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Republic of Iraq
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Long-Term Strategies of Water Resource Development Scenarios for the Euphrates River Basin in Iraq

A Thesis

Submitted to the College of Engineering / University of Babylon in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Engineering / Civil Engineering / Water Resources

By

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Supervised by

Asst. Prof. Dr. Imad Habeeb Obead

2023 A.D **1445 A.H**

بِسْمِ اللهِ الرَّحْمَنِ الرَّحِيمِ

أَمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِرَةَ وَيَرْجُوا رَحْمَةَ رَبِّهِ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُولُوا الْأَلْبَابِ

صدق الله العلي العظيم

سورة الزمر - الآية (9)

Dedication

I offer my love and regards to ***my parents, my wife, and my dear daughters****.*

Mercy to all those who supported me in any respect during the achievement of the thesis Creation.

Dheyaa

2023

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First, praise is to Allah.

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Dheyaa

2023

Supervisors' Certificate

I certify that this thesis entitled **"Long-Term Strategies of Water Resource Development Scenarios for the Euphrates River Basin in Iraq"** was prepared and submitted by **"Dheyaa Hamdan Dagher"** under my supervision as a partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering / Civil Engineering / Water Recourses at University of Babylon.

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We certify that we have read this thesis entitled ***"Long-Term Strategies of Water Resource Development Scenarios for the Euphrates River Basin in Iraq"*** presented by ***" Dheyaa Hamdan Dagher"*** and as an examining committee, we examined the student in its content and in what is connected with it, and that in our opinion it meets standard of a thesis for the degree of Doctor of Philosophy in Engineering / Civil Engineering / Water Resources.

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الخلاصة

تم استخدام منهج البرمجة الديناميكية التفاضلية المنفصلة (DDDP) في هذه الدراسة لتقدير التشغيل الأمثل لثلاثة خزانات : حديثة ، الثرثار ، والحبانية. طورت الدراسة دوال هدف وقيود لتقليل خسائرالتدفقات الخارجة والتخزين وأشتقاق منحنيات قواعد التشغيل المثلى. استخدم نموذج الامثلية بيانات التدفق التاريخية من أكتوبر 2000 إلى سبتمبر 2021 كبيانات مدخله الى DDDP . كما تناولت الدراسة سيناريوهات مختلفة لكل خزان ، مثل تقليل اطلاق مياه الارواء والاهوار ، وإعطاء الأولوية لاطلاق المياه الى القطاعات البلديه، البيئية، والصناعيه. ايضا تم استخدام نظام تقييم وتخطيط المياه (WEAP) لتقدير الإطلاقات المائية من خزانات حوض نهر الفرات (ERB).

بالنسبة لخزان حديثة ، تم الاخذ بنظر الاعتبار السيناريو H1 والذي تضمن تخفيض اطلاق مياه الارواء بنسبة 50٪ للمساحة المروية الحقيقية ، وايضا تم تخفيض اطلاق المياه لمناطق لأهوار الى 75٪ من الاحتياجات السنوية الفعلية على التوالي. بالنسبة لخزان الثرثار تم اعتماد سيناريوهين : TH1 الذي كان سيناريو التشغيل المقترح الاول ، و TH2 الذي كان سيناريو بديل يتضمن استغلال الخزين الميت للخزان. بالنسبة لخزان الحبانية ، تم اعتماد السيناريو HB والذي تضمن تخفيض اطلاق مياه الارواء بنسبة 50٪ من الاحتياج الحقيقي للمساحات الزراعية.

تم تغذية نموذج الامثلية بالبيانات المناخية الحالية والمستقبلية. حيث تم اعتماد سيناريوهات لتغير المناخ للفترة ، SSP1-2.6 يغطي الفترة (2020-2039) ، و SSP2- 4.5 للفترة (2040-2059).

وقدرت الدراسة أن خزان حديثة سيسهم بنسبة 69٪ من الاحتياجات المائية داخل حوض نهر الفرات (ERB) ، حيث يساهم كل من خزان الثرثار وبحيرة الحبانية بنسبة 23٪ و 8٪ على التوالي. في حالة تطبيق السيناريوهات H1 و TH1 و HB لخزانات حديثة ، الثرثار والحبانية، تم تقدير إجمالي الطلب على المياه من ERB للفترة من أكتوبر 2022 إلى سبتمبر 2059 بـ 646666 (مليون متر مكعب)، مع تجهيز إجمالي للمياه قدره 624835 (مليون متر مكعب) ، مما أدى إلى حدوث عجز قدره 21830- (مليون متر مكعب) .

من خلال تطبيق السيناريوهات H1 و TH2 وHB ، تم تقدير إجمالي الطلب على المياه من ERB بمقدار 646666 (مليون متر مكعب)، مع تجهيز إجمالي للمياه قدره 664436 (مليون متر مكعب)، مما أدى إلى توافر فائض من المياه قدره 17770 (مليون متر مكعب).

توضح نتائج WEAP أعلى متوسط لإطلاق المياه من خزان حديثه كان لمحافظة الأنبارحيث يعادل 651 مليون متر مكعب. ايضا إطلاق المياه الى محافظة المثنى من خزان حديثه أعلى من محافظة ذي قار، حيث أن السبب الرئيسي هو أن المساحات المروية في المثنى أكبر منها في ذي قار. إطلاق المياه من خزان الثرثار الى محافظة بابل أعلى باستمرار من محافظة الديوانية بسبب أن المساحات المروية في بابل أكبر منها في الديوانية. يظل الفرق المتوسط بين قيم إطلاق المياه للمحافظتين ثابتًا نسبيًا، حيث يساوي 63.67 مليون متر مكعب.

وفقًا لسيناريوهات تغير المناخ ، ستزداد الحاجة إلى مياه الري في المستقبل. مع ارتفاع درجة الحرارة وتذبذب في كميات هطول الأمطار, وزيادة التبخر.

Abstract

The Discrete Differential Dynamic Programming (DDDP) approach was used in this study to estimate the optimal operation of three reservoirs: Haditha, Tharthar, and Habbaniyah. The study developed objective functions and constraints to minimize release and storage losses and to derive optimum operation rule curves. The optimization model used the historical monthly inflow data from October 2000 to September 2021 as input data to the DDDP. The study also considered various scenarios for each reservoir, such as reducing irrigation and marshland water releases, and prioritizing municipal, environmental, and industrial water releases. Additionally, the Water Evaluation and Planning (WEAP) System was used to estimate releases from the Euphrates River Basin (ERB) reservoirs.

The Haditha Reservoir, scenario H1 was considered, which included a 50% reduction of actual irrigation water releases, and a 75% reduction of marshland water releases from actual annual needs respectively. Tharthar Reservoir two scenarios were adopted: TH1 which was the proposed first operating scenario, and TH2 which was an alternative scenario involving utilization of the reservoir's dead storage. The Habbaniyah Reservoir, scenario HB was adopted, which included a 50% reduction of actual irrigation water release needs for the agricultural areas.

The optimization model was fed by current and future climate data. Climate change scenarios were adopted, SSP1-2.6 covering the period (2020-2039), and SSP2- 4.5 for the period (2040-2059).

This study estimated that the Haditha Reservoir would contribute 69% of the water needs inside the ERB, with the Tharthar reservoir and Habbaniyah Lake contributing 23% and 8% respectively. In the case of applying scenarios H1, TH1 and HB for Haditha, Tharthar and Habbaniyah Reservoirs, the total water demand

from ERB for the period from October 2022 to September 2059 was estimated at 646,666 MCM, with a total water supply of 624,835 MCM, resulting in a deficit of -21,830 MCM. Through applying scenarios H1, TH2 and HB, the total water demand from ERB was estimated at 646,666 MCM, with a total water supply of 664,436 MCM, resulting in a water surplus of 17,770 MCM.

WEAP model results show the highest average water release from Haditha Reservoir was to Anbar province, equivalent to 651 MCM. Also, water release to Al Muthanna province from Haditha reservoir is higher than to Thi-Qar province, because the irrigated areas in Al Muthanna are larger than in Thi-Qar. Water release from Tharthar reservoir to Babil province is consistently higher than to Diwaniyah province because the irrigated areas in Babil are larger than in Diwaniyah. The average difference between the water release values for the two provinces remains relatively constant, equal to 63.67 MCM.

According to climate change scenarios, the need for irrigation water and evaporation from the surface of the reservoirs will increase in the future, due to rising temperatures and fluctuations in rainfall quantities and increasing in evaporation.

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List of Symbols

Symbol	Title	Dimension
A	Area	L^2
Kc	Coefficients crops	-
ETc	Crop evapotranspiration	LT^{-1}
ρ_w	Density of Water	ML^{-3}
Re	Effective rainfall	LT^{-1}
H_t	Head	L
Q	Inflow	L^3
ν	Kinematic viscosity	ML^{-2}
R_n	Net radiation at the crop surface	LT^{-1}
EF	Power-generation efficiency	-
ETo	Reference Surface Evapotranspiration	LT^{-1}
R_t	Release	L^3
H_S	Sensible heat flux	LT^{-1}
G	Soil heat flux density	LT^{-1}
S	Storage	L^3
T	Temperature	°C
u_2	Wind speed	LT^{-1}

List of Abbreviations

Abbreviation	Definition
CCKP	Climate Change Knowledge Portal
CWTP	Compact Water Treatment Plant
DDDP	Discrete Differential Dynamic Programming
ERB	Euphrates River Basin
GAP	Global Agricultural Partnership
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
MCM	Million Cubic Meter
MENA	Middle East and North Africa
MoP	Ministry of Planning
MoWR	Ministry of Water Resources
NCFWRM	National Center for Water Resources Management
NDP	National Development Plan
NEMP	New Eden Master Plan
SSP	Shared Socio-economic Pathway
SWLRI	Strategy for Water and Land Resources in Iraq
TDS	Total Dissolved Solid
VBA	Visual Basic for Application
WEAP	Water Evaluation and Planning System
WSE	Water Surface Elevation
WTP	Water Treatment Plant
WPP	World Population Prospects

Chapter One

Introduction

1.1 General Overview

Management of water Systems has benefits for people and economies. Numerous services are available through these systems. The benefits of water systems management extend beyond meeting basic human needs to encompass environmental sustainability, economic development, and the overall quality of life for communities. However, it is imperative that water systems provide even the most fundamental demands for clean water and sanitary conditions in many world regions. Many of these water resource systems need to be more capable of sustaining and enhancing biodiverse ecosystems. The ecosystem is a biological community of interacting organisms and their physical environment. Development activities and water and sediment flow regime changes are just a few typical problems (Loucks and Van Beek, 2017).

1.2 Statement of the Problem

The implications of poor ERB management accumulate over time. Inflow thresholds over the past two decades have raised serious concerns about water resources in Iraq. There are many factors involved in the development and exacerbation of such a problem:

1. Iraq's water rights have been infringed upon by the construction of the Global Agricultural Partnership (GAP) project in Turkey, which repeatedly violates existing international water agreements. The monopolization of water resources from Tigris and Euphrates Rivers by this project will have negative consequences on agricultural productivity and the well-being of millions of

individuals who rely on these rivers for various purposes, including drinking water and daily household needs.

2. The growth in water demands is a significant challenge many regions face due to the expansion of consumption sectors, population growth, and unregulated urbanization. As the population and urban areas expand, there is an increased demand for water resources to support the growing demands of households, industry, and agriculture. Unfortunately, this often leads to unregulated consumption and inefficient use of water resources, further exacerbating the water scarcity issues.
3. The deterioration of surface water quality can be attributed to the escalation of pollution and salinization.
4. The agricultural sector, evaporation, and precipitation in the region have been profoundly influenced by the effects of climate change on the Euphrates and Tigris reservoirs. Changes in precipitation patterns have led to lower reservoir inflows, reducing their water storage capacity. It has reduced water availability for irrigation, affecting agricultural production and crop yields. Additionally, higher temperatures and lower humidity levels have increased the reservoirs' evaporation rate. The changing climate has also led to more frequent and severe droughts and depleting reservoirs. These challenges highlight the need for better water management strategies and innovative solutions to address the water scarcity issues in the Euphrates region caused by climate change.

1.3 Objectives of the study

Main Research Question: How can long-term integrated strategies, including (DDDP) optimization models, be effectively implemented to manage and allocate water resources in the Euphrates River Basin (ERB)?

The answer can be achieved according to the following:

1. Water Demand Forecasting: What methodologies are employed to accurately forecast water demands for various sectors within the ERB, including agriculture, municipal, industrial, environmental, and marshlands?
2. Reservoir Operation Optimization: How can the Discrete Differential Dynamic Programming (DDDP) framework be applied to estimate optimal monthly releases from ERB reservoirs, considering specific water demand, inflow, and storage scenarios?
3. Operating-Release Decision-Making: What decision-making processes are involved in determining reservoir releases that minimize storage and outflow deficits while addressing other system stresses? How do these processes account for hydrological uncertainty, water quality standards, and the impact of climate change?
4. Long-Term Management Strategies and Rule Curves: What methods are utilized to develop long-term management strategies and rule curves for optimizing the utilization of discharges from major ERB reservoirs in Iraq?

1.4 Organization of the Thesis

The thesis chapters are as follows:

1. In chapter one of the thesis, the researcher discusses the challenges in managing water systems Arab Area, specifically in Iraq. The study focuses on the Euphrates River Basin and its challenges due to climate change, increasing demand, and unsustainable management practices.
2. Chapter two provides an overview of the existing literature related to the research subjects.

3. Chapter three describes the Euphrates River Basin and some projects built on the river, particularly in Iraq. In addition, the chapter discusses the methods for calculating reference evapotranspiration (ETo) and projecting the evaporation of reservoirs.
4. Chapter four presents the formulation of the Discrete Differential Dynamic optimization problem.
5. Chapter five covers various topics related to data sources and methods of projection of the future water requirements in the water budget element of the ERB. This chapter discusses the climatic model and how it is used to project the demand for irrigation, Evaporation, and rainfall. Additionally, the chapter introduces the rule curve of the storage and water surface elevation relation, and the inflow rate of the reservoirs.
6. Chapter six discusses various aspects of water management in the ERB. The chapter begins with a discussion on climate change, it then delves into agricultural water demand and validation of the demand, as well as evaporation of reservoirs and validation of these models. The chapter also covers industrial and municipal water requirements and the optimization model results.
7. Chapter seven introduces the conclusion of the optimization model along with its implications for water management. Finally, this chapter provides recommendations for future research and water management policies, emphasizing the need for continued monitoring and assessment of the Euphrates River Basin.

Chapter Two

Review of Literature

2.1 Management of Water Recourses

The construction of significant water infrastructure projects in Turkey and Syria upstream has led to a reduced seasonal variation in the flow pattern of the ERB. Within the ERB, which encompasses Iraq, Syria, and Turkey, water is primarily utilized for hydropower generation, the agricultural sector, and drinking water supply. The agricultural demand is the most significant water consumer, comprising more than 70% of the overall water consumption (UN-ESCWA, 2013).

Iraq is presently confronted with a critical water scarcity crisis, and this predicament is predicted to deteriorate in the coming years. According to future projections, the anticipated water supply is expected to be 43,000 and 17,610 million cubic meters (MCM) in 2015 and 2025, respectively. Meanwhile, the current demand is estimated to fall within the range of 66,800 to 77,000 MCM (Al-Ansari, 2013). The flow of the Tigris and Euphrates Rivers is predicted to continue declining, and by 2040, there is a risk of these rivers completely drying up. Urgent and effective measures are required to address this issue. The government should take decisive actions and develop a strategic vision for water management that includes research and development, regional collaboration and coordination, improvements in the agricultural and sanitation sectors, and investments in research and development. These policies should prioritize essential areas including agriculture, regional collaboration, water supply and sanitation, as well as research and development (Al-Ansari, 2013).

Hydraulic infrastructure and irrigation projects were less numerous and comprehensive than they needed to be to have a significant impact on river discharge. After that, riparian countries began using their water extensively because of rising population expansion and development. Turkey has initiated an ambitious endeavor known as the GAP project to address these challenges. Furthermore, the Middle East is grappling with intensified water scarcity issues due to climate change impacts. This has exacerbated water shortages and compromised water quality in lower riparian countries like Syria and Iraq. The situation has put large agricultural regions at risk of desertification soon. As a result, tensions have arisen among riparian nations and there is a potential for further conflicts. It is crucial to undertake actions at the international, regional, and national levels to address these pressing issues (Al-Ansari et al., 2018).

Water quality in Syria and Iraq is deteriorating, leading to increased salinity levels in certain areas, exceeding the natural levels. The discharge of irrigation water into the river is a major contributor to this decline, as it introduces harmful substances like fertilizers and pesticides. Consequently, water quality has been significantly impacted, with salinity levels rising by approximately 13 pe rcent since the late 1990s. The escalating salinization in the lower region of the Euphrates basin is a pressing concern. However, obtaining accurate data is challenging due to the current security situation in Iraq. Nonetheless, a report from 1995 reveale d that an estimated 17 million tons of salt were discharged into the Arabian Gulf through the General Drain Stream, an artificial drainage canal designed to treat water affected by high salinity (Lahn, and Shamout, 2015).

The decline of flow in the Tigris and Euphrates Rivers poses a significant national crisis in Iraq. While negotiations between the involved nations continue, the

Iraqi Government implements effective measures for the responsible management of water resources. Public awareness campaigns regarding water scarcity and the potential adverse effects of the Global Agricultural Partnership (GAP) project on both the environment and people's lives should be prioritized. Additionally, the establishment of a dedicated scientific institute is necessary to conduct research and studies related to water resources and agricultural practices (Al-Ansari and Knutsson, 2011).

2.2 Impact of Climate change

The global community is confronted with a significant challenge of climate change, primarily caused by the rising concentrations of greenhouse gases (GHGs) in the atmosphere (Zakaria et al., 2013). Observations of atmospheric greenhouse gases are useful climate indicators because they can be used to show the influence of human activities (e.g., emissions) on the climate system (Bruhwiler et al., 2021).

Due to Iraq's location in a semi-arid region that is highly susceptible to climate change, water shortages will become an issue for the people on an increasing basis (Abahussain et al., 2002). Growing climate-related water risks will increase the demand for adaptation to climate change. It will also make cross-border water cooperation more complex. Heavy reliance on freshwater resources from outside each country territory increases Iraq vulnerability to water insecurity. Incentives for upstream governments to fully use water resources also increase with water stress in the face of growing demand and scarcity (Pohl et al, 2014).

Climate change influences substantially impacts water availability and consumption when developing strategic plans. For both riparian nations to benefit from favorable conditions for their water resources, particularly in the case of transboundary basins, a shared understanding and the establishment of cooperative actions are crucial (Al-Faraj et al., 2016).

Iraq water supply declined by 30% in the 1980s, and by 2030, it is anticipated to have decreased by as much as 50%. Between 2015 and 2025, it is anticipated that overall water supply will decline by up to 60%. The hydroelectric capacity affects major dams in Iraq. The deficient rainfall during the winter of 2017–2018, about a third below average, will be followed by an arid summer in 2018. Another 30% crop loss is projected over the previous year. Iraq climate is shaped by its geographical position, situated between the arid conditions of the Arabian desert and the humid subtropical climate of the Persian/Arabian Gulf. The country is divided into two primary climate zones: an arid lowland desert in the south and a semi-arid steppe in the north (Lossow, 2018).

The flow of water in the Euphrates, Tigris, and their tributaries has been diminished by the construction of irrigation projects upstream, as well as the impacts of climate change. This has led Iraq to face a crisis characterized by water scarcity, both presently and in the future. The responsibility for managing the country's water supply falls under Iraq's Ministry of Water, but mismanagement of resources has further compounded the problem. This is not just a localized issue, but a regional one. Addressing this challenge would require engaging in discussions and negotiations with all riparian nations involved (Al-Ansari and Adamo, 2018).

Abbas et al. (2016) conducted a study using the soil and water assessment tool (SWAT) to examine the potential consequences of climate change on water resources in the Diyala River Basin. The researchers employed six general circulation models (GCMs) to assess the impacts of climate change across three emission scenarios: A2, A1B, and B1. The findings of the study offer valuable insights into effectively managing future water resources and agricultural productivity.

Abbas et al. (2018) discussed the latest trends and long-term predictions of water resources in northeast Iraq, along with measures for adapting to climate change. The study investigated the link between climate change and its effects on water resources by utilizing the widely used SWAT model.

Osman et al. (2019) conducted a study on the effects of climate change on the flows of the Greater Zab River in Iraq. The findings indicated that the catchment area is projected to experience a substantial decrease in total annual flow in the distant future, particularly during winter and spring seasons, with a potential reduction ranging from 25% to 65%. These flow reductions are expected to have significant consequences for existing agricultural practices in the catchment region.

Salman et al. (2021) presented a study focusing on the future agricultural water stress in Iraq by analyzing the climatic water availability (CWA) and crop water demand (CWD) under different radiative concentration pathways (RCPs). The results indicated a considerable decline in CWA, with an annual rate of up to (-34/year) from 2010 to 2099 under RCP8.5. This decline in CWA was more pronounced during the summer season (-29/year) compared to a minor decrease in winter (-1.3/year). Additionally, this research revealed an increase in CWD for all major crops across all scenarios. Summer crops showed the highest increase in CWD, reaching approximately 320 mm, while winter crops exhibited the lowest increase of around 32 mm under RCP8.5 in the distant future (2070-2099). The findings also emphasized that the combination of declining CWA and rising CWD would result in a significant rise in crop water stress in Iraq.

Ethaib et al. (2022) conducted a comprehensive assessment of water scarcity in the Thi-Qar governorate by employing GIS estimation, analyzing environmental data, studying the climate change impacts, and detecting changes in marshes over a period of thirty years from 1991 to 2021. The results emphasized the existence of a severe water scarcity problem in the study area, leading to detrimental consequences for the local population. The study provided valuable scientific insights that can aid decision-makers in effectively tackling and managing the issues linked to water scarcity in the area.

Various researchers have utilized the Climate Change Knowledge Portal (CCKP) of the World Bank Group as a method for projecting climate data. Lar et al. (2018) employed the CCKP to examine the range of climate change effects on rice production in Lower Ayeyarwady Delta of Myanmar. They considered climate change scenarios such as RCP4.5 and RCP8.5, encompassing both moderate and extreme projections. Haque and Khan (2022) utilized the CCKP to assess the climate change impact on food security in Saudi Arabia. Similarly, Boluwade (2021) employed the CCKP to evaluate the impacts of climate change on the water-energy-food nexus in regions facing water scarcity, focusing on the design of information databases.

2.3 Water Demands for Crops and Irrigation Requirements

The climate change impact scenarios on crop water demands and irrigation requirements can be significant. With changing weather patterns and altered precipitation rates, it is essential to assess and adapt to the evolving water requirements for agriculture. An accurate estimation of the crop water needs and irrigation requirements, considering the changing climatic conditions, is crucial to ensure sustainable water management. Implementing effective water resource planning and management strategies, along with the adoption of advanced agricultural technologies and enhanced irrigation methods, can mitigate the adverse impacts of climate change on crop yields. These measures are crucial for promoting the long-term sustainability of agriculture.

The crop water requirements (CROPWAT) model is a comprehensive software tool that accurately estimates the water needs of crops by analyzing input data including soil information, weather conditions, and crop characteristics. It also provides valuable insights into irrigation scheduling and strategies for different crop types. CROPWAT 8.0, created by FAO, functions as a valuable tool for assisting in the decision-making process of water resource development and management (Ashish et al., 2021).

Ewaid et al., (2019) conducted a study in the southern province of Thi -Qar, Iraq, the CROPWAT 8.0 software package together with its associated climate water (CLIMWAT 2.0) tool was utilized to establish the crop water requirements (CWRs) and irrigation schedules for various key crops. The reference crop evapotranspiration (ETo) was determined using the CROPWAT tool. The application of the CROPWAT model proved advantageous in accurately computing the agricultural irrigation needs for effective water management in the case study. However, the study noted that differences in climate could account for variations in the water footprint of wheat production in different provinces of Iraq.

Abdulhadi and Alwan (2021) utilized the CROPWAT 8.0 simulation program to assess the water requirements of irrigated palm trees in Fadak Farm, Karbala. Their findings provided valuable insights to farm management regarding the precise irrigation water needed for optimal tree growth. The research highlighted issues with the current irrigation scheduling system on the farm, which led to excessive irrigation during certain months like November, December, January, February, and

March, resulting in water loss. Conversely, the study indicated a decrease in water supply to the plants during May, June, and July. These calculations shed light on the water scarcity challenges faced by Iraq in recent years, which can be attributed to various factors such as climate change and the dam's construction by neighboring countries.

Ewaid et al. (2021) utilized the CROPWAT software, specifically the option of the crop water requirement, to estimate the water footprint (WF) of rice cultivation in seven provinces of Iraq in 2017. The objective was to gain a deeper understanding of the actual water requirement for irrigating significant crops such as rice, and to assess the effects of human water consumption on water volume and distribution. They also suggested ways to improve water management in rice cultivation to ensure food security in the face of increasing demand and water scarcity.

Saeed et al. (2021) conducted an assessment to understand the spatial and temporal sensitivity of irrigation water requirements in response to a changing climate. They specifically examined the climate change impact on the net irrigation water requirement (NIWR) for sixteen crops in four irrigation projects situated in arid and semi-arid regions of Iraq. To project the temperature and rainfall changes, the study utilized climate models for three time periods spanning from 2021 to 2080 under various representative concentration pathways (RCPs). The results indicated that climate change is anticipated to increase the NIWR for the crops analyzed, although the degree of sensitivity varied depending on the specific crop and location.

Al-Ansari et al., (2021) examined the water requirements and water footprints of key crops, specifically wheat, in Iraq. They employed simulation models like FAO CROPWAT 8.0, CLIMWAT 2.0, and Aqua-Crop. The study highlighted climate change as a contributing factor to the water scarcity issues faced by Iraq. In previous decades, Iraq's climate was classified as subtropical semi-dry, with ample water resources. However, this situation has undergone significant changes. Various factors, including the construction of multiple dams on the Tigris and Euphrates Rivers by neighboring countries, inefficient water usage, and mismanagement, have contributed to the exacerbation of water scarcity and the need for more sustainable consumption practices. To address the prevailing drought conditions, there is an urgent requirement to prioritize reducing water consumption and implementing effective water resource management strategies.

Saeed et al., (2022) utilized the CROPWAT-8 software to predict the future crop evapotranspiration and net irrigation water requirements for 19 crops traditionally grown in Salah-addin Province in Iraq, suggesting that this adaptation process may be able to temper the anticipated loss of at least partially of water availability and population growth for sustainable water resources. Their findings indicated that the projected climate change in the region predicts a hotter and drier environment by 2080, characterized by rising temperatures and reduced precipitation. Consequently, the study revealed an expected increase in evapotranspiration rates, resulting in a higher annual demand for irrigation water in the studied area.

2.4 Optimization Models in River Basin Management

Developing mathematical models to optimize water management in river basins under climate change aids decision-making by assessing various scenarios and suggesting the best approach to balance competing water demands and ensure sustainable resource use. Additionally, incorporating climate change scenarios is critical for managing water resources in an uncertain future.

Raje and Mujumdar, (2010) conducted a study that focused on assessing the climate change impact on the performance of the Hirakud reservoir, a multipurpose reservoir located on the Mahanadi River in Orissa, India. Their objective was to derive adaptive policies to mitigate the potential effects of climate change on the reservoir's performance. The study examined the influence of climate change on hydropower generation and evaluated four performance indices, namely reliability, resiliency, vulnerability, and deficit ratio, specifically related to hydropower. To address the climate change impacts on the reservoir operation, the study utilized a case study approach and employed stochastic dynamic programming to develop an optimal monthly operating policy. The results revealed that climate change is likely to lead to a decrease in hydropower generation and reliability, while increasing the deficit ratio and vulnerability, particularly concerning hydropower and irrigation.

Ashofteh et al., (2013) presented a study to investigate the influence of climate change on the inflow volume of a reservoir and downstream water demand in East Azerbaijan river basin. The researchers employed climate change scenarios, hydrological models, and optimization models to evaluate the impact of climate change on reservoir performance indicators. The study focused on a period from 2026 to 2039 and considered three climate change scenarios based on the emission scenario greenhouse gas (A2). The modeling results indicated a 0.7% decrease in the long-term of the average annual runoff volume compared to the base period of 1987 - 2000. However, assuming a constant cultivation area, the average long-term annual water demand volume for crops exhibited a 16% increase.

Pereira et al., (2014) conducted a study to assess the impact of climate change on the water-energy nexus in the Iberian Peninsula. The researchers employed a coupled hydrological and power market model to examine the effects of the precipitation and temperature changes on hydropower production, electricity demand, and irrigation water use. In this research a stochastic dynamic programming approach was used to develop operating rules for the integrated system given hydrological uncertainty. The study also established operational rules for the integrated system considering the uncertainty of hydrological conditions. It concluded that climate change will pose increased difficulties in achieving a balance between agricultural, power generation, and environmental goals in the management of Iberian reservoirs.

Kucukmehmetoglu and Oral, (2014) made enhancements to the Inter Temporal Euphrates and Tigris River Basin Model (ITETRBM), which is a transboundary water resources allocation model based on linear programming. Their improvements aimed to maximize the net economic benefit derived from the allocation of limited water resources for various purposes such as energy generation, urban development, agriculture, and transportation. The study also examined the climate change impact on the transboundary water resources and proposed a model that utilizes DEM (Digital Elevation Model) and GIS-based databases for the optimal allocation of these resources in the Euphrates and Tigris Basin (ETRB).

Ahmadi et al., (2015) examined the impact of climate change on water resources systems and the hydrologic cycle. Their study employed a climate model to project temperature and precipitation patterns for various timeframes in the 21st century, considering a greenhouse gas emission scenario. Additionally, a hydrologic model was utilized to simulate river basin inflow and optimize reservoir operations across different climate scenarios. The findings demonstrated that implementing adaptive reservoir management practices can enhance the reliability of hydropower generation and reduce vulnerability associated with climate change.

Ashofteh et al., (2015) devised and implemented a multi-objective genetic programming algorithm to optimize the operating rules of the Aidoghmoush

Reservoir in Iran. Their study incorporated both current and projected climatic conditions. The researchers focused on two key objectives: maximizing the reliability of meeting irrigation demand and minimizing vulnerability to irrigation deficits. By employing their algorithm, they aimed to develop efficient reservoir-operating rules that would enhance irrigation reliability and reduce the risk of water shortages. The study used a climate model to simulate future climatic conditions and found that incorporating these changes into reservoir-operating rules led to significant improvements in performance compared to using rules based on current climatic conditions.

Ho et al., (2015) introduced a novel hybrid optimization approach that merged the harmony search and incremental dynamic programming algorithms to optimize the operation of the Huong Dien hydroelectric dam in central Vietnam. Their study aimed to maximize hydropower energy generation, prevent flooding, and ensure the availability of drinking and irrigation water. The researchers also examined the climate change impact on water resources within the basin, specifically analyzing how altered precipitation patterns directly affected water availability and runoff. Moreover, they investigated changes in temperature, radiation, and humidity to forecast the influence of evapotranspiration.

Turner and Galelli, (2016) presented a software package named "reservoir" that consolidated various established methods of reservoir storage analysis. The researchers developed a model that simplified the routing of runoff data through storage, offering tools for capacity design, release policy optimization, and performance analysis. In their study, they demonstrated the capabilities of the reservoir package using 271 runoff records obtained from the Global Runoff Data Centre (GRDC). The GRDC is a center that collects, manages, and provides access to global river discharge data. It serves as an international repository for information related to river discharge and streamflow. The main objective was to assess the sensitivity of water supply performance to climate change. To achieve this, they introduced a hypothetical projection to perturb the inflow record and employed a stylized design storage to determine the yield under the projected climate scenario.

Emami and Koch, (2017) conducted a study to estimate the climate change impact on water supply from Boukan Dam, located on the Zarrine River, which serves as the primary inflow for Lake Urmia in Iran. The researchers employed a rainfall-runoff model and a water management model to simulate the current and future availability of water resources in the basin. They also optimized the operation of Boukan Dam by prioritizing water allocation for various sectors within the basin. The study examined the consequences of climate and demand variations on dam operation by comparing average water budgets and supply/demand ratios between future scenarios and historical data using the Community Earth System Model (CESM). The results indicated that the region is expected to face more severe water shortages in the future due to climate change and escalating water demands.

Rungee and Kim, (2017) undertook a study to evaluate the potential consequences of climate change on water resources planning and management, with a specific focus on the Norris Reservoir operated by the Tennessee Valley Authority in United States of America.

They employed a hydrologic model and a general circulation model to forecast future inflows and assess the effectiveness of the reservoir's current operating guide. The objective was to gain insights into the reservoir's response to climate change and explore possibilities for further optimization. The study presented a methodology for the evaluation and optimization of existing systems, highlighting the importance of integrating projected climate change as a tool to assess reservoir operations.

Al-Janabi et al. (2018a) developed an optimization model for the allocation of reclaimed wastewater in agricultural irrigation, aiming to enhance the efficiency of water allocation and crop selection in cultivated farmlands in Iraq. The primary goal was to maximize net benefits and identify practical water conservation measures that could mitigate the potential impacts of droughts and water shortages. The study emphasized the role of climate change as a contributing factor to water scarcity in Iraq, which is expected to exacerbate in the future. The researchers highlighted the uncertainties associated with climate change, which could result in more severe shortages in surface water resources as river flows decrease and demands increase in neighboring countries such as Turkey, Syria, and Iran.

Abera et al. (2018) evaluated the present and future operations of the Tekeze reservoir in Ethiopia for hydropower generation, considering the impact of climate change. They employed simulation and optimization models to assess the influence of climate change on reservoir inflow and optimize the release, storage, and pool levels of the hydropower reservoir. The findings of the study can provide guidance to water resource planners and managers in developing reservoir operation techniques that account for the effects of climate change, thereby enhancing power production. The study emphasized the impact of climate change on reservoir inflow, revealing an increase in annual and monthly inflows, except during dry months from May to June, under different climate scenarios.

Al-Janabi et al. (2018b) addressed the water governance challenge in Iraq by examining the effects of different water appropriation systems on farm and basin profitability. They evaluated the impact of three water appropriation systems on farm income under varying water supply scenarios using an irrigation water model and nonlinear programming optimization. The study considered normal, dry, and drought water supply scenarios, considering the climate change influence on rainfall patterns, temperature, and water availability.

Guo et al. (2020) investigated the impact of future climate change on the operation of cascade reservoirs in the Hanjiang River basin in China. They proposed an adaptive operation rule to mitigate potential adverse effects on water supply and power generation. The adaptive operation rules were developed using the Pareto archived dynamically dimensioned search (PA-DDS) algorithm and based on future projections from global climate change models (GCMs) for the period 2021 -2100.

Mohammadi et al. (2020) examined the need to deviate from the prevailing Standard Operation Policy (SOP) and adopt the Modified Linear Decision Rule (MLDR) policy for the Karaj hydropower dam reservoir in Iran. They evaluated the two policies by analyzing several performance indices related to the reservoir system and hydropower energy generation. The study discussed the impact of climate change on water resources management, particularly in regions with dry climates, and emphasized the growing challenge of freshwater resource shortages. The researchers suggested that climate change is exacerbating the shortage of freshwater resources, necessitating effective water resources management strategies.

Nourani et al. (2020) developed an integrated framework that combined simulation and optimization techniques to optimize the operation rule curve of the Shahrchay reservoir in Iran, considering different climate change scenarios. They utilized artificial neural networks and a hybrid Wavelet-M5 model to downscale precipitation and temperature data from general circulation models and simulate inflow into the reservoir. The study predicted changes in precipitation and temperature under various climate change scenarios and used this information to optimize the operation rule curve of the reservoir system. The findings indicated a decrease in water availability and a potential decline in average long-term annual runoff volume compared to the reference period.

Thomas et al. (2021) examined the potential impacts of climate change on the water resources of the Narmada basin in central India. They employed the Soil and Water Assessment Tool (SWAT) and climate models to analyze the effects of climate change on water availability. The researchers explored adaptation strategies to address these challenges, including optimal water resources management approaches using simulation-only and genetic algorithm-based simulation-optimization techniques. The analysis indicated that changes in precipitation patterns and warming trends could contribute to increase variability in water availability, resulting in lower overall water availability and higher water demands in the future.

2.5 Application of Water Evaluation and Planning System (WEAP)

The Water Evaluation and Planning System (WEAP) is a robust software tool used for water resources planning and management. It has been widely applied in assessing and managing water resources in different regions, including river basins, under changing climatic conditions. The utilization of WEAP in river basin management under climate change has the potential to improve decision-making processes and promote sustainable water resource management. However, it is crucial to note that the effectiveness of the tool relies on the quality and availability of data, as well as the accuracy of the models employed. Therefore, careful consideration of data sources, model calibration, and scenario assumptions is necessary to ensure the reliability of the results.

Rasul (2010) employed the WEAP software to manage the water resources of Alana Valley in the Kurdistan region of Iraq. They utilized various data, including climatic data, hydrologic data, and Geographic Information System (GIS) layers, to provide an integrated view of Integrated Water Resources Management (IWRM). The study analyzed the annual runoff in normal years and the need for a reservoir or system of reservoirs to meet all demands during the summer, indicating that the availability of water resources could be affected by climate change.

Alazzy et al. (2014) assessed the future water demand in the Euphrates and Aleppo basin (EAB) in Syria, considering the potential impact of climate change on the region's water resources. They used the WEAP model to analyze the influence of climate change on water demand in the industrial, domestic, and agricultural sectors until the year 2050. The findings suggested that the projected scenarios might not be sustainable in bridging the gap between water supply and demand by 2050. The climate change projections indicated a reduction in precipitation of 21% under the A2 scenario and 12% under the B2 scenario, with a corresponding temperature increase of approximately 2.5°C under the A2 scenario and 2°C under the B2 scenario. These climate changes resulted in a significant shortfall in meeting water demand over time in the EAB basin.

Al-Mohseen (2016) evaluated the effect of the Bekhma Reservoir system on the water management plan for a selected area in the Greater Zab River Basin. The WEAP model was used to develop streamflow scenarios in three different ways. The research investigated the effects of the Bekhma Dam on the water resources system of the Greater Zab River Basin when it was first installed. The results demonstrated an improvement in the system's performance in terms of reliability and a reduction in unmet expectations. The study also discussed the sustainable water supply for civil, agriculture, and hydropower requirements in the Greater Zab River Basin, which could be affected by changes in climate patterns.

Mourad and Alshihabi, (2016) analyzed the supply and demand of hydrology and water resources research across different countries and regions. They identified potential imbalances in manuscript supply and demand at sub-country levels and suggested ways to address them. The study recommended that future studies should focus on climate change in the Euphrates and Tigris regions and proposed the use of downscaled climate projections from Global Climate Models (GCMs) to develop plausible climate change scenarios for the region.

Al-Ansari et al. (2019) discussed the water shortage problem in Iraq and Syria, highlighting its expected exacerbation in the future due to climate change and other factors. They focused on the impact of water shortage on agriculture crops, natural plants, and the environment in general. The research stated that temperatures are projected to increase while rainfall is expected to decrease by 15 -25%, leading to a reduction in surface water resources by 29-73%. The results showed a depletion of groundwater resources and an increase in transpiration, which will have negative impacts on agriculture crops, natural plants, and the environment in general.

Noon et al. (2021) implemented the WEAP software to manage water resources in Euphrates River, specifically testing the model in the Anbar Province and examining past trends in water resource management. The study simulated current demand scenarios, including reference and water tax scenarios, which are essential for decision-makers and water resource managers. The results indicated that the western region of Iraq is arid, experiencing a scarcity of rain that leads to severe drought and significant impacts on water resources in terms of quality and quantity.

Al-Mukhtar and Mutar (2021) used the WEAP model to evaluate and analyze the current and future water resource management balance. They calibrated and validated the model using monthly streamflow data from the Tigris River's Sarai station. They then fed the calibrated model with multiple future scenarios for the years 2020-2040, including average population growth rate, halved river discharges, and coupled high population with halved water flow scenario. The study highlighted climate change as a major stressor on water resources in Iraq, affecting the availability of water for domestic and agricultural sectors.

Talib and Shamkhi (2022) focused on evaluating the performance of the WEAP model in simulating streamflow in the Diyala River Basin in Iraq. They discussed the impacts of climate change on water resources in the region. The study found a gradual decrease in rainfall by 20% over the study period, which would impact the surface inflows of the river and its tributaries. The temperature also increased gradually by 5.4% over the study period.

Sulaiman et al. (2022) developed a model for the optimal allocation of water resources in Rutba city, located in western Iraq, with a focus on sustainability and economic efficiency. Utilizing the WEAP model, they evaluated both current and future water demand in the city from 2021 to 2030. The study emphasized the importance of effectively managing diverse water sources in desert cities, particularly considering climate change and the growing population. Additionally, the research proposed an optimal management strategy to achieve a balance between water resource supply and demand in Rutba city, considering the associated costs of water transfer.

Naqi et al. (2022) used the WEAP model to estimate water availability allocated for different demands in the Diyala River basin. They provided a methodology to assist water managers and decision-makers in developing better watershed management plans and strategies. The study highlighted the vulnerability of the shared Diyala River basin between Iraq and Iran to the climate change impacts.

Dagher and Obead (2023) conducted an analysis to estimate water demand in the Iraq's lower Euphrates River Basin. They utilized the WEAP model, CROPWAT, and statistical techniques to forecast water demand for agricultural, municipal, and industrial purposes. The research also examined the climate change impact on water demand in Muthanna and Thi-Qar Provinces. The results showed that the municipal demand for Muthanna reaches a maximum of 211.4 MCM in 2059 and a minimum of 98 MCM in 2022, while the demand for Thi -Qar is higher at 377.2 MCM and a minimum demand of 174.8 MCM in the same year. This difference is due to the larger population of Muthanna compared to Thi-Qar.

2.6 Summary

Previous studies have focused on the Tigris and Euphrates as a general case and have not addressed the simultaneous long-term optimal operation policies for the reservoirs Haditha, Tharthar, and Habbaniyah in the Euphrates River basin. This suggests a need for further research to develop a strategy for managing all three reservoirs in the face of challenges such as climate change, population growth and increasing water demand.

Chapter Three

Theoretical Background and Methods

3.1 Net Irrigation Water Requirements Calculation

Several software employs the equation of Penman-Monteith to evaluate reference evapotranspiration. CROPWAT Model generates irrigation schedules as one of its outputs, and the Penman-Monteith approach can be modified to determine the reference surface evapotranspiration (*ETo* mm/day) (Allen et al.,1998). The value of ETo can be mathematically calculated using the following expression:

$$ETo = \frac{\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3.1)$$

Where R_n is the net radiation at the crop surface (mm/day), G is the soil heat flux density (mm/day), T is the air temperature (°C), u_2 is the wind speed (m/s), e_s and e_a is the saturation and actual vapor pressure (KP_a), Δ is the slope vapor pressure curve (KP_a/°C), γ is the psychrometric constant (KP_a/°C).

