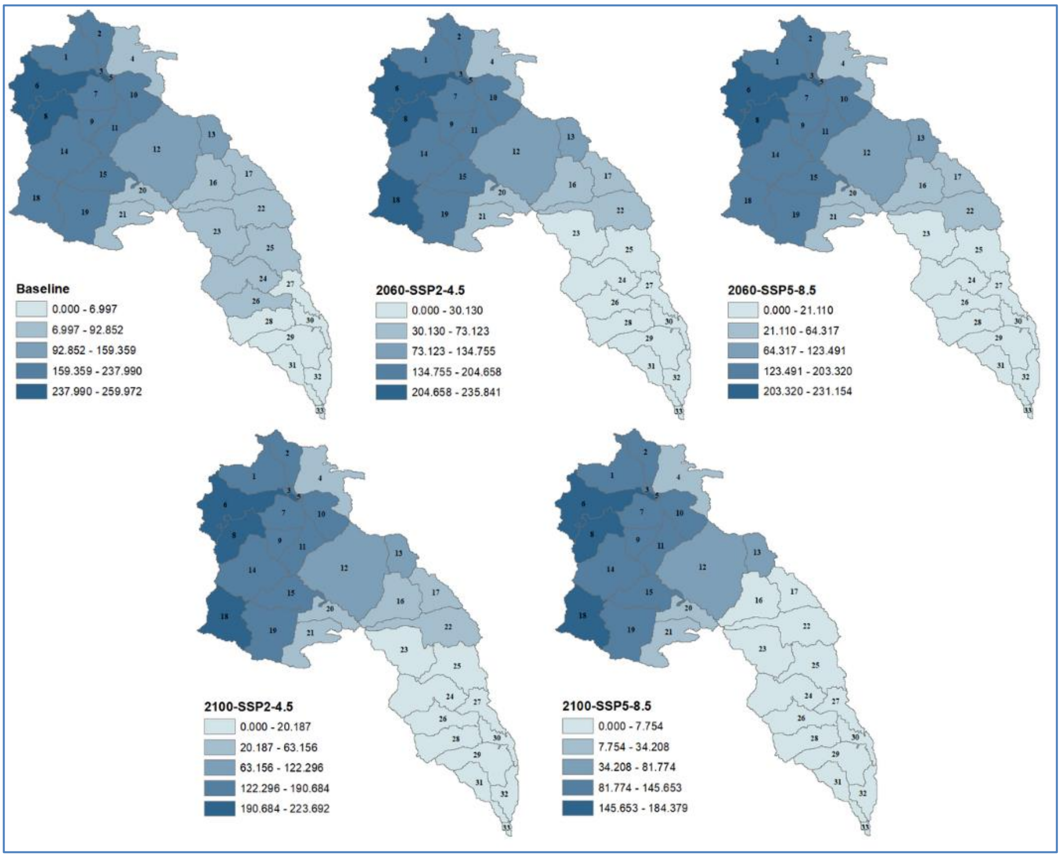


The results indicated a decrease in the groundwater recharge values, due to low precipitation rates and high evapotranspiration rates, where the highest value in the catchment was in sub-basin 8 where the value is 259.972 mm, where it changed by (-9.28%), (-11.08%) for the 2060 period under SSP2-4.5 and SSP5-8.5 scenarios respectively, while it changed by (-13.95%) and (-29.07%) for the 2100 period under the SSP2-4.5 and the SSP5-8.5 scenarios respectively.

Figure 9 shows the spatial distribution of GW recharge and changes in the sub-basin level of the branch basin under its SSP2-4.5 scenario, SSP5-8.5 for 2060 and 2100 periods.

Figure 9

Spatial distribution of the groundwater recharge in the Faria catchment under SSP2-4.5 and SSP5-8.5 for 2060 and 2100



The results of climate change have also had an impact on the elements of the water balance in time during one year's months.

Where the rise in temperature in the catchment has directly reflected on potential evapotranspiration, which expresses the maximum amount of water that can evaporate from the surface of the Earth or through the plant into the atmosphere in a situation where there is unlimited availability of water, where this element has increased significantly relative to the values of baseline, The average annual was about 1083.56 mm, while in the 2060 period increased to 1190.71 mm and 1231.46 mm under SSP2-4.5 and SSP5-8.5 scenarios respectively, also it has become 1250.01 mm and 1442.18 mm in the 2100 period under both scenarios respectively.

The water balance in the catchment indicates that ET will consume a greater percentage of precipitation rather than the contribution of this percentage to the SRO, as the average annual ET according to baseline was about 105.88 mm while it increased by (3.15%) under the SSP2.4.5 scenario in the 2060 to (9.64%) under the SSP5-8.5 scenario in the 2100.

The overall rate of runoff also decreased at a rate ranging from (-15.43%) under the SSP2-4.5 scenario in the 2060 to (-43.31%) under the SSP5-8.5 scenario in the 2100, while underground feeding decreased by (-8.81%) under the SSP2-4.5 scenario in the 2060 to (–27.43%) under the SSP5-8.5 scenario in the 2100.