The values within the term $\left(\frac{900}{T+273}\right)$ in Equation (3.1) correspond to the conversion of the unit of the term from (MJ/°C day) to (mm/°C day). The values within the term $(1 + 0.34u_2)$ in Equation (3.1) represent the adjustment of the wind speed values at the standardized height (2m) to the wind speed at the standardized height of the crop 0.12 m.

The psychrometric constant γ is a parameter used in meteorology and environmental science to describe the relationship between the saturation vapor pressure and temperature. The value of γ can be expressed as:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} \tag{3.2}$$

Where P is the atmospheric pressure (kPa), λ is the latent heat of vaporization, 2.45 (MJ/kg), and ε is the ratio molecular weight of water vapour/dry air = 0.622.

T_{mean} is defined as the average of the daily maximum (T_{Max}) and minimum temperatures (T_{Mini}). The value of the T_{mean} can be expressed as:

$$T\ mean = \frac{T_{Max} + T_{Mini}}{2} \tag{3.3}$$

The value of e_s and e_a can be expressed in Eq. (3.4) and Eq. (3.5):

$$e_s = \frac{e^o(T_{Max}) + e^o(T_{Mini})}{2} \tag{3.4}$$

$$e_a = e^o(T_{wet}) - \gamma_{psy}\left(T_{dry} - T_{wet}\right) \tag{3.5}$$

Where $e^o{}_{TMini}$ and $e^o{}_{Tmax}$ are the saturation vapour pressure at daily minimum and maximum temperature (kPa),respectively, $(T_{dry} - T_{wet})$ is the wet bulb depression, with T_{dry} and T_{wet} are the dry and wet bulb temperature.

The value of the slope vapor pressure curve Δ can be expressed as:

$$\Delta = \frac{4098\ e^o(T)}{T + 237.3} \tag{3.6}$$

The constant value 4098 is associated with the latent heat of vaporization for water and the gas constant. Similarly, the constant value 237.3 pertains to the conversion of temperature from Kelvin to Celsius.

The soil heat flux density G can be expressed as:

$$G = C_S \frac{T_i + T_{i-1}}{\Delta t} \Delta z \tag{3.7}$$

Where C_S is the capacity of soil heat (MJ/m^2°C), T_i , and (T_{i-1}) is the temperature at the time i and (i-1), Δt is the time interval, Δz is effective soil depth (m). The wind speed u_2 can be expressed as:

$$u_2 = u_z \frac{4.87}{ln(67.8\,Z - 5.42)} \Delta z \tag{3.8}$$

The constant 4.87 is specific to logarithmic wind profile. The term $ln(67.8\,Z - 5.42)$ represents the logarithmic profile function. It arises from the logarithmic wind profile equation and is used to account for the vertical variation of wind speed. Z is the height of measurement above ground surface (m). Net radiation R_n is the difference between the incoming net shortwave and longwave radiation R_{ns} and R_{nl} , respectively.

$$R_n = R_{ns} - R_{nl} \tag{3.9}$$

$$R_s = (a_s + b_s(\frac{n}{N}))R_a \tag{3.10}$$

$$R_{ns} = (1 - \alpha)\, R_s \tag{3.11}$$

Where R_s is the solar or shortwave radiation, α is the albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop (dimensionless). The duration of sunshine (n) represents the actual number of hours of sunlight, while N maximum possible sunshine duration in a day. R_a is the extraterrestrial radiation, and $a_s + b_s$ is the fraction of extraterrestrial radiation reaching the earth on clear days (n = N).

Crop evapotranspiration ETc is calculated by multiplying the reference crop evapotranspiration by the coefficient of crop.

$$ETc = Kc * ETo \tag{3.12}$$

Kc is the crop coefficient (dimensionless) (Allen et al.,1998). The source of the equations from (3.1) to (3.12) is (Allen et al.,1998).

Net irrigation water requirements (*NIWR*) determine by using the formula (Naidu and Giridhar,2016):

$$NIWR = ETc - Re \tag{3.13}$$

Where *Re* is the effective rainfall (mm/day), ETc is the crop evapotranspiration (mm/day).

3.2 Evaporation of the Reservoirs

Evaporation is a natural occurrence that takes place on the surface of reservoirs, contributing significantly to the hydrological cycle and greatly influencing water resource management. The evaporation of water from reservoirs carries significant economic and environmental consequences. Economically, it can lead to water shortages affecting agriculture and industries, causing financial challenges and operational disruptions. Environmentally, it disrupts ecosystems, diminishes biodiversity, and degrades water quality. In some regions, these losses can form a considerable proportion of the total water supply, resulting in water scarcity and heightened competition for water resources (Bazzi et al., 2021).

3.2.1 Energy Budget Method

Chow et al. (1988) presented a method focusing on a specific water surface area and identified net radiation flux as the primary source of heat energy, measured in watts per square meter. They observed that water provides a sensible heat flux to the stream of the air and a ground heat flux (G) (Watt/ m^2) to the ground surface, leading to equation (3.14):

$$\frac{Dh}{dt} = R_n - H_S - G \tag{3.14}$$

Here, *Dh/dt* represents the evaporation rate input to the system from external sources(mm/day), and H_S represents the sensible heat flux (mm/day) to the air stream. Chow et al. (1988) further assumed that the water temperature in the control volume remains constant in time, and the only change in the stored heat within the control volume is the change in the internal energy for the water evaporated, which is equal to $(m_v L_v)$, where L_v is the vaporization latent heat, m_v is the vapor flow rate. Hence, Eq. (3.14) can express as:

$$R_n - H_S - G = m_v L_v \tag{3.15}$$

m_v (Kg/s) can be rewritten as:

$$m_v = \rho_w A E_v \tag{3.16}$$

Where E_v = -*Dh/dt* (m/s) is the evaporation rate. From Eq. (3.17) with $A = 1$ m^2, Eq. (3.16) can be solved for E_v (m/s):

$$E_v = \frac{1}{L_v \rho_w} (R_n - H_S - G) \tag{3.17}$$

If both the sensible heat flux H_S and ground heat flux G are zero, the evaporation rate E_v can be calculated by the following equation:

$$E_v = \frac{R_n}{L_v \rho_w} \tag{3.18}$$

L_v can be rewritten as:

$$L_v = 2.501 \times 10^6 - 23707\,(T) \tag{3.19}$$

The value 2.501 x 10^6 is a constant representing the latent heat of vaporization for water (Chow et al.,1988). It is the amount of energy required to convert one unit mass of liquid water at its boiling point into vapor without a change in temperature. Where T is the temperature in °C and L_v in joules (J / kilogram), ρ_w are shown in Appendix – A1. Figure 3.1 shows all the parameters used to estimate the evaporation rate.

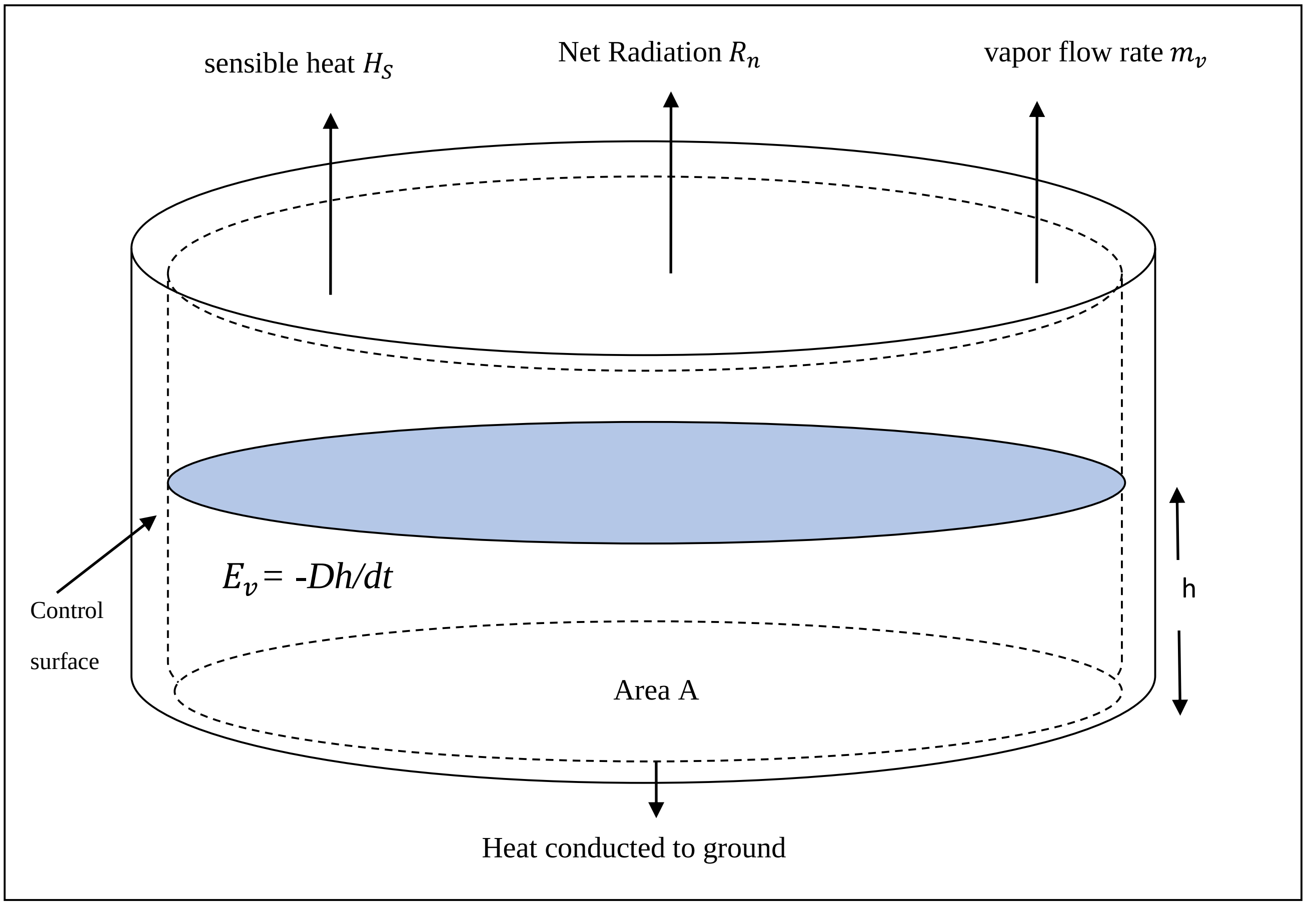

Figure 3.1: Definition diagram for the control volume of continuity and energy equations (After Chow et al.,1988).

3.3 Study Area Description

3.3.1 Euphrates River Basin

The Euphrates River, spanning a length of 2,786 km, is the longest river in Western Asia. It originates in the eastern Turkey mountains near the city of Erzurum in the Armenian highlands. The Euphrates River is formed by the convergence of its western and eastern tributaries, Murat and Karasu, which rise at an elevation of nearly 3,000 (m.a.s.l). The merging of these tributaries occurs at Keban town, where the Keban dam is located just 10 km downstream in a narrow gorge (UN-ESCWA, 2013).

From Keban, the Euphrates flows southward, receiving water from various small tributaries and wadis before crossing into Syria at Karkamis (Turkey) and Jarablus (Syria). The river continues for 455 km from the confluence of Karasu and Murat to the Syrian-Turkish border. Within Syria, three tributaries-Sajur, Balikh, and Khabour-contribute to the Euphrates. These tributaries receive water from Turkey through other tributaries or groundwater, resulting in shared basins between Turkey and Syria. The Euphrates River originates in Turkey, passes through Syria, and eventually joins the Tigris River in the Shatt al-Arab in Iraq. ERB covers approximately 440,000 km^2, with Iraq occupying 47%, Syria 22%, and Turkey 28% of the total surface area. Jordan accounts for 0.03% and Saudi Arabia 2.97% of the basin area (UN-ESCWA, 2013). Figure 3.2 shows the Euphrates River Basin. The Euphrates River supplies water to several provinces located within its basin, including Anbar, Babil, Diwaniyah, Najaf, Karbala, Muthanna, and Thi-Qar. The distribution of these provinces within the ERB can be seen on the map shown in Figure 3.3.

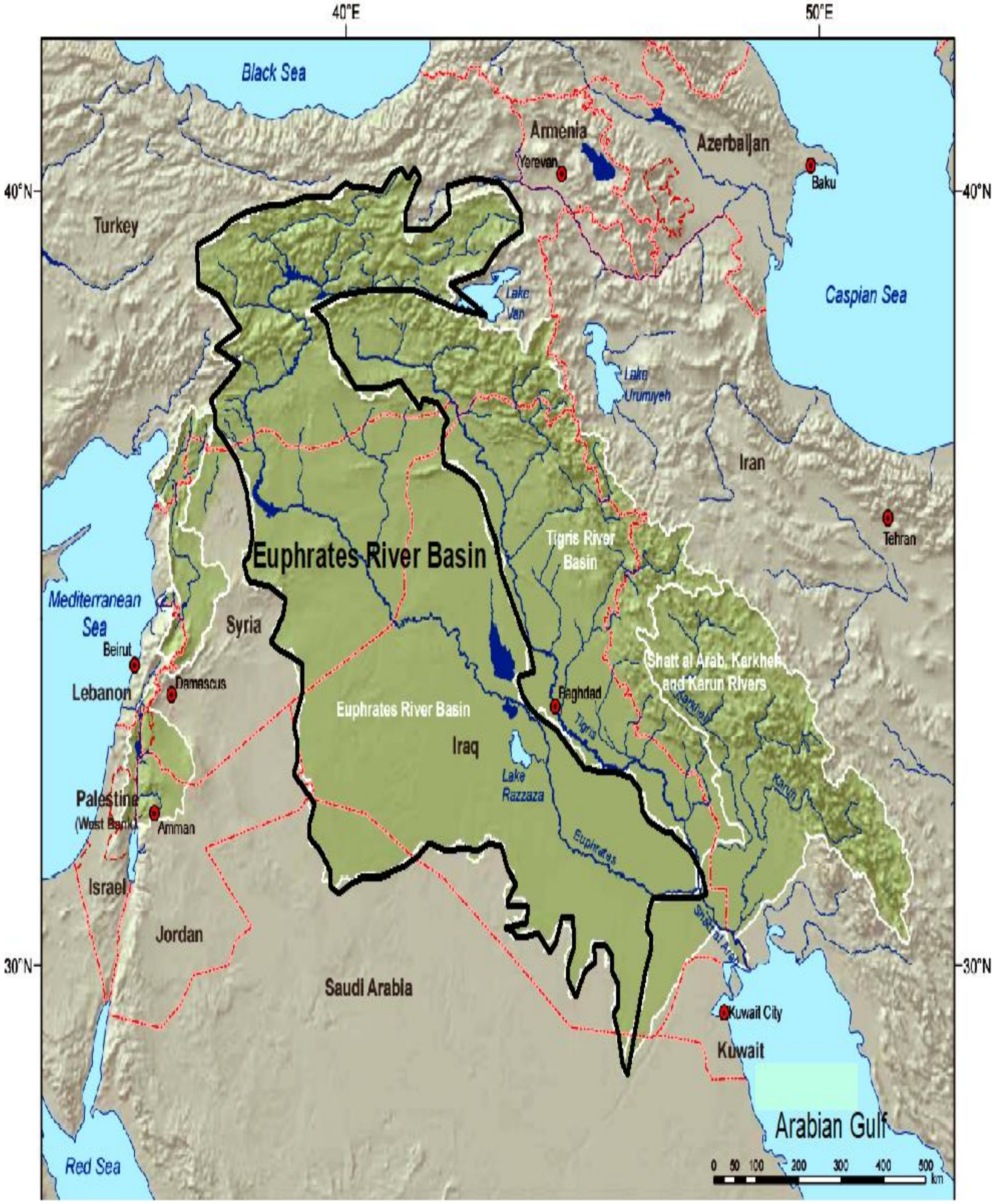

Figure 3.2: Euphrates River Basin (UN-ESCWA-BGR, 2013)

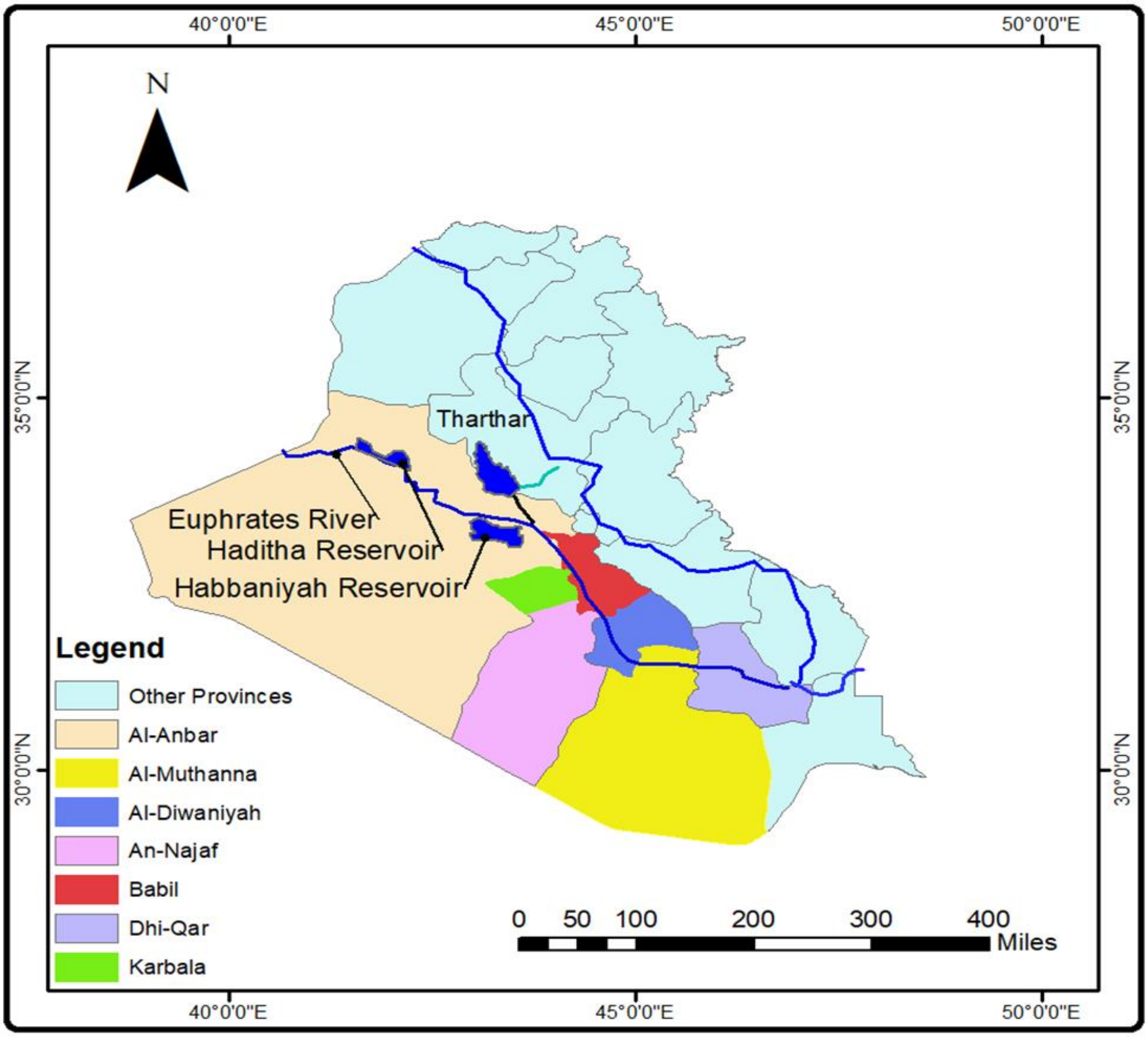

Figure 3.3: Map of the provinces and the main reservoirs on the ERB (www.diva-gis.org/gdata)

3.3.2 Study Area

Dams and many projects were built on the Euphrates River stream for irrigation and hydropower generation. The projects consist of the following:

The Haditha Reservoir is situated on the Euphrates River, approximately 270 km northwest of Baghdad, near the town of Haditha in Iraq. It is created by the Haditha

Dam, which is a 9.4 km long earth-fill dam. The powerhouse of the dam consists of six Kaplan turbine units, with a maximum capacity of 660 MW. The spillway structure comprises six gates. The sill level of the spillway is at an elevation of 134 (m.a.sl). At maximum pool, the spillway has a maximum discharge capacity of 11000 m^3/s. The design operating pool elevation is at 147.0 (m.a.sl), and the reservoir has a storage capacity of 8200 MCM. A satellite view of the Haditha Dam and Reservoir can be seen in Figure 3.4 (NEMP, 2006).

Figure 3.4: Satellite view of Haditha Dam and Reservoir (edited by researcher) (Earth Google Maps,2023)

The Tharthar diversion regulator is make up of two partitions. The left partition consists of four gates, each measuring 8 meters by 7 meters, with a discharge capacity of 600 m3. This partition marks the starting point of the Tharthar -Tigris Canal, which converges with the Tigris River upstream of Baghdad city. The second partition, built perpendicular to the Tharthar-Euphrates Canal, also has four gates measuring 8 meters by 7 meters, with a discharge capacity of 500 cubic meters per second. This regulator controls the flow of water in the Tharthar-Euphrates Canal, which joins the Euphrates River near Habbaniyah City. The Tharthar-Euphrates Canal stretches for 26.8 kilometers and was originally constructed in 1976 to transfer water to the Euphrates River (Abdullah et al., 2019). Figure 3.5 displays a satellite view of the Tharthar Reservoir and the Regulator.

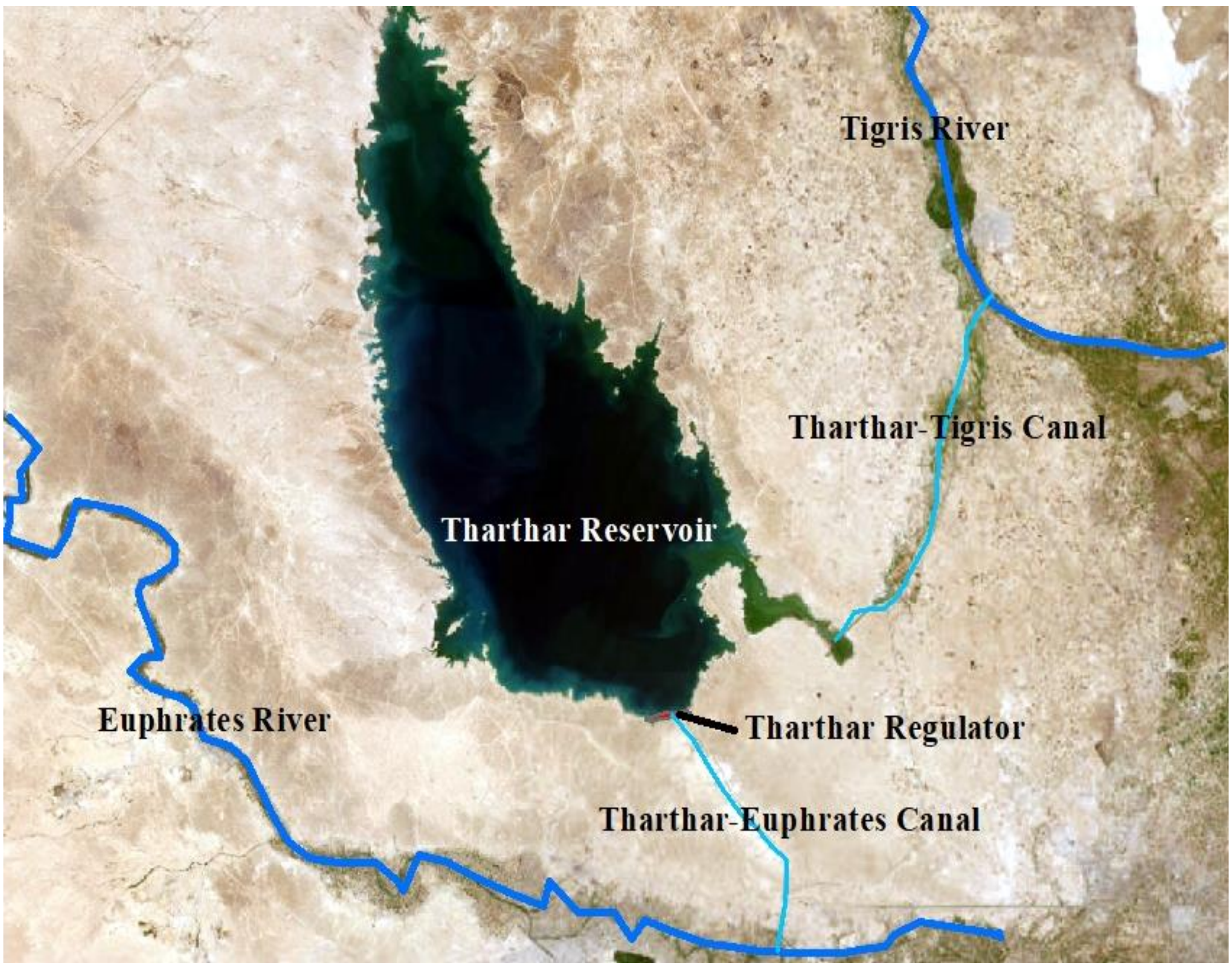

Figure 3.5: Satellite view of Tharthar reservoir and regulator (edited by researcher) (Earth Google Maps,2023)

Until the Haditha dam, with a capacity of 2500 MCM, the Habbaniyah Reservoir was considered the principal project to defend against floods on the Euphrates River (Abdullah et al., 2019). The Habbaniyah Reservoir is located on the Euphrates River, 115 km downstream of Haditha Dam in the Anbar province. The Dibban regulator is located on the canal downstream from Habbaniyah Reservoir, approximately 5 km from its confluence with the Euphrates. This regulator controls the discharges from the Habbaniyah Reservoir (NEMP,2006). Figure 3.6 illustrates the Habbaniyah Reservoir and its regulator.

Figure 3.6: Satellite view of Habbaniyah Reservoir (edited by researcher) (Earth Google Maps,2023)

3.4 Water Evaluation and Planning System

Water Evaluation and Planning (WEAP) System is a model for integrated water resources management. It is designed to help users understand how water resources are allocated and used in a particular region or river basin. Some of the key features of WEAP include:

1. Water Allocation: WEAP allows users to simulate different scenarios for water allocation, including surface water and groundwater sources, to understand how different management strategies might affect water availability.
2. Demand Management: WEAP also includes tools to model water demand, including agricultural, domestic, and industrial uses. This allows users to understand the impact of changes in water demand on overall water availability.
3. Climate Change: WEAP can be used to simulate the impact of climate change on water availability, including changes in precipitation patterns and temperature.
4. Water Quality: WEAP also includes tools to model water quality, including contaminants and pollutants, which can affect water availability and human health.

WEAP is highly recommended for studying and analyzing the research problem at hand. One of its notable strengths is the ability to adjust the complexity level according to specific analysis requirements. This customization feature allows the analyst to account for limitations resulting from limited data availability or other constraints. (Sieber and Purkey,2015). Figure 3.7 illustrates the five main views of the WEAP model.

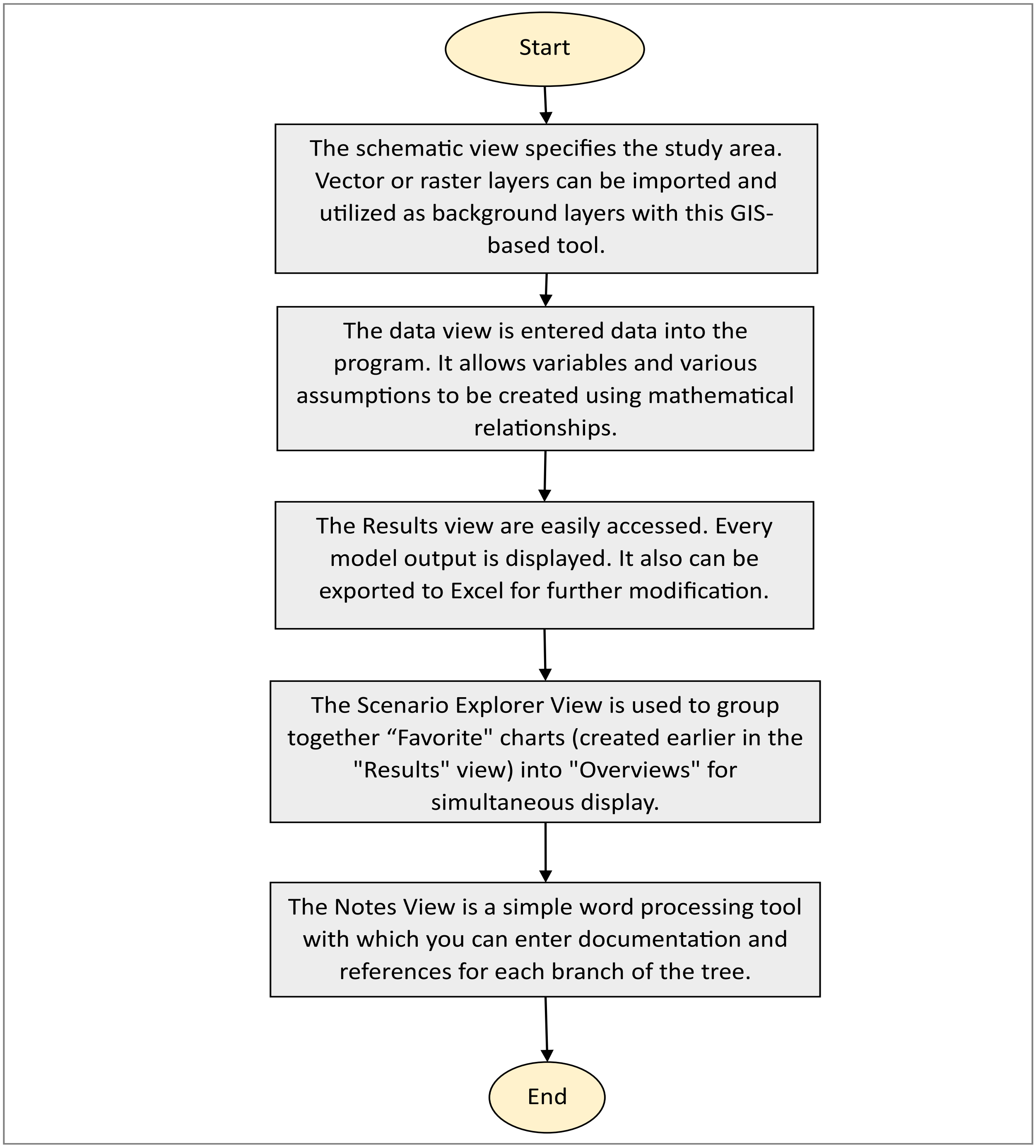

Figure 3.7: Flow chart of the five main views for the WEAP model

3.4.1 Modelling Process of WEAP

The modelling of reservoirs using the WEAP consists of the following steps (Levite et al.,2003):

1. The first step in the process is to provide a snapshot of the system's resources, supplies, and actual water demand.
2. Building scenarios is the next step, which involves creating sets of future trends based on factors such as policies, and other relevant influences on water supply, water demand, and hydrology.
3. The final step is to evaluate the scenarios, considering the adequacy of water resources and assessing the potential environmental impacts associated with each scenario.

3.4.2 Objectives and Methodology for Modeling

The objective of using the WEAP model is twofold. The first objective is to simulate the provinces' future monthly or yearly supply fed from the three reservoirs (Haditha, Tharthar, and Habbaniyah). The second objective is to compare the calculated supply by WEAP and optimization models.

This study presents a methodology for optimizing the operation of multi-objective multiple reservoirs in the ERB, considering climate change, population growth, and industrialization. The utilization of WEAP applications typically involves a series of steps. The first step in the process involves defining the study, which includes establishing the system components and time frame and configuration of the problem. Afterward, the basic parameters are identified, such as the current year and forecast intervals. The methodology of the WEAP Model is depicted in Figure 3.8, providing a visual representation of the flow chart.

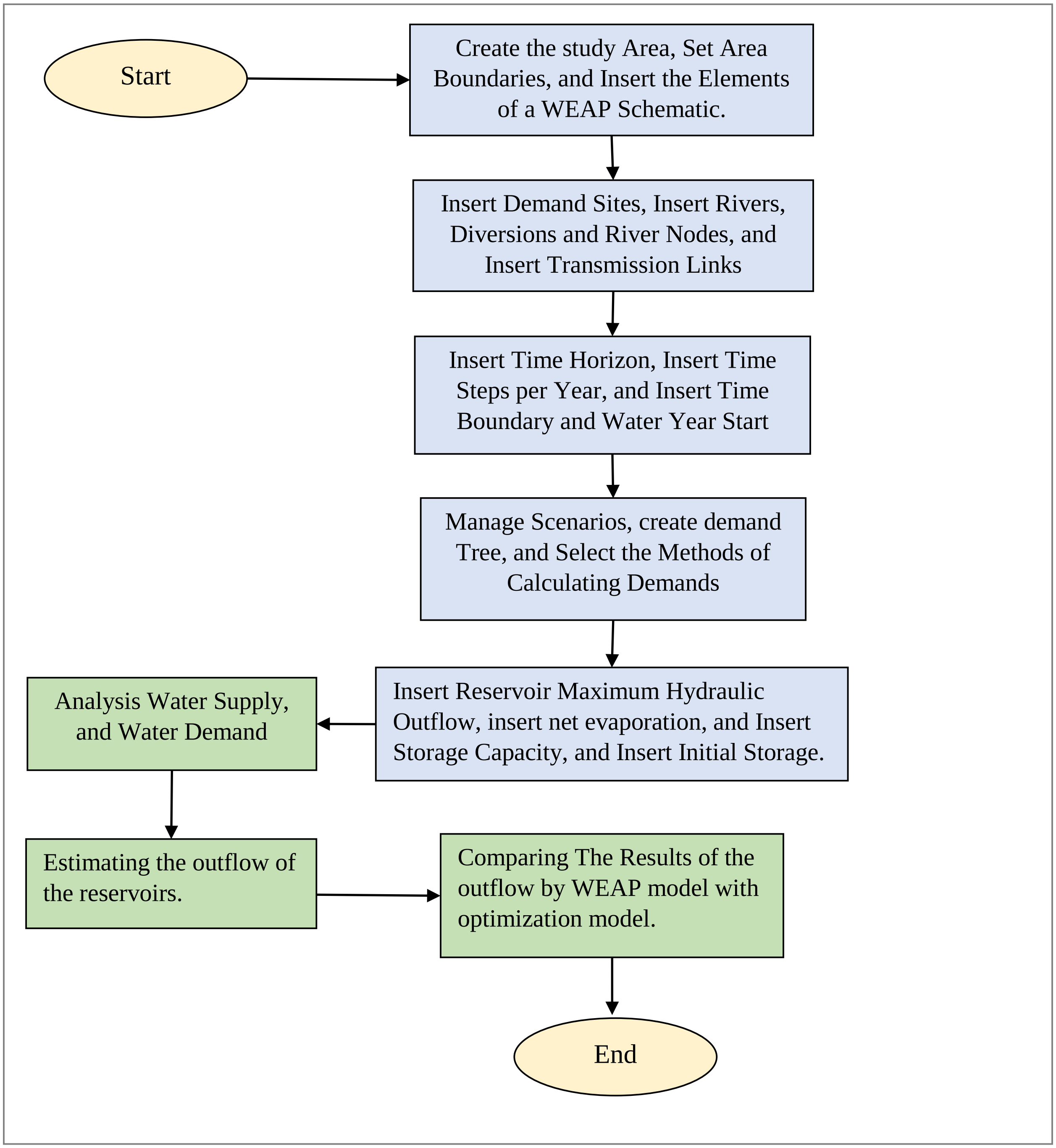

Figure 3.8: Flow chart of the WEAP Model methodology

3.4.3 Euphrates River Basin Modeled using WEAP

The operation scenarios for the three reservoirs have been chosen to match those in the optimization model (outlined in Chapter Five). The optimization model will use three categories of scenarios: the first comprises climate change scenarios, while the second divides inflow scenarios into wet and dry years. The third category includes scenarios involving reduced demand for hydropower, irrigation, environmental, and marshland demand. The same hydrological, climate, reservoir, and sectors demand data used in the optimization model will also be used in the WEAP model. According to the inflow, storage, WSE, and Area recorded from October 2000 to September 2021 by National Center for Water Recourses Ministry in Iraq (NCFWRM,2022), the main scenarios of the operation for the three reservoirs can be derived.

3.4.4 Limitations of the Modelling Process

There are several limitations of the modelling process for WEAP include:

1. Data availability: The accuracy of the modeling process depends heavily on the availability and quality of data in the ERB.

2. Simplifications in the model: The WEAP model involves a simplified representation of the complex hydrological system in the Euphrates River Basin.

3. Climate change uncertainty: The climate change impact on the hydrological system is highly uncertain, and the projections of future climate conditions may be subject to a wide range of uncertainties. This can make it difficult to accurately predict the climate change impact of the reservoirs in the Euphrates River Basin.

4. Assumptions and uncertainties in demand projections: The WEAP model also relies on assumptions and projections of future demand for water, energy, and other resources.

5. Political and social factors: Water resources management in the Euphrates River Basin is influenced by various political and social factors, which may need to be fully accounted for in the modelling process. These factors can significantly impact the management of the reservoirs and the availability of water resources for different users.

3.4.5 Mass Balance Constraints

WEAP's monthly water accounting relies on the fundamental principles of mass balance equations, where total inflows are equated to total outflows, accounting for any alterations in storage, particularly in reservoirs. Every node and link in WEAP have a mass balance equation, and some have additional equations which constrain their flows (e.g., inflow to a demand site cannot exceed its supply requirement, link losses are a fraction of flow). Each mass balance equation becomes a constraint in linear programming.

$$\sum Inflow = \sum Outflow + Addition\ to\ Storage \tag{3.20}$$

which can be rewritten as:

$$Inflow - Outflow - Addition\ to\ Storage = 0 \tag{3.21}$$

Addition to Storage only applies to reservoirs and aquifers. Addition to Storage is positive for an increase in storage and negative for a decrease in storage. Outflow includes consumption and losses (Sieber and Purkey,2015).

Chapter Four

Formulation of Discrete Dynamic Optimization Problem

4.1 Introduction

DP (Dynamic Programming) is a suitable method for solving problems that involve sequential decision-making. These types of problems require decisions to be made sequentially based on the current state of the system. An example of a sequential decision problem is reservoir operation, which involves deciding how much water to release in each period based on the amount of water currently stored (Vedula and Mujumdar, 2005). In the following chapter, we will discuss how DP problems are formulated and solved for concerning the present research problems.

4.2 Overview of Optimization Models for Operating of Reservoirs System

There are two broad categories of models for optimizing the operation of large-scale reservoirs system, namely, deterministic, and stochastic models. In general, the optimization models used for solving such problems require heavy computational resources and storage capacity. Deterministic models provide a single solution based on fixed input values, while stochastic models consider uncertainties and provide a range of potential outcomes, making them more robust in handling real-world variability. To overcome this challenge, a sequential or decomposition approach is often utilized to effectively implement the solution algorithms. In this research work, a deterministic reservoir operation model is adopted. The Deterministic models assume that the inflow into the reservoir is constant and accurately predicted. In this study, the yearly inflow rate is categorized based on whether it corresponds to a wet or dry year. The numerous review in the literature suggests that deterministic methods are the most satisfactory that effectively address the challenges of dimensionality that arise in large-scale systems (Batista et al., 2008; Giuliani et al., 2021; and Saab et al., 2022).

4.2.1 Deterministic Optimization Models for Reservoirs System

The optimization model utilized is deterministic in nature and involves modifying hydrological inputs with a range of equi-probable sequences. The deterministic optimization model is executed once for each input sequence (Vedula and Mujumdar, 2005).

Deterministic reservoir systems are those in which the inflows and outflows are known with certainty. These systems can be modeled using various theoretical and methodological approaches. The governing principle that is based on modeling deterministic reservoir system operation is the mass balance equations that involve using mass balance equations to model the reservoir system. These equations relate the inflow, outflow, and storage of water in the reservoir over time. The basic equation used is (Soares and do Carmo, 2021):

Change in storage = Inflow – Outflow (4.1)

This method requires accurate measurements of inflows and outflows, some common methods used for modeling deterministic reservoir system operation:

1) Linear programming is a mathematical technique that centers on maximizing or minimizing a linear objective function while adhering to a set of linear constraints. In the case of reservoir system operation, the objective function aims to maximize water supply, minimize costs, or achieve a combination of both. The constraints encompass water balance equations, reservoir capacity, and operational constraints. (Lin and Rutten,2016).

2) Dynamic programming: Dynamic programming involves solving a sequence of decision problems over time. In the case of reservoir system operation, the decisions could include the amount of water to release or store at each time step. The objective is to maximize a long-term objective function, such as maximizing water supply or minimizing costs (Myo et al,2020).

4.3 Schematic Diagram of the ERB Hydro-system

The ERB is a complex hydrological system in Iraq. This river basin is a vital source of water for millions of people and plays a crucial role in supporting agriculture, industry, and energy production in the region. Figure 4.1 provides a schematic diagram that outlines the node components of the ERB system, including the main river channel, tributaries, reservoirs, and irrigation canals. The diagram helps to illustrate the intricate relationships and interactions between these components and how they work together to sustain the river basin ecosystem. A river basin ecosystem refers to a complex and interconnected network of living organisms, their physical environment, and the dynamic interactions within a specific river basin or watershed. The water entering from the Syrian-Iraqi border flows through the Generally, a schematic diagram of the ERB system would aim to provide a visual representation of the various components and processes that make up this complex and vital ecosystem. It can help to inform decision-making around water resource management, and sustainable development in the region.

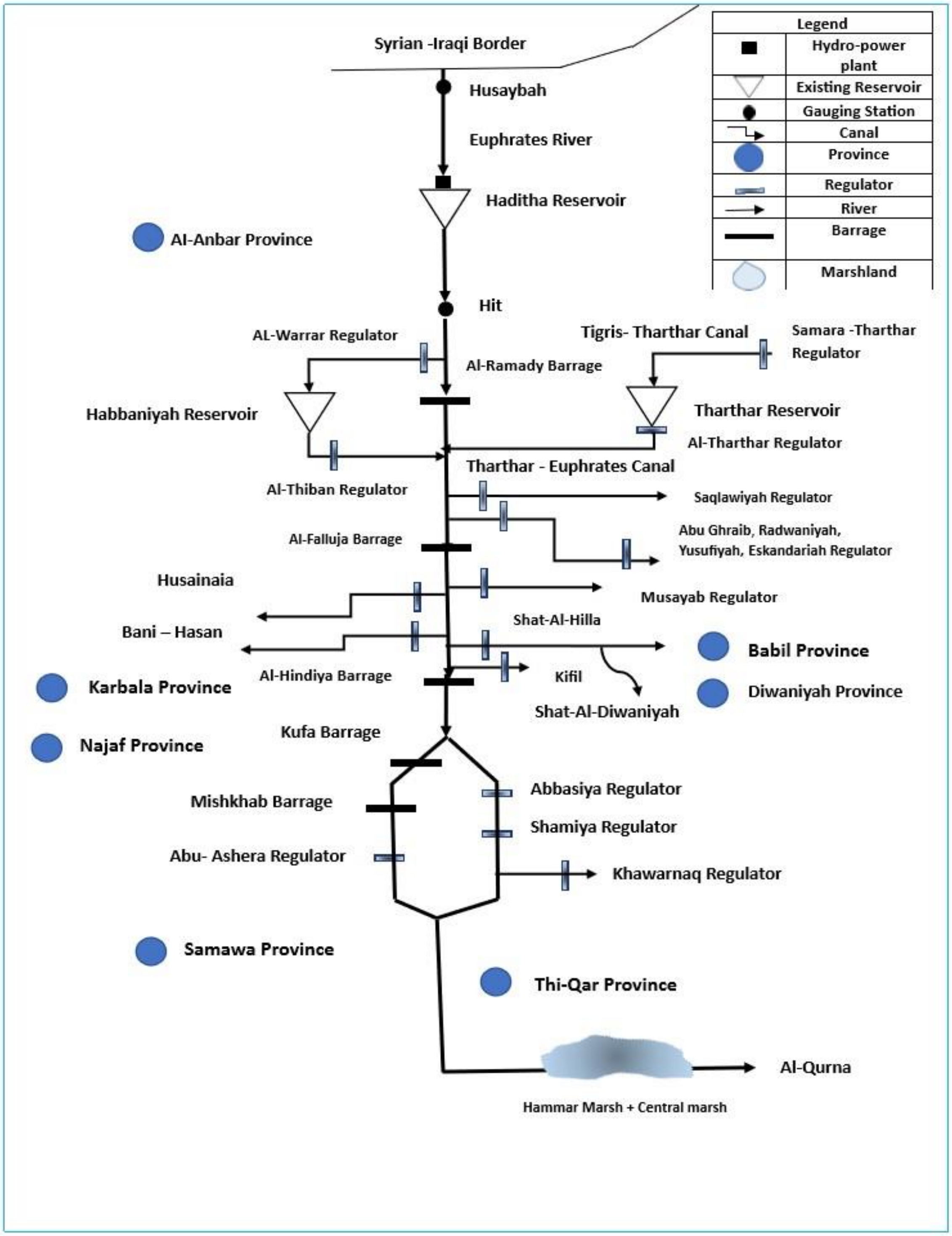

Figure 4.1: Schematic diagram of the ERB system.

4.3.1 Description of the Schematic Diagram

Husaybah gauge station is located upstream of the Euphrates River near the Haditha Reservoir. Haditha Reservoir, located upstream and supplied by a hydropower plant, provides water to the Euphrates River for various purposes, such as generating electricity, irrigation, municipal use, industrial use, and environmental preservation. After the Haditha Reservoir, there is a second gauge station located in the city of Hit, along the path of the Euphrates River. Excess water from the river releases through the Habbaniyah Reservoir via a side canal regulated by the AL-Warrar Regulator. The released water flows back into the Euphrates River via another side canal regulated by Al-Thiban Regulator. The Tigris River feeds the Tharthar Reservoir through the Samara-Tharthar Regulator and controls the released water to the Euphrates River by Al-Tharthar Regulator. The canal that transfers the water from Tharthar Reservoir to the Euphrates River is called the Euphrates Arm.

Many projects of irrigation are situated on the left side of the ERB. These projects released the water by canals and controlled the water by regulators such as Saqlawiyah, Abu Ghraib, Radwaniyah, Yousifia, Eskandariah, Greater Mussaiyab, and Kifil. The area lands of these projects are shared between three provinces Anbar, Baghdad, and Babil.

As the Euphrates River passes through the Thi-Qar Province, it provides water to the Hammar Central Marshes. Finally, the Euphrates River merges with the Tigris River at Qurna. Appendix – A1 displays the minimum and maximum discharge values for the major and minor gauge station, dams, and barrages. Additionally, it includes the design discharge information for the minor barrages and regulators.

4.4 Decision Variables of the ERB Hydro-system

Long-term reservoir operation is a problem that involves determining the optimal release and storage of water in a reservoir over a planning period to minimize expected water losses from system operation. This problem is particularly relevant for the management of hydrological systems and can be implemented in building the mechanism of the network reservoirs in a system, such as the Euphrates and (ERB) Hydro-system, which consists of several reservoirs, including Haditha, Tharthar, and Habbaniyah.

The decision variable, denoted as R_t, represents the optimal release of water from reservoir k at time t, while the state variable, denoted as S_t, represents the storage at time t. Natural inflow of the reservoir, denoted as Q_t, represents the amount of water that flows into the reservoir at time t. The objective of the long-term reservoir operation problem is to find the optimal values of these variables that minimize the expected sum of water losses from system operation over the planning period. This problem is important for the efficient management of water resources, and solutions can be found using discrete dynamic optimization techniques.

Figure 4.2 shows the variables of the ERB Hydro-system, including the reservoirs, inflows, and decision and state variables. It illustrates how the variables are interconnected and how their values change over time as water flows into and out of the reservoirs. By understanding and optimizing these variables, efficient management of water resources in the ERB Hydro-system can be achieved. The maximum and minimum values of the decision and state variables and the natural inflow of the three reservoirs (Haditha, Tharthar, and Habbaniyah) are presented in Appendix – A1.

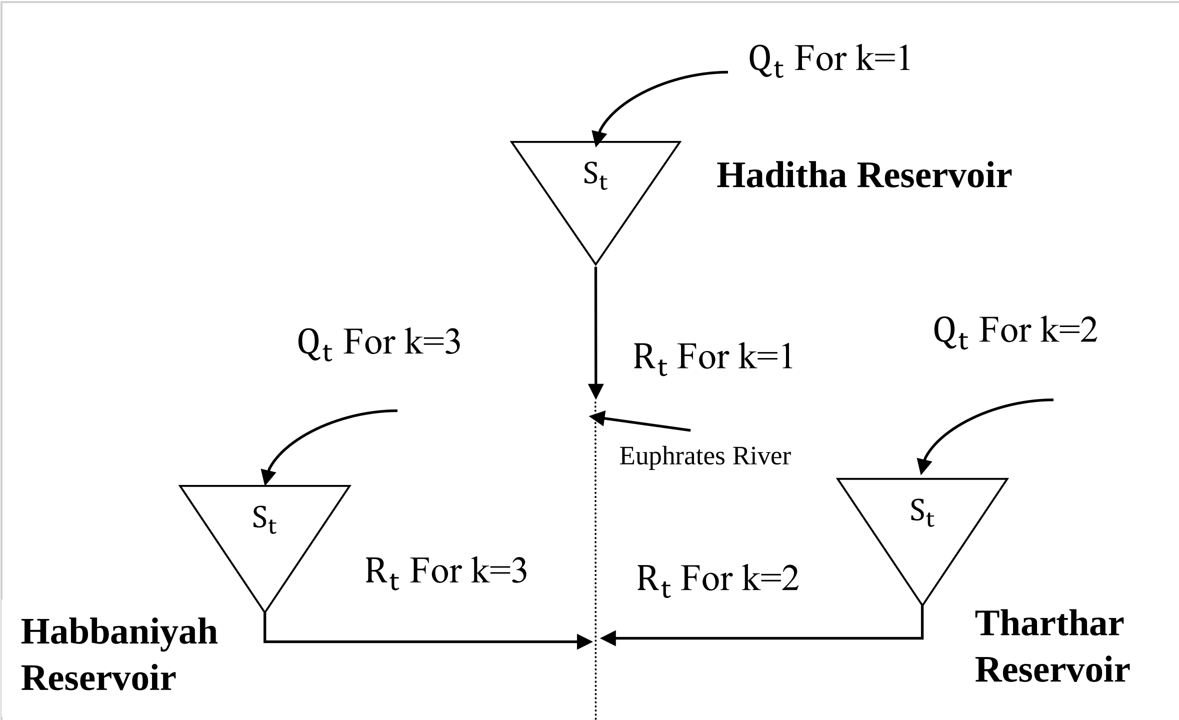

Figure 4.2: Diagram of the decision and state variables of the ERB Hydro-system

4.5 Data Base of the ERB Hydro-system

The inflow data is an essential aspect of the hydrological system as it indicates the amount of water entering the reservoirs from various sources. NCFWRM (2022) has measured the inflow data of Haditha and Tharthar Reservoirs from October 2000 to September 2021, and the Habbaniyah Reservoir inflow data from October 2005 to September 2021. The maximum, minimum, and average inflow data of Haditha, Tharthar, and Habbaniyah Reservoirs are presented in Appendix – A1.

4.6 Effects of Climate Change on The Reservoirs Operation

The changing climate has significant impacts on the hydrological cycle, which in turn affects the precipitation Pr_t, and evaporation Ev_t, into ERB reservoirs. Also, it leads to changes in the irrigation water demand. Hence, understanding the effect of climate change on the optimal operation of reservoirs is essential for sustainable water resources management, and it requires the integration of climate models, hydrological models, and reservoir operation models. This integration can help in identifying the most appropriate reservoir operation strategies under different climate scenarios, which can help in mitigating the adverse impacts of climate change on water resources and maximize the benefits of reservoirs. Individual climate models were processed separately to create a unified dataset for specific time intervals (2020-2039 and 2040-2059) representing the present and future. Relative changes in comparison to a common (RP) (1995-2014) were then calculated based on this dataset. Figure 4.3 shows the flowchart of the climate change effect on the estimation of the decision and state variable R_t and S_t.

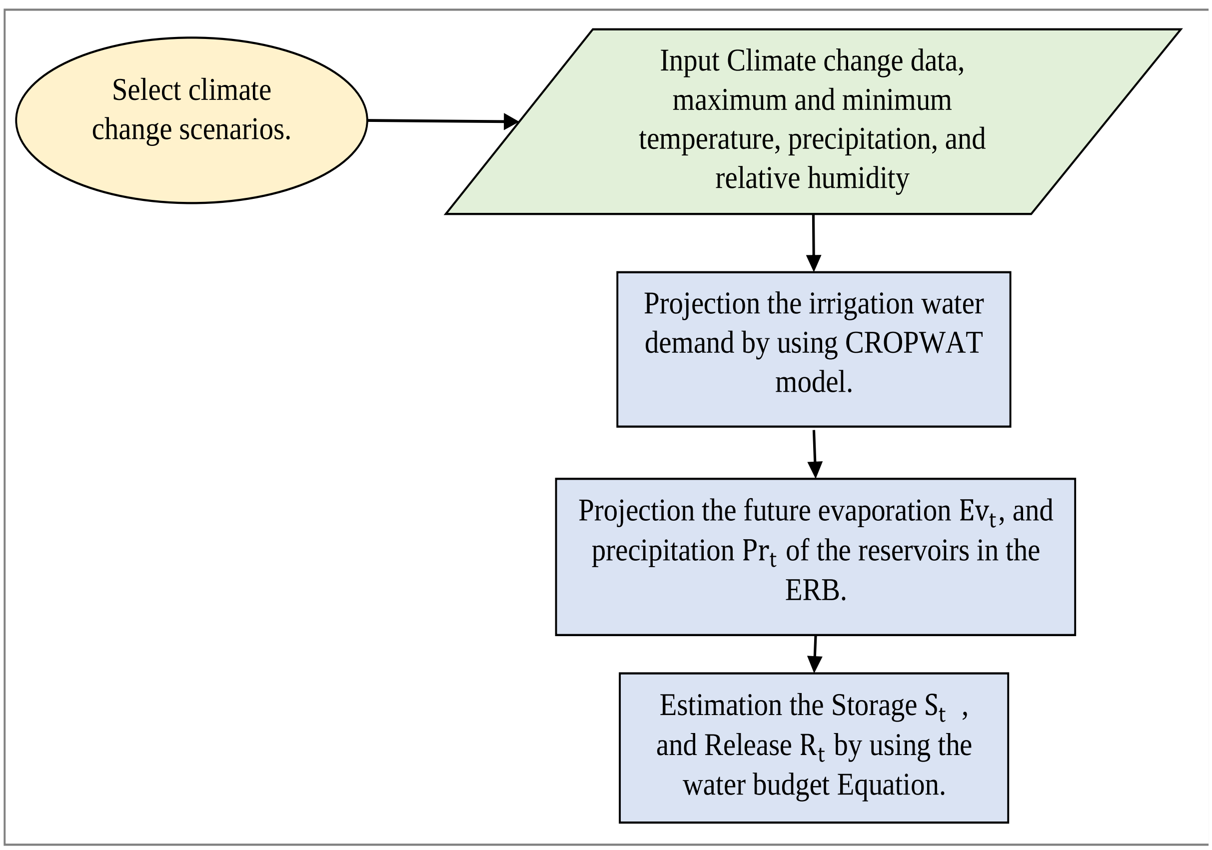

Figure 4.3: Flowchart of the climate change effects on the estimation of the decision and state variables.

4.7 Procedures of the Problem Solution

4.7.1 Discrete Differential Dynamic Programming Mechanism

The DDDP method is an enhanced incremental approach that effectively reduces both computer memory usage and computing time in dynamic programming. This method achieves this by dividing the original complex problem space into multiple smaller subspaces with reduced sizes (Feng et al., 2017).

At each stage *t*, a decision variable R_t must be made to move to the next stage ($t + 1$), associated with the mass balance equation can be referred to as the transition-state equation, which is expressed as follows (Goor,2010).

$$S_{t+1} = S_i + Q_t + Pr_t - Ev_t - R_t \tag{4.2}$$

In which: S_i is the initial storage, R_t is the release from the reservoir, Pr_t is the Precipitation on the reservoir, Ev_t is the Evaporation from the reservoir, Q_t is the inflow of the reservoir. Each decision depends on the system's current state, defined by the vector of state variables S_{t+1} . All variables in the mass balance equation are expressed in units of (MCM). A sequence of optimal decisions constitutes an optimal policy.

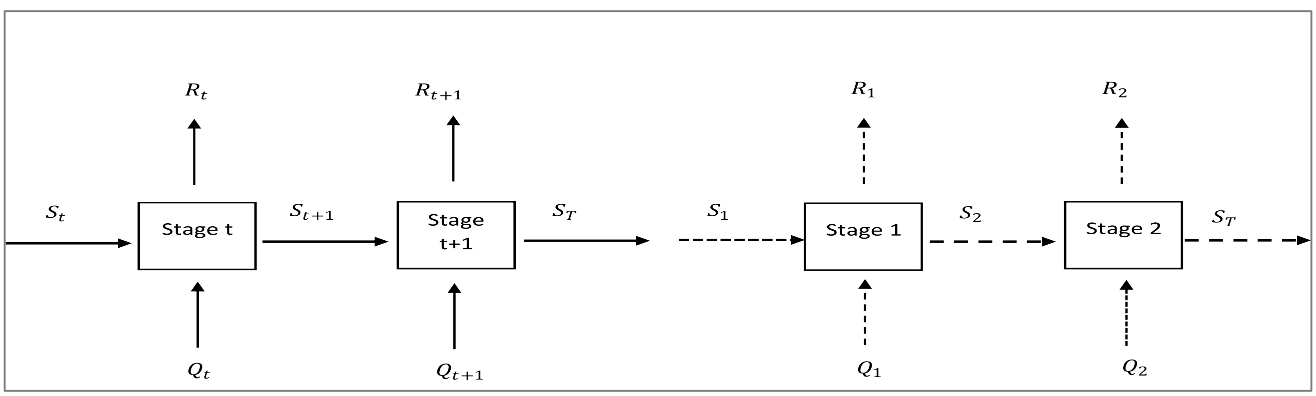

Figure 4.4: Dynamic programming mechanism of the reservoir’s operation

This procedure is illustrated in Figure 4.4 in the context of reservoir operation. It is obvious from Figure 4.4, the mechanism of reservoir operation as a transformation function that takes the state variable S_t and decision variable R_t at time *t* as inputs and produces the state vector S_{t+1}

4.7.2 Selection of the Initial Trajectory and the Corridor Width

In this study, the initial trial trajectory is represented by the initial storage of the reservoirs in the ERB (Haditha, Tharthar, and Habbaniyah). The next step consists of constructing a corridor around the initial trial trajectory, which specifies the limiting values of the state variables used in the optimization of the system. In this study, the width of the corridor around the initial trial trajectory is called δ_t . Where δ_t is the storage increment or change in storage. δ_t can be derived from the Eq. (4.2) and can be represented as the following:

$$\delta_t = Q_t + Pr_t - Ev_t - R_t \quad (4.3)$$

$$S_{t+1} = S_i + \delta_t \quad (4.4)$$

Where S_i is the initial storage or initial trial trajectory.

4.7.3 Derivation of the General Objective Function

Challenges such as climate change scenarios and population growth can have significant impacts on the operation of reservoirs in the ERB, as they can affect both the supply of water available for storage and the demand for water for various uses. These challenges can lead to increased losses in the system, which may need to be addressed through changes in the operation of the reservoir. Additionally, the violation of Iraq's water rights and lack of release to the ERB by neighboring countries can also impact the operation of reservoir systems in Iraq, as it can affect the inflow of water into the system and the amount of water that can be released downstream.

Therefore, the losses' function, F_t is the function described to minimize losses spillage and deficit for the storage and release. This objective function led to optimizing the operation of reservoir systems to face the various challenges and constraints. In a mathematical form, this function can be expressed as:

$$Minimize\ F_t = \sum_{t=1}^{T} Losses\ (S_{t+1}) \quad \text{where t=1,2…T} \tag{4.5}$$

Where F_t is the losses function of the operation reservoir system for the T period, and Losses (S_{t+1}) are the losses of the spillage and deficit for storage. Another objective of the reservoir system's release is to minimize losses related to under or over supply, ensuring that the released water meets the demand accurately.

$$Minimize\ F_t = \sum_{t=1}^{T} Losses\ (R_t) \quad \text{where t=1,2…T} \tag{4.6}$$

Where Losses (R_t) are the losses of the release from the reservoirs.

4.7.4 Derivation of the Constraints

The solution to the multistage decision-making problem represented by Equation 4.2 is not straightforward since (1) the future hydrological conditions are uncertain and (2) the water resources allocation problem is coupled in time. A decision today affects the availability of the resources for the future and therefore the future benefits of the system at each time step of the decision process (Goor, 2010). The relationship between a decision and its operating consequences, given the future hydrological conditions, is illustrated in Figure 4.5. According to Figure 4.5, the objective functions can be derived through the uncertainty associated with future hydrological conditions. The two operation decisions rule can be represented in two cases the deficit in the dry year and the spillage in the wet year.

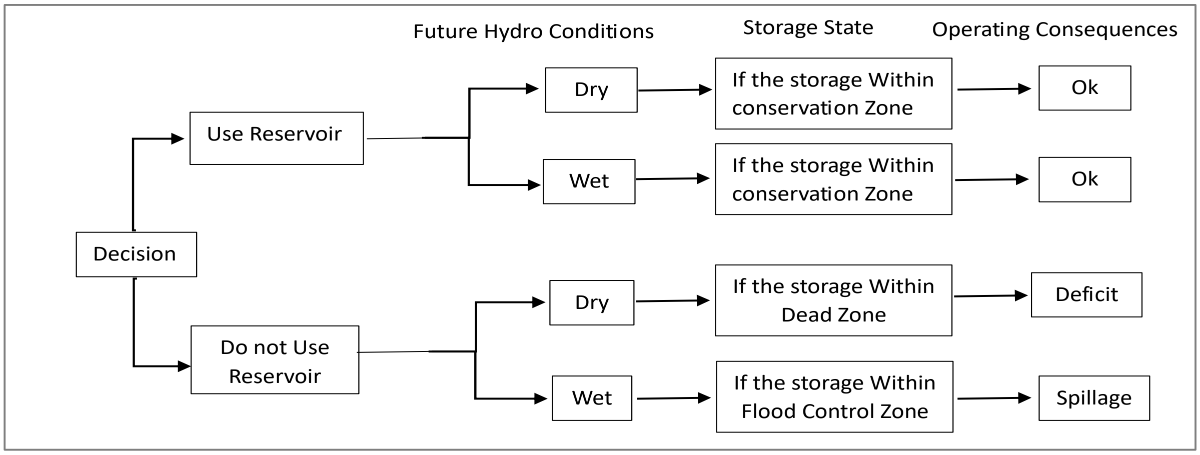

Figure 4.5: Decision tree of the reservoir operation (After Pereira et al., 1998)

4.7.5 Constraints of the Storage losses

The storage constraint imposes specific limits on the reservoir storage at different periods. At the beginning of the first operation period, the initial storage value should be known. In subsequent periods, the storage should remain within the specified range defined by the design criteria of the reservoirs. This can be expressed as:

$$Min.S < S_{t+1} < Max.S \tag{4.7}$$

Where *Min.S and Max.S* are the minimum and maximum storage limits; S_{t+1} is the sequence storage (Goor et al., 2011).

When the storage S_{t+1} more than *Max.S* the Eq. (4.5) can be adopted to calculate the spillage losses of the wet year as follows:

If $S_{t+1} > Max.S$, then $SL\ (S_{t+1}) = S_{t+1} - Max.S$ (4.8)

Otherwise, $SL\ (S_{t+1}) = 0$ (4.9)

The total spillage losses in the wet year can be represented by the following equation:

$$TSL = \sum_{t=1}^{T} SL\ (S_{t+1}) \quad (4.10)$$

Where TSL is the total spillage losses, and $SL\ (S_{t+1})$ are the spillage losses function of the storage. In the second case, if the storage S_{t+1} is less than *Min.S*, the deficit in the dry year can be calculated as follows:

If $S_{t+1} < Min.S$, then $SD\ (S_{t+1}) = S_{t+1} - Min.S$ (4.11)

Otherwise, $SD\ (S_{t+1}) = 0$ (4.12)

$$TSD = \sum_{t=1}^{T} SD\ (S_{t+1}) \quad (4.13)$$

Where TSD is the total storage deficit, and $SD\ (S_{t+1})$ is the storage deficit function.

4.8 Constraints of the Release Losses

The following constraint equation defines the feasible range for the release of water from the reservoir during the *t* month. The range is defined by two parameters: De_t and $Max.PF$. De_t represents the water demand of the environmental, agricultural, municipal, industrial and marshlands sectors in the downstream of the reservoirs. $Max.PF$ represents the maximum permissible flow downstream of the reservoir. This function can be expressed as:

$$De_t \leq R_t \leq Max.PF \quad (4.14)$$

In this case, the function of the spillage losses $SL\ (R_t)$ is used to calculate the amount of water that needs to be curtailed or reduced from the release, which is equal to the difference between the calculated release R_t and the maximum permissible flow ($Max.PF$).

If $R_t > Max.PF$ then $SL\ (R_t) = R_t - Max.PF$ (4.15)

Otherwise, $SL\ (R_t) = 0$ (4.16)

Similarly, the following equation is used when the release from the reservoir during the t month R_t is less than the monthly demand (De_t). In this case, the function of deficit $L\ (R_t)$ is used to calculate the amount of water that needs to be augmented or increased in the release, which is equal to the difference between the calculated release R_t and maximum permissible flow downstream of the reservoir ($Max.PF$). The following set of equations represents the criteria for calculating the losses as follows:

If $R_t > Max.PF$, then $L\ (R_t) = R_t - Max.PF$ (4.17)

Otherwise, $L\ (R_t) = 0$ (4.18)

$TLR = \sum_{t=1}^{T} L(R_t)$ (4.19)

Where TLR is the total losses due to release, $L(R_t)$ is the losses of the release. The second set of the constraint equations defines the feasible range for the release of water from the reservoir during the t month. The range is defined by two parameters: $Min.PF$ and De_t. $Min.PF$ represents the minimum permissible flow downstream of the reservoir. This function can be expressed as:

$Min.PF \leq R_t \leq De_t$ (4.20)

If $R_t < Min.PF$ then $L\ (R_t) = R_t - Min.PF$ (4.21)

Otherwise, $L\ (R_t) = 0$ (4.22)

If $R_t > De_t$, then $L\ (R_t) = R_t - De_t$ (4.23)

Otherwise, $L\ (R_t) = 0$ (4.24)

These functions are important tools for water managers to ensure that water resources are managed sustainably and efficiently. By controlling the release of water from the reservoir within the feasible limits, these functions help to balance the competing demands for water among various stakeholders, such as agricultural, municipal, and industrial users, and help to maintain the environmental and marshland requirements of the downstream ERB.

4.9 Water Quality Release Constraints

The constraint described in the following equation is related to the management of water quality in reservoirs. Specifically, it is used to ensure that the concentration of Total Dissolved Solids (TDS_t) in the released water from the reservoir is within acceptable limits. The water quality constraint considers the TDS_t as the significant controlling parameter. Therefore, the concentration constraint of the reservoir water released can be represented as:

If $TDS_t < M.AL.TDS_t$ (4.25)

If $TDS_t \geq M.AL.TDS_t$, then R_t=0 (4.26)

Otherwise, $R_t = De_t$ (4.27)

TDS_t is the total dissolved solid of the reservoir water during the *t* month (mg/l), and $M.AL.TDS_t$ is the Maximum Allowable Total Dissolved Solid. The function checks if the TDS_t concentration in the reservoir water during the t month TDS_t is greater than the maximum allowable TDS_t concentration $M.AL.TDS_t$. The reason for this function is to protect the downstream water quality from being negatively impacted by high TDS_t concentrations. Ensuring that the TDS_t concentration in the released water is within acceptable limits, this function helps to maintain the downstream water quality and ecosystem health. Overall, this function is an important tool for water managers and engineers to manage the water resources sustainably and responsibly, while also ensuring that the water quality is protected. By balancing the competing demands for water use and quality, this function helps to ensure that the reservoirs can be used for a range of purposes, including water supply, irrigation, and recreation, while also minimizing the environmental impacts.

4.10 Hydropower Constraints

The constraint described in the following equation is related to the operation of a hydropower plant. Specifically, it is used to regulate the outflow Qp_t from the power-generating outlets of the plant based on the level of water in the reservoir. This constraint depends on the maximum outflow from the power generating outlets *(Q.max)* of the hydropower unit in the Haditha reservoir. The constraint of the hydropower generation water released can represent as:

$$Q.min \leq Qp_t \leq Q.max \tag{4.28}$$

$$\text{If } Qp_t > Q.max, \text{ then } Qp_t = Q.max \tag{4.29}$$

$$\text{If } Qp_t < Q.min, \text{ then } Qp_t = Q.min \tag{4.30}$$

The function checks if the flow through the power outlets in the reservoir for the next time step Qp_t is more than maximum outflow from the power generating outlets *(Q.max)*, then the Qp_t is equal to *Q.max* . Also, it is less than *Q.min*, this means that the power-generating outlets will be shut down, and no water will be released from the reservoir for power generation. The following constraint describe the relation between WSE of the Haditha Reservoir WL_t and the minimum and maximum WSE of the Haditha Reservoir *WL. mini* and *WL. max*.

$$WL.Mini < WL_t < WL.max \tag{4.31}$$

$$\text{If } WL_t \leq WL.Mini, \text{ then } WL_t = WL.Mini \tag{4.32}$$

$$\text{If } WL_t \geq WL.max, \text{ then } WL_t = WL.max \tag{4.33}$$

Generally, these functions are a crucial tool for hydropower plant operators to manage the water resources sustainably and optimally, while also meeting the demands for electricity. By balancing the competing demands for water and power, this function helps to ensure that the hydropower plant can operate reliably and efficiently.

4.11 Methodology of the Optimization Model

The purpose of the model is to optimize the management of a reservoir system by determining the optimal release of water from the reservoir for various uses while meeting constraints related to storage, water supply, hydropower generation, water quality, and other factors. Figure 4.6 shows the flowchart of the methodology for the optimization model. The flowchart outlines the main steps involved in the optimization process, starting with the collection of data on the reservoir system, such as its capacity, inflows, and outflows. The data is then used to build a mathematical model of the system, which is used to simulate the reservoir's behavior under various scenarios and conditions such as climate change, inflow, and operation scenarios. The next step involves setting up the optimization problem, which involves defining the constraints and the objective function. The objective function specifies the goal of optimization, such as minimizing the losses of the deficit and spillage of the storage and release. The constraints represent the limits and requirements that must be met in the optimization, such as minimum and maximum storage, and minimum and maximum permissible outflow. The optimization algorithm is then applied to the problem, using the DDDP technique to find the optimal solution that meets the defined objective and constraints. The solution is then evaluated and verified through evaluation criteria analysis and simulation, to ensure that it is robust and reliable under different conditions. Overall, the flowchart provides a framework for systematically and efficiently optimizing the management of reservoir systems, while balancing multiple objectives and constraints.

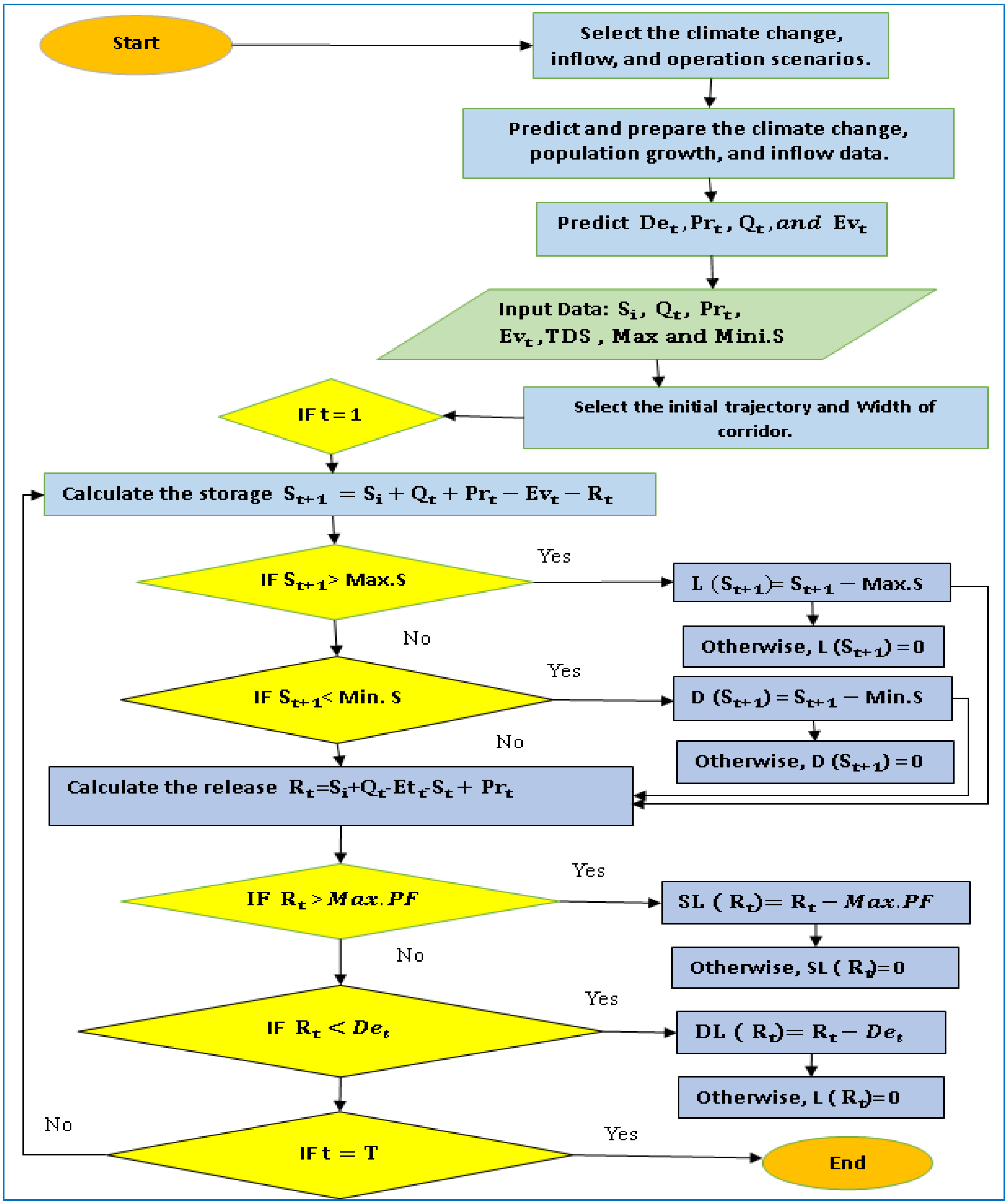

Figure 4.6: Flowchart of the methodology for the optimization model.

Chapter Five

Data Sources and Methods Under Consideration

5.1 Impacts of Future Climate Scenarios

Different future climate scenarios known as SSPs are associated with distinct pathways of societal development. These scenarios project a range of temperatures and total radiative forcing levels by 2100, from 'low' in SSP1-1.9 to 'high' in SSP5-8.5 and show both simulated and observed changes in climate across continents, and globally up to 2014 compared to the 1995-2014 average. Warming is projected to reach 1.9°C under SSP1-1.9 and 8.5°C under SSP5-8.5 by the year 2100, respectively. The scenarios of future climate change for global surface temperature presented by the Intergovernmental Panel on Climate Change (IPCC) in 2021 are significant because they provide a range of possible outcomes that can help inform policy decisions and guide mitigation efforts to limit the impacts of climate change. By exploring the different scenarios and their potential impacts, decision-makers can better understand the risks of different courses of action and make informed choices about how to address the challenges of climate change.

For the provinces located along the Euphrates River, three scenarios were chosen in this study as shown in Figure 5.1. The data for the initial scenario was derived from a reference period extending from 1995 to 2014. Subsequently, the following scenarios, aligned with SSPs 2.6 and 4.5, presented climate change data for the timeframes of 2020 to 2039 and 2040 to 2059, respectively.

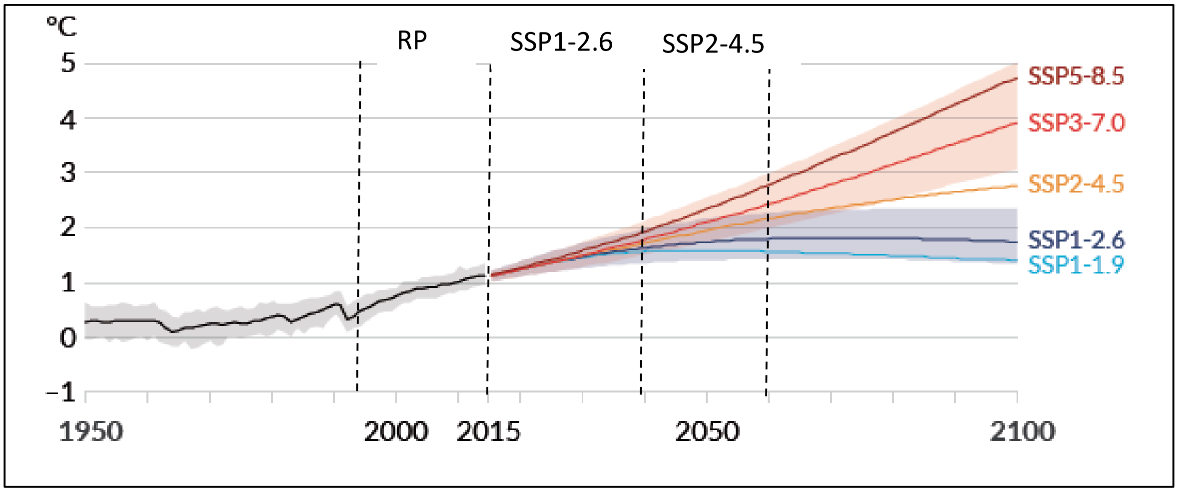

Figure 5.1: Scenarios of the future climate change for the global surface temperature (IPCC,2022).

5.1.1 Climate Change Knowledge Portal

This study utilized climate change data sourced from the Climate Change Knowledge Portal (CCKP). Specifically, the latest CMIP6 collection from the IPCC's Sixth Assessment Report was used. The researcher selected this data because it is widely recognized as a reliable and comprehensive source of information on climate change and is frequently used by researchers. Additionally, the IPCC is a leading authority on climate science, and its reports are among the most authoritative and up-to-date sources of information on climate change (El-Rawy, 2023).

Three scenarios (RP, SSP1:2.6, and SSP2:4.5) of climate change data were used to estimate the irrigation water demand of crops in Anbar, Babil, Baghdad, Diwnaiyah, Karbala, Najaf, Muthana, and Thi-Qar. The reference period for this analysis utilized the data acquired from 1995 to 2014.

The additional scenarios used in this study, namely SSPs 2.6 and 4.5, reflect the projected climate data from 2020 to 2039 and 2040 to 2059 for the provinces within the Euphrates River Basin (ERB) in Iraq. These scenarios provide information on the minimum and maximum temperature, precipitation, and relative humidity based on different levels of greenhouse gas emissions. The study examines the potential impact of these climate change scenarios on the hydrological system of the ERB, particularly in terms of the operation of reservoirs. Appendix – A2 presents the details of the parameters for the maximum and minimum temperature, precipitation, and relative humidity.

5.2 Requirements for Developing an Optimization Model

5.2.1 Demands for Irrigation Water

The present and potential weather data were inputted into CROPWAT-8, considering the climate change scenarios SSP1-2.6 and SSP2-4.5 relative to the period of 1995-2014. Values of crop coefficient vary among the crop species during the growing period of the same crop. Typical trends represent the crop coefficient curve during the growing period shown in Figure 5.2. As shown in this figure, only three values are required to describe and construct the crop coefficient curve: those during the initial stage (Kc initial), the mid-season stage (Kc-mid), and that the end of the late season (Kc-end) (Allen et al.,1998).

The Food and Agriculture Organization (FAO) calculated the crop coefficient factor crops (Saeed, 2022). Also, the average maximum plant heights, and the crop development stages are collected from data base of the CROPWAT 8 Software and (FAO,1998). The coefficients crops, maximum crop heights, and the lengths of crop development stages for various planting periods (days) are shown in the Appendix – A3.

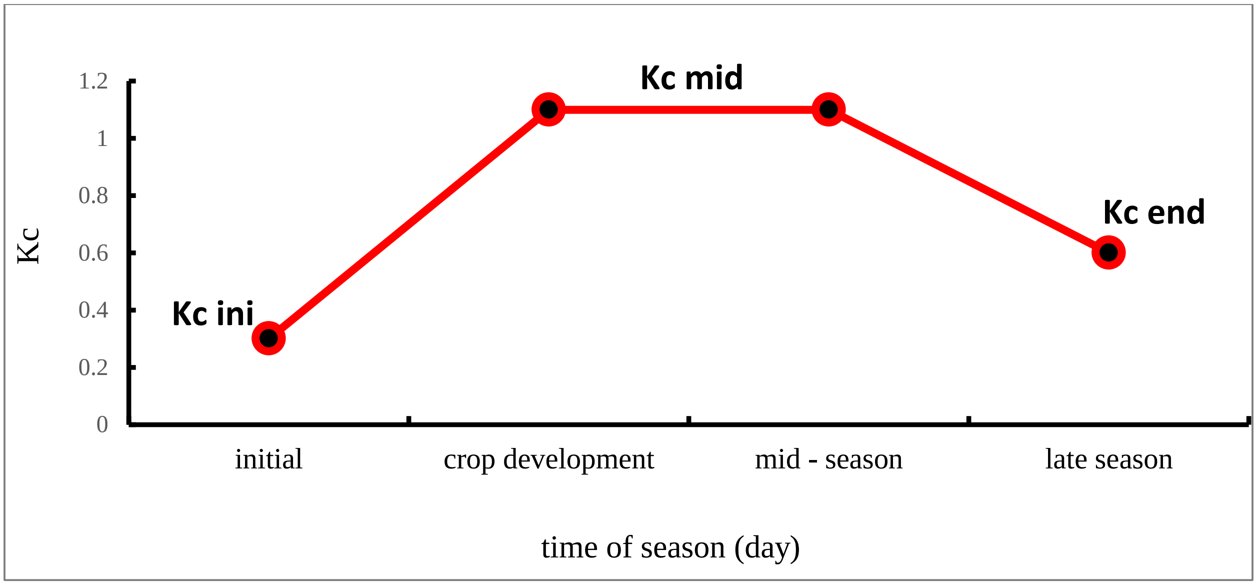

Figure 5.2: Crop coefficient factor curve (After Allen,1998)

5.2.2 Irrigated Areas

The net irrigated area depends on water supply from the Euphrates River was 1,118,807 hectares (JICA, 2016). The ERB provinces, namely Baghdad, Babil, Najaf, Diwaniyah, Muthanna, Karbala, Anbar, and Thi-Qar, cultivate a variety of strategic crops including 32 crops like barley, vegetables, wheat, citrus, and rice. The irrigated area for 28 projects spread across these provinces is given in Appendix – A3.

5.2.3 Projection of Municipal Water Demand

5.2.3.1 Projection of resident number

Projections are being conducted by the United Nations in 197 countries, including Iraq. These projections utilize models that consider the changing fertility rates in each respective area. Consequently, the annual percentage data on population growth is obtained from the United Nations in the form of a report known as the World Population Prospects in 2019 (WPP, 2019). Figure 5.3 shows the annual percentage change in Iraq's population growth. The last census in Iraq was in 1997; after that date, only estimates by the Ministry of Planning (MoP) in Iraq. The overall Iraqi population trends and the early growth rates were calculated based on these values. MoP in Iraq conducted population estimates in 2009 according to (1997) census (NDP, 2013). Figure 5.4 shows the population for the provinces in the ERB except for Baghdad because the Tigris River feeds it as drinking water and other domestic demand. Figure 5.5 shows the population in the provinces from 2009 to 2060.