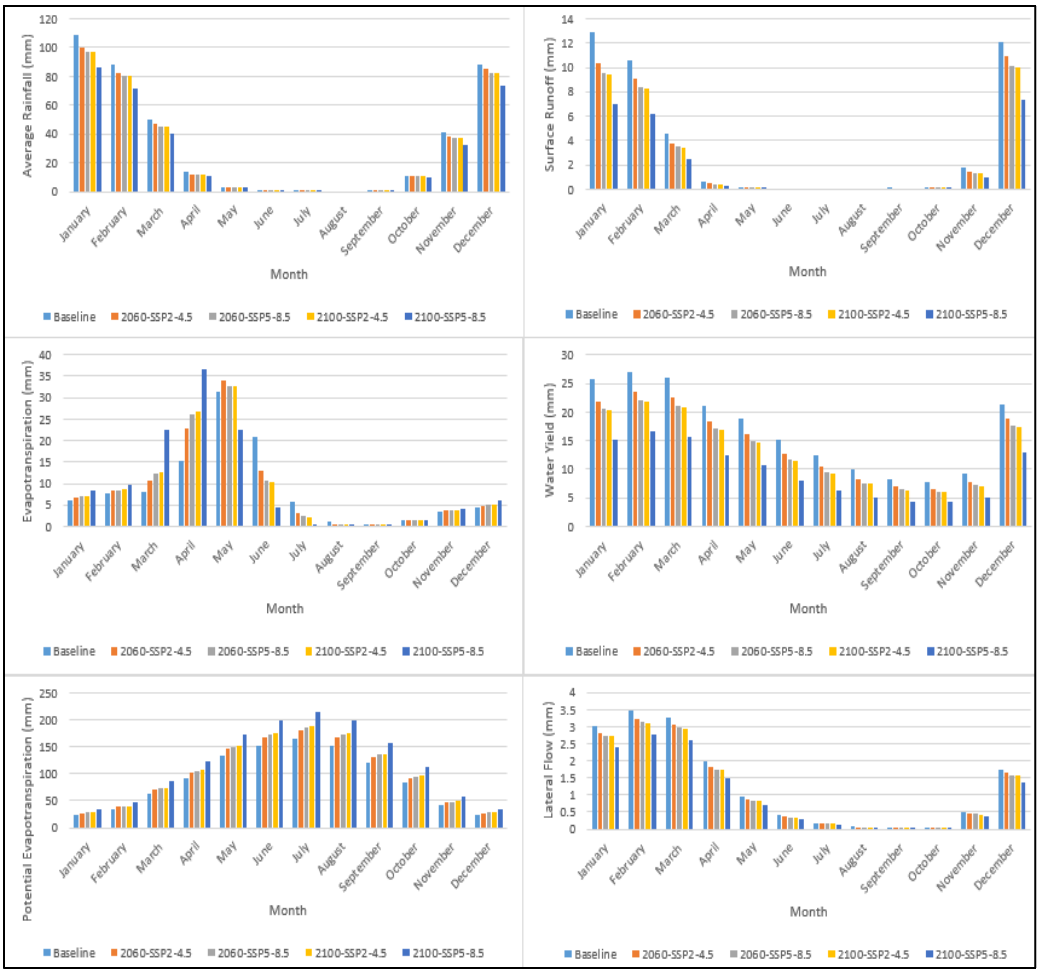
The water balance in the Faria catchment also indicates a significant decrease in the overall rate of WY, where the modal results indicate that the average annual for WY in baseline is about 202.85 mm, where the value will change by (-14.31%) under SSP2-4.5 scenario in the 2060 period to about (-42.50%) under SSP5-8.5 scenario in the 2100 period of the average under these different climatic conditions.

As a result of lower precipitation rates and increased demand for evaporation in the atmosphere as a result of higher temperatures, this will result in a decrease in WY rates.

Figure 10 shows the rate of hydrological elements in the Faria catchment per month for periods 2060 and 2100 under the SSP2-4.5 and the SSP5-8.5 scenarios.

Figure 10

Monthly averages of the hydrological elements in the Faria catchment



Chapter Four

Conclusions and Recommendations

4.1 Conclusions

The Faria catchment has a problem with water scarcity because it is classified as semi-arid area. This study focuses on a comprehensive analysis of the impact of climate change on the elements of water balance in the catchment.

The study included a future forecast of the five core elements (precipitation, minimum and maximum temperatures, relative humidity, solar radiation as well as wind speed) for 2060 and 2100 periods.

The SimClim AR6 software was used to apply future forecasting, using 23 GCM's under the influence of the medium emission scenario SSP2-4.5 and the high emission scenario SSP5-8.5 to see changes to the five elements.

The SWAT model was used to modeling the hydrological cycle of the Faria catchment and analyze the modal results. The model was calibrated using SWAT-CUP, where calibrated with measured data and verified. Hydrological modeling was done for both scenarios to determine the change in the hydrological elements.

The results of the study can be summarized as follows:

1. Results showed a clear increase in the minimum and maximum temperatures for both scenarios at the end of the century, with minimum temperatures increased by (3.36-3.47) ° C and (6.90-7.11)° C) under the influence of SSP2-4.5 and SSP5-8.5 respectively, while maximum temperatures increased by a rate between (3.52-3.69)° C and (7.22-7.57)° C under the influence of SSP2-4.5 and SSP5-8.5 respectively.
2. It is clear that changes in rainfall rates have decreased at all stations within the catchment, requiring planning for the future to make the most of them.

3. There is a decrease in relative humidity rates, so that with high temperatures and low precipitation rates, which reduces the air's ability to maintain good levels of relative humidity in the atmosphere.
4. The study showed a clear variation in the effect of climate change scenarios on the wind speed, with some stations expected to increase, while others were expected to decrease wind speed, due to several factors, notably other climatic factors, geographical factors and land use in the region.
5. The study predicted an increase in solar radiation changes, where this increase can be explained by global climate change, a decrease in clouds formation as a result of low water vapor, relative humidity and high temperatures.
6. The results of the SWAT model showed a clear decrease in runoff, as this was due to lower annual precipitation rates and increased temperatures, which increases the proportion of evapotranspiration in the total precipitation.

   The model results showed an increase in the evapotranspiration rates, where the higher temperatures and the increase in solar radiation enhances these rates increasing.
7. The lower water yield in the Faria catchment, which is due to lower precipitation rates and increased evapotranspiration, therefore requires good planning to improve the management of water resources in the catchment, and to take sustainable plans and strategies for dealing with this decrease in the WY as the phenomenon of climate change increases.

   The study found a rise in potential evapotranspiration rates throughout the catchment, due to high temperature rates and thus an increase in the energy available for evaporation of water from the region, increased solar radiation, low relative humidity as well as precipitation fluctuations, as these factors combined lead to an increase in PET rates.
8. The results indicated a decrease in groundwater recharge due to low precipitation amounts as well as high temperatures which are leading to an increase in the evapotranspiration rates, so the amount of infiltrated water amounts decrease.

The study summarizes the increasing of the apparent impact of climate change on climatic and hydrological elements over time, which threatens the water sustainability of the Faria catchment, so there is a need to implement sustainable programs to protect water and to adapt to this phenomenon.

Although this study represents the hydrological cycle of the Faria Catchment, there are many limitations to this study. First, the rainfall data used suffered from gaps and irregularities in monitoring, thereby affecting the accuracy and verification of the model, as well as data from global databases, although they provided comprehensive coverage, but may not accurately reflect changes in addition to the limited spatial accuracy of these sources on the representation of local climate phenomena.

As for soil and land use data, data from FAO and Geomolg may contain time variations compared to the study periods. In addition, the accuracy of the Digital Elevation Model (DEM) may affect precise determination of drainage basins and flow directions.

Finally, the accuracy of the results depends heavily on the quality of the data entered, and there may be local processes that are not fully represented, and these determinants reflect the need for improved local data to develop future studies.

4.2 Recommendations

According to the study findings, the following recommendations can be provided for future research that is relevant:

1. Study other climate scenarios and apply them to other catchments in Palestine to study their impact on water budget elements, to understand future projections on these elements.
2. Collect detailed, long-term data at finer temporal intervals for precipitation and surface runoff in the field, in order to better calibrate models and apply them to all watersheds in Palestine, so these approaches will enhance the accuracy of hydrological models and improve surface runoff estimates.
3. Apply the outputs of this study more comprehensively, to include other environmental and agricultural aspects.

List of Abbreviations

Abbreviation	Meaning
SWAT	Soil and Water Assessment Tool
SWAT-CUP	Soil and Water Assessment Tool Calibration and Uncertainty Program
GIS	Geographic Information System
SimClim	Simulated Climate
IPCC	Intergovernmental Panel on Climate Change
GCM	General Circulation Model
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathway
AR6	Sixth Assessment Report
R^2	Coefficient of Determination
NSE	Nash-Sutcliffe Efficiency
AMSL	Above Mean Sea Level
BMSL	Below Mean Sea Level
DEM	Digital Elevation Model
HRU	Hydrologic Response Unit
ET	Evapotranspiration
PET	Potential Evapotranspiration
WY	Water Yield
GW	Groundwater
SRO	Surface Runoff
RMSE	Root Mean Square Error
RSE	Relative Squared Error
RSD	Relative Standard Deviation

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Appendices

Appendix A

Tables

Table A. 1

The changes in the annual rainfall of the Faria catchment stations for 2060 and 2100

Station	Average annual precipitation (mm)	Change in 2060 (%)		Change in 2100 (%)	
		SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Tubas	415.2	-6.33	-9.15	-9.44	-19.38
Tammun	322.3	-6.39	-9.24	-9.53	-19.56
Al-Faria	198.6	-6.62	-9.54	-9.84	-20.2
Beit Dajan	379.1	-6.22	-8.99	-9.28	-19.04
Nablus	642.6	-5.83	-8.43	-8.69	-17.85
Talluza	630.5	-5.96	-8.62	-8.89	-18.25
S7	533.21	-6.04	-8.74	-9.01	-18.49
S8	556.92	-6.14	-8.87	-9.15	-18.77
S9	553.26	-6.28	-9.07	-9.36	-19.20
S10	437.03	-6.30	-9.11	-9.40	-19.28
S11	306.32	-6.41	-9.27	-9.56	-19.61
S12	277.61	-6.57	-9.50	-9.80	-20.11
S13	190.14	-6.72	-9.71	-10.02	-20.55
S14	148.76	-6.81	-9.84	-10.15	-20.82
S15	265.70	-6.66	-9.62	-9.92	-20.36

Table A. 2

Changes in the minimum and maximum temperatures for 2060 and 2100

Station	Minimum Temperatures				Maximum Temperatures			
	Change in 2060 (°C)		Change in 2100 (°C)		Change in 2060 (°C)		Change in 2100 (°C)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Tubas	2.27	3.28	3.38	6.94	2.38	3.44	3.55	7.29
Tammun	2.27	3.29	3.39	6.96	2.39	3.45	3.56	7.31
Al-Faria	2.3	3.33	3.44	7.05	2.44	3.53	3.64	7.47
Beit Dajan	2.28	3.29	3.4	6.98	2.4	3.47	3.58	7.34
Nablus	2.26	3.27	3.37	6.92	2.37	3.43	3.53	7.25
Talluza	2.26	3.27	3.37	6.92	2.37	3.43	3.53	7.25
S7	2.27	3.28	3.39	6.95	2.38	3.44	3.54	7.28
S8	2.26	3.27	3.38	6.93	2.37	3.43	3.53	7.25
S9	2.28	3.29	3.39	6.96	2.39	3.45	3.56	7.29
S10	2.28	3.30	3.40	6.98	2.40	3.47	3.58	7.34
S11	2.30	3.32	3.42	7.02	2.43	3.51	3.62	7.42
S12	2.30	3.32	3.43	7.03	2.44	3.52	3.63	7.45
S13	2.32	3.35	3.45	7.08	2.46	3.55	3.66	7.52
S14	2.32	3.36	3.47	7.11	2.47	3.56	3.68	7.55
S15	2.30	3.33	3.43	7.04	2.44	3.52	3.63	7.45

Table A. 3

Changes in the average relative humidity of the Faria catchment stations for 2060 and 2100

Station	Change in 2060 (%)		Change in 2100 (%)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Tubas	-1.09	-1.58	-1.63	-3.35
Tammun	-1.13	-1.63	-1.68	-3.46
Al-Faria	-1.33	-1.9	-1.98	-4.06
Beit Dajan	-1.15	-1.66	-1.7	-3.52
Nablus	-0.96	-1.39	-1.44	-2.95
Talluza	-0.98	-1.41	-1.45	-2.99
S7	-1.06	-1.54	-1.58	-3.25
S8	-1.03	-1.49	-1.53	-3.15
S9	-1.10	-1.60	-1.65	-3.37
S10	-1.20	-1.73	-1.79	-3.37
S11	-1.27	-1.83	-1.89	-3.88
S12	-1.29	-1.86	-1.92	-3.94
S13	-1.36	-1.96	-2.02	-4.14
S14	-1.40	-2.02	-2.09	-4.28
S15	-1.27	-1.84	-1.90	-3.89

Table A. 4

Changes in the wind speed of the Faria catchment stations for 2060 and 2100

Station	Change in 2060 (%)		Change in 2100 (%)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Tubas	0.04	0.06	0.06	0.18
Tammun	0.003	0.005	0.005	0.01
Al-Faria	-0.15	-0.22	-0.22	-0.46
Beit Dajan	0.36	0.52	0.54	1.09
Nablus	0.03	0.05	0.05	0.1
Talluza	0.25	0.36	0.37	0.76
S7	0.27	0.39	0.41	0.84
S8	-0.22	-0.32	-0.33	-0.68
S9	0.01	0.02	0.02	0.03
S10	-0.08	-0.11	-0.12	-0.24
S11	-0.14	-0.20	-0.21	-0.42
S12	0.03	0.05	0.05	0.10
S13	-0.02	-0.03	-0.03	-0.06
S14	0.18	0.26	0.27	0.54
S15	0.08	0.11	0.11	0.23

Table A. 5:

Changes in the solar radiation of the Faria catchment stations for 2060 and 2100

Station	Change in 2060 (%)		Change in 2100 (%)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Tubas	1.29	1.86	1.92	3.94
Tammun	1.27	1.84	1.89	3.89
Al-Faria	1.22	1.76	1.82	3.72
Beit Dajan	1.25	1.8	1.86	3.82
Nablus	1.26	1.82	1.87	3.84
Talluza	1.29	1.87	1.93	3.95
S7	1.26	1.82	1.87	3.84
S8	1.30	1.88	1.94	3.98
S9	1.28	1.84	1.90	3.90
S10	1.26	1.82	1.88	3.85
S11	1.24	1.80	1.85	3.80
S12	1.22	1.76	1.81	3.72
S13	1.19	1.72	1.77	3.64
S14	1.16	1.68	1.76	3.55
S15	1.21	1.75	1.80	3.70