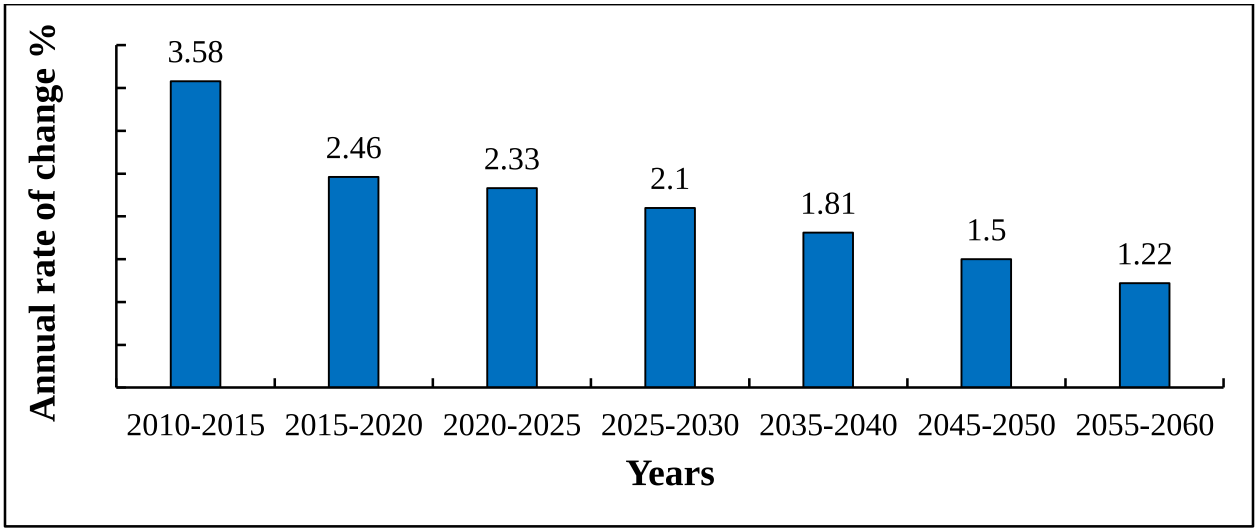

Figure 5.3: Rate of the population growth as a percentage (After WPP,2019).

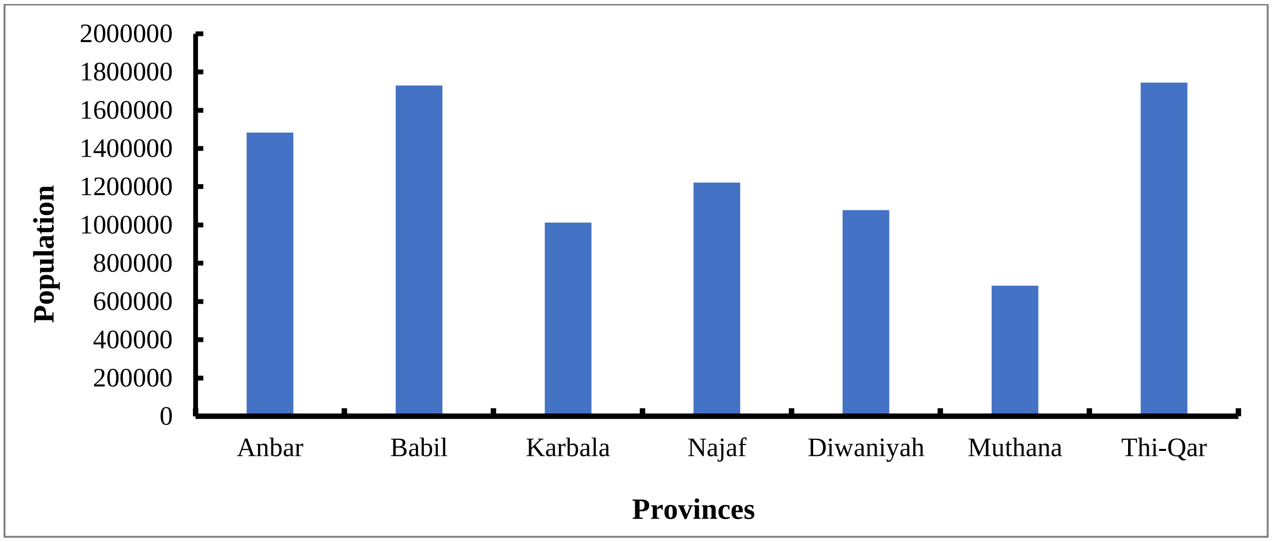

Figure 5.4: Population per province in 2009 in the study area (After NDP,2013).

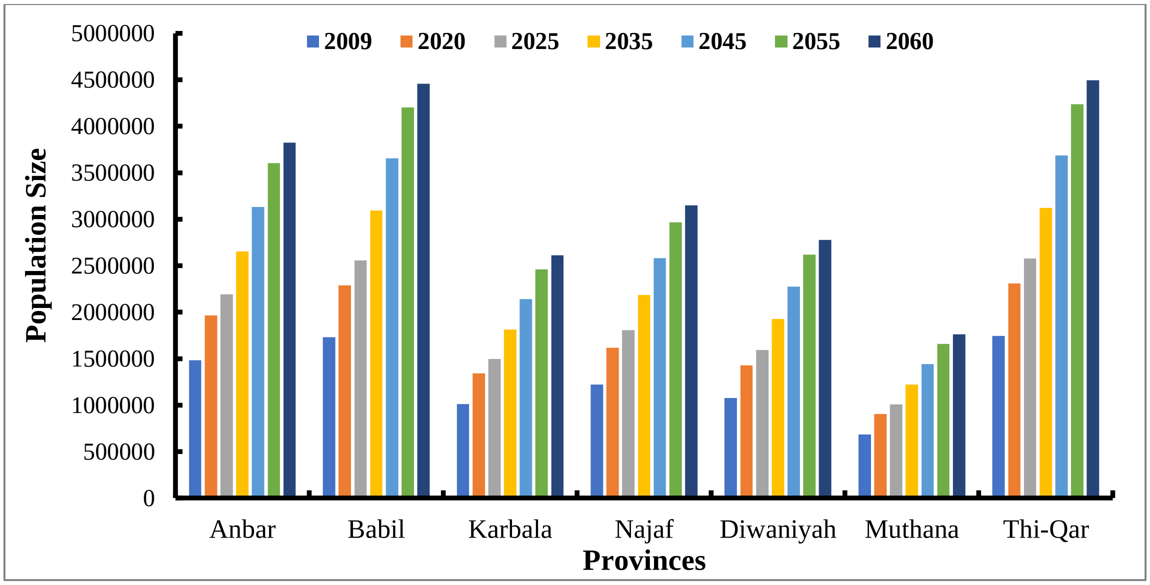

Figure 5.5: Projection of population size for the provinces from 2009 to 2060

5.2.3.2 Estimation of Municipal Water Demand

The Iraqi Ministry of Water Resources (MoWR) provided an estimation of the daily output of treated water. The study conducted to gather information on the treatment capacities of WTPs and CWTPs considered different water availabilities and demands in Iraq. Typically, WTPs are in central cities, while CWTPs are associated with districts and subdistricts. As a result, their treatment capacities vary based on the population they serve (Al-Janabi, 2019).

The SWLRI (2014) supplied data on the design capacity in cubic meters per second (m^3/s) for each of the Iraqi governorates. Al-janabi (2019) presented this information in Table 5.1, specifically focusing on the actual capacity of Water Treatment Plants (WTPs) and Compact Water Treatment Plants (CWTPs) at the governorate level.

Table 5.1: Capacity of Water Treatment Plants (WTPs) and Compact Water Treatment Plants (CWTPs) (After Al-janabi, 2019)

Actual Capacity (m^3/d)			
Governorate	WTBs	CWTPs	Total
Anbar	394418	177003	571421
Babil	245920	502408	748328
Karbala	242620	215283	457903
Diwaniyah	198773	188531	387304
Najaf	248960	233270	482230
Thi-Qar	209140	277182	486322
Muthanna	157017	114945	271962

By dividing the capacity of WTPs and (CWTPs) extracted data from Table 5.1 by the population for the provinces in Figure 5.6, it is possible to calculate the water demand per capita data for the years 2020 to 2060. Figure 5.6 presents the daily water demand for the provinces during the period from 2020 to 2060.

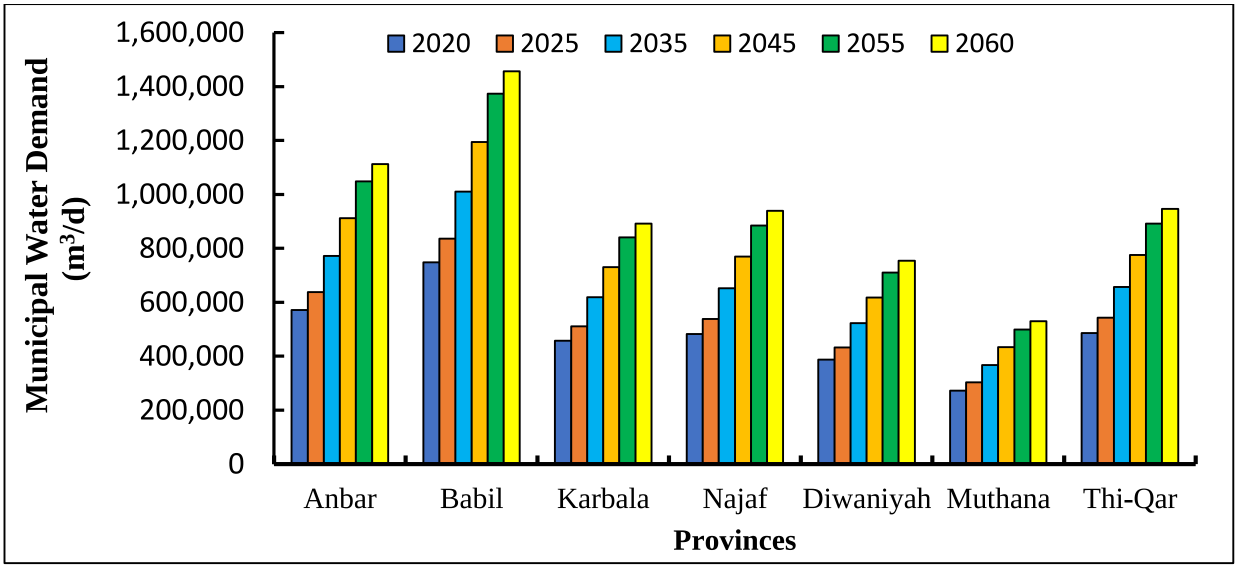

Figure 5.6: Projection of municipal water demand for the study area governorates from 2020 to 2060

5.2.4 Projection of Marshlands Water Demand

5.2.4.1 Introduction

The Hammar Marsh, renowned as one of Iraq's largest marshlands, is situated to the south of the Euphrates River, just before its confluence with the Tigris River at Al Qurna City. This stretch of the river runs from Al Nasiriyah City in Al Nasiriyah Governorate to Chibaeich City, located north of Basrah Governorate (Al-Merib and Jabber, 2019).

The area of the Central Marsh is situated between Missan to the north, Thi - Qar to the south and west, and Basrah to the south and east. The Central Marsh is encompassed by the Tigress River to the east and north, and the Euphrates River to the south (Fazaa et al,2018).

In terms of geography, the Iraqi marshes encompass a system of three main interconnected wetlands: the Central, and Hammar marshes, located in the southern region of Iraq. These marshes converge and flow into the Shatt al-Arab, ultimately directing these riparian waters towards the river's mouth and eventually out into the Arabian Gulf (Guarasci,2011). Figure 5.7 shows the location of the Marshes downstream of the ERB.

5.2.4.2 Estimation the Marshes Water Consumption

In 2016, the Japan International Cooperation Agency (JICA) presented data on the projected consumption of the marshes until 2035, which was conducted by the SWRLI (2014). According to the data, the Hammar and Central marshes receive 75% of their water from the Tigris River and 25% from the Euphrates River. Table 5.2 displays the annual consumption of the marshes before and after the reduction in the Euphrates River's contribution. Additionally, it provides the annual consumption excluding Hawizeh, which amounts to 1460 million cubic meters (MCM). To generate the demand data for the Hammar and Central Marshes from 2022 to 2060, can refer to the information presented in Table 5.2. Figure 5.8 depicts the projected water consumption for the marshlands based on the projected data by SWRLI (2014).

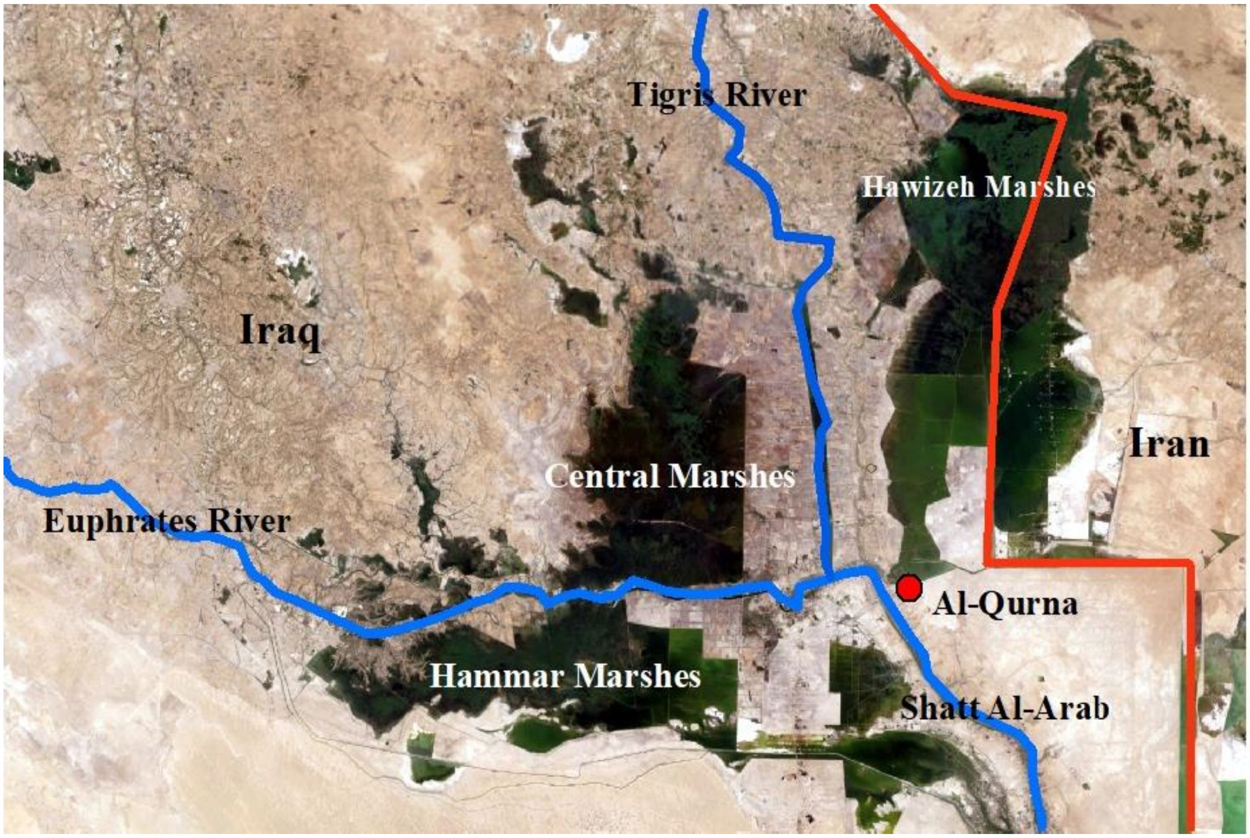

Figure 5.7: Marshes Locations in the ERB (edited by researcher) (Earth Google Maps,2023)

Table 5.2: Consumption water of the marshes (After SWRLI,2014).

Description	Annual Water Consumption (MCM)				
	2015	2020	2025	2030	2035
Total marshland water consumption	5388	7037	6554	6395	5825
marshland water consumption after excluding Hawizeh water consumption	3928	5577	5094	4935	4365
Net marshland water consumption = marshland water consumption after excluding Hawizeh water consumption×0.25	982	1394.25	1273.5	1233.75	1091.25

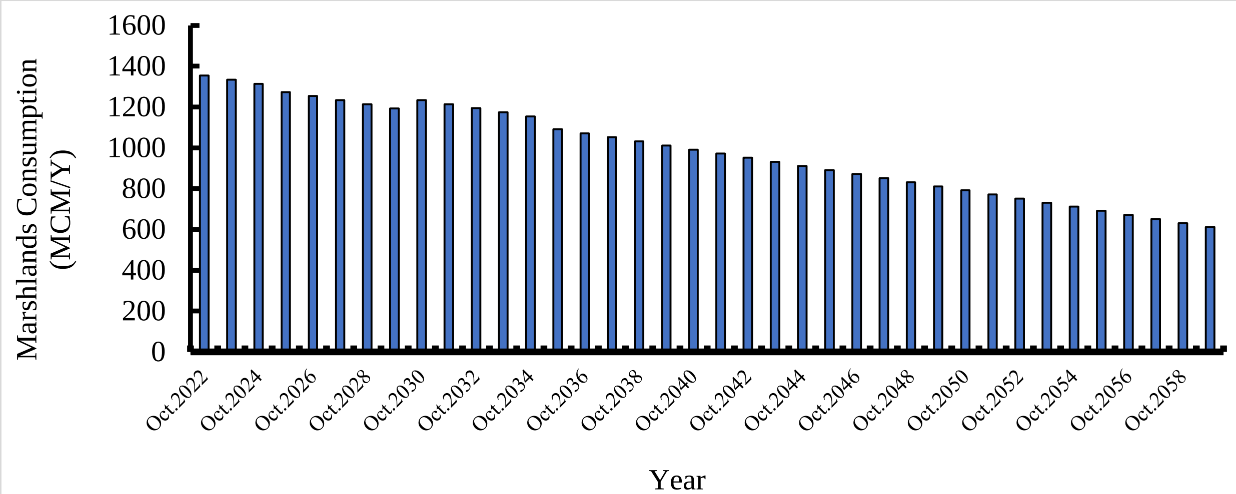

Figure 5.8: Projection of marshlands water consumption

5.2.5 Projection of Environmental Water Demand

To preserve aquatic life and ensure sustainable environmental protection for the water system, it is crucial to maintain minimum flow requirements. The SWLRI (2014) has provided recommendations for the minimum environmental flow that should be sustained in the Euphrates rivers, considering the current water conditions. In this study the values of downstream Haditha Reservoir equal 95 m^3/s from November to May, and equal 207 m^3/s from January to October (SWRLI, 2014).

5.2.6 Projection of Hydropower Water Demand

The hydro-power station is a vital component of Haditha dam and comprises six vertical turbines with a combined capacity to generate 660 MW. The Haditha dam serves multiple purposes, including hydroelectric power generation and regulation of the Euphrates River flow. In Appendix – A3, detailed information and hydraulic data about the Haditha turbines can be found, including upstream water levels and flow rates (Li et al., 2018). Power production can be expressed mathematically as a following:

$$P_t = (EF \times Qp_t \times \gamma \times H_t) /1000 \quad (5.1)$$

Where P_t is the power production, (MW); EF is power-generation units' efficiency, taken in this study as (90 %); Qp_t is the flow through the power outlets (m^3/s); γ is the unit weight of water, taken as (9.81 KN/m^3) (Yahya, 2013). Based on available hydraulic data can be calculated the water level of the Haditha Dam. The following equation expresses the subsequent relationship:

$$H_t = WL_t - WLr_t - h_l \quad (5.2)$$

H_t is the rated head (m), WL_t is the reservoir water level (m.a.s.l); WLr_t is the water level of the river (m.a.s.l); h_l is the head losses where equal 3m (Yahya, 2013). The downstream water level in the Euphrates River WLr_t can be calculated by Ali, (1994).

$$WLr_t = 0.1406 \ (Qp_t + 919.46)^{0.56} + 94.04 \quad (5.3)$$

5.2.7 Projection of Industrial Water Demand

The industrial water demand in Iraq can be categorized into different sectors, including oil fields and refineries (managed by the Ministry of Oil), thermo-power plants (under the control of the Ministry of Electricity), and other industries primarily supervised by the Ministry of Industry. (SWLRI, 2014) obtained industrial water consumption data and presented it as a report for Ministry of Water Resources in Iraq. This study estimated the industrial water consumption for Iraq's provinces for the years 2010, 2015, 2020, 2025, 2030, and 2035. The final projections of industrial water withdrawals for all sectors are presented in Figure 5.9 (Al-Janabi, 2019).

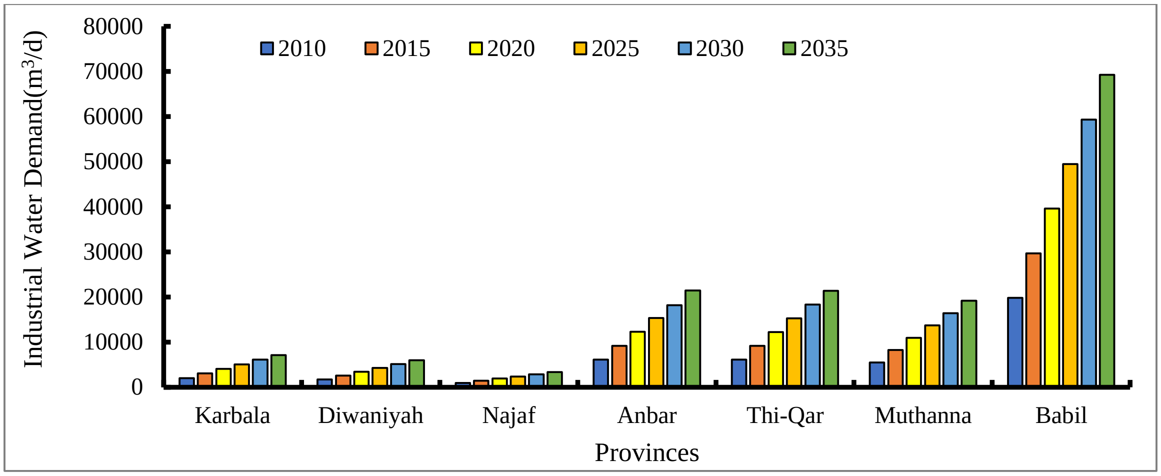

Figure 5.9: Projection of industrial water consumption for Iraq's provinces (After SWLRI, 2014)

5.3 TDS Problem of the Euphrates River Basin

When evaluating water quality, Total Dissolved Solid (TDS) levels below 600 mg/l are generally considered acceptable for drinking, while levels exceedingly approximately 1000 mg/l can significantly impair drinking water taste and quality (WHO, 2018). According to the irrigation standards set by the FAO, TDS concentrations ranging from 450 to 2000 mg/l will have only minor to moderate impacts on crops. Figure 5.10 illustrates the water TDS in the Haditha Reservoir, with the maximum value in March 758.6 mg/l and the minimum occurring in August 575.7 mg/l. The TDS measurements were sourced from NCFWRM (2022). The data on the TDS for Tharthar Reservoir is only available for 2020–2022, during which time the average value of the TDS was 781 mg/l. The dissolved solids for the Habbaniyah Reservoir in 2021–2022 were 675.7 mg/l. Haditha, and Tharthar Reservoirs, and the Habbaniyah Reservoir releases need to manage salinity. Hence, TDS values will be used to gauge the water's salinity for the three reservoirs. The average of the (M.AL.TDS) for drinking and irrigation water requirements are equal to 740 mg/l. This value is equal to the average of the values of the maximum TDS values of the three reservoirs.

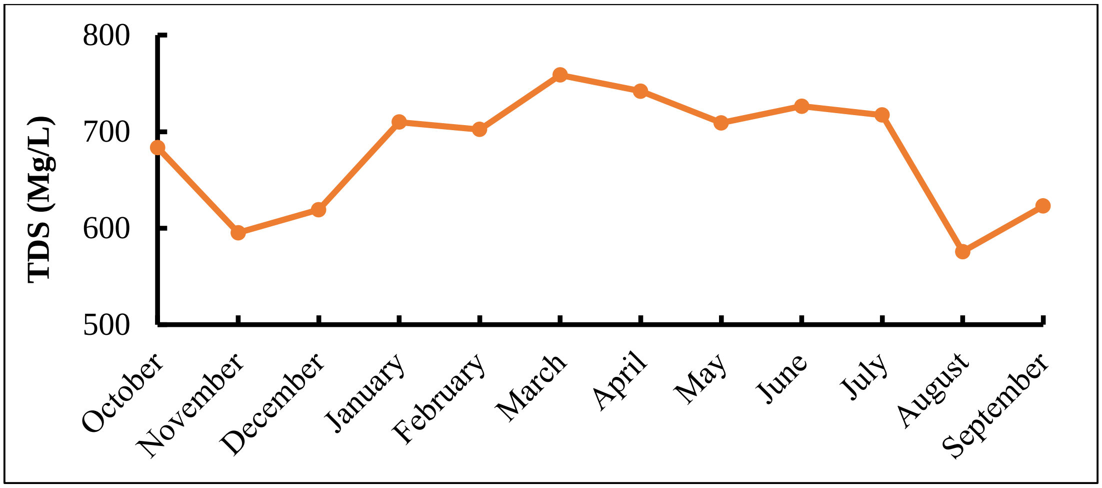

Figure 5.10: Average TDS of Haditha Reservoir (NCFWRM, 2022)

5.4 Rule Curves for Reservoirs along Euphrates Rive

Rule curves are water management guidelines that are used to manage reservoirs along a river system. They are typically developed based on historical data and are designed to ensure that there is enough water in the reservoir to meet the needs of various uses, such as water supply, hydropower generation, irrigation, and environmental needs.

5.4.1 Rule Curves of Haditha reservoir

The Haditha reservoir is a multipurpose project designed to serve various objectives. Its primary purpose is to enhance water storage for irrigation purposes and to manage and regulate the flow of the Euphrates River in Iraq. The auxiliary objective is power generation, while the tertiary aim is to provide some degree of control over extreme floods. The Haditha reservoir comprises the following zones:

1. Flood control zone, between the maximum water level and normal water level.

2. Conservation zone, between normal water level and minimum water level.

3. Inactive zone, or dead storage.

5.4.1.1 Operation Rule Curve

According to the available storage and elevation data by the NCFWRM (2022) can be adopted the records from October 2000 to September 2020 to construct the operation rule curves. The reservoir storage includes the average or conservation zone, upper zone (maximum allowable storage or flood control), and lower zones (minimum allowable or dead storage). Figures 5.11 and 5.12 represent the rule curve based on storage and water surface elevation for the Haditha Reservoir. During the first month of operation, it was assumed that the initial storage of the Haditha Reservoir would be set to the average value observed in October for that month, as indicated on the corresponding curves. In this study, the initial trial trajectory is represented by the initial storage of the reservoirs in the ERB (Haditha, Tharthar, and Habbaniyah) (see section 4.7.2). The primary data pertaining to the Haditha Reservoir is summarized in Table 5.3. The average rule curve was derived by calculating the average storage values obtained from the model over the period spanning from October 2000 to September 2020.

Table 5.3: Basic data of Haditha Reservoir (NCFWRM, 2022)

Storage in the reservoir	**Value (MCM)**	**Water Level**	**Value (m.a.s.l)**
Maximum Allowable storage	10000	Flood Control Level	150.2
Maximum Operational Storage	8280	Maximum Operational level	147
Minimum Operational Storage	570	Minimum Operational level	116.44

Minimum Storage of Hydropower Generation	770	Minimum WSE of Hydropower Generation	119
Minimum Allowable Storage	530	Dead storage level	100

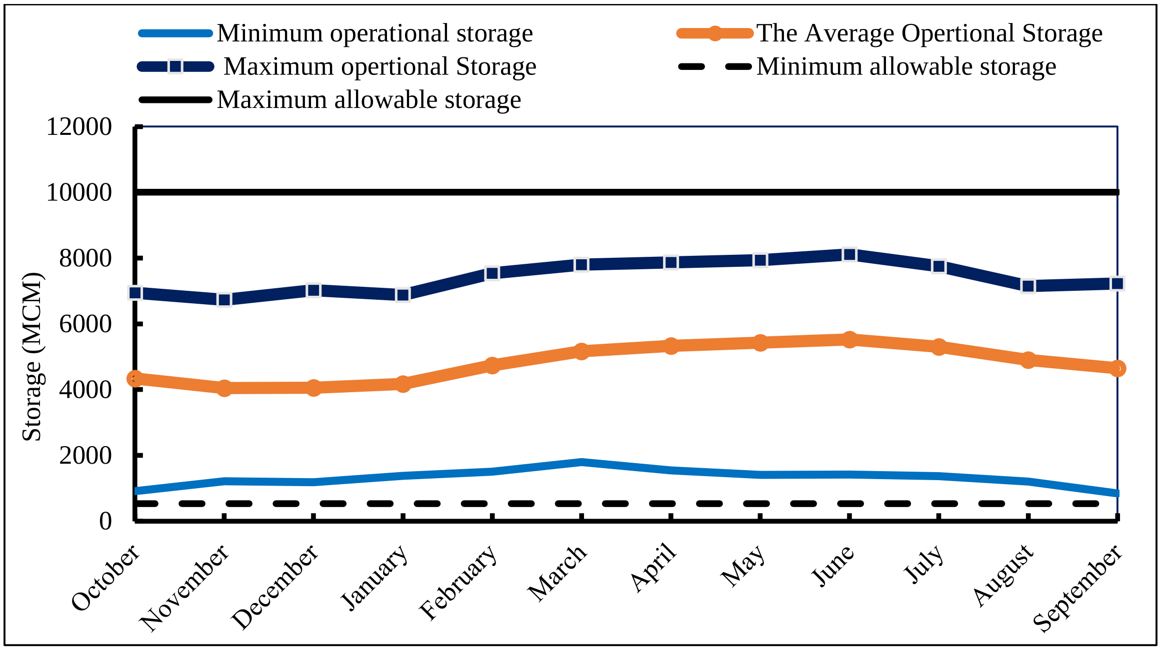

Figure 5.11: Rule curves based on the observed storage Haditha Reservoir

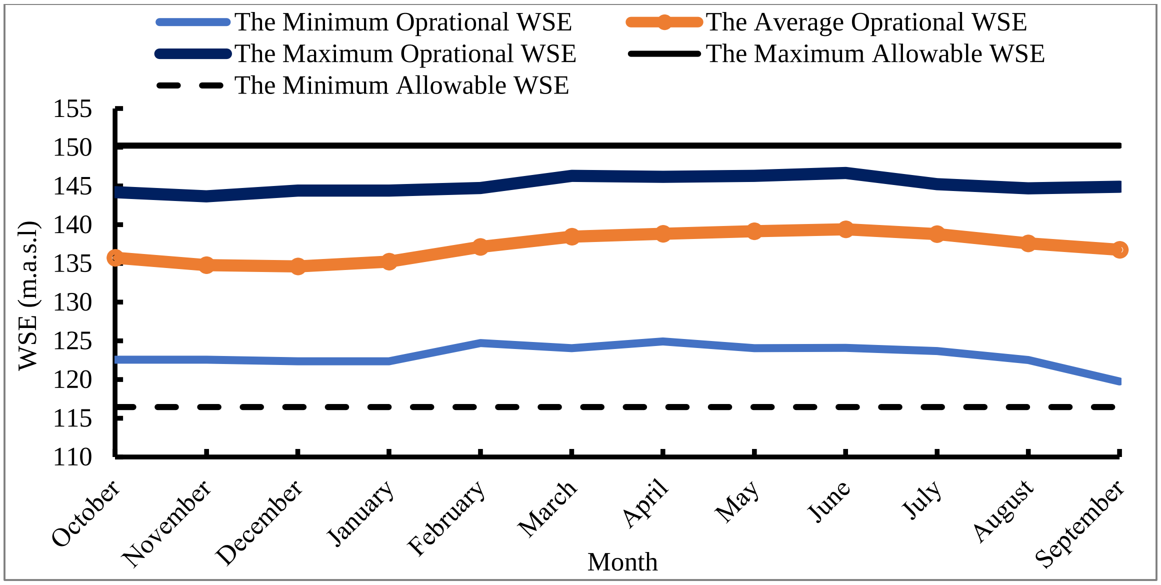

Figure 5.12: Rule curves based on observed water surface elevation for Haditha Reservoir

5.4.2 Rule Curve of Tharthar reservoir

Since 1956, the Tharthar Depression has been transformed into an artificial reservoir known as Tharthar Lake. It serves the purpose of collecting excess water from the Tigris River during flood seasons. The reservoir is connected to the Tigris and Euphrates Rivers through artificial canals. Specifically, the inlet canal draws water from the Tigris River, regulated by the Samarra Dam, which effectively manages the surplus water by directing it into the reservoir (Sissakian, 2011).

5.4.2.1 Operation Rule Curve

The operation Rule Curve of the Tharthar Reservoir can be derived from the available storage and elevation record from October 2000 to September 2020 by NCFWRM (2022). The primary data of the Tharthar Reservoir are briefly shown in Table 5.4. Figures 5.13 and 5.14 show the rule curve based on Storage and Water Surface Elevation for The Tharthar Reservoir, respectively.

Table 5.4: Basic data of Tharthar Reservoir (NCFWRM, 2022)

Storage in Reservoir	Value (MCM)	Water Level	Value (m.a.s.l)
Maximum Allowable storage	85000	Flood Control Level	65
Maximum Operational Storage	63280	Maximum Operational level	55.71
Minimum Operational Storage	41100	Minimum Operational level	42.5
Minimum Allowable Storage	39600	Dead storage level	40

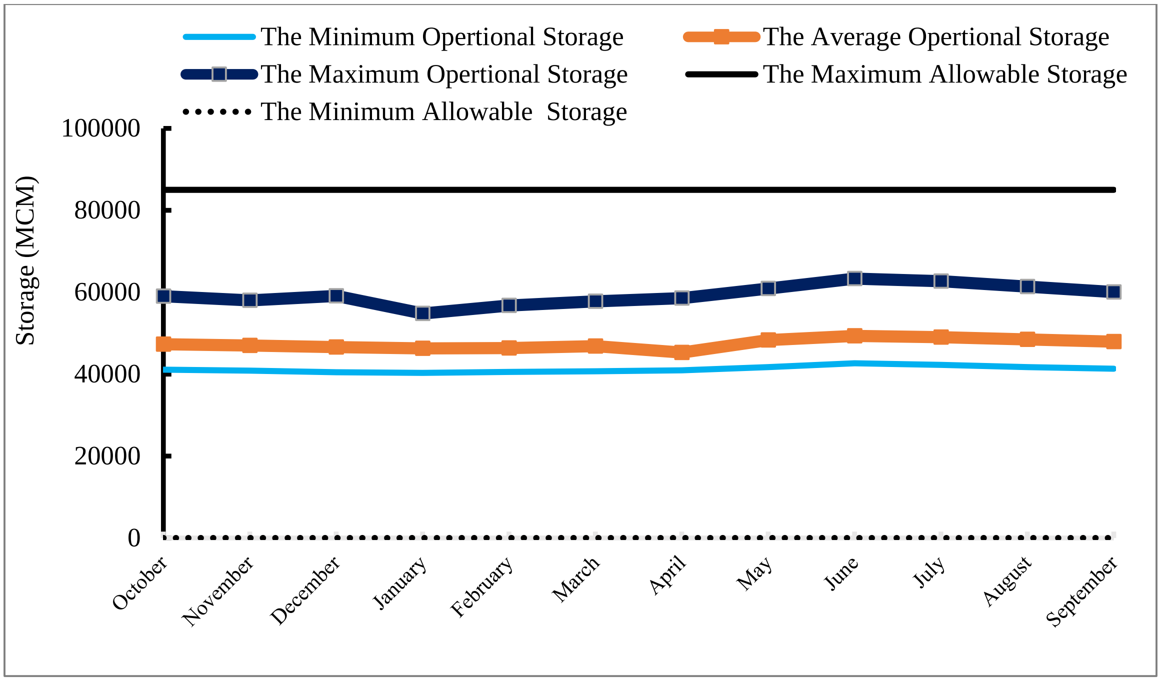

Figure 5.13: Rule curves based on the observed storage for Tharthar Reservoir

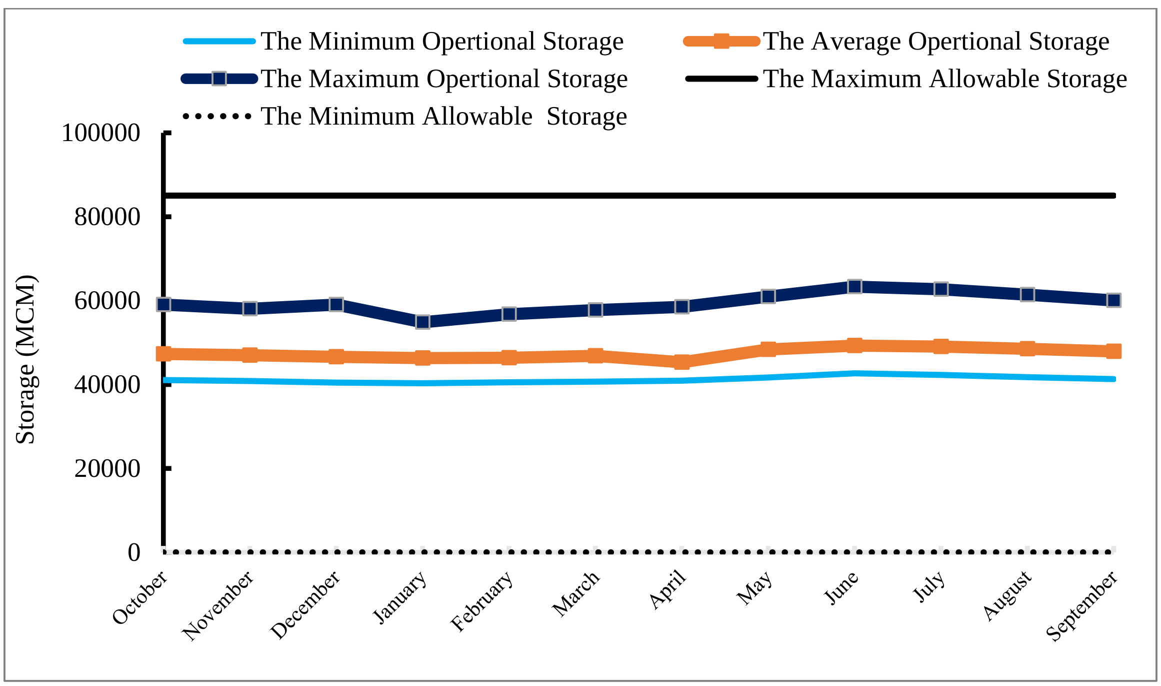

Figure 5.14: Rule curve based on observed water surface elevation of the Tharthar Reservoir.

5.4.3 Operation Rule Curve of Habbaniyah Reservoir

Water is discharged from the reservoir to regulate the flow back into the Euphrates River via the Dibban Canal, which has a capacity of 380 m³/s and spans a length of 13 km. The construction of the Dibban Canal was finalized in 1951. The bottom level of Habbaniyah Reservoir is situated at an elevation of 36 (m.a.s.l), while the maximum operational level reaches 51 (m.a.s.l) (Al-Hadithi 1979, Abdullah et al., 2019). The operation Rule Curve of Habbaniyah Reservoir can be derived from data from the NCFWRM (2022). Figures 5.15 and 5.16 show the rule curve based on Storage and Water Surface Elevation for Habbaniyah Reservoir, respectively. The primary data of the Habbaniyah Reservoir are briefly shown in the following Table.

Table 5.5: Basic data of the Habbaniyah Reservoir (NCFWRM, 2022)

Storage in the reservoir (MCM)	**Value**	**Reservoir water level (m.a.s.l.)**	**Value**
Maximum Allowable storage	3300	Flood Control Level	51
Maximum Operational Storage	2670	Maximum Operational level	49.61
Minimum Allowable Storage	740	Dead storage level	43

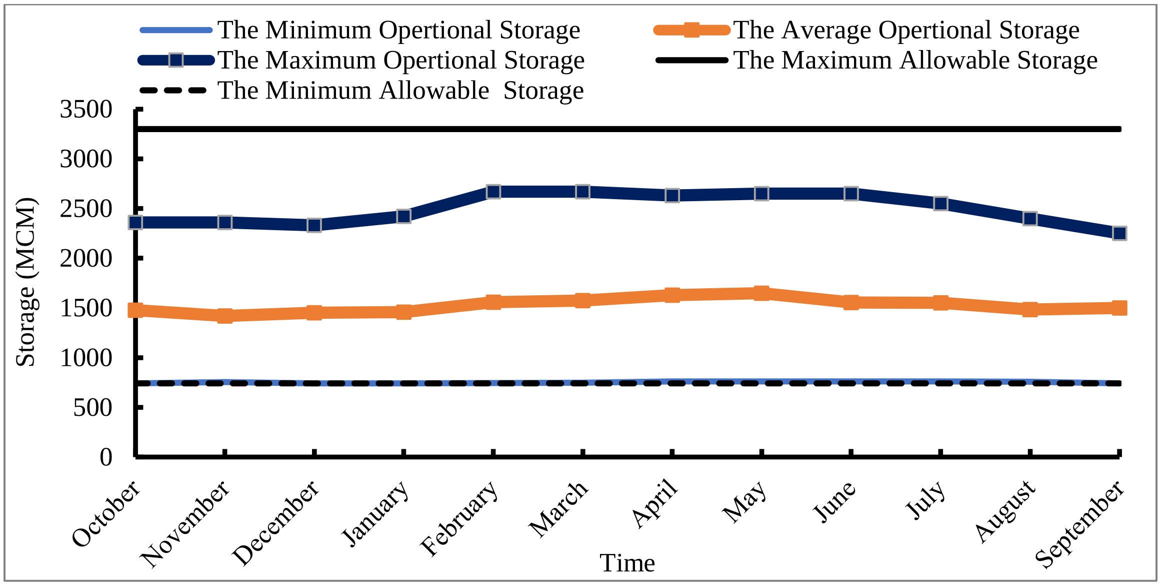

Figure 5.15: Rule curve based on observed storage for Habbaniyah Reservoir.

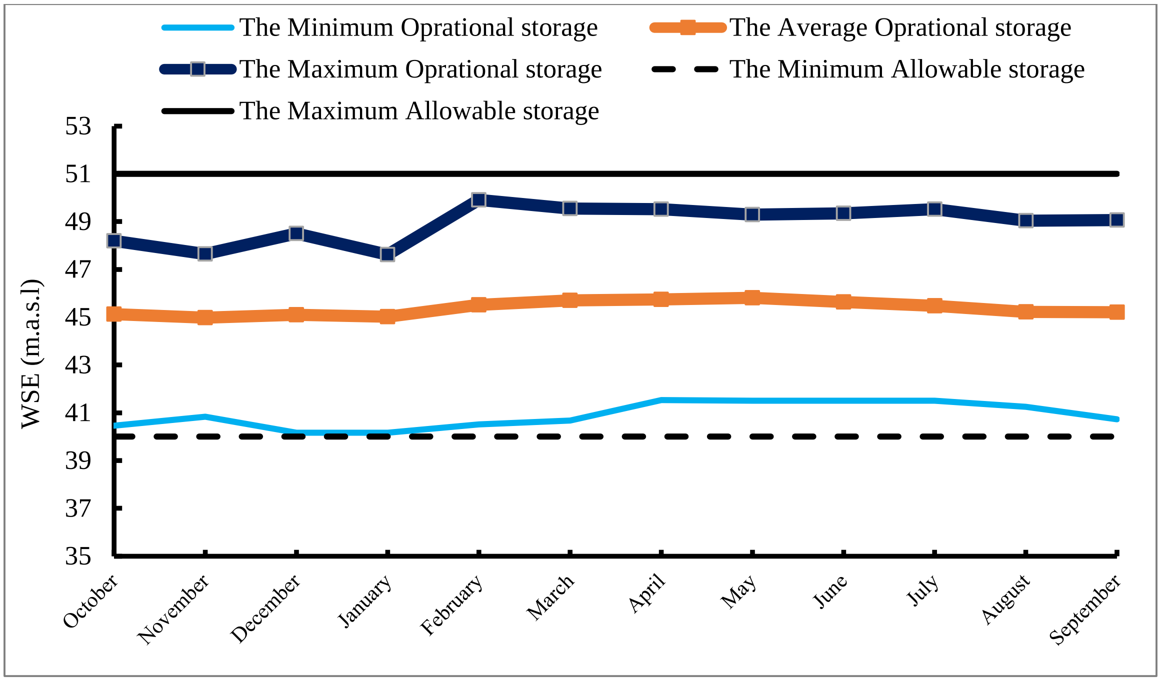

Figure 5.16: Rule curve based on the water surface elevation for Habbaniyah Reservoir

5.5 Storage and Water Surface Elevations Curves

The storage and water surface elevation (WSE) data recorded by the NCFWRM (2022) between October 2000 and September 2020 can be used to develop a WSE - Storage relationship for the three reservoirs.

Alghazali (2011) proposed best fit for equations for both the volume-elevation and the water surface area-elevation data of reservoirs. The shifted power equation is tested through two examples: Bastora reservoir and Al-Adheem reservoir and compared with other possible best fit equations. It is concluded that the shifted power equation is the best one, and thus it can be adopted to represent the best fit equation for both the storage-elevation and the water surface area- elevation data of reservoirs. In this study, the shifted power equation:

$$Volume = a\,(Elv. - b)^c \quad (5.4)$$

Where Elv is the water surface elevation in the reservoir (m). The parameter b in the Shifted power equation, Eq. (5.4), is proposed equal to the elevation corresponding to zero volume. The 00parameters a and c are proposed such that Eq. (5.4) gives minimum residual.

5.5.1 Proposed Best Fit Equations for Volume-Elevation Data

The scatter diagram of the volume-elevation data of Haditha, Tharthar, and Habbaniyah Reservoirs are look like that shown in Figures 5.17, 5.18, and 5.19. The scatter diagram of area-elevation data is like the scatter diagram of volume-elevation data. The difference is that volume-elevation data contain zero volume.

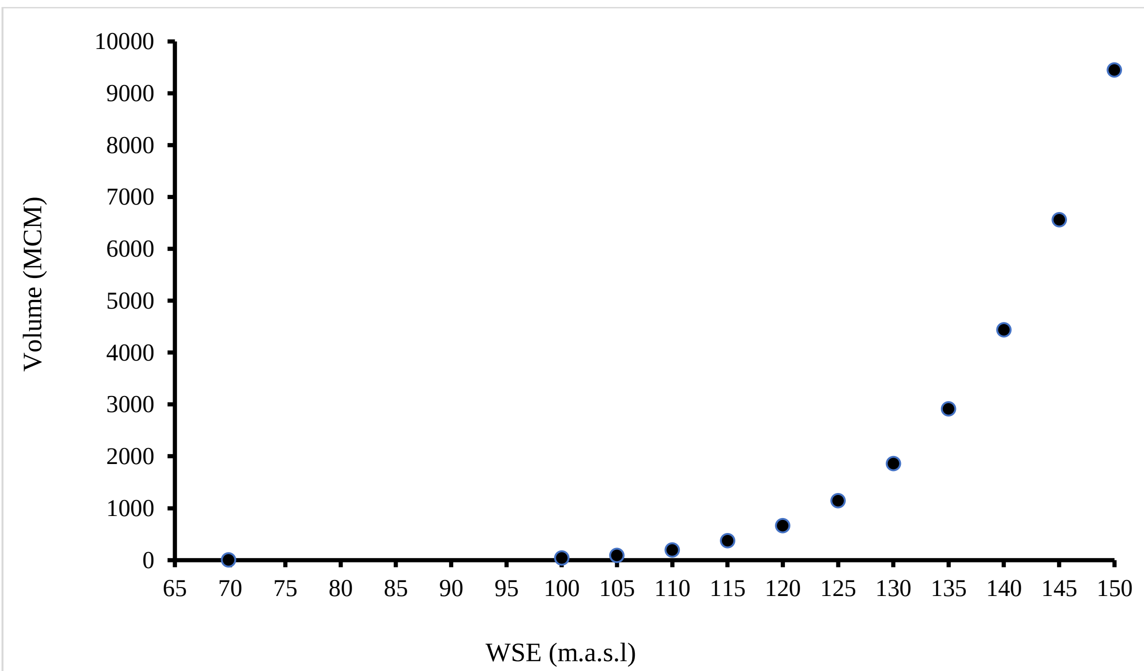

Figure 5.17: Scatter diagram of the volume-elevation data of Haditha Reservoir (NCFWRM, 2022)

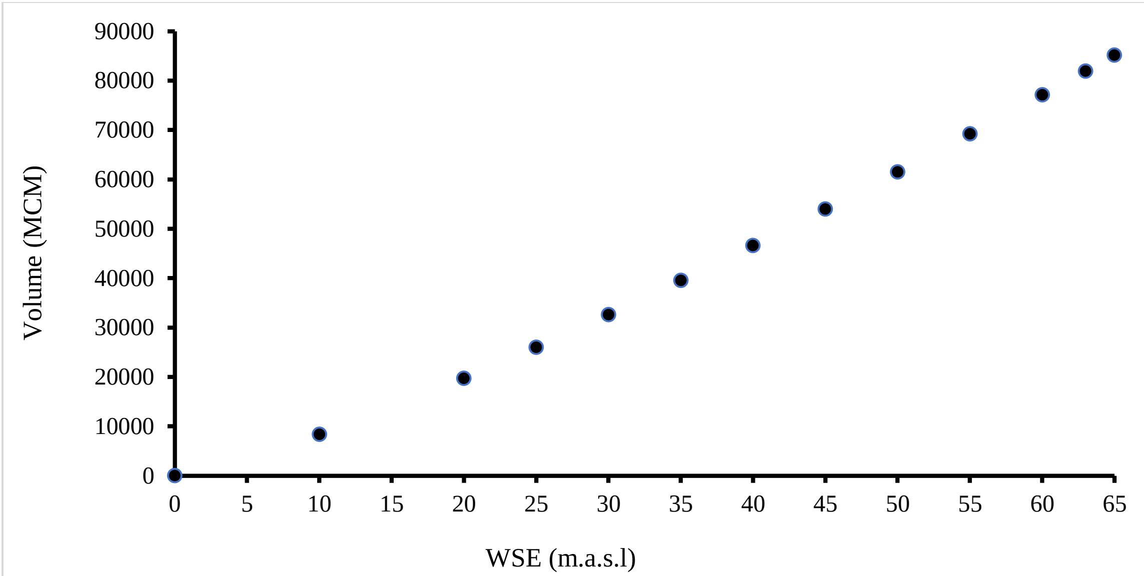

Figure 5.18: Scatter diagram of the volume-elevation data of Tharthar Reservoir (NCFWRM, 2022; Al-Hadithi 1979)

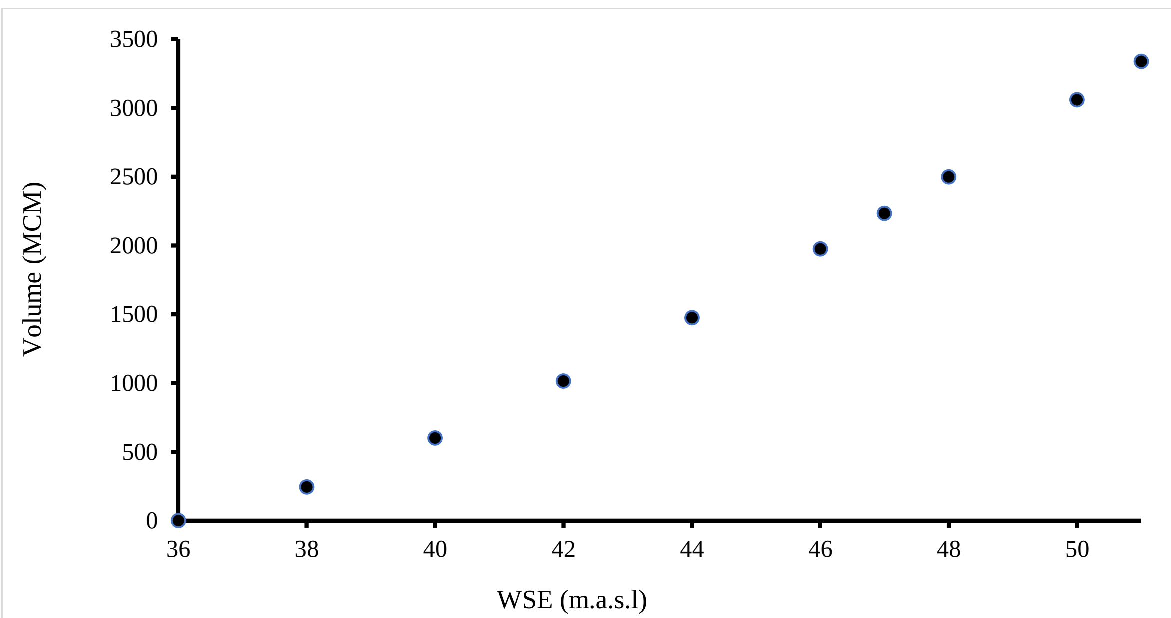

Figure 5.19: Scatter diagram of the volume-elevation data of Habbaniyah Reservoir (NCFWRM, 2022; Al-Hadithi 1979)

The current study presents the application of commonly available spreadsheet software, Microsoft Excel 2023, for the purpose of estimating the parameters of shifted power equation. These procedures consist of Generalized Reduced Gradient (GRG) Method. The GRG solver needs the initial values assumption for the parameter estimation where the parameter b is proposed equal to the elevation corresponding to zero volume, while the latter parameters (b and c) require the determination of the algorithm parameters. The GRG nonlinear solving method was developed by Smith and Lasdon (1992). This optimization algorithm is commonly used for solving nonlinear programming problems. It is widely employed in various fields, including operations research, engineering, and economics, for finding the optimal solutions to complex nonlinear optimization problems.
The following equation shows the final values of these parameters (a, b, and c) for volume-elevation data of Haditha Reservoir:

$$Volume_1 = 1.55\times10^{-7}\,(Elv.-69.86)^{5.664} \tag{5.5}$$

$Volume_1$ is the storage of the Haditha Reservoir (MCM). The following equation shows the final values of these parameters (a, b, and c) for volume-elevation data of Tharthar and Habbaniyah Reservoirs, respectively:

$$Volume_2 = 481\,(Elv.-0)^{1.24} \tag{5.6}$$

$$Volume_3 = 99\,(Elv.-36)^{1.3} \tag{5.7}$$

$Volume_2$ and $Volume_3$ are the storage of the Tharthar, and Habbaniyah Reservoirs (MCM). The scatter plots and corresponding perfect fitting curves depicting the volume-elevation data for Haditha, Tharthar, and Habbaniyah Reservoirs are illustrated in Figures 5.20, 5.21, and 5.22, respectively.

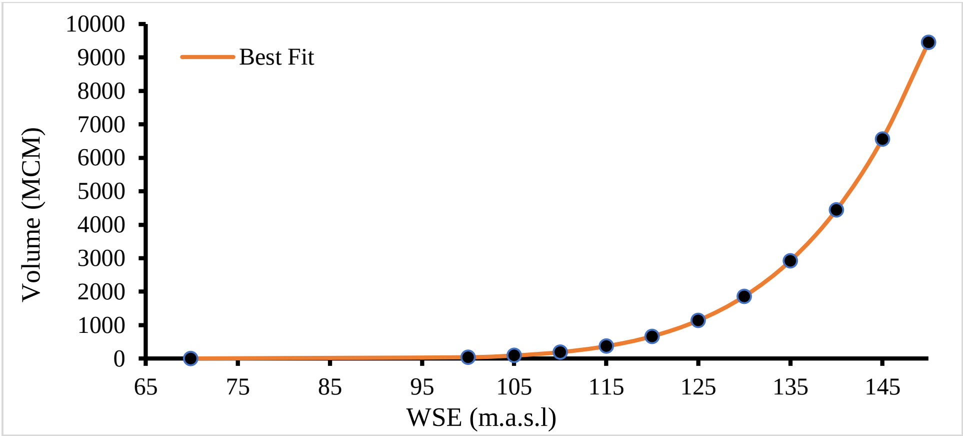

Figure 5.20: Best fit diagram of the volume-elevation data of Haditha Reservoir

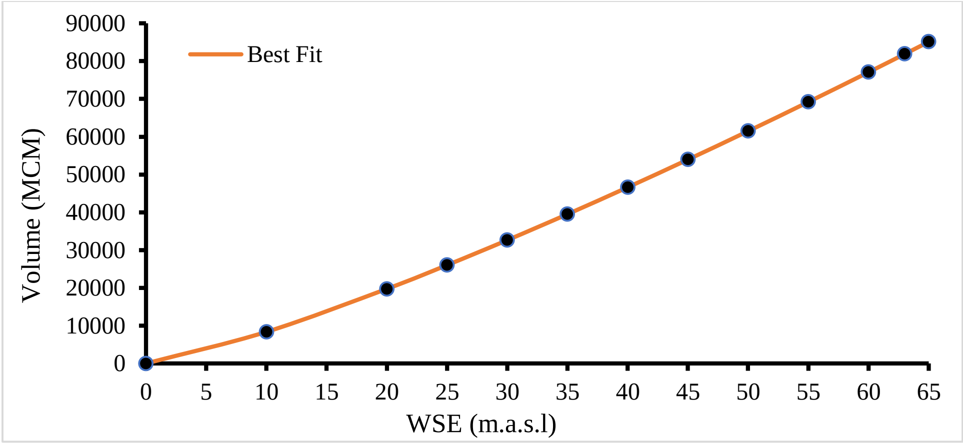

Figure 5.21: Best fit diagram of the volume-elevation data of Tharthar Reservoir

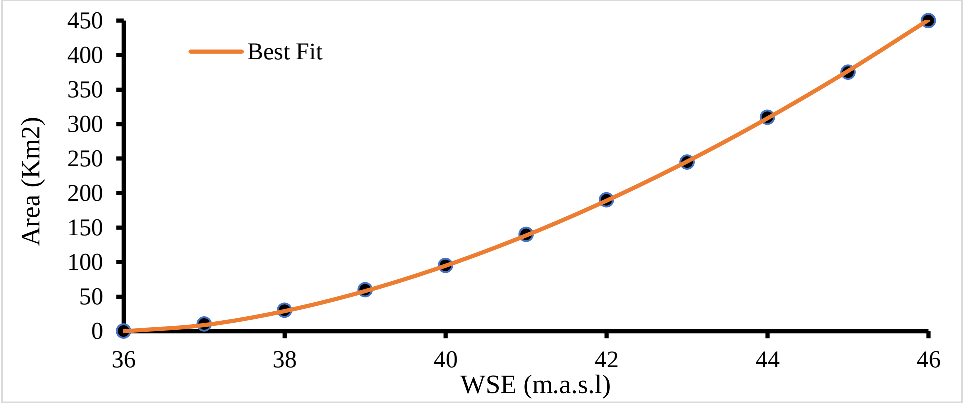

Figure 5.22: Best fit diagram of the volume-elevation data of Habbaniyah Reservoir

The coefficient of determination (R^2) is employed for assessing the correlation between the measured and the predicted (WSE) by apply the shifted power. In which:

$$R^2 = \frac{\left[\sum_{i=1}^{N}\left((x_i - \bar{X})(y_i - \bar{Y})\right)\right]^2}{\sum_{i=1}^{N}(x_i - \bar{X})^2 \sum_{i=1}^{n}(y_i - \bar{Y})^2} \quad (5.8)$$

Where; x_i and y_i are the measured and predicted values of the variable under consideration, $\bar{X}$ and $\bar{Y}$ are the averages of x, and y datasets, and N is the is the samples number (Moriasi et al., 2007). Table 5.6 shows the values of residual sum of squares and coefficient of determination of the model.

Table 5.6: Values of Residual Sum of Squares and Coefficient of Determination (R^2) between the measured and the predicted (WSE).

Reservoirs	Residual sum of squares	Coef. of determination
Haditha	99.2	0.9996
Tharthar	187.33	0.9999
Habbaniyah	28.09	0.9999

5.5.2 Proposed Best Fit Equations for Water Surface Area-Elevation Data

In this study, the best fit equation for the water surface area-elevation (the shifted power equation) is:

$$Area = d\,(Elv. - f)^g \quad (5.9)$$

The final values of the parameters d, f, and g are determined as mentioned in Eq. (5.4). The following equations show the final values of these parameters (d, f, and g) for water surface area -elevation data of Haditha, Tharthar and Habbaniyah Reservoirs:

$$Area_1 = 0.0003\ (Elv. - 86.66)^{3.5} \tag{5.10}$$

$$Area_2 = 9\ (Elv. - 0)^{1.4} \tag{5.11}$$

$$Area_3 = 9\ (Elv. - 36)^{1.7} \tag{5.12}$$

$Area_1$, $Area_2$ and $Area_3$ are the water surface area of the Haditha, Tharthar, and Habbaniyah Reservoirs (Km^2). Figures 5.23, 5.24, and 5.25 display the optimal fitting of scatter data representing the correlation between water surface area and elevation for Haditha, Tharthar, and Habbaniyah Reservoirs.

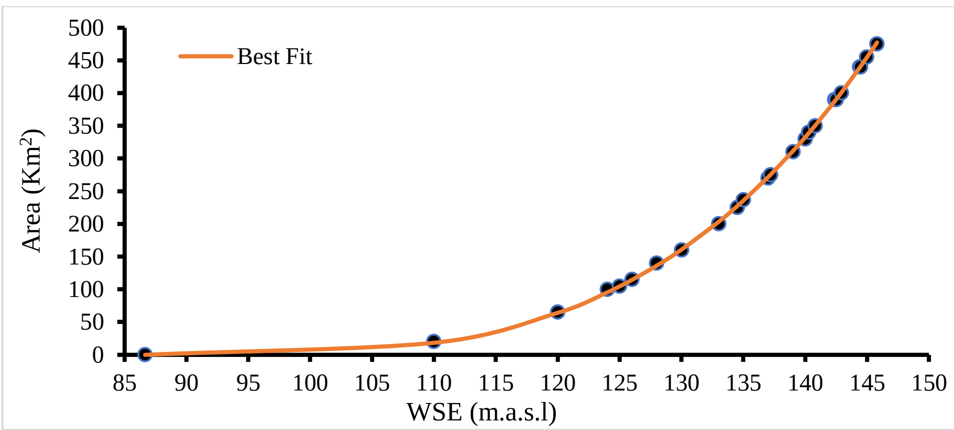

Figure 5.23: Best fit diagram of the water surface area -elevation data of Haditha Reservoir

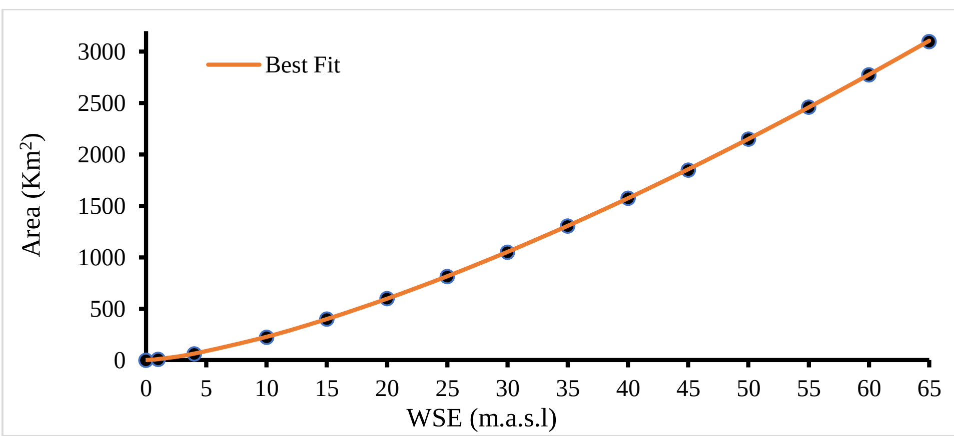

Figure 5.24: Best fit diagram of the water surface area -elevation data of Tharthar Reservoir

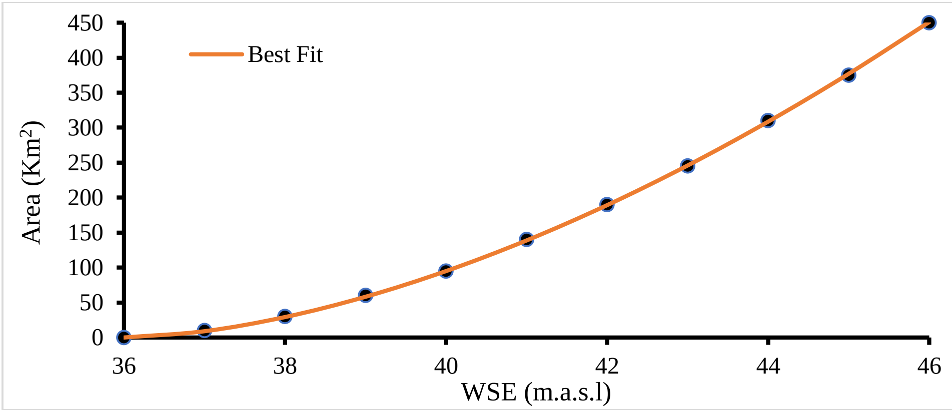

Figure 5.25: Best fit diagram of the water surface area -elevation data of Habbaniyah Reservoir

Table 5.7 shows the values of residual sum of squares and coefficient of determination between the measured and the predicted Area.

Table 5.7: Values of Residual Sum of Squares and the Coefficient of Determination (R^2) between the measured and the predicted Area.

Reservors	Residual sum of squares	Coef. of determination
Haditha	84.78	0.9998
Tharthar	124.12	0.9999
Habbaniyah	14.78	0.9999

5.6 Evaporation Model of ERB Reservoirs

5.6.1 Methodology of Evaporation model

The analysis of the evaporation model methodology should include identifying the inputs and outputs of the flowchart, the purpose of each step, and the potential issues or limitations of the model. The input includes the temperature, wind speed, and solar radiation. Using the energy budget method specifically Eq. (3.18) is to calculate the evaporation rate from the water surface of the reservoirs in the ERB. Also, this study will focus on the two scenarios of the estimation evaporation, SSP1-2.6 and SSP2-4.5, for the two periods 2020-2039 and 2040-2059, with respect to the reference period (RP) 1995-2014. One effect is that the warmer temperatures can increase the rate of evaporation. This can cause a decrease in the water levels of reservoirs, leading to a decrease in the amount of water available for agriculture, industry, and other uses. Furthermore, a larger area size of reservoirs can also lead to an increase in the rate evaporation from the water surface of the ERB Reservoirs. Figure 5.26 shows the flowchart methodology of evaporation model. Table 5.8 shows the maximum, minimum, and average for the results of the evaporation model.

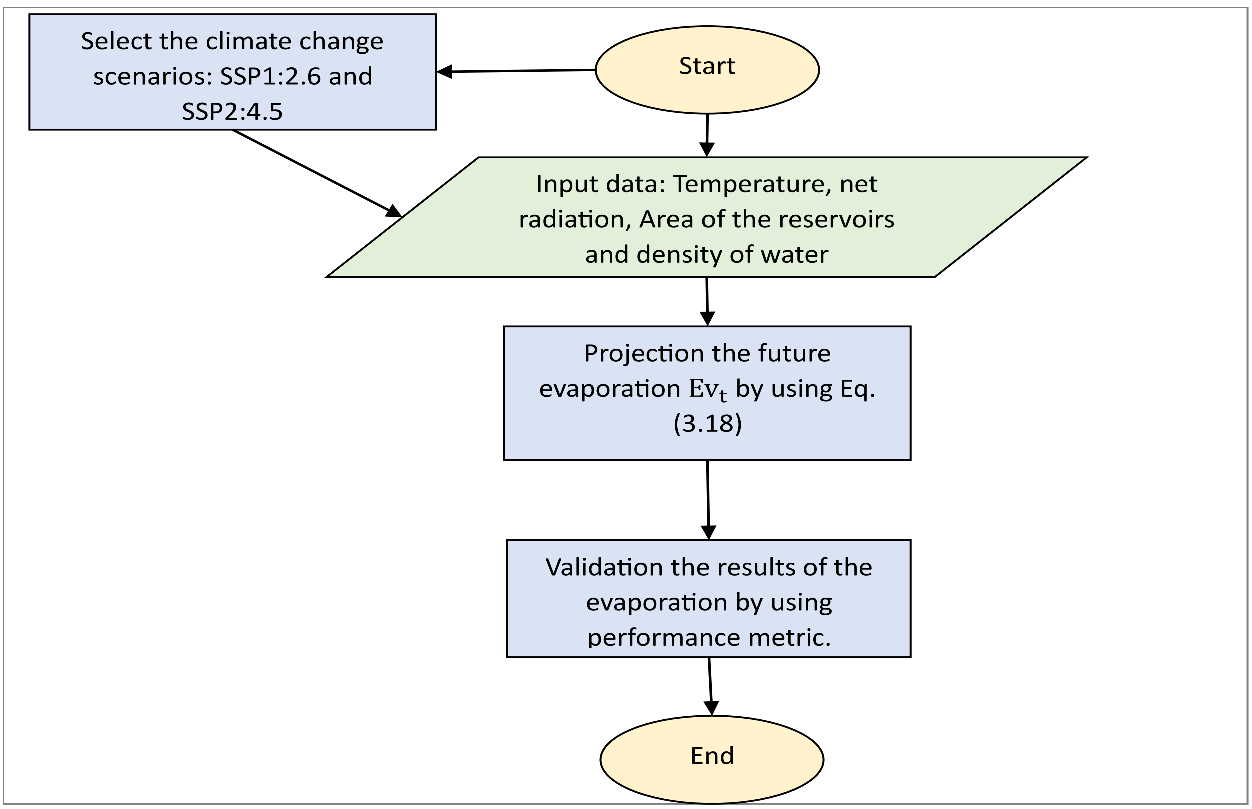

Figure 5.26: Flowchart Methodology of evaporation model

5.6.2 Spatial Distribution of Evaporation from the Reservoirs

The digital elevation model (DEM) is acquired from the website (www.eorc.jaxa.ip) with a cell size of 12.5*12.5. Figure 5.27 displays the elevation map of the reservoirs within the Euphrates River Basin (ERB). The DEM converts to elevation map by the Arc GIS program. Figure 5.28 shows the spatial distribution of the evaporation from the water surface of the ERB reservoirs. The figure utilizes the three scenarios RP, SSP1:2.6, and SSP2:4.5 to illustrate the spatial distribution of the evaporation for Input data: Temperature, net radiation, Area of the reservoirs and density of water Validation the results of the evaporation by using performance metric Projection the future evaporation Ev_t by using Eq. (3.18) End Start Select the climate change scenarios: SSP1:2.6 and SSP2:4.5 28 the three reservoirs. Table 5.10 shows the maximum, minimum, average, and standard deviation for the results of the evaporation model.

Table 5.8: Maximum, minimum, and average, of the monthly evaporation model.

Reservoir	Climate Change Scenario	Maximum (mm)	Minimum (mm)	Average (mm)
Haditha	RP	228.72	119.65	184.68
	SSP1:2.6	175.37	145.19	154.98
	SSP2:4.5	203.63	117.5	154.13
Tharthar	RP	256.97	123.68	176.47
	SSP1:2.6	290.55	148.9	204.12
	SSP2:4.5	348.02	191.51	255.68
Habbaniyah	RP	346.76	244.39	290.59
	SSP1:2.6	319.27	288.45	308.49
	SSP2:4.5	379.11	258.97	330.56

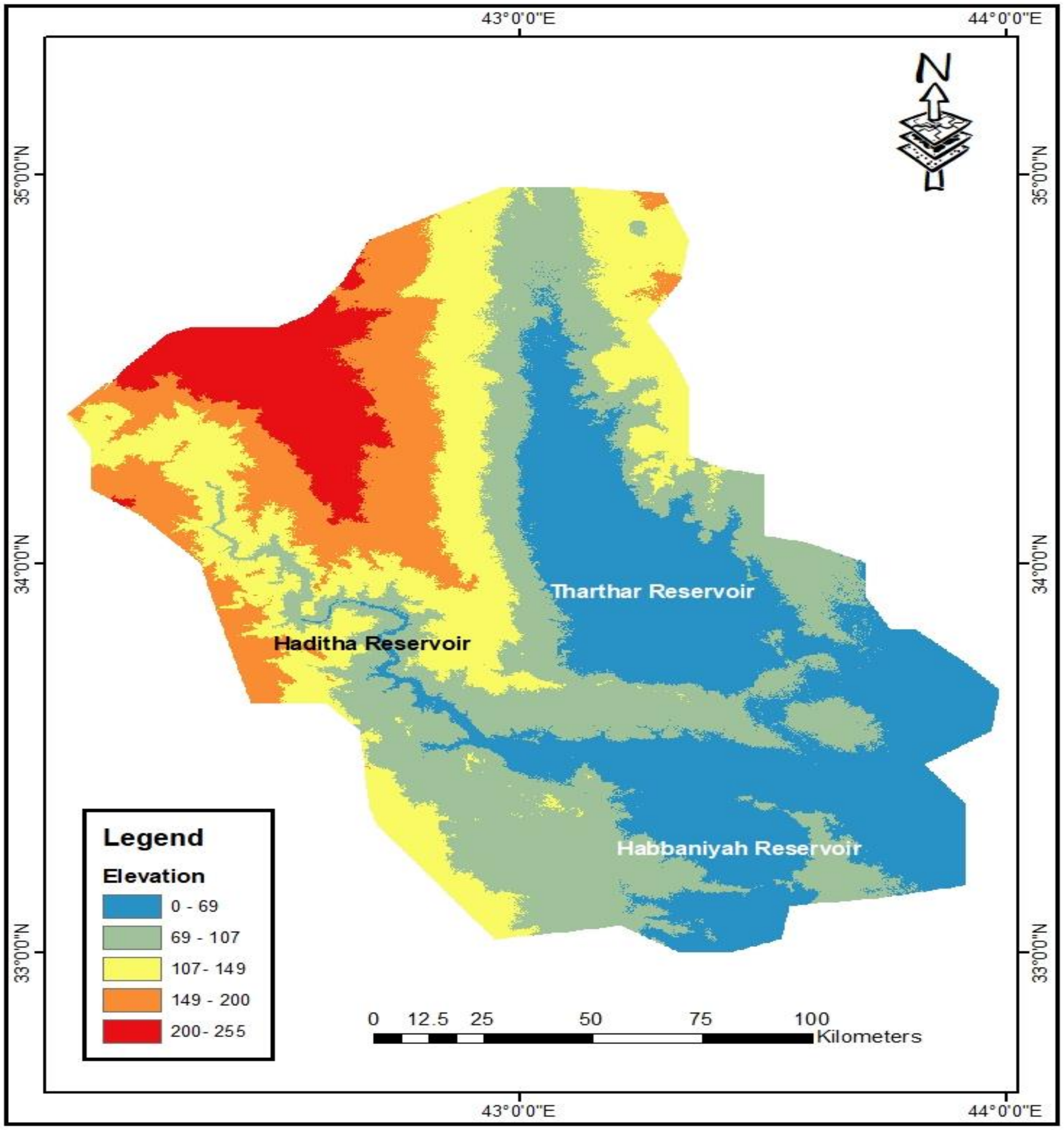

Figure 5.27: Elevation map of the ERB reservoirs, the source of the DEM is (www.eorc. jaxa. ip)

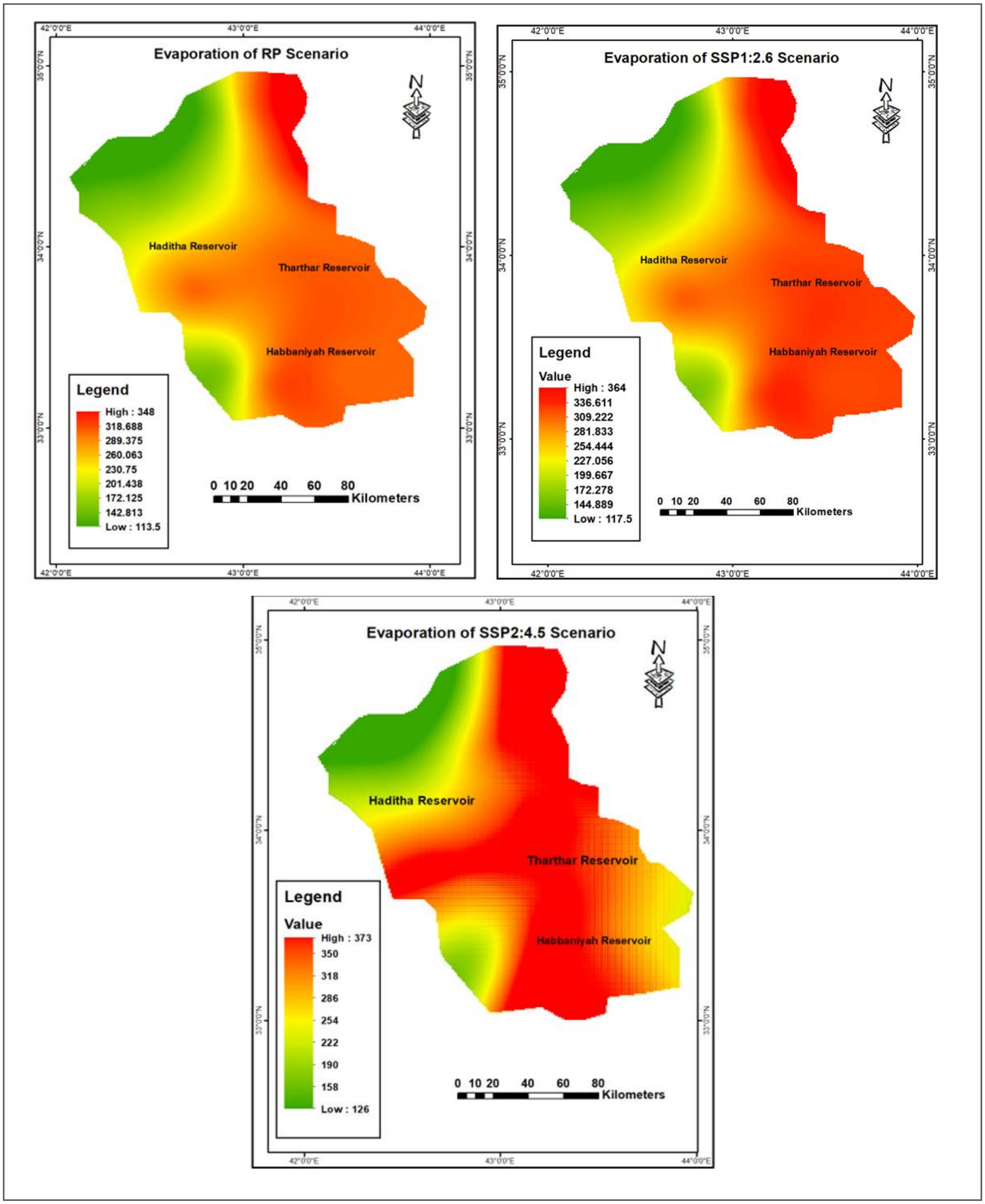

Figure 5.28: Spatial distribution of the evaporation in the ERB reservoirs

5.7 Precipitation on the Reservoirs within Study Area

The Euphrates River basin, known for its historical significance, has been experiencing a concerning trend of decreasing precipitation in recent years. This decline in rainfall has significant effects on various aspects of the river basin, including the reservoirs, river flow, and surrounding areas. Furthermore, the climate change scenarios known as SSP1:2.6 and SSP2:4.6 depict variations in the reduction of precipitation levels across reservoir surface areas.

In the Tigris River Basin, heavy rainfall events lead to amplified runoff and water flow, particularly in the area surrounding the Samara Barrage. This phenomenon has been observed during recent seasons, as the Tharthar Reservoir witnessed a substantial rise in the inflow water imports due to heavy rainfall. This inflow of water conveyances from Tigris River to the Tharthar Reservoir by the Tigris – Tharthar Canal. This study relies on estimating the precipitation amount based on the boundary of the reservoirs surface water area, like the approach used in the previous section to estimate evaporation rate. The source of the reservoir's precipitation data is the CCKP, where Table 5.9 shows the maximum, minimum, average, and standard deviation of the monthly precipitation data.

Table 5.9: Maximum, minimum, and average of the monthly precipitation data.

Reservoir	Climate Change Scenario	Maximum (mm)	Minimum (mm)	Average (mm)
Haditha	RP	346.71	113.43	224.60
	SSP1:2.6	351.96	117.5	228.85
	SSP2:4.5	361.26	126.37	237.94
Tharthar	RP	347.67	113.52	234.49
	SSP1:2.6	362.80	127.94	249.05

	SSP2:4.5	379.11	148.69	267.11
Habbaniyah	RP	348.02	124.90	240.69
	SSP1:2.6	363.77	139.18	255.22
	SSP2:4.5	373.60	148.57	264.85

5.8 Inflow Rates to the Reservoirs within Study Area

Based on the inflow data recorded by NCFWRM (2022) from October 2000 to September 2021, within the Euphrates River Basin, the inflow to the Haditha Reservoir represents 57% of the total water inflow of the ERB, while the Tharthar reservoir and Habbaniyah Lake contribute 32% and 11% respectively.

5.8.1 Projections for the Inflow of Water into Reservoirs

Based on the available inflow data from the National Center for Water Resources Management (NCFWRM) covering the period of October 2000 to September 2021 for Haditha and Tharthar Reservoirs and from October 2005 to September 2021 for Habbaniyah Reservoir.

Figure 5.29 displays the average annual inflow rate for Haditha Reservoir, which is the primary source of inflow to the ERB. In order to establish the primary operation scenarios for the reservoirs, the data presented in Figure 5.29 can be utilized to establish the inflow rate.

The analysis of the annual inflow rate indicates that any value greater than the average is classified as a wet year, while any value below the average is classified as a dry year, as shown in Figure 5.30. This classification of consecutive wet and dry years can be used as a reference for the operation of Haditha Reservoir during the planning period from October 2022 to September 2059. Accordingly, the years within this period can be classified as two wet years and four dry years based on this scenario.

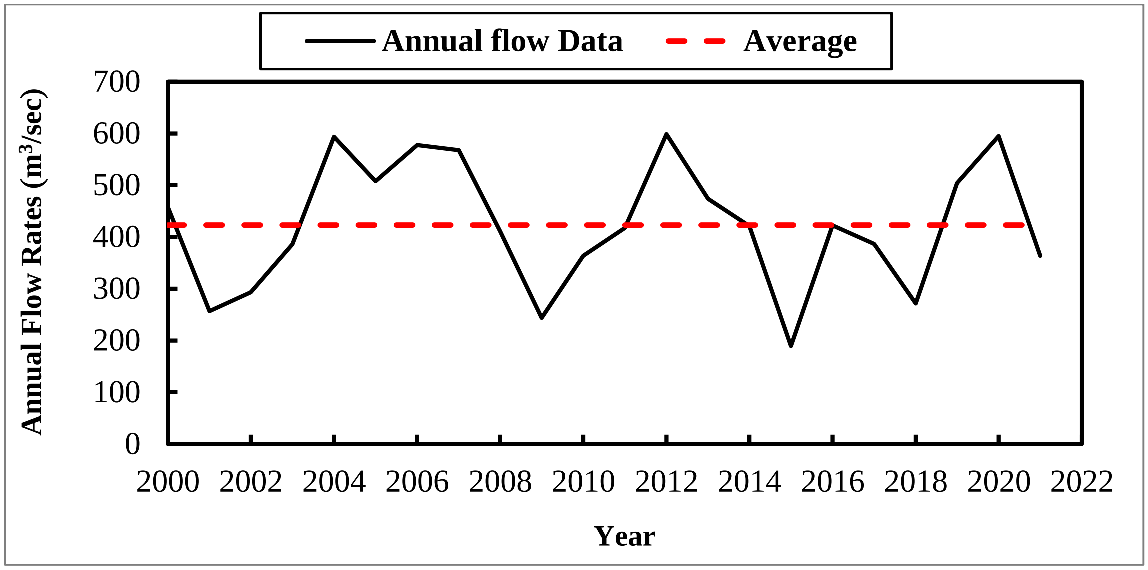

Figure 5.29: Annual inflow rate of the Haditha Reservoir (NCFWRM, 2022)

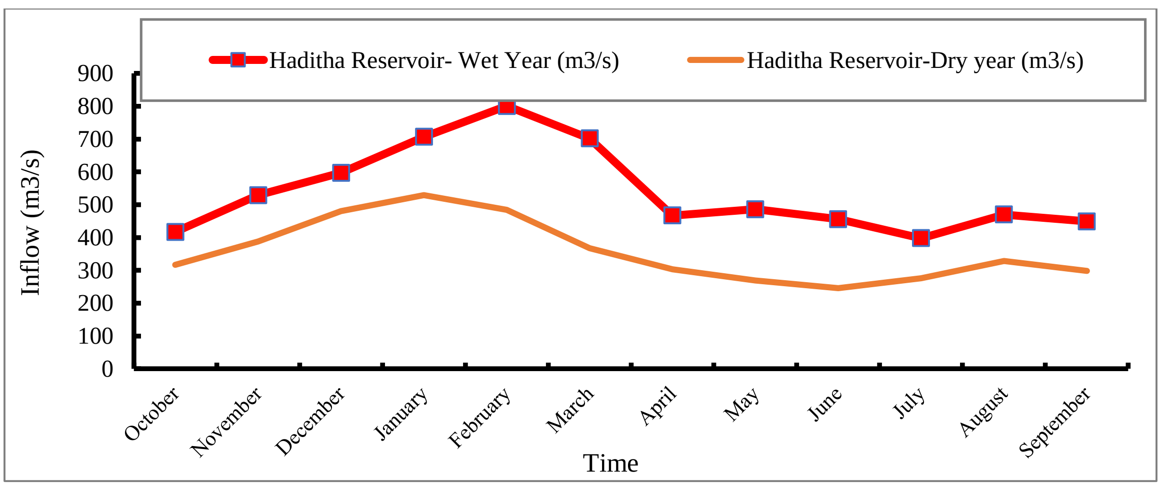

Figure 5.30: Inflow of Haditha Reservoir as a dry and wet years (NCFWRM, 2022)

Figures 5.31 and 5.32 show the annual and average inflow rate of the Tharthar, and Habbaniyah. Figures 5.33, and 5.34 show the average monthly inflow of the reservoirs Tharthar, and Habbaniyah in dry and wet years, respectively.