Appendix B

Figures

Figure B. 1

3D Map of the Faria Catchment

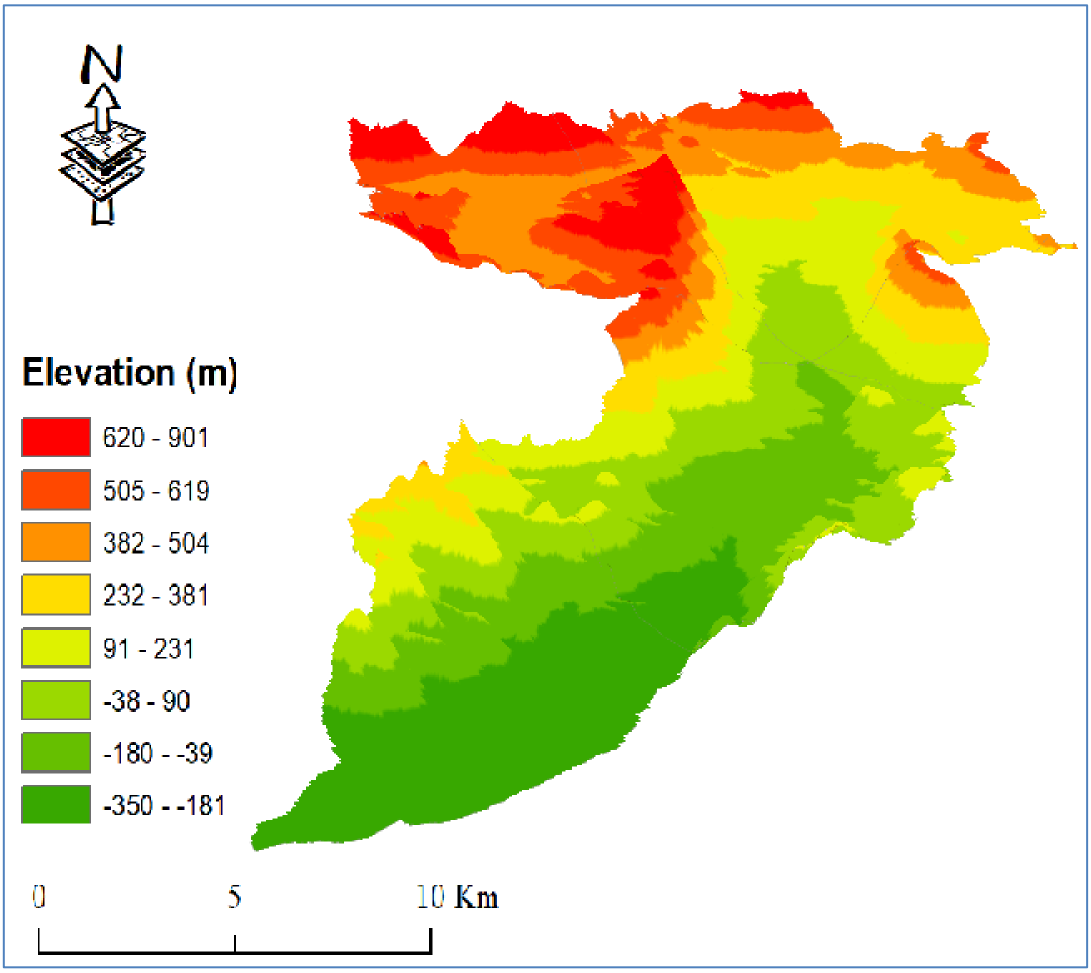


Figure B. 2

Global forecast database by 2100 for SSP2-4.5 and SSP5-8.5 scenarios (Source: ClimSystems Ltd)