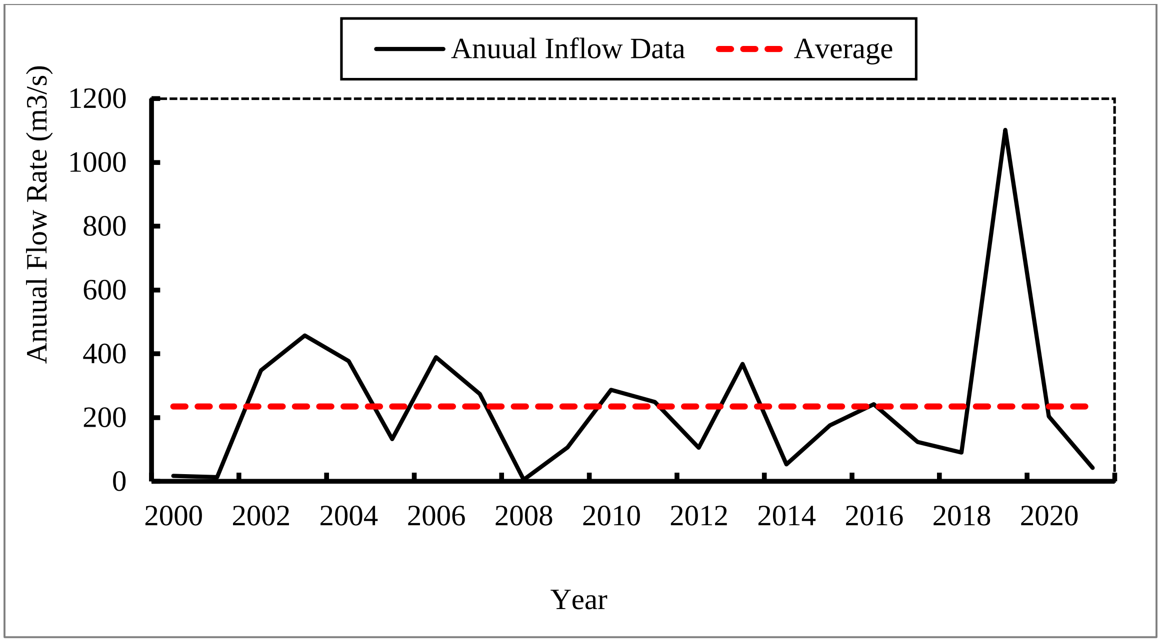

Figure 5.31: Annual inflow rate of the Tharthar Reservoir (NCFWRM, 2022)

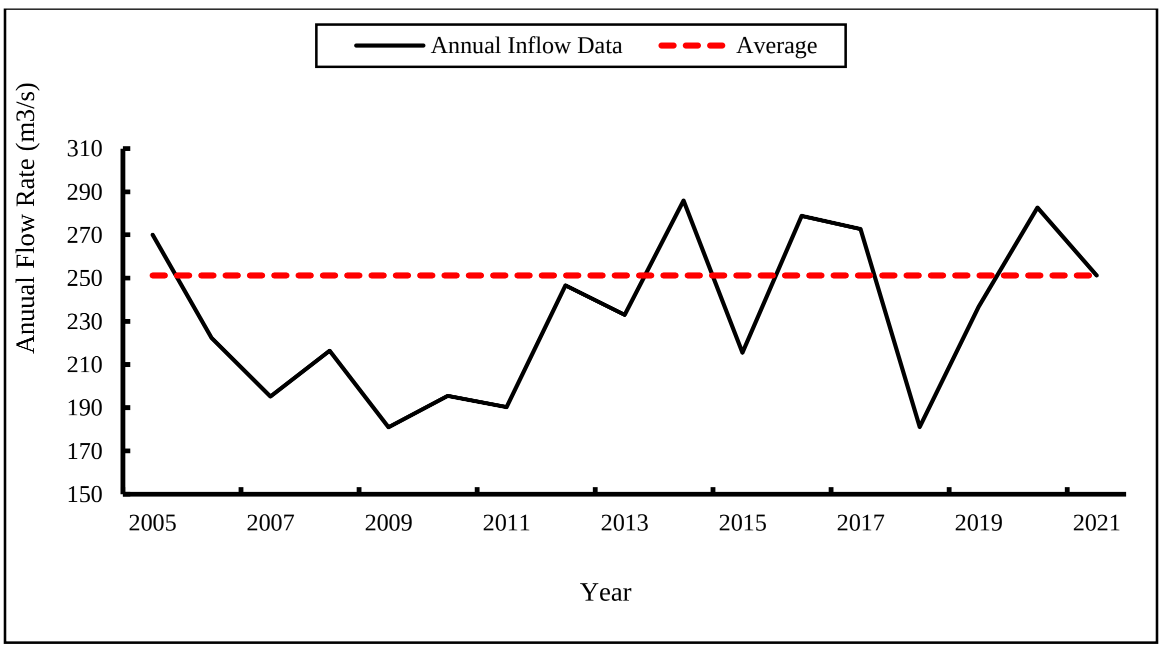

Figure 5.32: Annual inflow rate of the Habbaniyah Reservoir (NCFWRM, 2022)

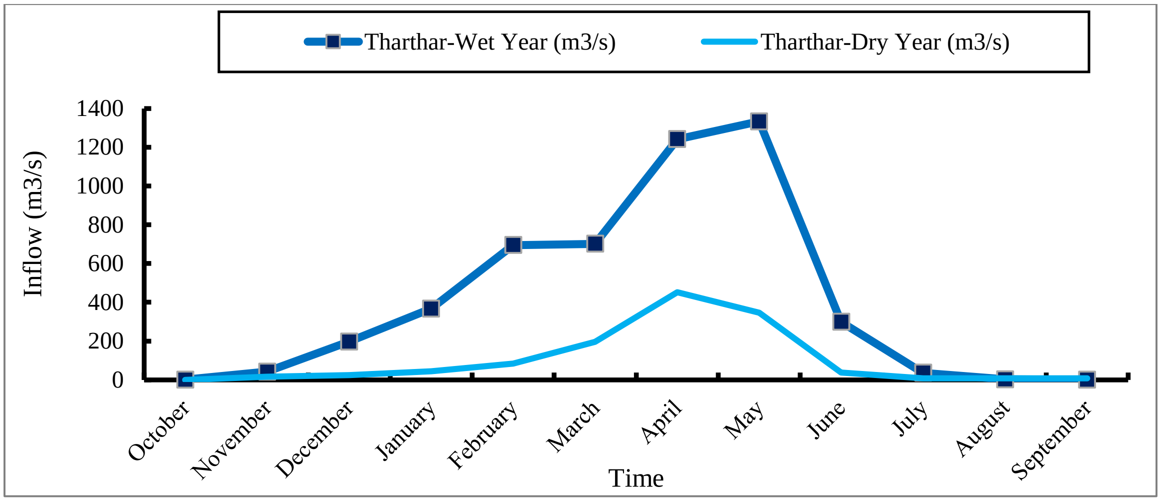

Figure 5.33: Inflow of the Tharthar Reservoir as a dry and wet years (NCFWRM, 2022)

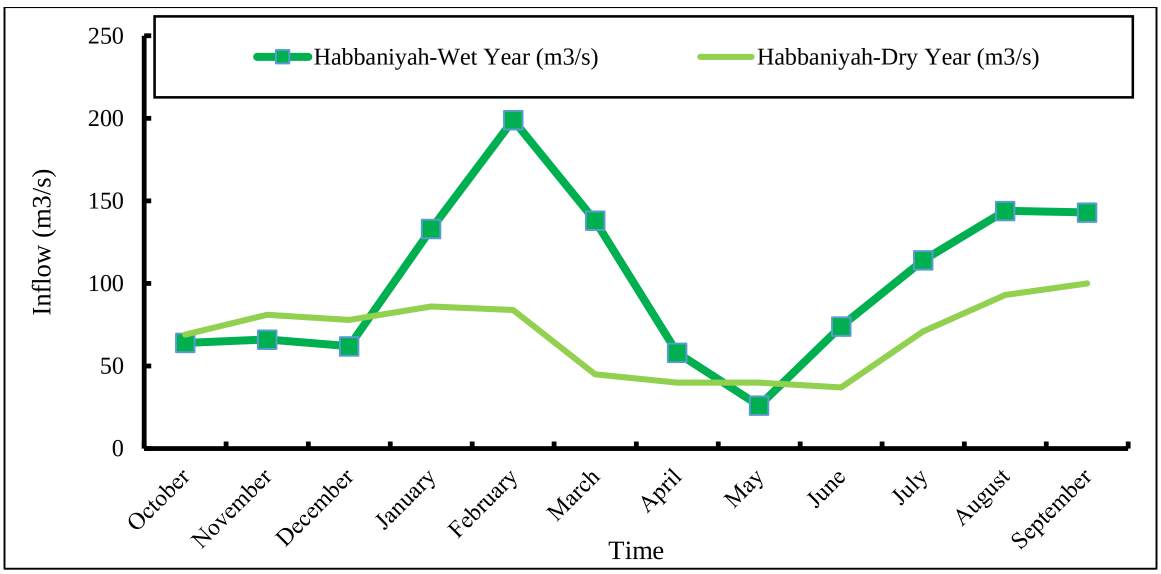

Figure 5.34: Inflow of the Habbaniyah Reservoir as a dry and wet years (NCFWRM, 2022)

5.9 Euphrates River Basin Development Scenarios

The Euphrates River Basin faces significant challenges due to climate change and human activities, which can have adverse impacts on the region's water resources, agriculture, and socio-economic development. Therefore, developing effective scenarios for the development of the Euphrates River Basin is crucial for ensuring sustainable water resource management and enhancing the well-being of local communities. These scenarios can contribute to achieving sustainable development goals in the Euphrates River Basin.

5.9.1 Haditha Reservoir Development Scenarios

Scenarios provide a vision of potential future outcomes, particularly regarding factors that could impact the balance between water demand and supply. For Iraq, ensuring socio-economic development goals such as access to safe drinking water, irrigation for farmers, and industrial water supply is essential. However, uncertainties such as the availability of water from the Euphrates River for distribution among riparian countries, the impact of water conservation projects upstream, and climate change must be considered.

By developing alternative scenarios, water resource planners can analyze various possible futures and identify the best strategy to manage uncertainties. To tackle the drought in the coming years until 2060, a strict operating plan is necessary, which entails cutting consumption across sectors except for municipal and industrial uses.

In order to mitigate the risk of reservoir depletion stemming from heightened demand for irrigation water within the Euphrates Basin Region (EBR), attributed to suboptimal irrigation efficiency and considerable losses associated with the utilization of surface irrigation methods, a strategy has been devised. This strategy entails a 50% reduction in the specified water irrigation requirements, acknowledging the imperative to curtail actual demand. Furthermore, the water allocation for marshlands is concomitantly reduced to 25% of the established need, considering a 75% decrease in water demand for marshes reliant on the Tigris River as a primary water source.

The scenarios differ in terms of the reduction in demand across these sectors: In the first scenario (H1), the criteria for this scenario can also be suggested where the amount of water needed for agriculture represents 50% of the irrigated area, the water needed for marshlands is equal to 75% of the real annual need, respectively.

The second scenario (H2): The water requirements for water supply for the Municipal, Industrial, agricultural requirements, wetlands restoration as marshland, environmental release is equal to 100 % of the real annual need.

5.9.2 Tharthar and Habbaniyah Reservoirs' Scenarios

The percentage of the reduction in the various sectors of the demand represent the targets of the optimal operation that feeding this sector. First scenario TH1, where the amount of water needed for agriculture represents 50% of the irrigated area can be used to operate the Tharthar Reservoir. However, a different scenario must be used due to the storage deficiency. As a result, scenario TH2 is an alternative scenario for operating the Tharthar Reservoir. It includes drawing water from the reservoir's dead storage because MoWR in Iraq has put floating pumping stations on the dead storage to capitalize on the drought. When the storage in the conservation zone is depleted, Tharthar's dead storage equals 39600 MCM. The scenario HB can be adopted in the Habbaniyah Reservoir operation where the amount of water demand for agriculture represents 50% of the irrigated area. Figure 5.33 shows an image of the floating pumping stations on the dead storage of Tharthar Reservoir.

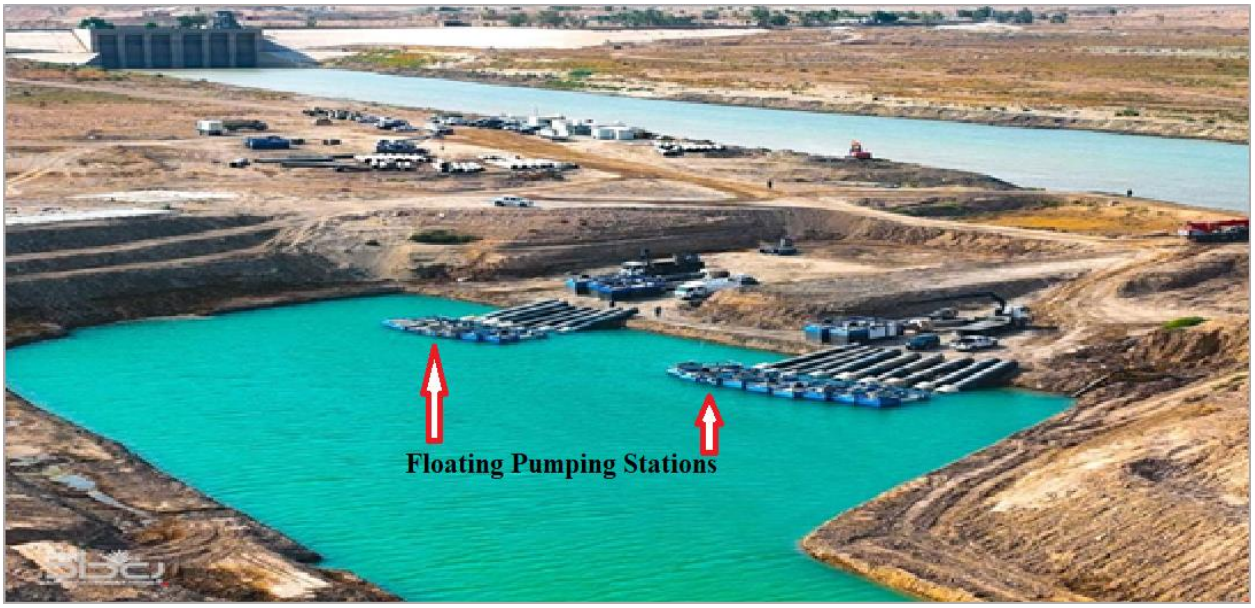

Figure 5.35: Image for the floating pumping stations of Tharthar Reservoir (www.kitabat.info)

5.10 Assumptions of the Multi-Reservoirs System

In the management and operation of reservoirs and the distribution of water to the governorates along the river basin, it is necessary to establish the following assumptions:

1-The operation required for the planning period of October 2022 to September 2059 must include the operation of the Haditha Reservoir only to supply water for the provinces of Anbar, Baghdad, Najaf, Muthana, and Thi-Qar, while Babil and Diwaniya province from Tharthar Reservoir, additionally supply the water for Karbala from the Habbaniyah Reservoir, where the provinces (Babil and Diwaniya) are situated on the bottom of Tharthar Reservoir.

2-Because the Tigris River is supplied by a few water sources inside Iraq, including Al-Khaboor, Dokan, Upper Zap River, Lower Zap River, Al-Udhaim, and Diyala

River, the Tharthar Reservoir is only used to supply the Euphrates River during the operational season.

5.11 Optimization-Based Modeling of Water Conservation and Hydropower Projects

Visual Basic for Application (VBA) software associated with Microsoft Excel is an efficient tool used for data analysis and processing. VBA facilitates the development of custom programs and the automation of frequently performed operations. It is frequently used in hydropower and water conservation project planning (Yan and Hongliang, 2012).

Furthermore, after the development of new optimum operation rule curves for the reservoir using DDDP, it is possible to operate the reservoir using other modelling software such as WEAP. In this study, the priorities of water use are established, with municipal water being more critical than irrigation in case of a deficit. Monthly analyses are carried out for the water year to evaluate the impacts of hydrological droughts in the system. To ensure a comprehensive evaluation, a sufficiently long period should be selected, and in this study, the period of 2023-2060 is chosen as the reference scenario and 2022 as the current scenario. WEAP is a demand-based software that can automatically convert population and agricultural areas to water use if the monthly water use rate is known, and the capacity of all transmission links can be determined. Figure 5.34 shows the flow chart methodology of the optimal operation scenarios. The details of the programming codes of Haditha, Tharthar, and Habbaniyah Reservoirs are shown in Appendix – C1.

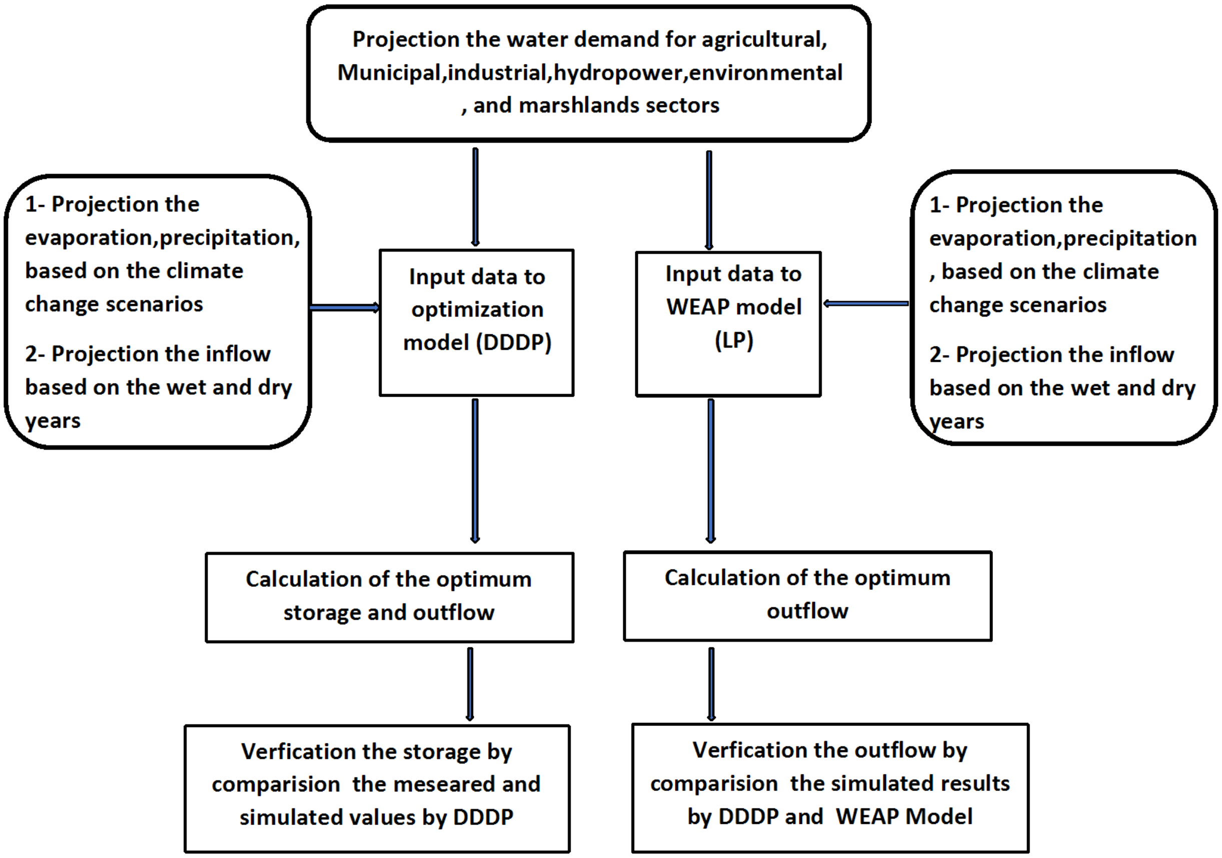

Figure 5.36: Flow chart methodology of the optimal operation scenarios

5.12 Validation for Modeling and Operation Policies

The evaluation of the performance of the modeling system under the projecting of the climate change data is an essential objective of this study. The performance ratings for evaluating the model are as follows:

1-The coefficient of determination (R^2) quantifies the extent to which the model explains the variance in measured data. (Moriasi et al., 2007). R^2 is employed to evaluate both calibration and validation outcomes of the model (Khazaipoul et al., 2019).

2- The Nash-Sutcliffe Efficiency (NSE) or coefficient of efficiency gauges the agreement between observed and simulated data, specifically by comparing them to the 1:1 line representing equal values. Unlike the coefficient of determination, NSE assesses the resemblance of observed values to the measured-predicted data relationship, rather than the best-fit linear regression line (Chu et al., 2004). The conformance between simulated and observed data is evaluated using NSE (Khazaipoul et al., 2019). NSE is calculated as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{N}(X_{obs} - X_{sim})^2}{\sum_{i=1}^{N}(X_{obs} - \bar{X}_{obs})^2} \qquad (5.13)$$

Where X_{obs} and X_{sim} are the observed and simulated values variables, $\bar{X}_{obs}$ is the average of the observed values, and N is the samples number (Moriasi et al., 2007). Acceptable performance levels are typically considered within the range of 0.0 to 1.0. NSE values ≤ 0.0 indicate that the mean observed value is a better predictor than the simulated value, indicating unacceptable performance (Moriasi et al., 2007).

3- Percent bias (PBIAS): it measures the tendency of the simulated data to be on average either larger or smaller than their observed counterparts (Moriasi et al., 2007).

$$\text{PBIAS} = \frac{\sum_{i=1}^{N}(X_{obs} - X_{sim})}{\sum_{i=1}^{N} X_{obs}} \times 100 \qquad (5.14)$$

The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model overestimation bias, and negative values indicate model underestimation bias.

Chapter Six

Results and Discussion

6.1 Implications of Climate Change

The Climate Change Knowledge Portal (CCKP) uses the multi-model ensemble from the Coupled Model Intercomparison Project (CMIP6) to generate climate data. The CCKP is an online platform that provides access to a wide range of climate data, information, and tools to support decision-making and planning in the context of climate change. The CCKP fills the critical need by providing a wealth of climate data, including historical records and future projections, and tailored to individual countries such as Iraq and subnational regions like the Iraqi provinces.

This study investigates the impact of climate change on the evaluation of optimal operation strategies for the Haditha, and Tharthar Reservoirs, and Habbaniyah Reservoir. The primary focus is on the estimation of three crucial parameters: agricultural demand, evaporation, and precipitation. The projected climate data for Anbar and Babil Provinces are chosen as representative samples to analyze the effects of climate change on the ERB. The projected maximum and minimum temperature, precipitation, and relative humidity data are implemented under the three scenarios of climate change: RP, SSP1-2.6, and SSP2-4.5, for the three period 1995-2014, 2020-2039, and 2040-2059, respectively.

Figures 6.1 shows the differences between the historical and projected data of the maximum annual temperature for Anbar and Babil provinces during the period of the three scenarios. The maximum annual temperature for Babil province is higher than Anbar, the average difference between the two provinces is equal (2.84, 3.67, and 3.17) °C of the RP, SSP1-2.6, and SSP2-4.5 scenarios, respectively. The maximum temperatures in both provinces are expected to increase over time. The maximum temperatures of Anbar province record 28.4, 29.43,29.57,30.4, and 31.13 °C in 1995, 2014, 2020, 2040 and 2059. The maximum temperatures of Babil province equal 31.32, 32.33, 33.24, 33.26, 33.93 °C in 1995, 2014, 2020, 2040 and 2059, respectively. The average annual maximum temperatures of Anbar province equal 28.94, 30, and 30.8 °C of the RP, SSP1-2.6, and SSP2-4.5 scenarios, respectively. While the average maximum temperatures of Babil province equal 31.78, 33.67, and 33.68 °C for the same scenarios.

Figure 6.2 shows the differences between the historical and projected data of the minimum annual temperature for Anbar and Babil provinces during the period of the three scenarios. The minimum annual temperature for Babil province is higher than Anbar, the average difference between the two provinces is equal 2.51, 2.56, and 2.62 °C of the RP, SSP1-2.6, and SSP2-4.5 scenarios, respectively. The minimum temperatures in both provinces are expected to increase over time. The minimum temperatures of Anbar province record 13.33, 14.41,14.5 ,15.39, and 16.03 °C in 1995, 2014, 2020, 2040 and 2059. The minimum temperatures of Babil province equal 15.82, 16.68, 17.1, 18.17, 18.61 °C in 1995, 2014, 2020, 2040 and 2059, respectively. The average minimum temperatures of Anbar province equal 13.93, 14.87, and 15.64 °C of the RP, SSP1-2.6, and SSP2-4.5 scenarios, respectively. While the average minimum temperatures of Babil province equal 16.44, 17.43, and 18.26 °C for the same scenarios.

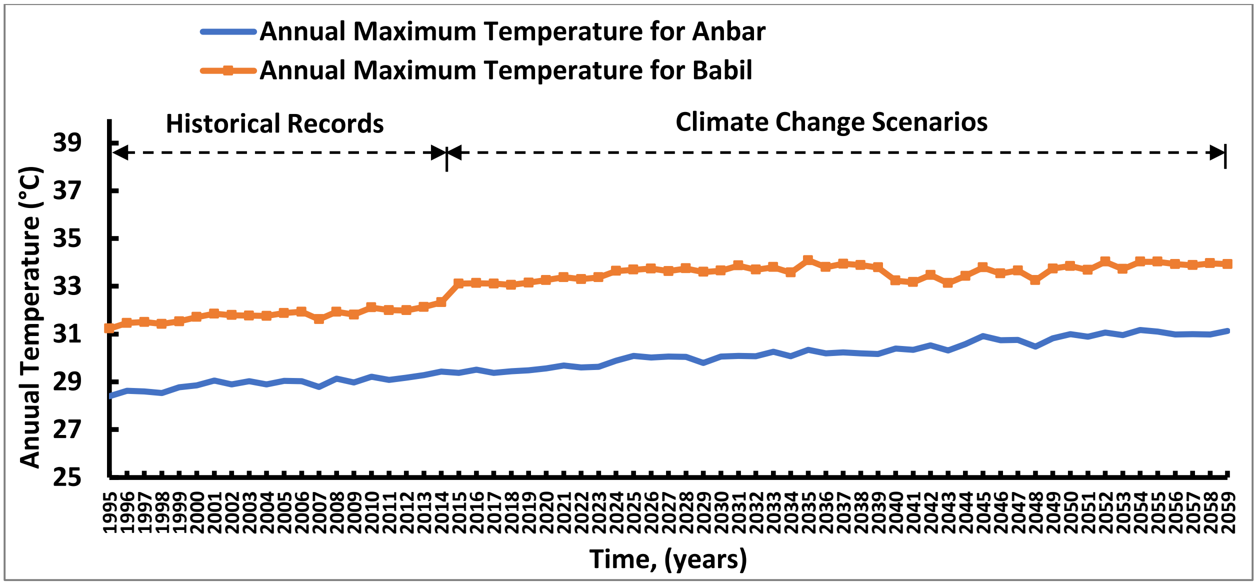

Figure 6.1: Time series of maximum annual temperature for Anbar and Babil provinces (CCKP, 2022)

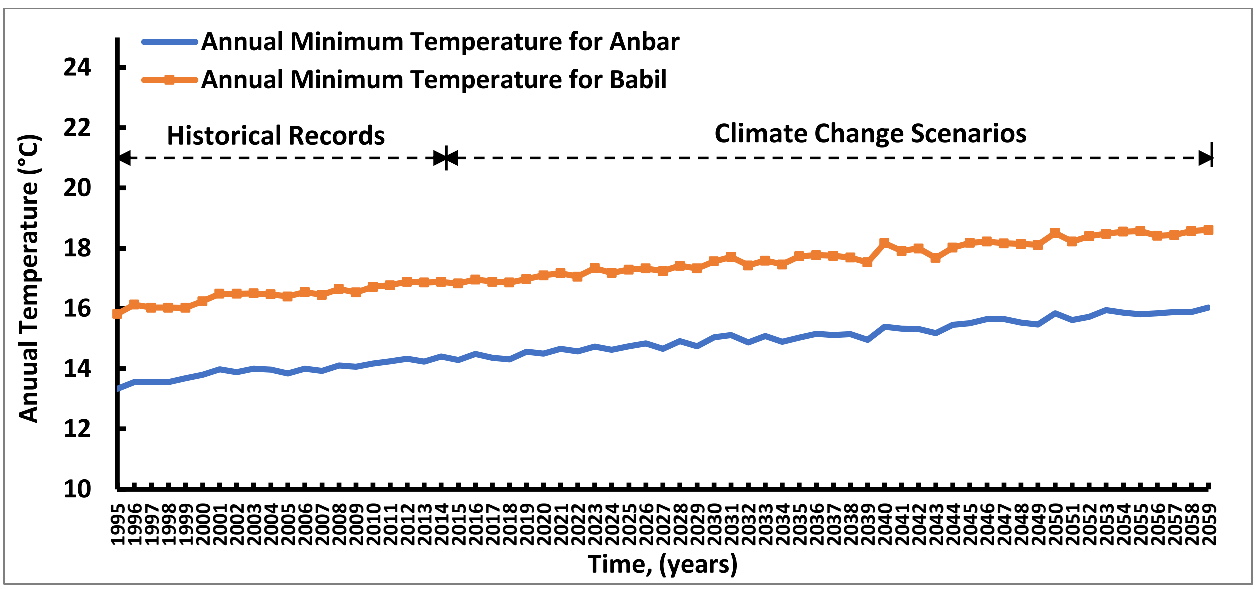

Figure 6.2: Time series of minimum annual temperature for Anbar and Babil provinces (CCKP, 2022)

Figure 6.3 shows that the precipitation for Anbar province is higher than Babil, the average difference between the two provinces is equal 6.38, 5.57, and 2.27 mm of the RP, SSP1-2.6, and SSP2-4.5 scenarios, respectively. The total annual precipitation in both provinces is expected to fluctuate over time. The total annual precipitation of the Anbar province records (64.6, 63.35, 65.02, 59.77, and 83.02) mm in 1995, 2014, 2020, 2039 and 2059. The total annual precipitation of the Babil province equal (54.01, 66.41, 70.53, 62.38, 80.2) mm in 1995, 2014, 2020, 2039 and 2059, respectively.

Figure 6.4 shows the projected annual relative humidity in Anbar fluctuated between a maximum of 37.42 % and a minimum of 34.48 %. At the same time, Babil ranged from a maximum of 35.28 % to a minimum of 31.56 %. The annual relative humidity appears to be greater in the Anbar Province compared to the Babil Province. The annual relative humidity in both provinces is expected to fluctuate over time. The annual relative humidity of Anbar province records 35.9, 37.17, 36.99, 37.01, and 36.33 % in 1995, 2014, 2020, 2040 and 2059. The relative humidity of Babil province equal (32.93, 34.27, 34.44, 34.2, and 34.15) % in 1995, 2014, 2020, 2040 and 2059, respectively.

The annual relative humidity of Anbar and Babil provinces aligns with the findings of the (IPCC, 2022). The observed relative humidity changes in both provinces fall within the range of 3.0 % to 3.72 %, which corresponds to the simulated changes in global warming. This range is consistent with the projected relative humidity changes for the Iraq region, which range from 0.1 to 10 % (IPCC, 2022). These results indicate that the relative humidity variations observed in Anbar and Babil provinces are within the expected limits of climate change impacts in the region, as outlined by the IPCC.

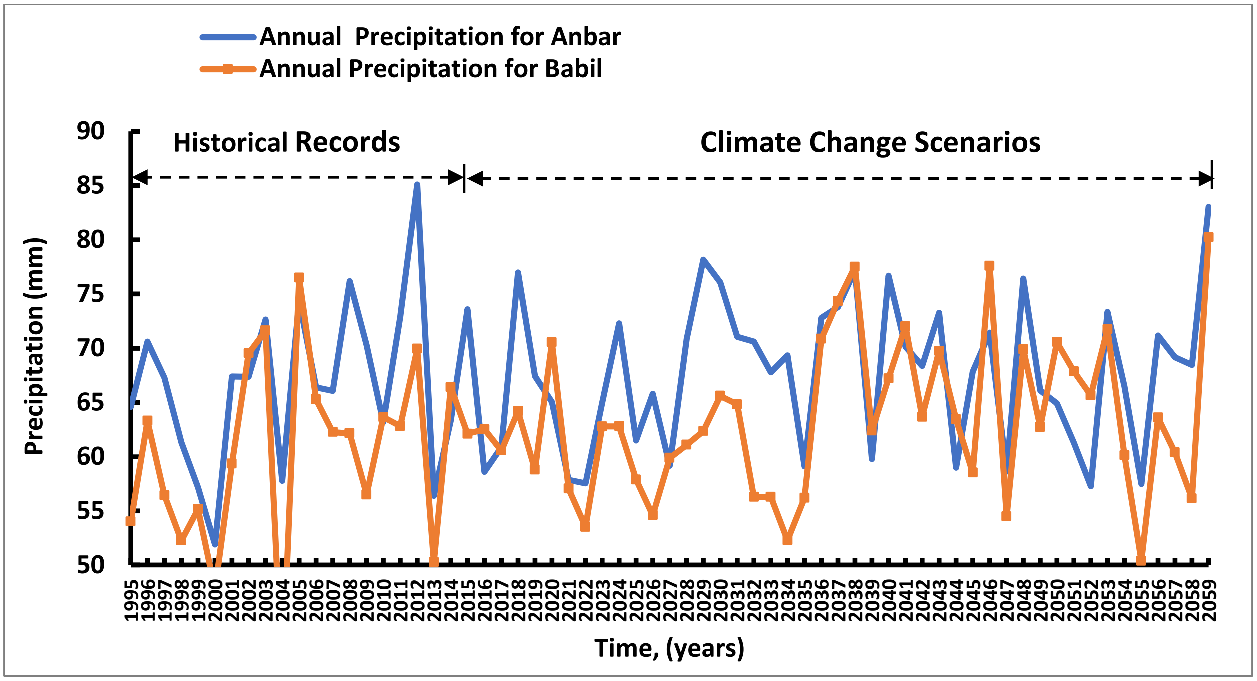

Figure 6.3: Time series of annual precipitation for Anbar and Babil provinces (CCKP, 2022)

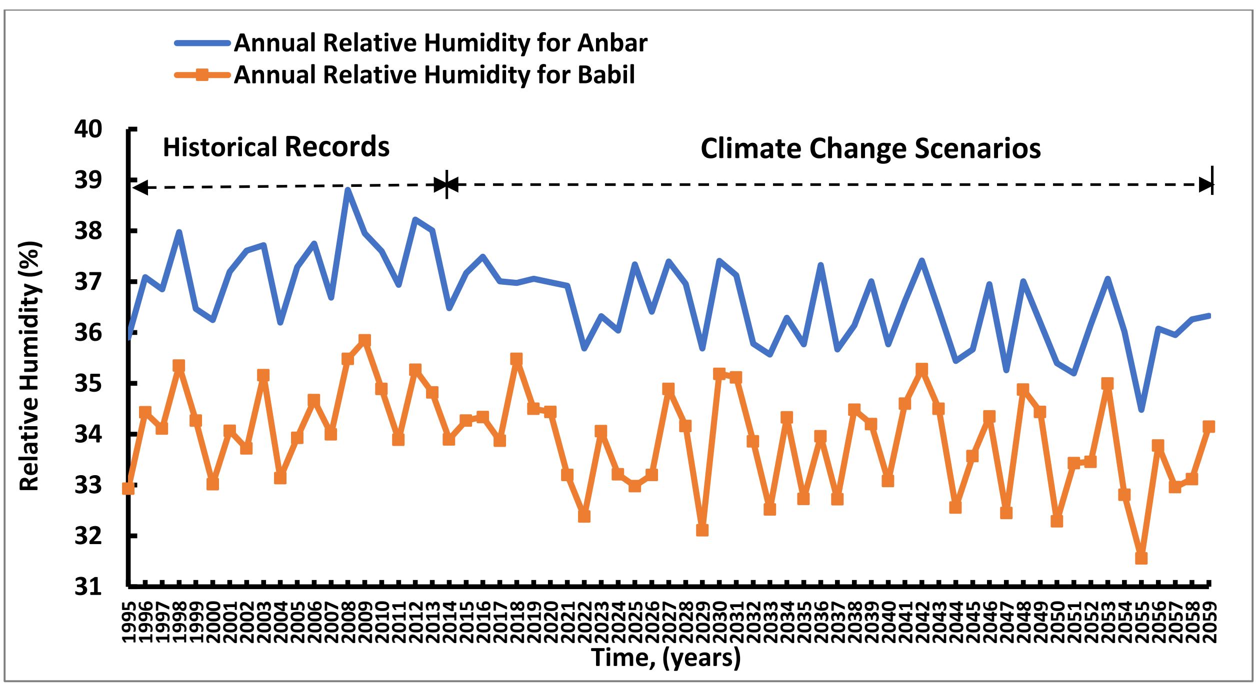

Figure 6.4: Time series of relative Humidity for Anbar and Babil provinces (CCKP, 2022)

6.2 Water Demand for Agricultural Requirements

The present and future climate data provided can indeed be utilized in The CROPWAT model. CROPWAT helps to assess the water requirements for agricultural crops. By incorporating climate data, such as maximum and minimum temperature, precipitation, and relative humidity into the model, it becomes possible to estimate crop water requirements and optimize irrigation management strategies.

Figure 6.5 shows the monthly projected Evapotranspiration (ETo) for the three scenarios of the climate change RP, SSP1-2.6, and SSP2-4.5, for Anbar Province. The months of May to September have relatively high values, equal to or more than 200 mm/month, and the months of October to April showed the lowest ETo, equal to or less than 150 mm/month, coinciding with the dry and rainy seasons, respectively. The ETo values for RP scenario range from 49.6 mm to 296.98 mm, with an overall average of 157.12 mm. For SSP1-2.6 scenario, the monthly ETo ranges from 61.69 mm to 392.77 mm, with an average of around 202.35 mm. The average monthly ETo for SSP2-4.5 scenario ranges from 62 mm to 400.21 mm, with an average of 206.35 mm. These differences in average ETo values provide insights into the potential changes in water requirements and irrigation management under different climate change scenarios. The ETo values exhibit seasonal patterns. Generally, the values tend to increase from the beginning of the year, peak in the middle to late summer, and then gradually decrease towards the end of the year for all three scenarios.

Figure 6.6 shows the monthly irrigation water demand for Anbar Province. The total annual irrigation water demand was estimated at 1421,1467 and 1619 MCM for the three climate change scenarios. In the RP scenario, the irrigation water demand ranges from 17.9 to 231.8 MCM/month, with an overall average of approximately 218.58 MCM/month. Under the SSP1-2.6 scenario, the demand varies between 17.4 and 239.4 MCM/month, with an average of around 225.74 MCM/month. In the SSP2-4.5 scenario, the irrigation water demand ranges from 16.2 to 286.1 MCM/month, with an average of approximately 293.75 MCM/month. When comparing the irrigation water demand among the scenarios, it is evident that the SSP2-4.5 scenario has the highest average water demand, followed by the SSP1-2.6 scenario and the RP scenario. The disparities in average water demand between the RP and SSP1-2.6 scenarios are relatively minor, suggesting similar requirements in terms of irrigation water. However, the difference between the RP and SSP2-4.5 scenarios is more substantial, indicating a significantly higher water demand in the SSP2-4.5 scenario.