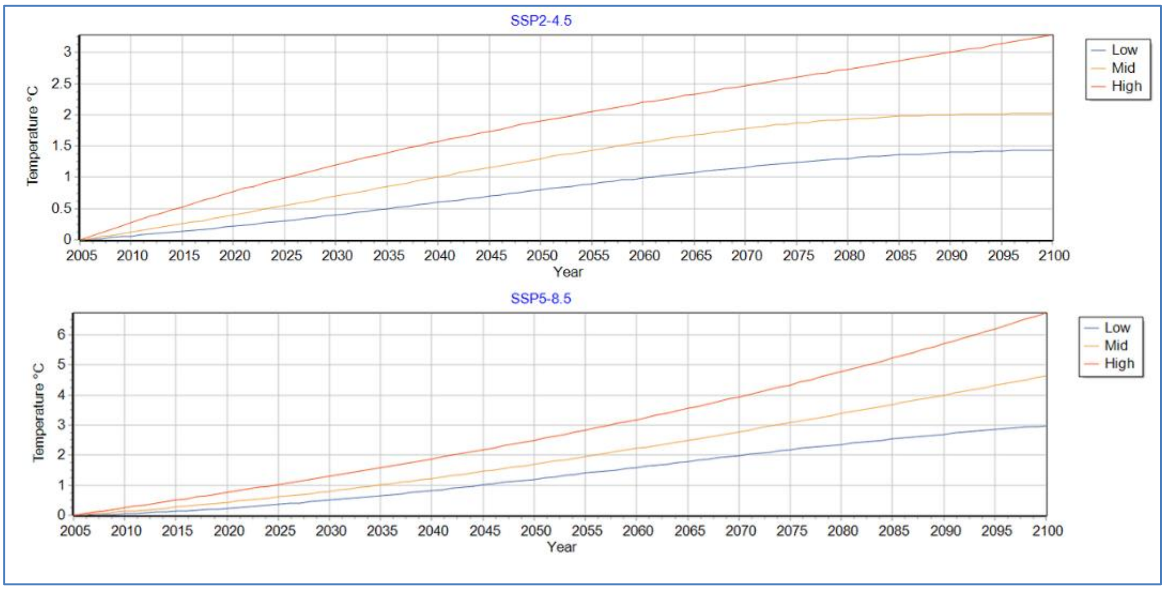


Figure B. 3

Soil types in the Faria catchment

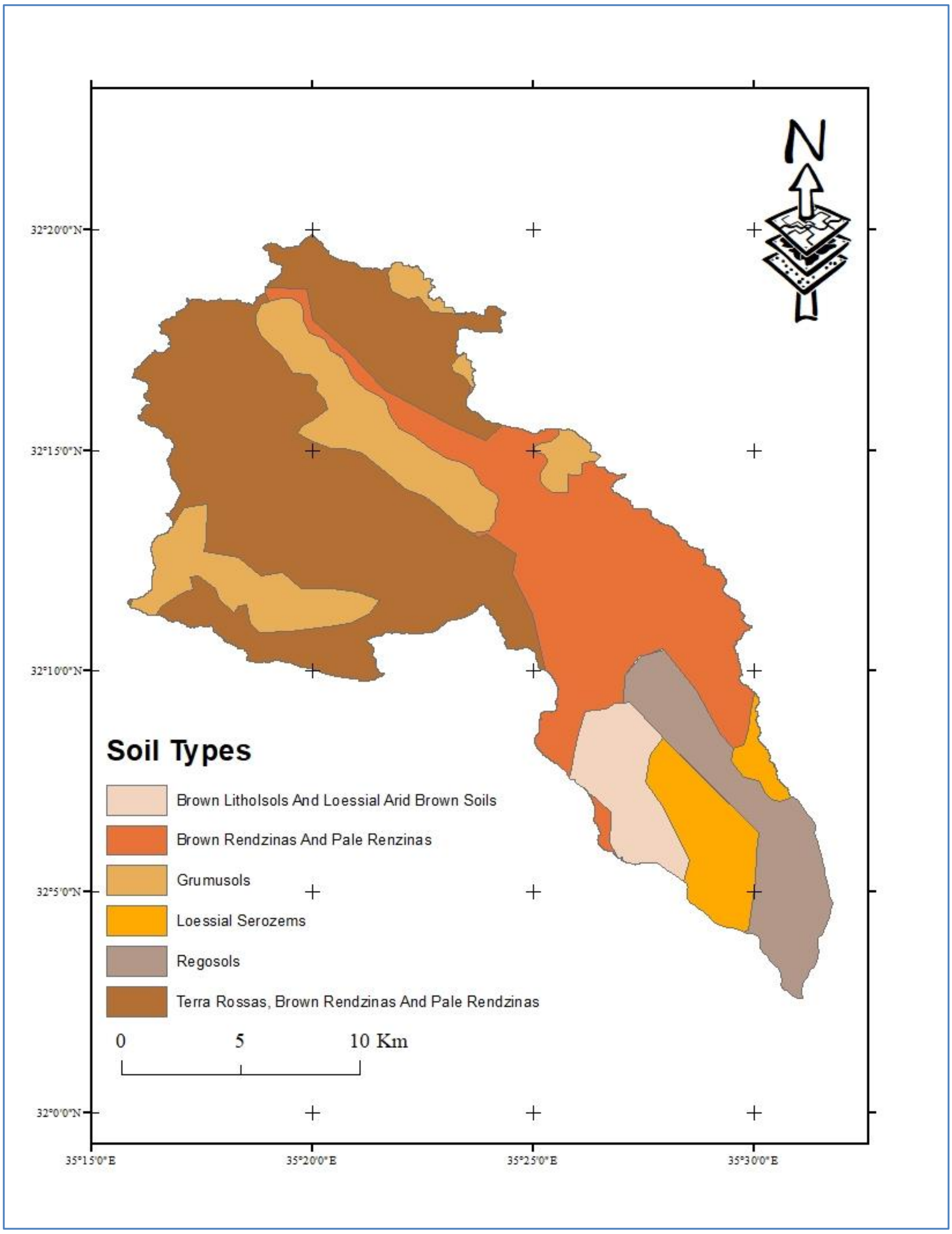


Figure B. 4

Land use classifications in the Faria catchment

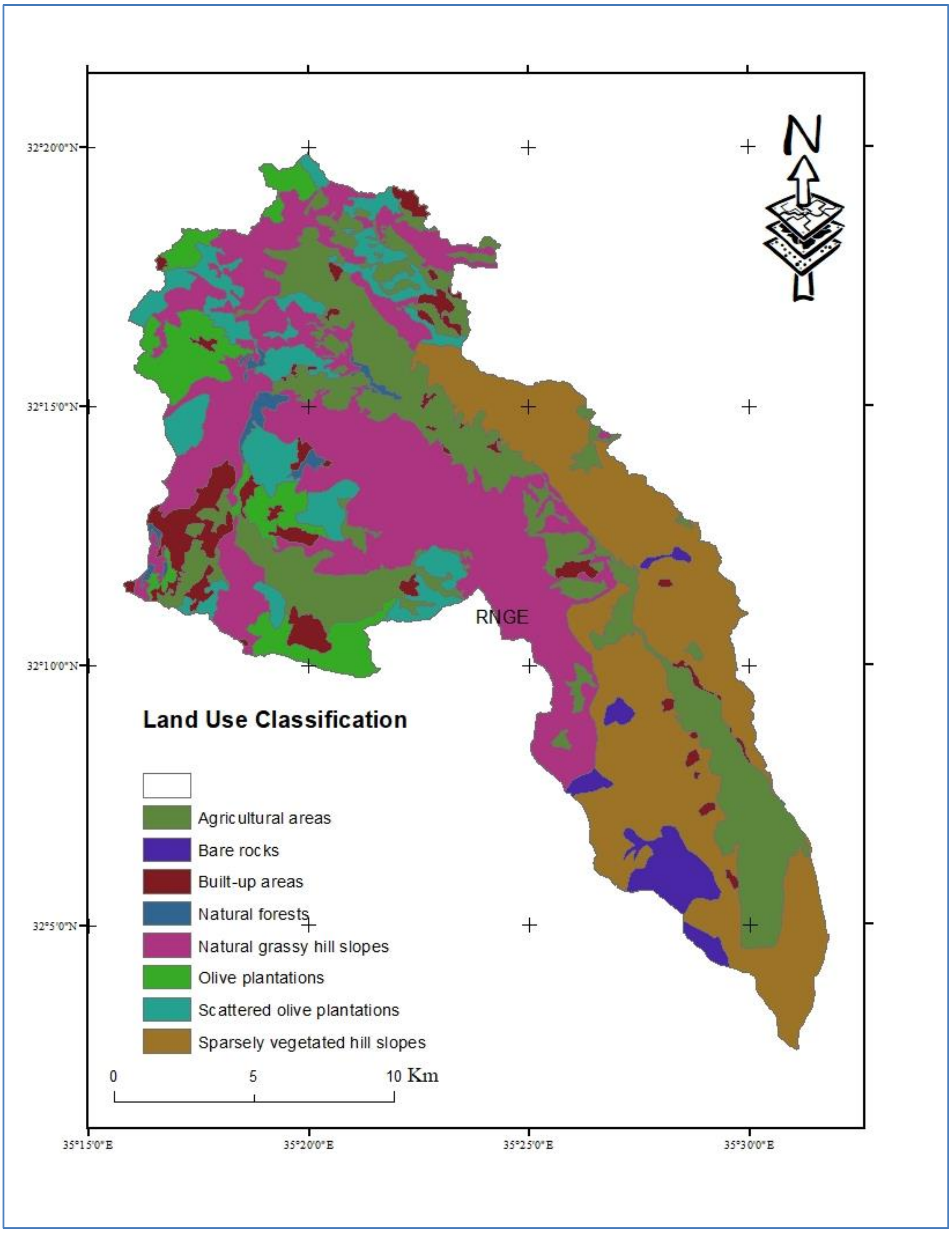


Figure B. 5

Surface runoff at the badan sub-catchment outlet (2004-2005)

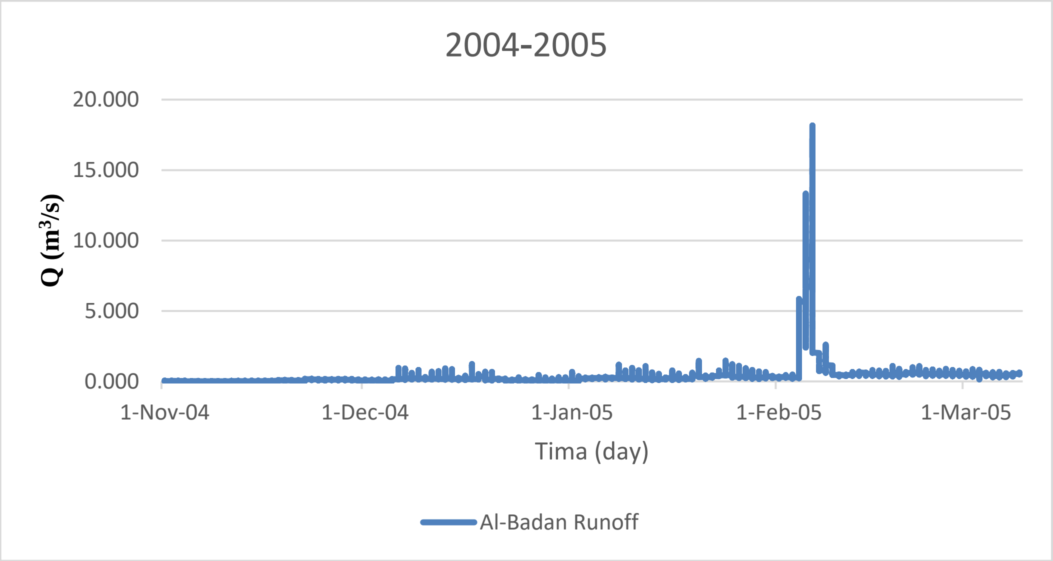


Figure B. 6

Surface runoff at the badan sub-catchment outlet (2005-2006)

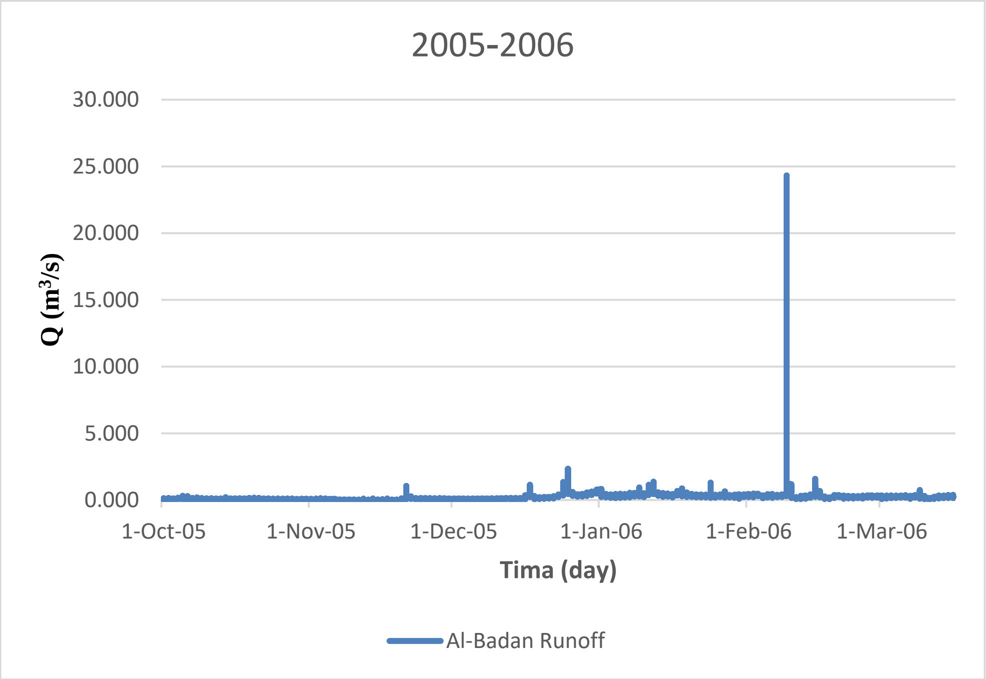


Figure B. 7

Surface runoff at the badan sub-catchment outlet (2006-2007)