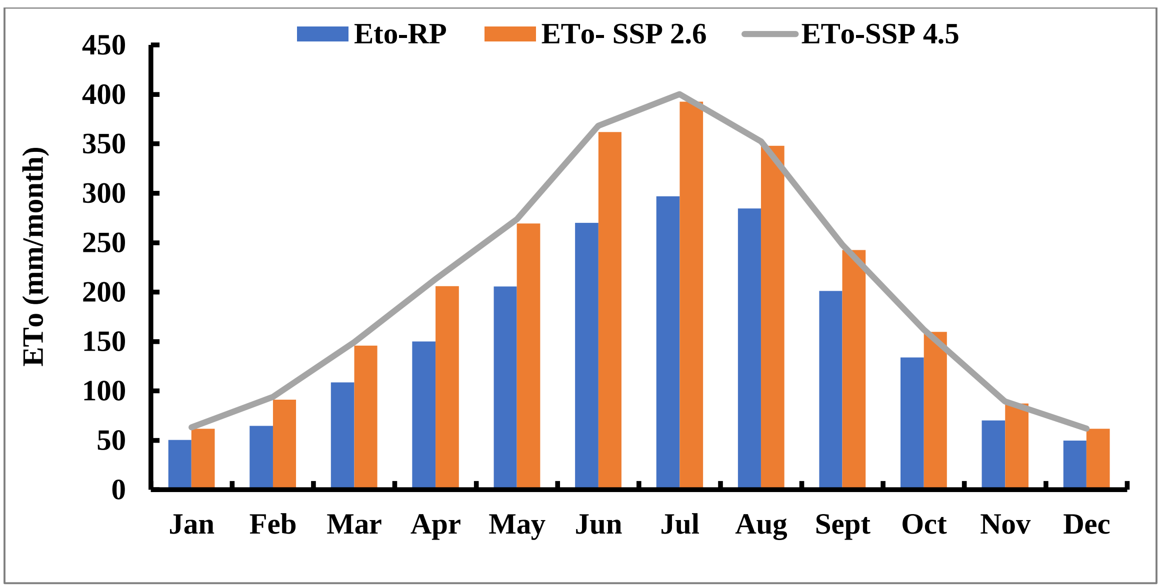

Figure 6.5: Monthly projected ETo of the climate change scenarios for Anbar

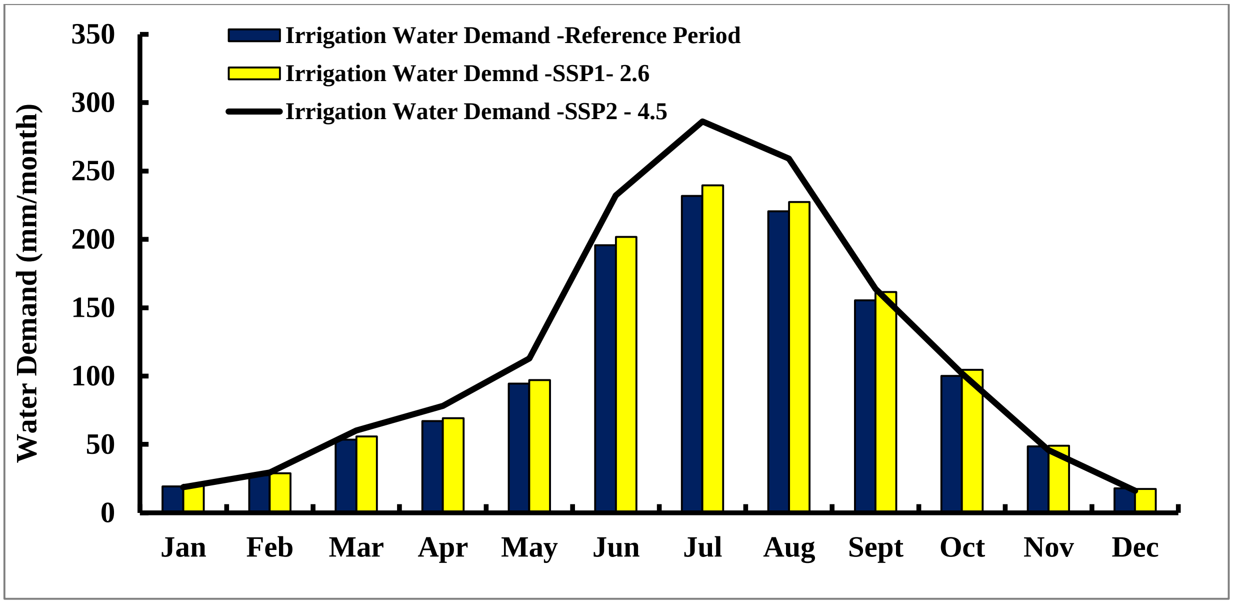

Figure 6.6: Projection of the irrigation water demand for Anbar Province

Figure 6.7 illustrates the monthly variations in evapotranspiration (ETo) from May to September, with values exceeding 240 mm/month, while the months of October to April exhibit lower ETo levels, typically below 200 mm/month. These patterns align with the dry and rainy seasons, respectively. The ETo values for RP scenario range from 62.93 mm to 343.48 mm, with an overall average of 187.46 mm. For SSP1-2.6 scenario, the monthly ETo ranges from 64.79 mm to 349.37 mm, with an average of around 195.66 mm. The average monthly ETo for SSP2-4.5 scenario ranges from 62 mm to 429.97 mm, with an average of 224.20 mm.

During the dry season, the combination of high temperatures and low relative humidity leads to increased evapotranspiration rates. Conversely, in the rainy season, the frequent rainfall, high relative humidity, and relatively lower temperatures contribute to lower ETo values. These variations in ETo can be attributed to the dynamic interplay of these factors, resulting in significant fluctuations both within and between seasons. The ETo for other provinces are shown in Appendix – B1.

Figure 6.8 shows the monthly irrigation water demand for Babil Province for the three climate scenarios. The total annual irrigation water was estimated at 3969, 4138, and 4763 MCM. In the RP scenario, the irrigation water demand ranges from 39.75 to 744.23 MCM/month, with an overall average of 330.72 MCM/month. Under the SSP1-2.6 scenario, the demand varies between 40.44 and 771.05 MCM/month, with an average of around 344.84 MCM/month. In the SSP2-4.5 scenario, the irrigation water demand ranges from 44.24 to 940.58 MCM/month, with an average of 396.89 MCM/month.

The impact of climate change on water irrigation demand in Anbar and Babil provinces is evident from the following findings: For Anbar Province, there is an estimated increase of 3.2% in water demand from 2020 to 2039, and a further increase of 14% from 2040 to 2059. In the case of Babil Province, the projected increase in water demand is 12% from 2020 to 2039, and a larger increase of 20% from 2040 to 2059. This aligns with the consensus of the researchers Saeed et al., (2021), Al-Ansari et al., (2021), Ewaid et al., (2021), and Abdulhadi and Alwan, (2021) who also indicate that climate change contributes to increased irrigation water demand and scarcity in Iraq. These studies emphasize the importance of considering climate change in managing water resources and highlight the need for improved water management practices to cope with the projected increases in irrigation water demand. The projected irrigation water demand for the other provinces is shown in Appendix – B1.

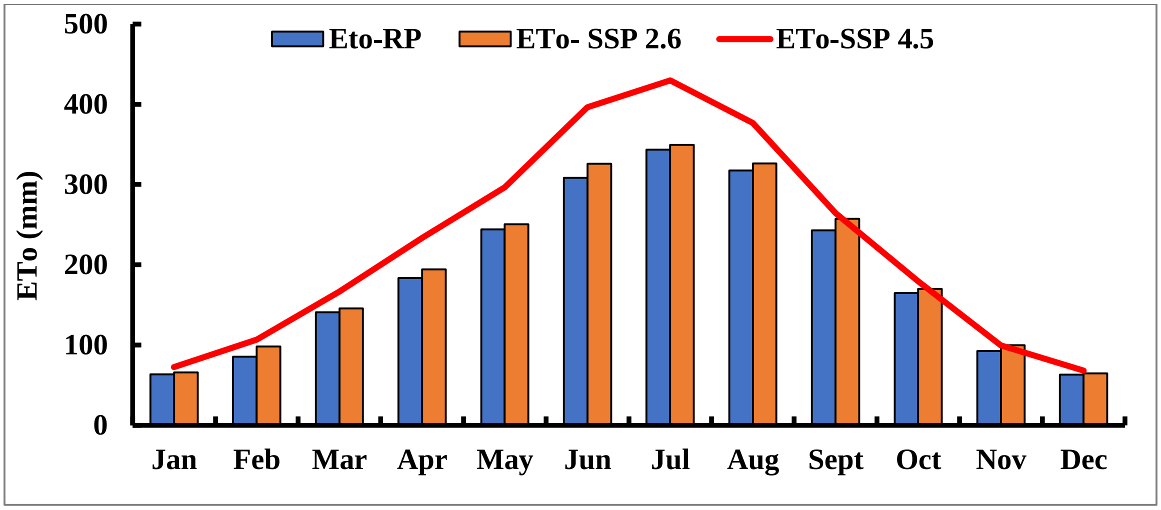

Figure 6.7: Projected ETo of the climate change scenarios for Babil Province

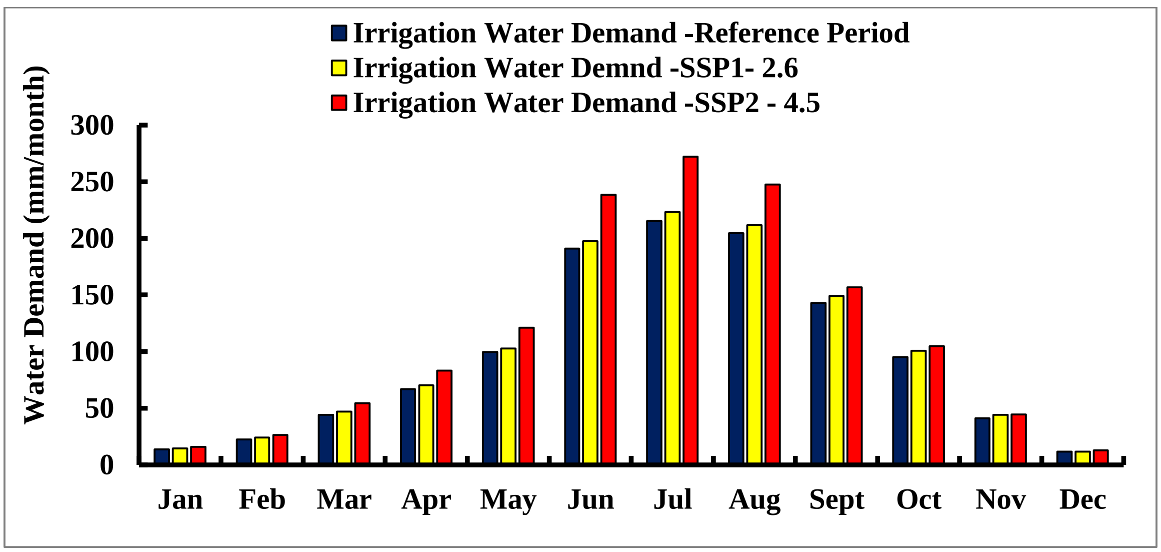

Figure 6.8: Projected irrigation water demand for the Babil Province.

6.3 Validity of Projections from Agricultural Model

The reference evapotranspiration ETo is one of the most important variables calculated by the CROPWAT program, so it was chosen for the program verification process. R^2, PBIAS, and NSE can be used in calculating the differences between the observed ETo by NEMP, (2006), and simulated ETo by the CROPWAT program. Table 6.1 shows the value of the R^2, PBIAS, and NSE for the provinces Anbar, Babil, Najaf, Diwaniyah, Baghdad, Karbala, Muthanna, and Thi-Qar.

Table 6.1: R^2, PBIAS, and NSE for the comparison between the observed and estimated ETo.

Province	R^2	PBIAS	NSE
Anbar	0.98	8.47	0.91
Babil	0.98	13.14	0.94
Najaf	0.97	0.18	0.74
Diwaniyah	0.98	25.39	0.99
Baghdad	0.98	1.08	0.94
Karbala	0.98	9.21	0.87
Muthanna	0.56	36.9	0.51
Thi-Qar	0.95	43.67	0.60

Table 6.1 shows the high R^2 values of the Anbar, Babil, Najaf, Diwaniyah, Thi-Qar, Baghdad, and Karbala provinces, ranging from 0.95 to 0.98. This indicates a strong correlation between the observed and predicted values for these provinces. Muthanna province has lower R^2 values of 0.56 suggesting a weaker correlation between the observed and predicted values.

PBIAS measures the average tendency of the predicted values to be overestimated or underestimated compared to the observed values. Najaf and Baghdad have the minor PBIAS value, indicating a minor bias in the predictions for this province. The minor bias means the predicted values deviate slightly from the observed values. Anbar and Karbala provinces have low biases, indicating a low bias in the predictions for this province. The lower bias means that the average deviation between predicted and observed values is relatively smaller compared to other provinces. Thi-Qar Province has a high bias, while Diwaniyah and Muthanna provinces have significant biases, suggesting a high bias in the predictions for this province. The higher bias means the predicted values have a more pronounced deviation from the observed values. The significant bias refers to the magnitude or impact of the bias suggesting a notable difference between the predicted and observed values.

An NSE value closer to 1 indicates a better fit between the observed and predicted values. Diwaniyah has the highest NSE value of 0.99, suggesting a strong agreement between the observed and predicted values in this province. Muthanna and Thi-Qar have the lowest NSE value of 0.51 and 0.60, indicating a poorer fit between the observed and predicted values compared to other provinces. Baghdad, Babil, Anbar, and Karbala also have relatively high NSE values, indicating a good fit between the observed and predicted values.

Overall, Anbar, Babil, Diwaniyah, Thi-Qar and Baghdad provinces demonstrate favorable performance across most parameters, indicating a strong correlation, low errors, and good fit between observed and predicted values. Conversely, of Muthanna province exhibit relatively poorer performance with lower correlation and larger biases.

6.4 Evaporation from the Reservoirs in the Study Area

For development of available water resources, it is necessary to reduce losses due to water evaporation from the open reservoirs surfaces as well as to restrict the water depletion (JICA, 2016).

Figure 6.9 shows the monthly evaporation rate of the Haditha Reservoir. The projected evaporation results from Haditha Reservoir can be summarized as follows: During the reference period, evaporation rates ranged from 113.44 mm in December to 346.71 mm in June, with an overall average of 224.60 mm. Under the SSP1:2.6 scenario, evaporation rates were slightly higher, with values ranging from 117.5 mm in December to 351.96 mm in June, with an overall average of 228.85 mm. For the

SSP2:4.5 scenario, evaporation rates were higher compared to both the reference period and SSP1:2.6, ranging from 126.37 mm in December to 361.26 mm in June, with an overall average of 237.94 mm. These findings indicate a seasonal pattern, with higher evaporation rates during the summer months and lower rates during the winter months. The differences in evaporation rates among the scenarios provide insights into potential variations in evaporation patterns under different climate scenarios for Haditha Reservoir.

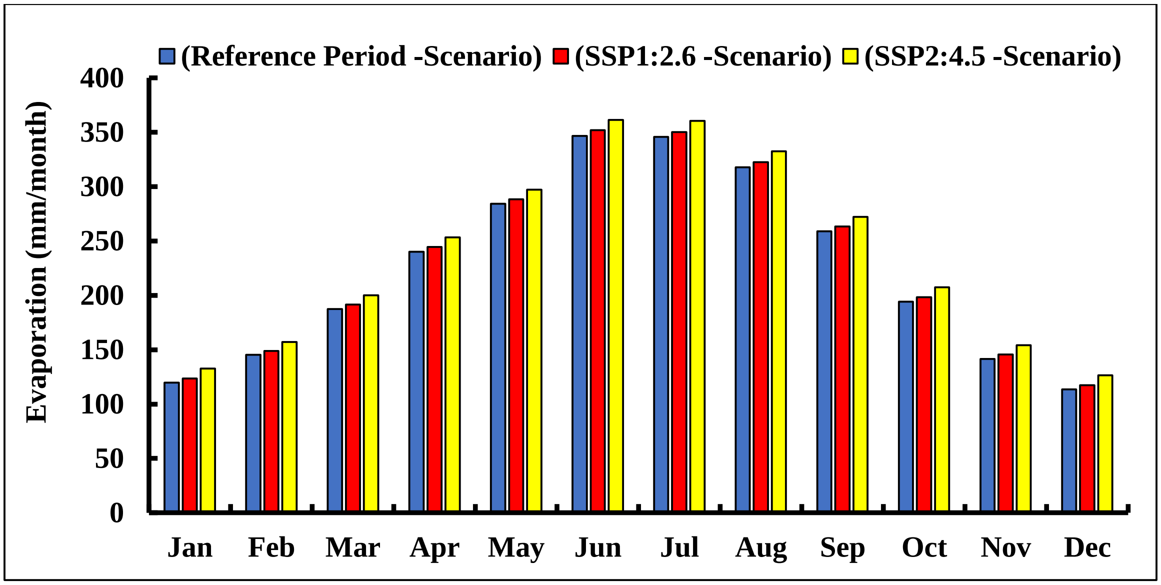

Figure 6.9: Monthly evaporation rate from Haditha Reservoir

Figure 6.10 shows the monthly evaporation rate from Tharthar Reservoir. The evaporation rates from Tharthar Reservoir were examined to understand the projected changes in evaporation under different scenarios. The analysis revealed that during the reference period, spanning from December to June, the evaporation rates varied from 113.53 mm to 347.67 mm, with a mean value of 225.07 mm. In the SSP1:2.6 scenario, the evaporation rates were slightly higher, ranging from 127.94 mm in December to 362.80 mm in June, with an average value of 239.58 mm. The SSP2:4.5 scenario exhibited even higher evaporation rates compared to both the reference period and SSP1:2.6, ranging from 148.69 mm in December to 379.11 mm in June, with an average value of 257.78 mm.

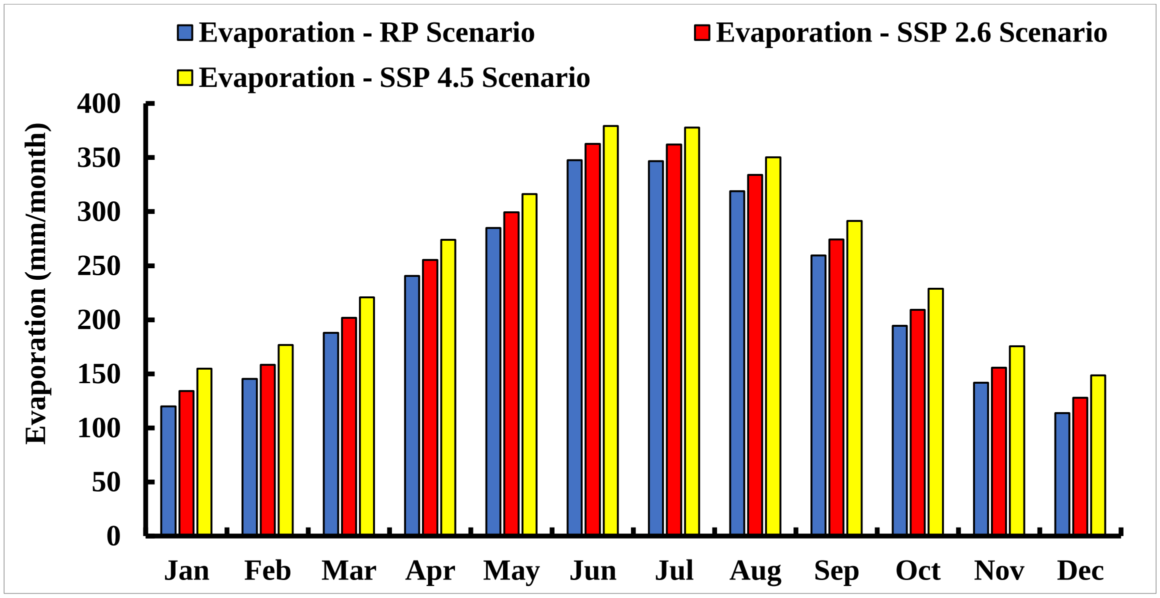

Figure 6.10: Monthly evaporation rate from Tharthar Reservoir

Figure 6.11 shows the monthly evaporation rate from Habbaniyah Reservoir. The projected evaporation rates from Habbaniyah Reservoir were analyzed to examine the potential changes in evaporation under different scenarios. The findings can be summarized as follows: During the reference period, spanning from December to June, the evaporation rates ranged from 113.44 mm to 346.02 mm, with an average value of 224.60 mm. Under the SSP1:2.6 scenario, the evaporation rates showed a slight increase, ranging from 117.50 mm in December to 351.96 mm in June, with an average value of 228.86 mm. Comparatively, the SSP2:4.5 scenario exhibited higher evaporation rates than both the reference period and SSP1:2.6, ranging from 126.37 mm in December to 361.26 mm in June, with an overall average of 237.94 mm. These results indicate a noticeable increase in evaporation rates under the SSP2:4.5 scenario.

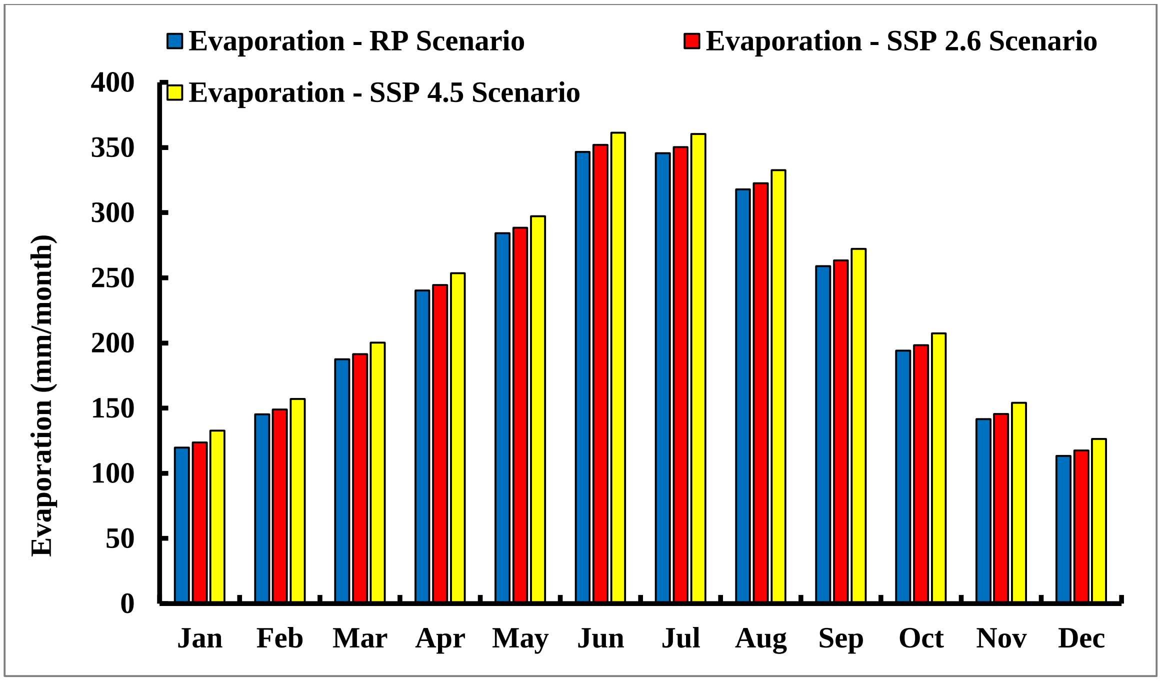

Figure 6.11: Monthly evaporation rate from Habbaniyah Reservoir.

The projected evaporation rates for Haditha Reservoir under different climate change scenarios indicate an increase in evaporation due to rising temperatures, contrasting with the reference period of 1995-2014. The annual evaporation demand for Haditha Reservoir is estimated to be 889 MCM for the SSP1:2.6 scenario and 940 MCM for the SSP2:4.6 scenario. This represents a 2.45% increase in evaporation rate for the period 2020-2039 and a 7.7% increase for the period 2040-2059 compared to the reference period.

Similarly, for Tharthar Reservoir, the annual evaporation demand is projected to be 4991.04 MCM for SSP1:2.6, and 5371.70 for SSP2:4.6. This corresponds to a 6.07% increase in evaporation rate for 2020-2039 and a 12.73% increase for 2040-2059 compared to the reference period.

Additionally, for Habbaniyah Reservoir, the annual evaporation demand is estimated to be 840.92 MCM for SSP1:2.6, 836.16 MCM for SSP2:4.6. This signifies a 5.82% increase in evaporation rate for 2020-2039 and a 9.34% increase for 2040-2059 compared to the reference period.

This study supports the findings of previous research on the impact of climate change on reservoir evaporation rates. Helfer et al., (2012), Althoff et al., (2020), and Bazzi et al., (2021) concluded that evaporation rates would increase due to rising surface air temperatures caused by climate change. Their findings highlighted the significant influence of climate change on evaporation, particularly during spring and summer seasons. Consequently, water availability in these reservoirs would be reduced, especially during the dry season.

6.5 Validity of Evaporation Model Projections

Table 6.2 presents the results of a comparison between the monthly evaporation rates calculated using the Energy Budget Method and the observed evaporation rates by NEMP (2006) for three reservoirs (Haditha, Tharthar, and Habbaniyah). The comparison is being made using four statistical criteria: R^2, NSE, and PBIAS. These criteria are used to evaluate the performance of the evaporation model being used to simulate the monthly evaporation rates.

Table 6.2: Statistical parameters of validation of evaporation model

Reservoir	R^2	PBIAS %	NSE
Haditha	0.95	-12.30	0.84
Tharthar	0.95	-12.53	0.84
Habbaniyah	0.92	-12.30	0.78

Table 6.2 provides the coefficient of determination (R^2) for all three reservoirs indicating a strong relationship between the observed and predicted values.

The percent bias (PBIAS) for Haditha and Habbaniyah Reservoirs is -12.30% and for Tharthar Reservoir is -12.53%. These values indicate a slight underestimation of the predicted values compared to the observed values. This suggests that the model tends to slightly underestimate the actual values in these reservoirs.

The Nash-Sutcliffe efficiency (NSE) values for Haditha, Tharthar, and Habbaniyah reservoirs are 0.84, 0.84, and 0.78 respectively. These values indicate a moderate model performance, with 0.84 suggesting a relatively high degree of agreement between the observed and predicted values in Haditha and Tharthar reservoirs, and 0.78 indicating a slightly lower agreement in the case of Habbaniyah reservoir.

Overall, the results of the parameters in Table 6.2 show that the models used for these reservoirs have a strong correlation (R^2) with the observed data, and reasonable PBIAS and NSE values.

6.6 Precipitation on Reservoirs Boundary

The analysis of Figure 6.12 provides insights into the precipitation patterns at Haditha Reservoir, considering different scenarios and the reference period. During the reference period, the monthly precipitation rates range from 5.99 mm in October to 9.09 mm in April. Under the SSP1:2.6 scenario, the precipitation rates exhibit slight variations, ranging from 5.38 mm in October to 9.79 mm in November. Comparatively, the SSP2:4.5 scenario shows similar precipitation patterns, with values ranging from 5.72 mm in October to 11.23 mm in May. It is notable that the June, July, and August months have negligible precipitation across all scenarios.

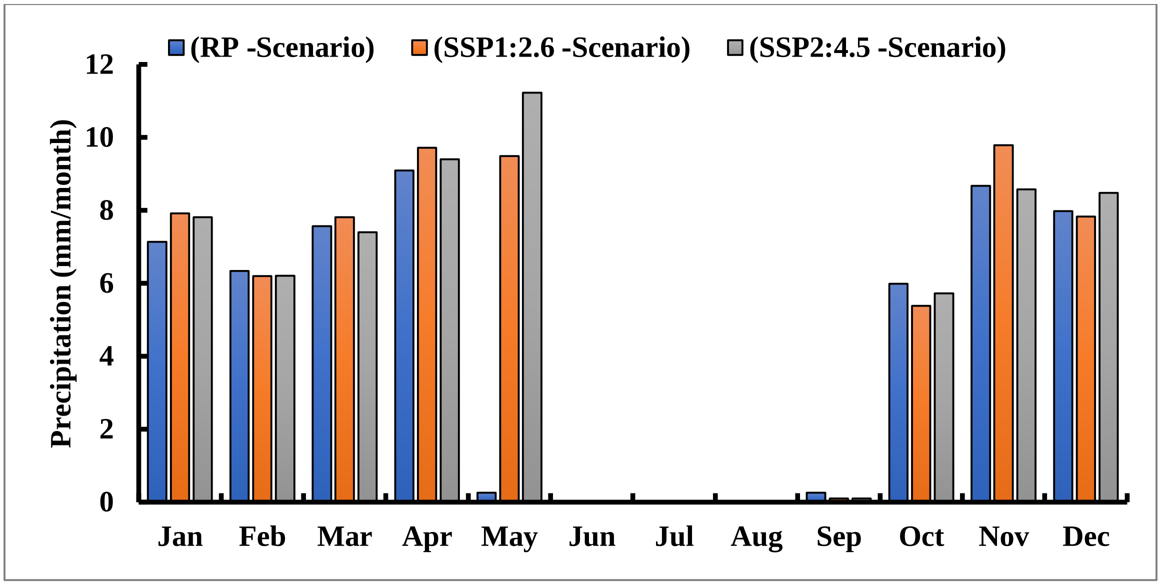

Figure 6.12: Monthly precipitation rate of the Haditha Reservoir

Figure 6.13 reveals the precipitation patterns at Tharthar Reservoir, considering different scenarios and the reference period. During the reference period, the monthly precipitation rates range from 9.965 mm in January to 17.535 mm in April. Under the SSP1:2.6 scenario, the precipitation rates exhibit some variability, ranging from 8.43 mm in February to 12.075 mm in April. Similarly, the SSP2:4.5 scenario shows comparable precipitation patterns, with values ranging from 7.88 mm in February to 12.07 mm in April. Notably, the June, July, and August months have significantly lower precipitation across all scenarios, with values ranging from 0.03 mm to 1.98 mm.

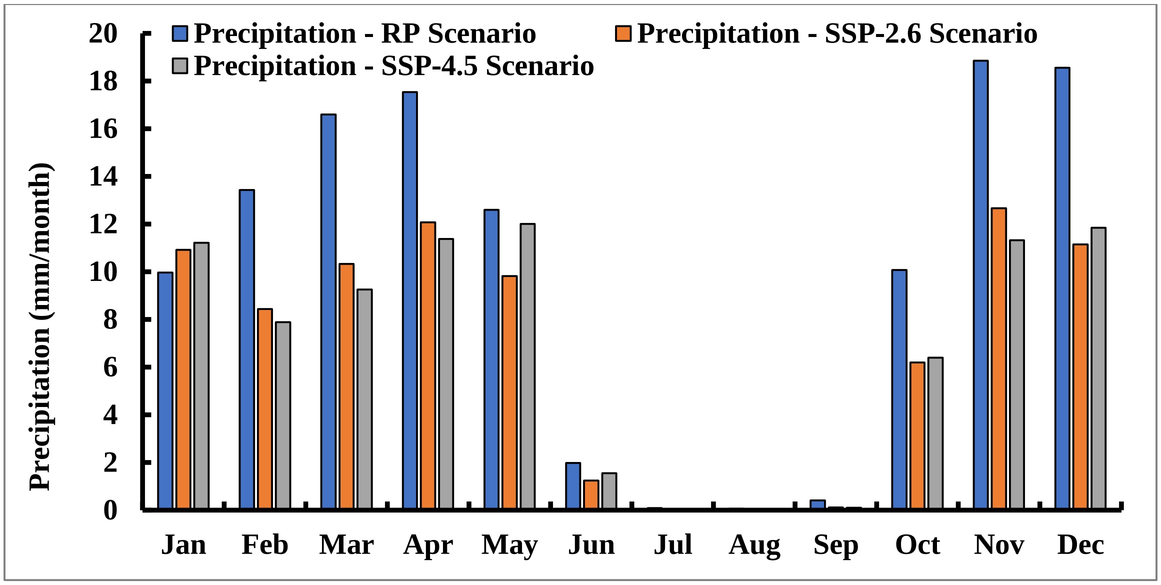

Figure 6.13: Monthly precipitation rate of the Tharthar Reservoir

Figure 6.14 represents the precipitation patterns at Habbaniyah Reservoir, considering the reference period and two different scenarios: SSP1:2.6 and SSP2:4.5. During the reference period, the monthly precipitation levels range from 6.34 mm in February to 9.09 mm in April. Under the SSP1:2.6 scenario, the precipitation rates show slight variations, ranging from 6.19 mm in February to 9.72 mm in April. Similarly, the SSP2:4.5 scenario exhibits comparable precipitation patterns, with values ranging from 6.21 mm in February to 11.23 mm in May. Overall, the analysis highlights the variations in precipitation rates throughout the year and under different scenarios, emphasizing the importance of considering climate scenarios in assessing water resources and reservoir management planning for the Reservoirs.

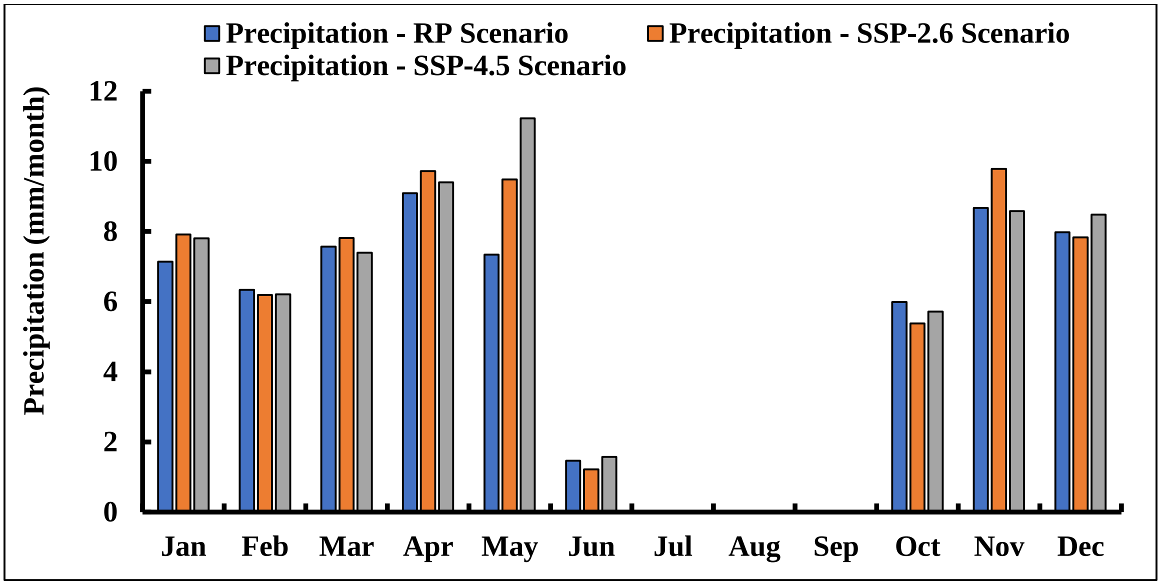

Figure 6.14: Precipitation rate of the Habbaniyah Reservoir

6.7 Water Demand for Municipal Purposes

The estimation of future water withdrawal values was constructed by multiplying the projected population figures with the anticipated per capita water demand. It is essential for the Haditha Reservoir to operate optimally to fulfill the annual needs of the Municipal sector.

Figure 6.15 represents the municipal water demand for Haditha Reservoir over a span of several years. From 2022 to 2059, the municipal water demand gradually increases. In 2022, the demand is 719.42 million cubic meters (MCM), and it steadily rises each year, reaching a peak of 1363.0 MCM in 2059. The average annual increase in the consumption of municipal demand is equal to 17.89 MCM.

Figure 6.16 represents the municipal water demand for Tharthar Reservoir over a span of several years. From 2022 to 2059, the municipal water demand shows a gradual increase. In 2022, the demand is 439.23 MCM, and it steadily rises each year, reaching a peak of 807.52 MCM in 2059. The average annual increase in the consumption of municipal demand is equal to 9.94 MCM.

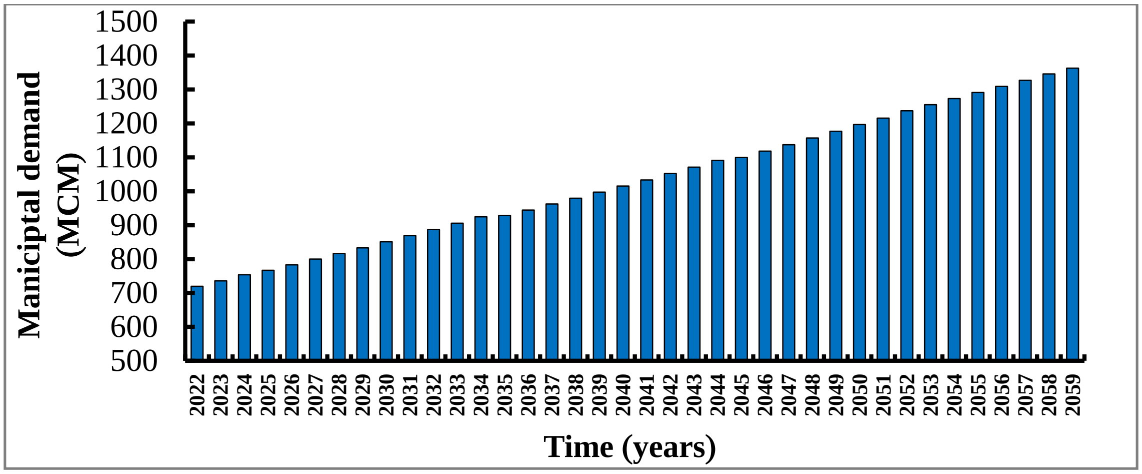

Figure 6.15: Projected municipal water demand of the Haditha Reservoir

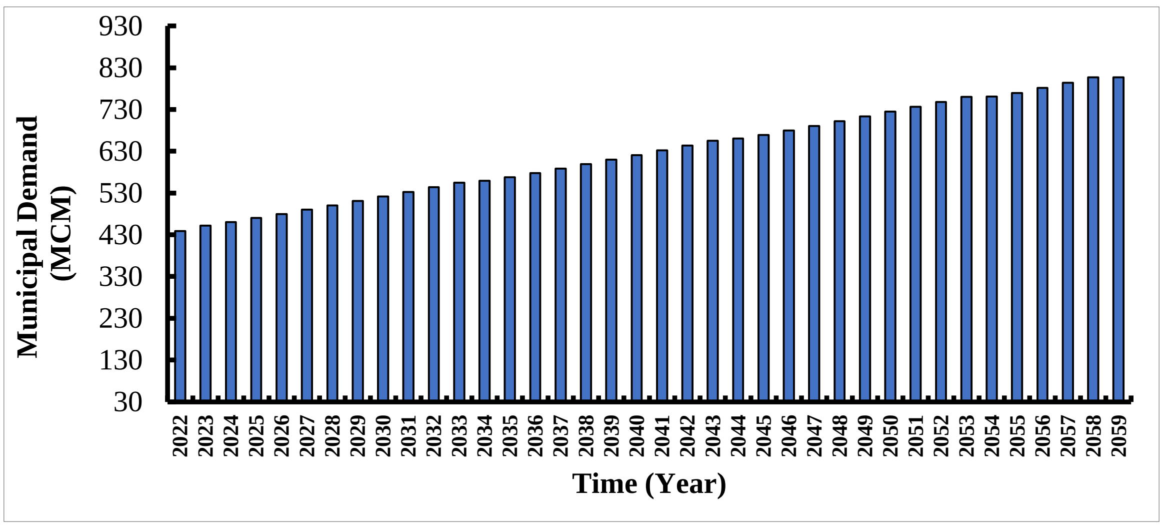

Figure 6.16: Projected municipal water demand of the Tharthar Reservoir.

Figure 6.17 shows the projected municipal water demand of the Habbaniyah Reservoir. The provided data represents the municipal water demand for Habbaniyah Reservoir. From 2022 to 2059, the municipal water demand shows a gradual increase. In 2022, the demand is 177.10 million cubic meters (MCM), and it steadily rises each year, reaching a peak of 324.94 MCM in 2059. The average annual increase in the consumption of municipal demand is equal to 3.99 MCM.

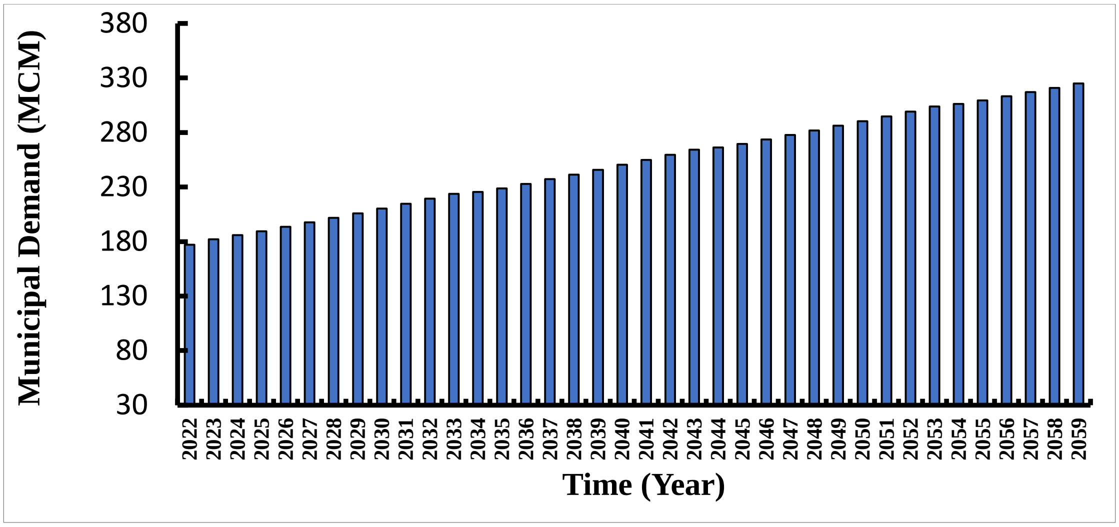

Figure 6.17: Projected municipal water demand of the Habbaniyah Reservoir.

The municipal water demand shows an overall upward trend, indicating a growing need for municipal water supply. This study’s findings align with the findings of other researchers who have investigated the impact of population growth on water demand in different regions. Xiao-jun et al., (2015), Arsiso et al., (2017), Zubaidi et al., (2020) found that population growth led to an increase in municipal water demand. They suggested demand management strategies and highlighted population growth as a challenging factor for estimating urban water demand, putting strain on the municipal water system.

6.8 Water Demand for Industrial Purposes

The projected values of the future total annual water for industrial withdrawals covering the period 2022-2059 for the provinces of the Haditha Reservoir (Anbar, Najaf, Muthanna, and Thi-Qar) are shown in Figure 6.18.

Figure 6.18 shows the minimum value of the annual industrial demand is equal to 15.08 MCM in 2022, while the maximum is 40.31 MCM in 2059. The average annual increase in the consumption of municipal demand is equal to 0.68 MCM.

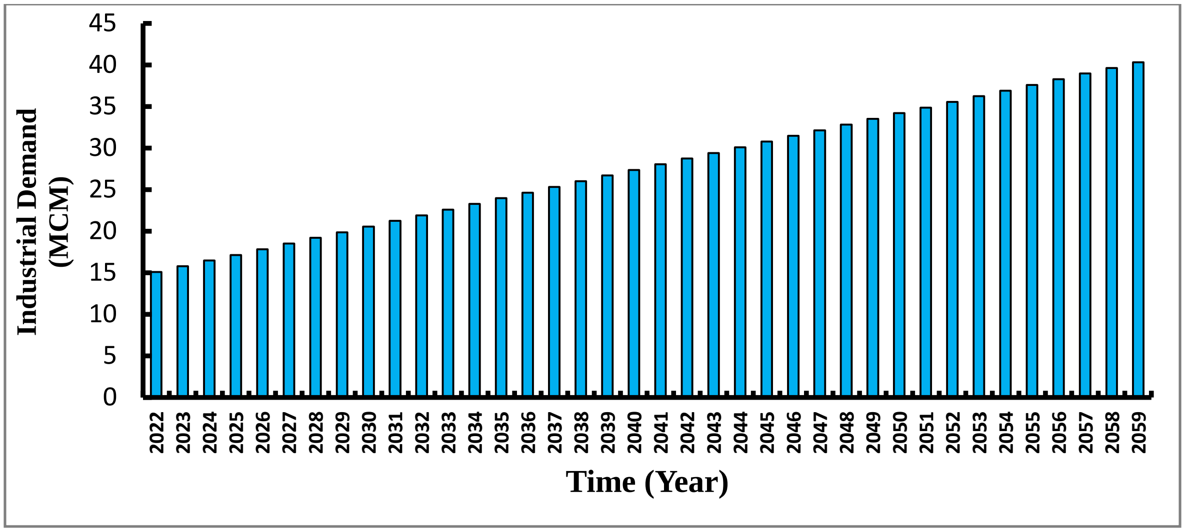

Figure 6.18: Annual industrial water demand of the Haditha Reservoir

The projected values of the future total annual water for industrial withdrawals covering the period 2022-2059 for the provinces of the Tharthar Reservoir (Diwaniyah and Babil) are shown in Figure 6.19. The minimum value of the annual municipal demand of Tharthar Reservoir is equal to 18.21 MCM in 2022, while the maximum is 47.28 MCM in 2059. The average annual increase in the consumption of municipal demand is equal to 0.80 MCM.