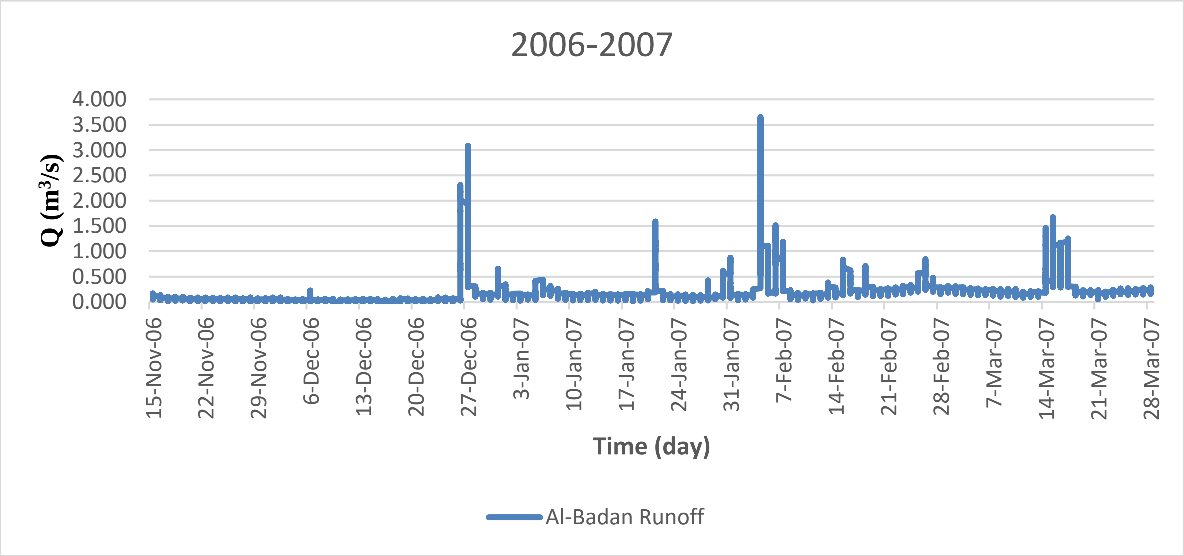


Figure B. 8

Sub-basins, outlets, reaches and the streams of the Faria catchment

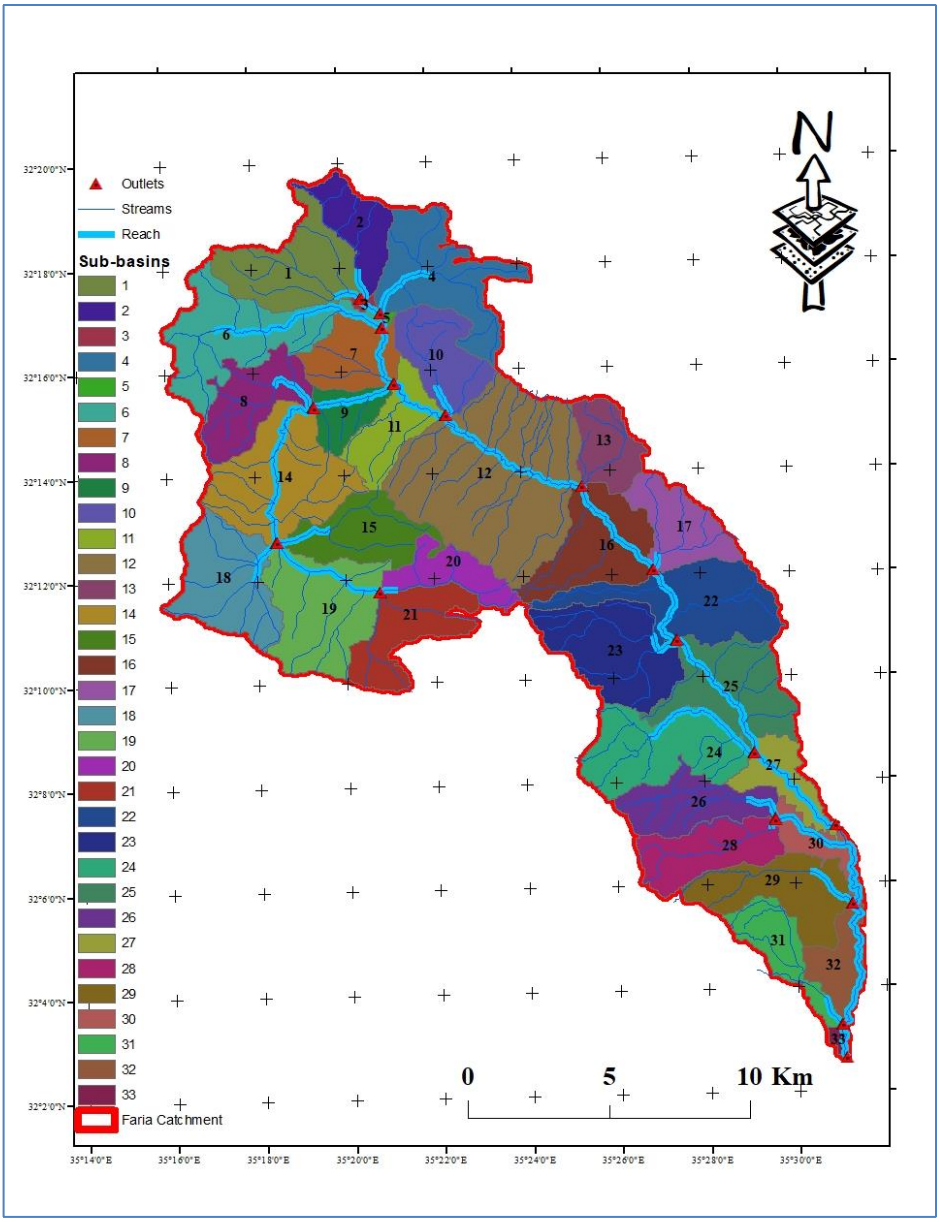


Figure B. 9

Spatially precipitation changes in the Faria catchment

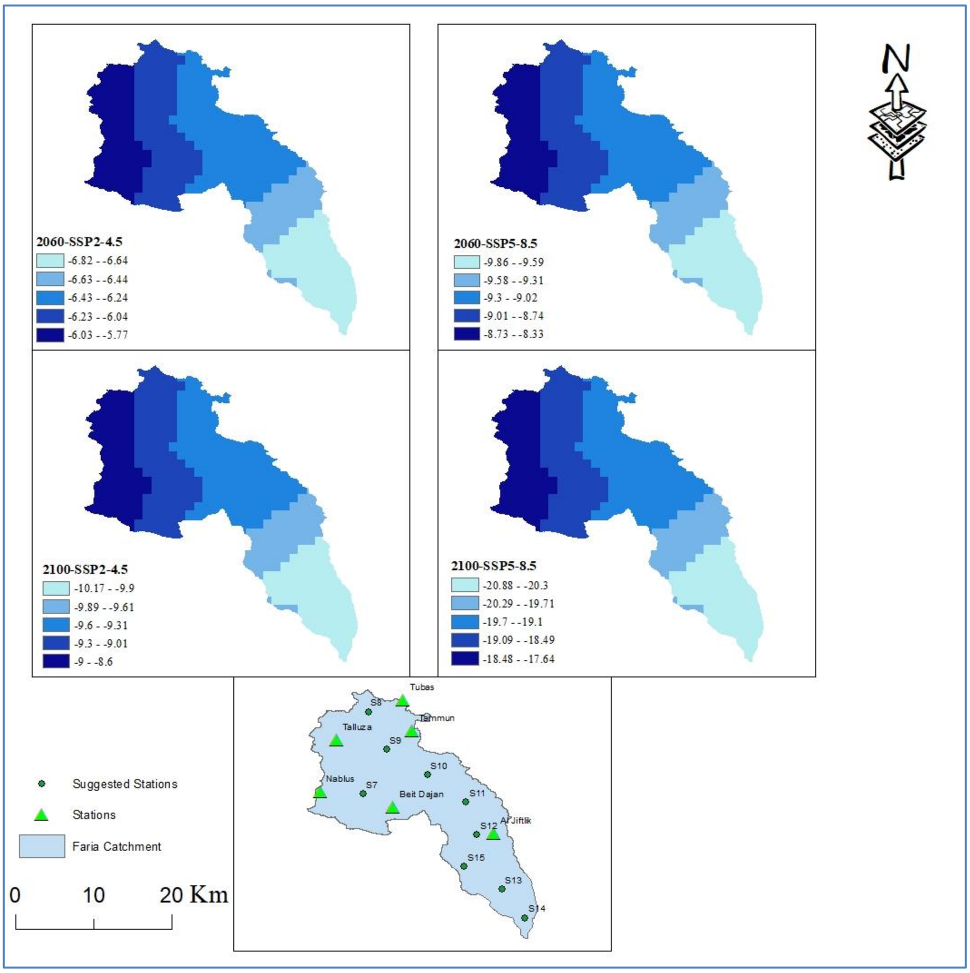
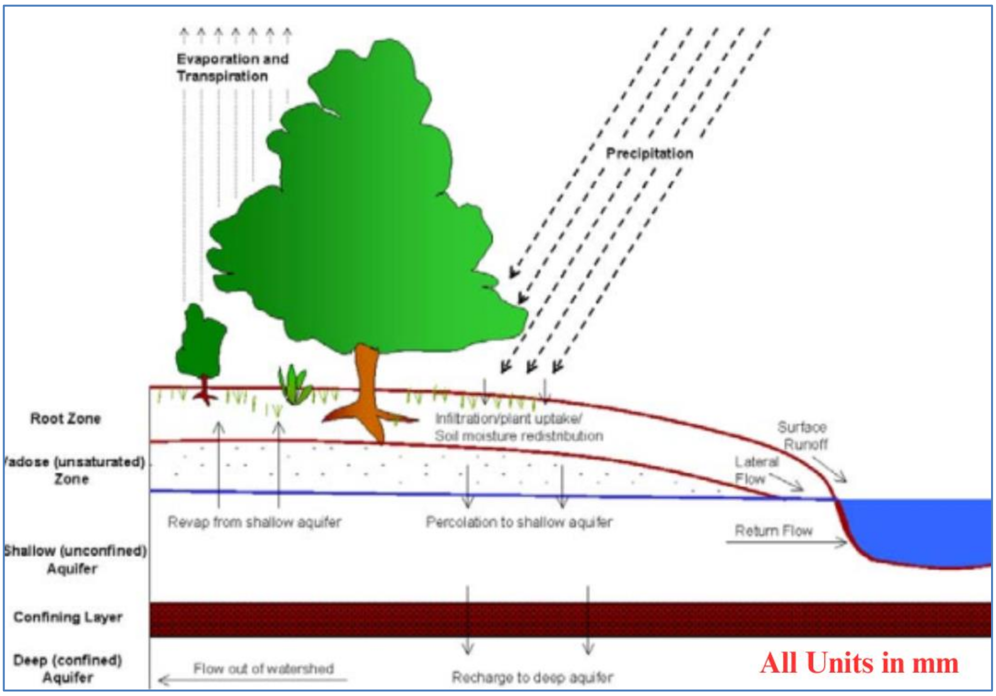


Figure B. 10

Hydrologic cycle components in SWAT



جــامعـــــة النجاح الوطنية

كليـــة الدراســـــات العليـــا

آثار تغير المناخ على الموازنة المائية في حوض الفارعة، فلسطين

إعداد

قيس دراغمه

إشراف

د. عبد الحليم خضر

قدمت هذه الرسالة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

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الملخص

إن دراسة تأثير تغير المناخ على عناصر الدورة الهيدرولوجية في حوض الفارعة أمر بالغ الأهمية، كون المنطقة تصنف على أنها شبه قاحلة، وأن العديد من سكان المنطقة يعتمدون على الزراعة، بالتالي فإن هنالك حاجة لفهم مستقبل المياه في المنطقة؛ بسبب النمو السكاني السريع وتوسع الأنشطة البشرية.

تتضمن الدراسة تحليل التغيرات المستقبلية للعناصر المناخية ودراسة تأثيرها على الدورة الهيدرولوجية. تستخدم الدراسة برامج لدراسة تغير المناخ (SimClim AR6) والنمذجة الهيدرولوجية لحوض الفارعة (نموذج SWAT) لفهم تأثيرات هذه الظاهرة

تم استخدام البيانات المناخية اليومية للفترة (1990−2021) لبناء النموذج الهيدرولوجي، وللتأكد من دقة النتائج استخدم برنامج SWAT-CUP بمعاملات الأداء الإحصائية مثل معامل التحديد (R^2) و Nash Sutcliff Efficiency (NSE)، مما يعزز موثوقية النمذجة.

تم تحليل التغيرات في العناصر الخمسة (هطول الأمطار، درجات الحرارة الدنيا والقصوى، الرطوبة النسبية، الإشعاع الشمسي، وسرعة الرياح) باستخدام 23 نموذج عالمي GCM's تحت السيناريو المتوسط SSP2-4.5 والسيناريو العاليSSP5-8.5 على مدى فترات مستقبلية (2060 و 2100).

أظهرت النتائج انخفاضا في معدلات الهطول والرطوبة النسبية, مما أدى الى انخفاض في تغذية المياه الجوفية بنسبة (−8.81%) في سيناريو SSP2-4.5 في 2060 و (−27.43%) في سيناريو SSP5-8.5 في 2100, وانخفض الجريان السطحي بنسبة ما بين (−15.43%) في سيناريو SSP2-4.5 في 2060 الى −43.31%) في سيناريو SSP5-8.5. كما أظهرت النتائج ارتفاعا في درجات الحرارة مما أدى الى

زيادة في معدلات التبخر النتحي بنسبة(3.14%) في سيناريو SSP2-4.5 في 2060 و(9.64%) في سيناريو SSP5-8.5 في 2100. بالإضافة الى ذلك، فقد أظهرت النتائج زيادة في الإشعاع الشمسي واختلافا في سرعة الرياح.

أظهرت النتائج انخفاضا في العائد المائي، حيث انخفض بنسبة (−14.31%) في سيناريو SSP2-4.5 في 2060 و(−42.5%) في سيناريو SSP5-8.5 في 2100، مما يهدد بشكل كبير الموارد المائية، لذلك هناك حاجة ملحة لإيجاد خطط للتكيف مع ظاهرة التغير المناخي وتطوير كفاءة استخدام المياه لتعزيز استدامتها.

تؤكد الدراسة على اهمية تعزيز النمذجة الهيدرولوجية من أجل فهم تأثير التغيرات المناخية على الموارد المائية، بالإضافة الى تطبيقها على جميع مستجمعات المياه في فلسطين كون مصادر المياه فيها محدودة. توصي الدراسة بتعزيز التعاون بين صناع القرار والباحثين لمواجهة التحديات المتوقعة للتغير المناخي بالإجراءات التي تقلل من اثاره، وكذلك وضع خطط التكيف معها.

الكلمات المفتاحية: التغير المناخي، النمذجة الهيدرولوجية، نموذج SWAT،SimClim AR6 ، الموازنة المائية، المناطق شبه القاحلة، حوض الفارعة، دولة فلسطين.