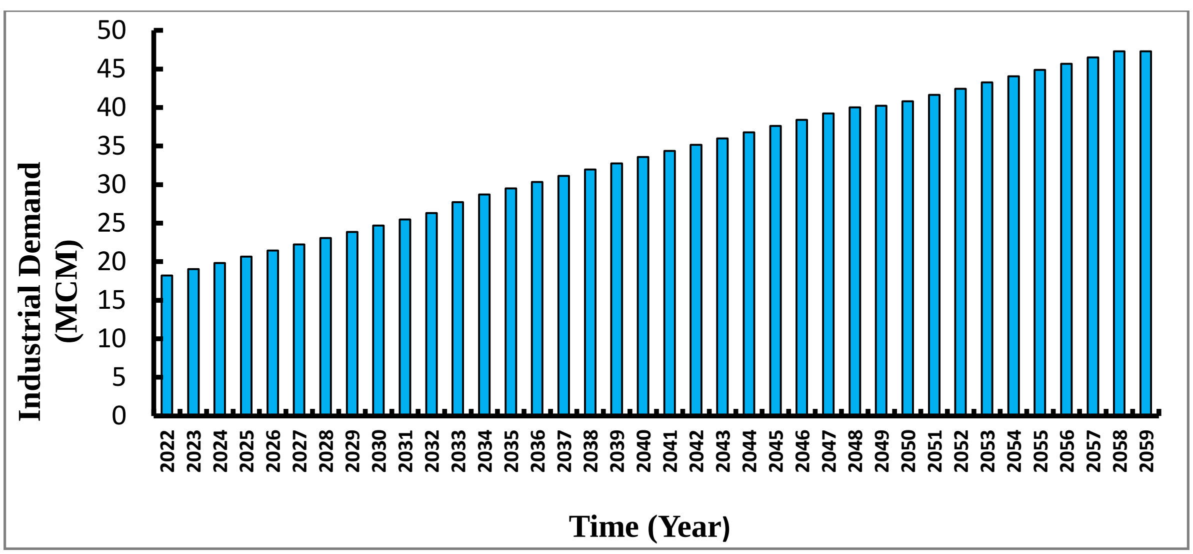

Figure 6.19: Annual industrial water demand of the Tharthar Reservoir

The projected values of the future total annual water for industrial withdrawals covering the period 2022-2059 for the province of the Habbaniyah Reservoir (Karbala) are shown in Figure 6.20. The minimum value of the annual municipal demand of Habbaniyah Reservoir is equal to 1.65 MCM in 2022, while the maximum is 4.43 MCM in 2059. The average annual increase in the consumption of municipal demand is equal to 0.075 MCM.

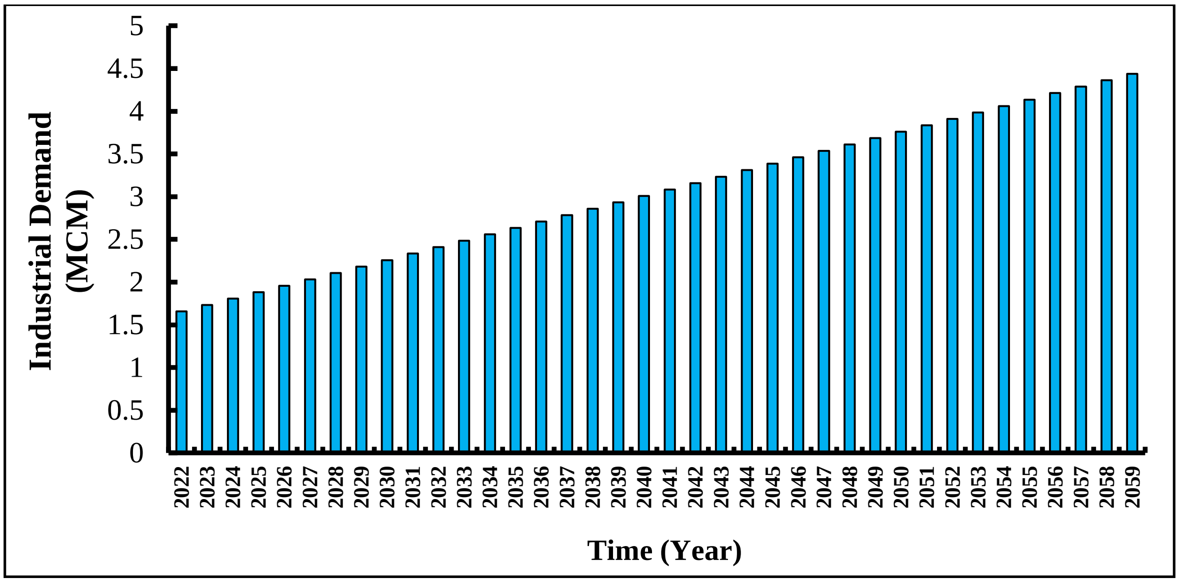

Figure 6.20: Annual industrial water demand of the Habbaniyah Reservoir

6.9 Predictions of the Optimization Models

6.9.1 Optimal Operation of Haditha Reservoir

Two cases developed as follows implementing the optimization model on the input data, incorporating the objective functions, and applying the constraints:

6.9.1.1 First Case of Optimal Operation of Haditha Reservoir

In the first scenario (H1), the criteria for this scenario can be suggested where the amount of water needed for agriculture represents 50% of the irrigated area, the water needed for marshlands is equal to 75% of the real annual need, respectively.

Implementing scenario H1 in the optimal operation of the Haditha Reservoir using the optimization model ensures a safe plan based on minimal loss in storage and release throughout the planning period for the river basin. This period will be covered from October 2022 to September 2059. The estimated combined deficit and spillage losses for storage and release amount to 2957 MCM and 4400 MCM, respectively.

In Figure 6.21, the optimal total annual release from Haditha Reservoir reveals two distinct periods: 2022-2039 and 2040-2059. During the first period, from 2022 to 2059, the release shows a gradual upward trend, rising from 13402 to 14836 MCM. This moderate increase aligns with the climate change scenario of SSP1:2.6. However, in the subsequent period from 2040 to 2059, there is a significant increase in the release.

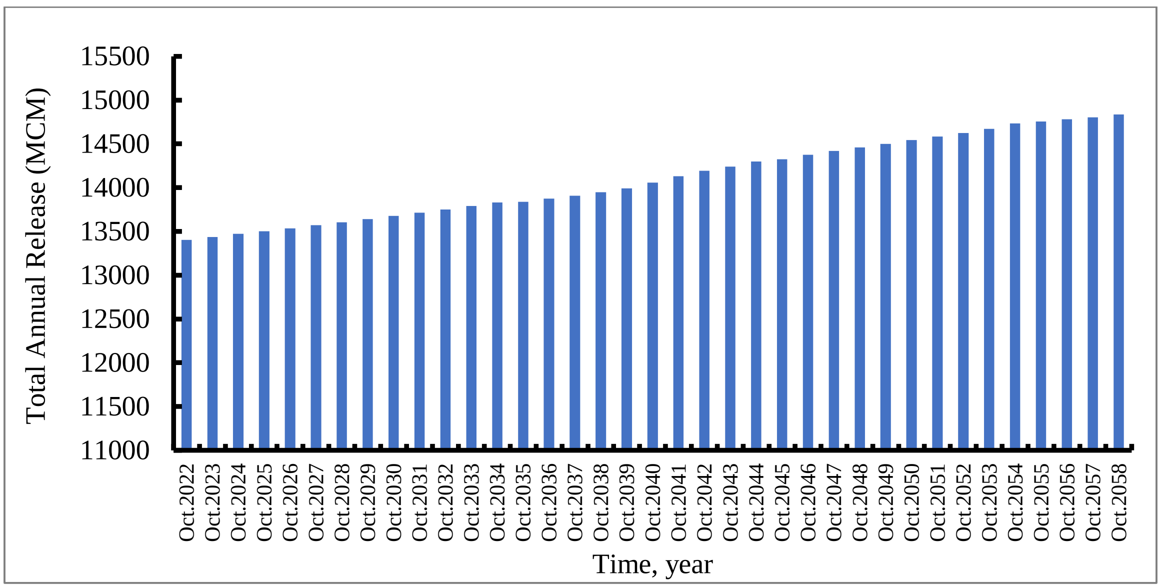

Figure 6.21: Optimal total annual release from Haditha Reservoir for operation of first case.

6.9.1.2 Second Case of Optimal Operation of Haditha Reservoir

The second scenario (H2) represents the water requirements for water supply for the population, agricultural requirements, wetlands restoration as marshland, environmental, and hydropower release are equal to 100 % of the real annual need.

During the period covering from October 2022 to September 2059, implementing scenario H2 in the optimal operation of the Haditha Reservoir is considered unsafe. This was due to the presence of a significant maximum deficit in both storage and release, which accumulates to a total of 130749 MCM throughout the planning period for the river basin. In Figure 6.22, demonstrates a gradual increase in total annual release, starting at 15388 MCM in 2022 and reaching 15677 MCM in 2039. This upward trend aligns with the projected climate change scenario of the SSP1:2.6. Moving on to the second period from 2040 to 2059, the optimal release experiences a more substantial rise. It begins at 15709 MCM in 2040 and reaches 16285 MCM in 2059. This notable increase can be attributed to the climate change scenario of SSP2:4.5.

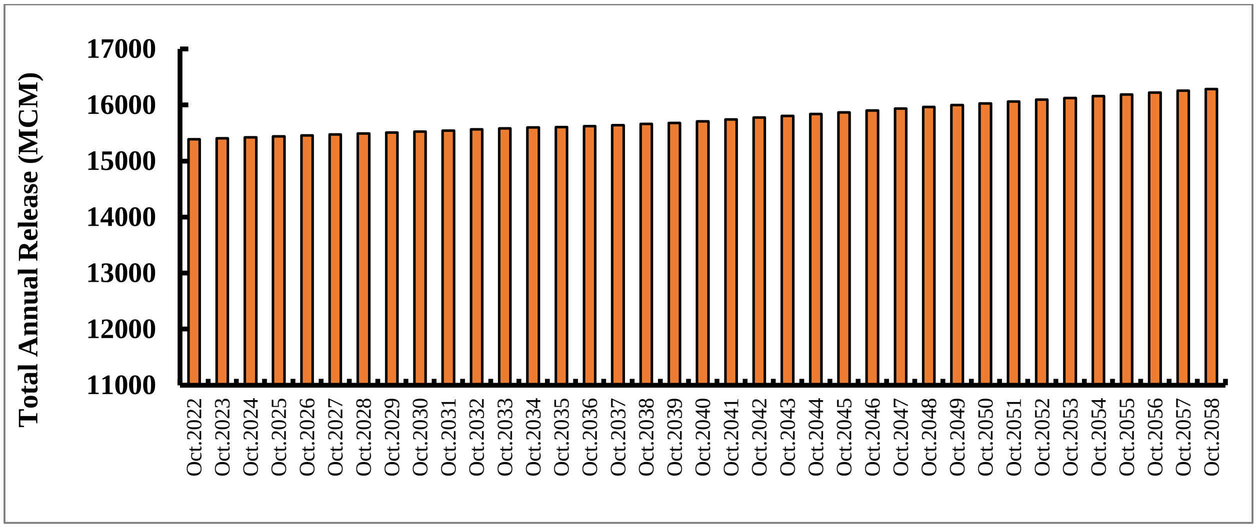

Figure 6.22: Optimal total annual release from Haditha Reservoir for operation of second case.

6.9.2 Optimal Operation of Tharthar Reservoir

After running the model as the same of the Haditha Reservoir, the following two cases for the Tharthar Reservoir:

6.9.2.1 First Case of Optimal Operation of Tharthar Reservoir

The first scenario, TH1, considers the water requirements for agriculture, where 50% of the irrigated area is allocated for the operation of the Tharthar Reservoir. However, implementing scenario TH1 in the optimal operation of the Tharthar Reservoir using the optimization model leads to an unsafe plan. This plan results in a significant loss in storage capacity and release throughout the planning period for the river basin. The cumulative losses due to the deficit in storage and release amount to 52,671 MCM. The deficit in storage and release in the Tharthar Reservoir can be attributed to several factors. Firstly, the high evaporation rate from the reservoir's surface area contributes to the reduction in available water. Additionally, the excessive consumption of water for irrigation and domestic needs further depletes the reservoir's storage. Furthermore, the region experiencing low precipitation levels results in limited replenishment of the reservoir. Lastly, the low inflow of water to the reservoir exacerbates the deficit, collectively leading to the observed storage and outflow challenges.

6.9.2.2 Second Case of Optimal Operation of Tharthar Reservoir

The scenario TH2 is an alternative scenario for operating the Tharthar Reservoir. It includes drawing water from the reservoir's dead storage because (MoWR) has put floating pumping stations on the dead storage to capitalize on the drought. When the storage in the conservation zone is depleted, Tharthar’s dead storage equals 39600 MCM. Scenario TH2 presents a viable alternative as it results in smaller losses in storage and release compared to Scenario TH1. The cumulative losses from the deficit in storage and release amount to 13071 MCM. By implementing the second case, the reduction in these losses reaches an impressive 75%.

Based on Figure 6.23, the annual release from the Tharthar Reservoir remains unchanged between the first and second cases. However, the notable difference between these cases lies in the storage aspect, specifically in relation to Scenario TH2. While the release remains consistent, Scenario TH2 presents a distinct variation in storage, highlighting its influence on reservoir capacity and water management. The data in Figure 6.23 represents the optimal total annual release from 2022 to 2039, the annual release gradually increases from 4110.60 MCM to 4542 MCM. This upward trend indicates the management strategy applied during this period. However, from 2040 onwards, the annual release remains relatively stable, ranging from 4569 MCM to 5030 MCM in 2059.

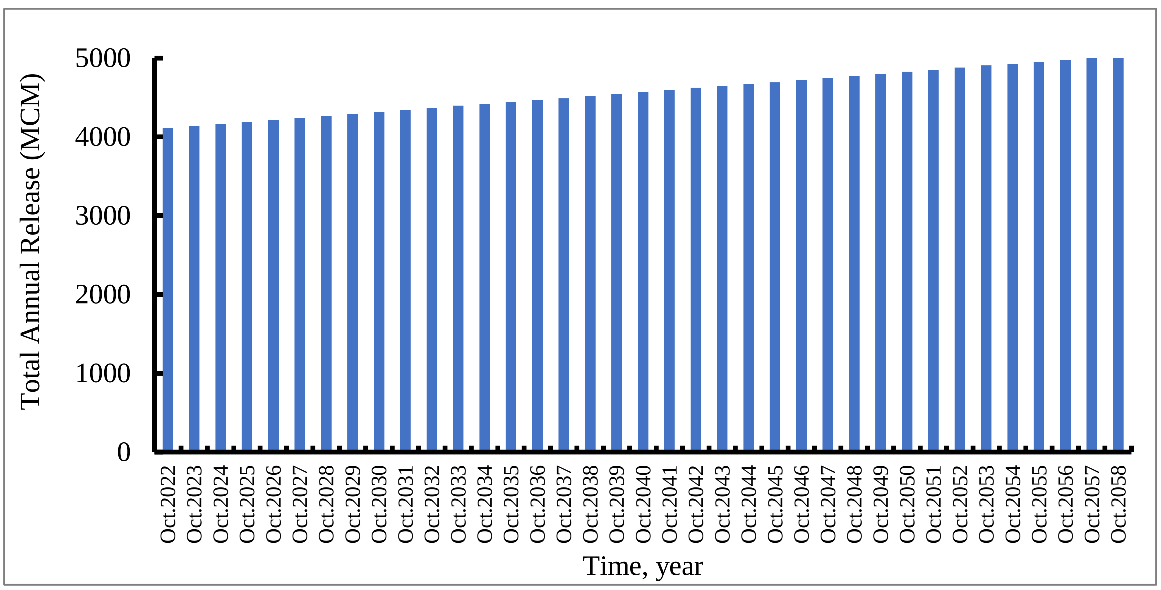

Figure 6.23: Optimal total annual release from Tharthar Reservoir for operation of first and second case.

6.9.3 Optimal Operation of Habbaniyah Reservoir

Habbaniyah Reservoir, like other reservoirs in the ERB, suffers from a reduction in the inflow rate. However, the scenario HB can be adopted in the Habbaniyah Reservoir operation where the amount of water demand for agriculture represents 50% of the irrigated area. Figure 6.24 shows the optimal total annual release from the Habbaniyah Reservoir of scenario HB. The minimum value of the release represents the water year 2022, where the total annual release is equal to 458.21 MCM, and the maximum value in the water year 2059, where the total annual release is equal to 647.7 MCM.

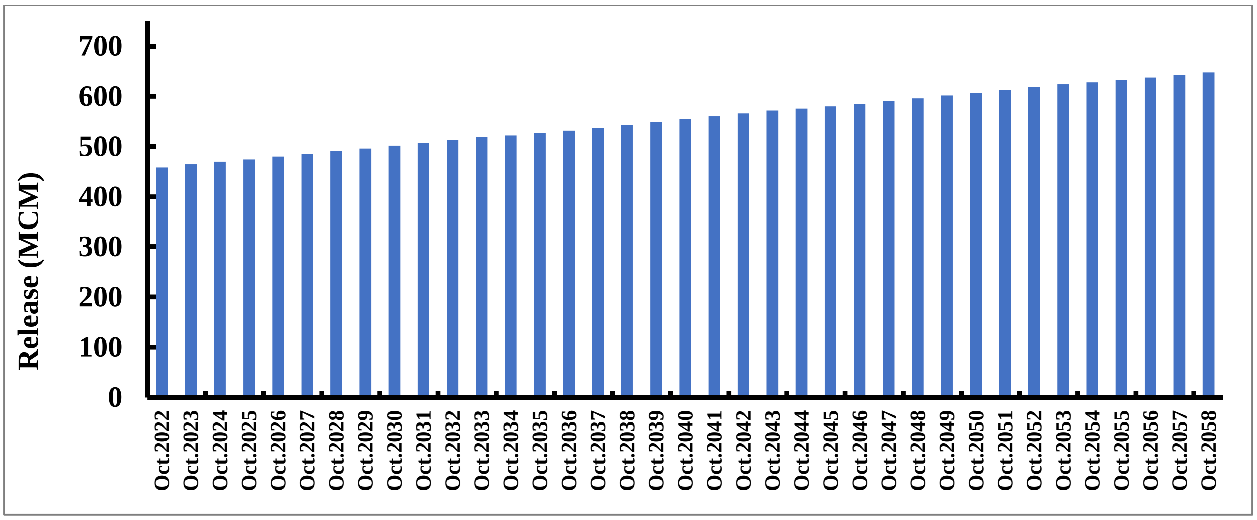

Figure 6.24: Optimal total annual release from Habbaniyah Reservoir for operation of scenario HB

6.10 Determination of Operating Policies for Reservoir Systems

Effective reservoir management strategies are the crucial aim of this study, therefore, the proposed procedure for calculating set release and role curves is illustrated herein.

6.10.1 Optimal Policies for Operating of Haditha Reservoir

One of the key findings from the optimization model is the monthly release, which represents the operational policies. These policies indicate the average monthly release of water. Based on Figure 6.25, the release ranges from 816.85 MCM in December to 1362.27 MCM in July. The release gradually increases from December to June, reaching its peak in July, and then decreases in the following months. The lowest release occurs in December for the first case. In the second case, the release ranges from 893.40 MCM in December to 1984.06 MCM in July. Like the first case, the release increases from December to June, reaching its maximum in July. However, the release values in the first case are generally higher than in the first case for each corresponding month. The average release values in the second case are consistently higher than in the first case for all months.

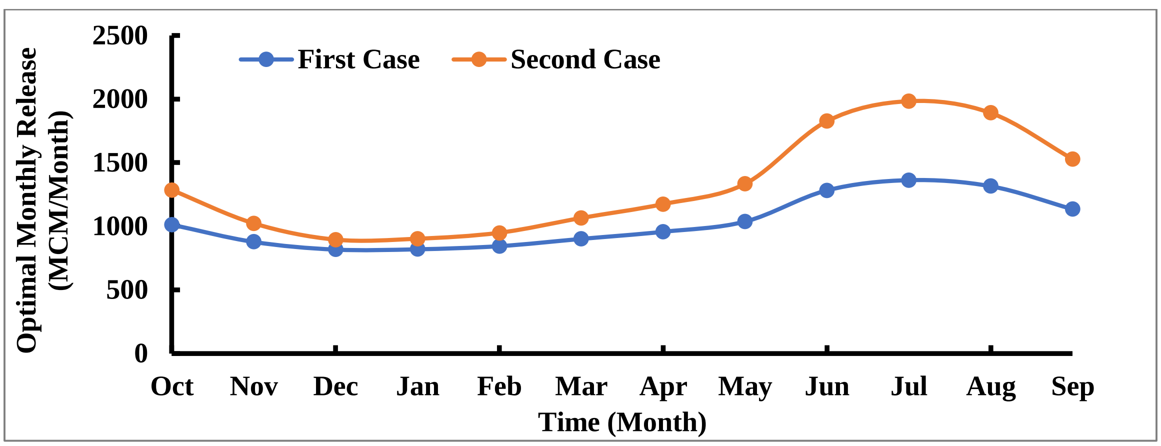

Figure 6.25: Monthly release for operating of Haditha Reservoir in the first and second cases

Figure 6.26 shows the comparision of the three curves of the optimal monthly release: the first is the current or the water year 2022; the second is the midterm or the water year 2040; and the third is the long term or the water year 2059. In the current year, there has been a rise in releases for both the short-term and long-term periods, amounting to 3.8% and 5.8% respectively. In the current strategy, the releases ranges from 791.52 MCM in December to 1313.15 MCM in July. The average releases for the current strategy is 997.78 MCM. The total releases for the current strategy over the year is 11973.36 MCM. In the short-term strategy, the releases ranges from 816.08 MCM in December to 1337.71 MCM in July. The average releases for the short-term strategy is 1021.89 MCM. The total releases for the short-term strategy over the year is 12262.73 MCM. In the long-term strategy, the releases ranges from 839.19 MCM in December to 1406.80 MCM in July. The average releases for the long-term strategy is 1057.95 MCM. The total releases for the long-term strategy over the year is 12695.35 MCM. In general, there is a gradual increase in releases from October to July across all strategies, with the peak occurring during the summer months. The average releases and total release are highest in the long-term strategy, followed by the short-term strategy and the current strategy. These results indicate that as the strategies progress from the current to the long term, there is an increasing trend in the releases values, reflecting the evolving water management plans and potential changes in water demand and availability.

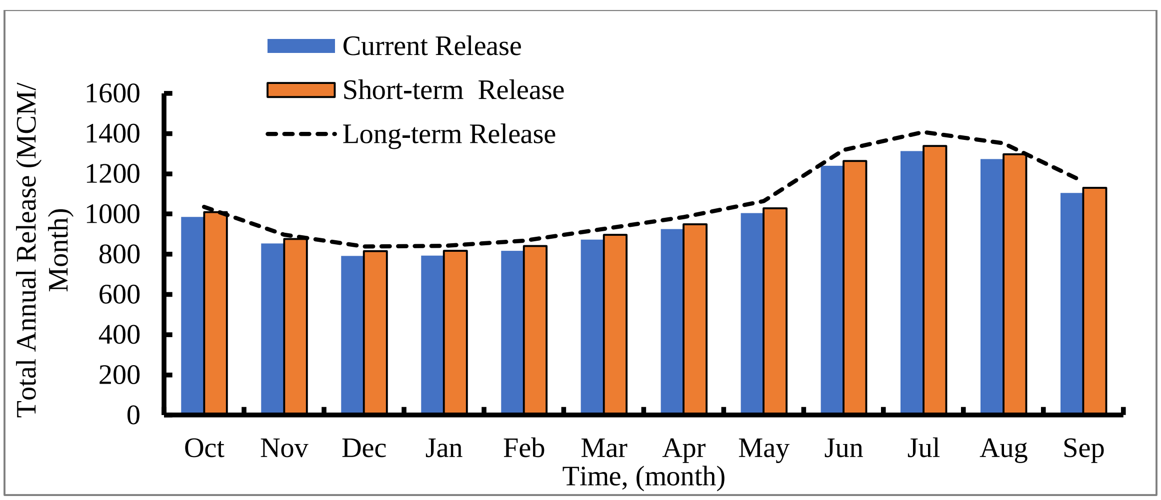

Figure 6.26: Monthly release for operating Haditha Reservoir in the current, short and long term.

6.10.1.1 Climate Change Impact on Optimal Operating Release Policies

The combination of higher temperatures, reduced rainfall, and lower relative humidity leads to an increased need for irrigation water demand.

Figure 6.27 shows the long-term optimal operating rules of irrigation water demand for Haditha Reservoir. The total annual irrigation water release (TAIWR) from the Haditha reservoir shows a consistent pattern over the years. In 2022, the TAIWR stood at 2863 (MCM). However, starting from 2023, there has been a notable rise in the yearly water release, eventually stabilizing at 3009 MCM by the year 2059.To further understand the trends in water release, it is important to consider the yearly water release pattern. From 2022 to 2039, there is a consistent and steady release indicating a stable water irrigation allocation policy over the long term. It is important to highlight that after the year 2039, there is a significant rise in release values. This increase can be attributed to the growing agricultural water demand caused by the climate change scenario known as SSP2-4.5 from 2040 to 2059. The rise in global temperatures and the fluctuation in precipitation patterns contribute to this heightened demand.

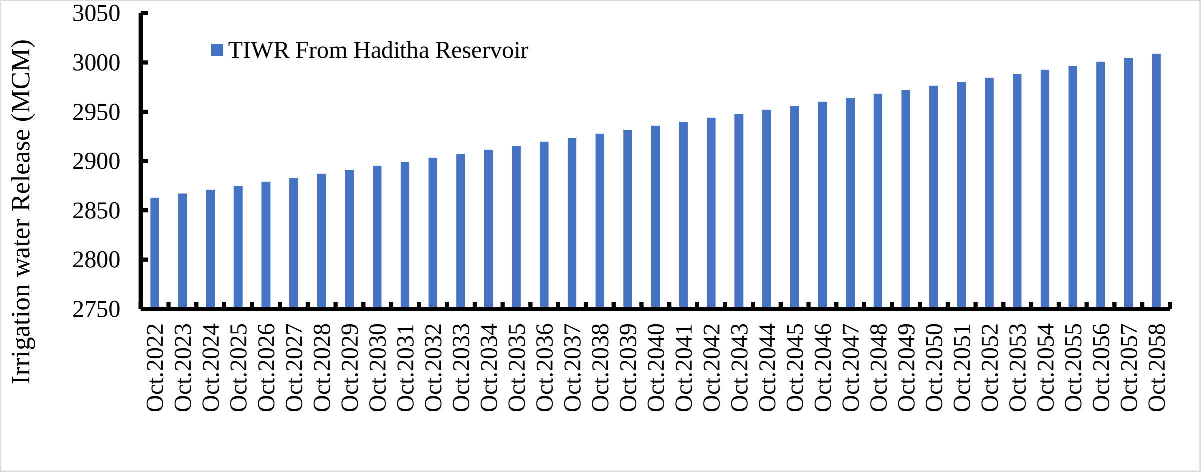

Figure 6.27: Long-term optimal operating rules of irrigation water release from Haditha Reservoir

6.10.1.2 Population Growth Impact on Optimal Operating Release Policies

Population growth is a significant factor that influences various aspects of society. The impact of population growth on the release of municipal and industrial water release from the Haditha reservoir is a critical concern for policymakers.

Figure 6.28 shows long-term optimal operating rules of municipal and industrial water release from Haditha Reservoir and population size. The total annual agricultural water release from the Haditha reservoir shows a consistent pattern over the years. In 2022, the total annual water release was 2864 MCM. However, from 2023 onwards, there has been a significant increase in the annual water release, which has stabilized at 3008 MCM in 2059. To further understand the trends in water release, it is important to consider the yearly water release pattern. From 2022 to 2039, there is a consistent and steady release indicating a stable water irrigation allocation policy over the long term. It is important to highlight that after the year 2039, there is a significant rise in release values. This increase can be attributed to the growing agricultural water demand caused by the climate change scenario known as SSP2-4.5 from 2040 to 2059. The rise in global temperatures and the fluctuation in precipitation patterns contribute to this heightened demand. Based on Figure 6.28, During the period from 2022 to 2059, a clear and consistent trend of population growth emerged, as indicated by the continuous increase in the population size.

The initial population of 7,113,672 Capita in 2022 exhibited a steady and progressive rise each year, culminating in a final population size of 12,925,929 Capita in the end of planning period. This upward trajectory reflects a substantial and sustained growth in the overall population over the specified timeframe. Simultaneously, there was a noticeable upward trend in the water release from both the municipal and industrial sectors during the period under consideration. Starting at 734.51 MCM in 2022, the water release demonstrated a consistent annual increase, eventually reaching a value of 1350.48 MCM at the end of the planning period. This trend emphasizes the escalating demand for water resources to accommodate the needs of the municipal and industrial sectors. The average municipal water demand per year, amounting to 1050 MCM, is associated with a population size of approximately 10,019,225 Capita. This average value represents the collective water consumption of the population over the planning period.

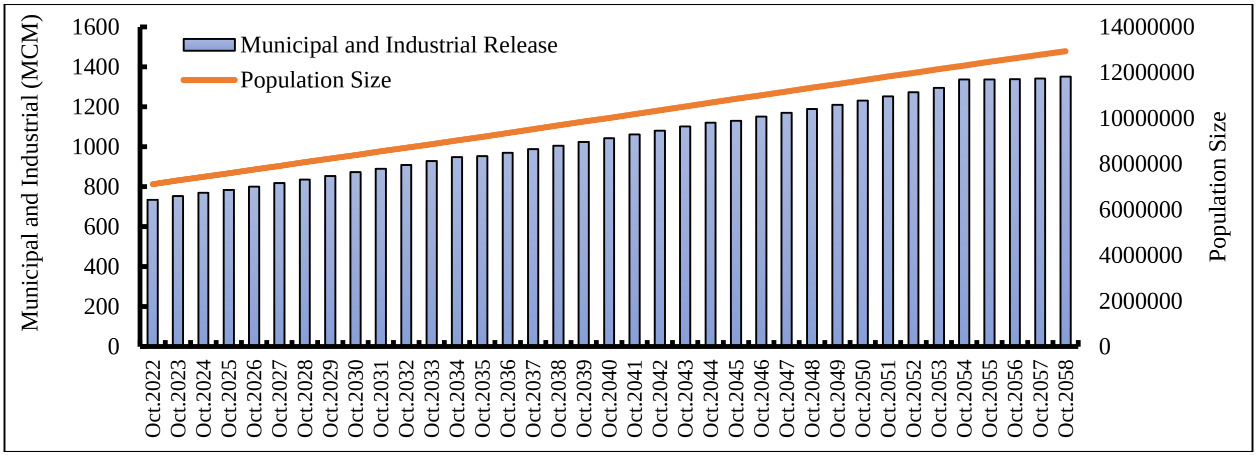

Figure 6.28: Long-term optimal operating rules of municipal and industrial water release from Haditha Reservoir and population size.

6.10.2 Optimal Policies for Operating of Tharthar Reservoir

The operational guidelines for Tharthar Reservoir can be applied to both scenarios, showcasing the monthly policies for maximum and minimum release. These policies outline the recommended approaches for managing the reservoir, ensuring an optimal balance between water release and conservation.

Figure 6.29 shows the monthly release for optimal operation of Tharthar Reservoir in the first and second cases, respectively. In the second, the alternative scenario TH2 can decrease the deficit in storage for operating the Tharthar Reservoir. The monthly release ranges from 96.98 MCM in December to 861.80

MCM in July. The release gradually increases from January to June, reaching its peak in July, and then decreases in the following months. The lowest release occurs in December. There is a general trend of higher releases in the latter half of the year, with the highest releases occurring in July and August. This could be due to a combination of factors, including the demand for water, the availability of water in the reservoir, and the constraints on the system.

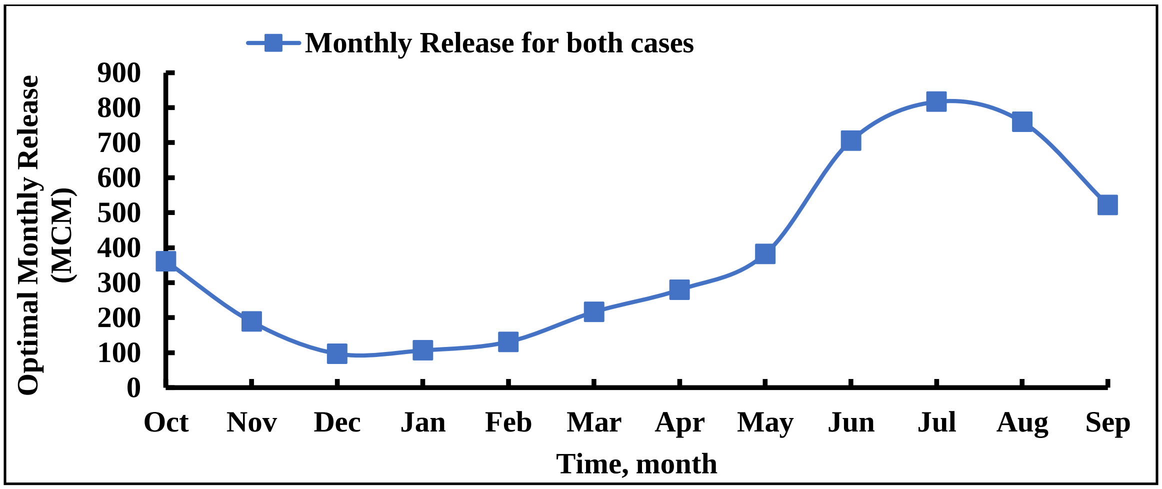

Figure 6.29: Monthly release for operating of Tharthar Reservoir for both cases

Figure 6.30 appears to be showing the optimal release values for Tharthar Reservoir for three different periods: the current year (2022), the mid-term (2040), and the long-term (2059). It appears that there is an increase in the release values for the mid-term and long-term compared to the current year. These increases represent percentages of 16.4% and 18%, respectively. In the current strategy, the release ranges from 80.21 MCM in December to 723.23 MCM in July. The average release for the current strategy is 342.55 MCM. The total release for the current strategy over the year is 4110.60 MCM. In the mid-term strategy, the release ranges from 97.05 MCM in December to 882.23 MCM in July. The average release for the mid-term strategy is 398.65MCM. The total release for the mid-term strategy over the year is 4783.80 MCM. In the long-term strategy, the release ranges from 113.92 MCM in December to 899.24 MCM in July. The average release for the long-term strategy is 415.33 MCM. The total release for the long-term strategy over the year is 4983.96 MCM.

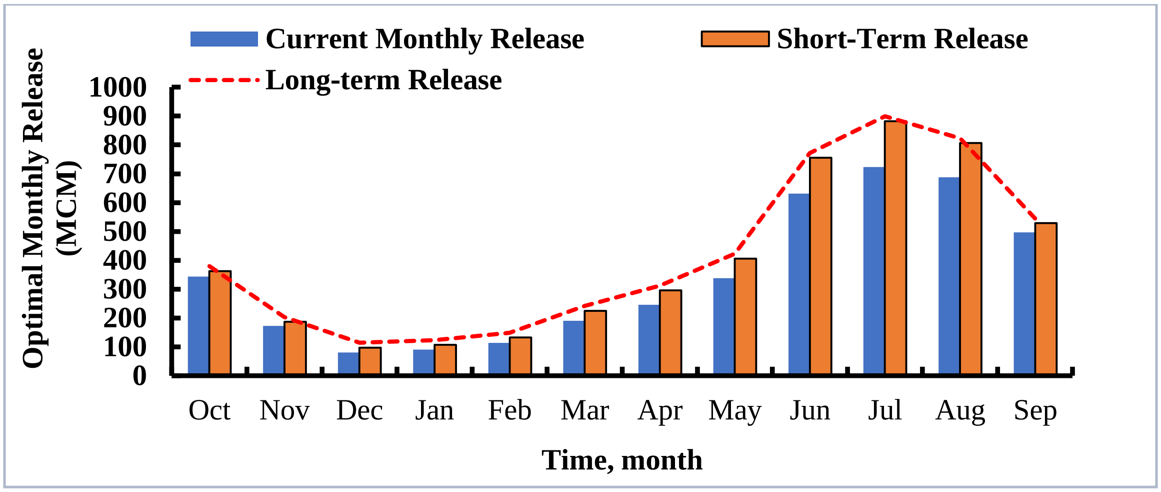

Figure 6.30: Optimal monthly release for operating Tharthar Reservoir in the current, mid, and long-term strategies.

6.10.2.1 Climate Change Impact on Optimal operating Release Policies

Figure 6.31 shows the long-term optimal operating rules of irrigation water release from Tharthar Reservoir. In 2022, the TAIWR stood at 3653 MCM. However, starting from 2023, there has been a notable rise in the yearly water release, eventually stabilizing at 4167 MCM by the year 2059. From 2022 to 2059, the TAIWR consistently reflects a steady discharge, indicating the presence of a resilient and enduring long-term water allocation policy. This upward trend is primarily linked to the increasing TAIWR resulting from the anticipated effects of the climate change scenarios (SSPs: 2.5 and 4.6).

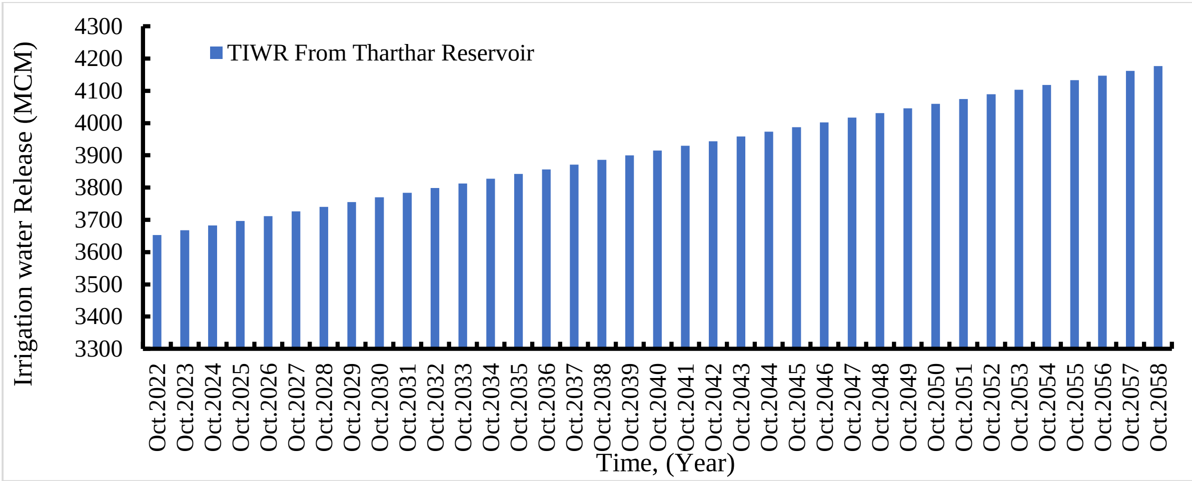

Figure 6.31: Long-term optimal operating rules of irrigation water release from Tharthar Reservoir.

6.10.2.2 Population Growth Impact on Optimal Operating Release Policies

The population growth exerts a substantial impact on various societal aspects, extending to the release of municipal and industrial water from the Tharthar reservoir. Figure 6.32 serves as a crucial resource, providing valuable insights into the long-term optimal operating rules governing water release, side by side with the corresponding population size.

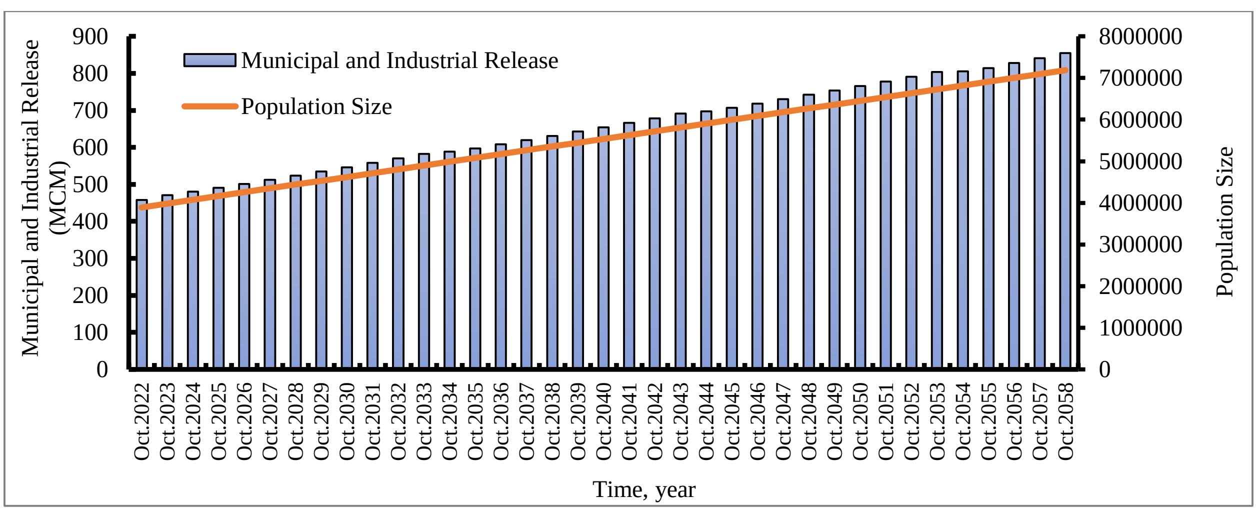

Figure 6.32: Long-term optimal operating rules of municipal and industrial water release from Tharthar Reservoir and population size

6.10.3 Optimal Policies for Operating of Habbaniyah Reservoir

In Figure 6.33, the maximum release is observed in April, amounting to 80.8 MCM, while the minimum release occurs in October at 25.38 MCM. The pattern of optimal monthly release for operating Habbaniyah Reservoir differs from that of Haditha and Tharthar Reservoirs. The maximum monthly release for Habbaniyah Reservoir is in April, whereas for Haditha and Tharthar Reservoirs, is in July. This difference can be attributed to the maximum irrigation water demand for Habbaniyah Reservoir in April, while for Haditha and Tharthar Reservoirs, it is in July.

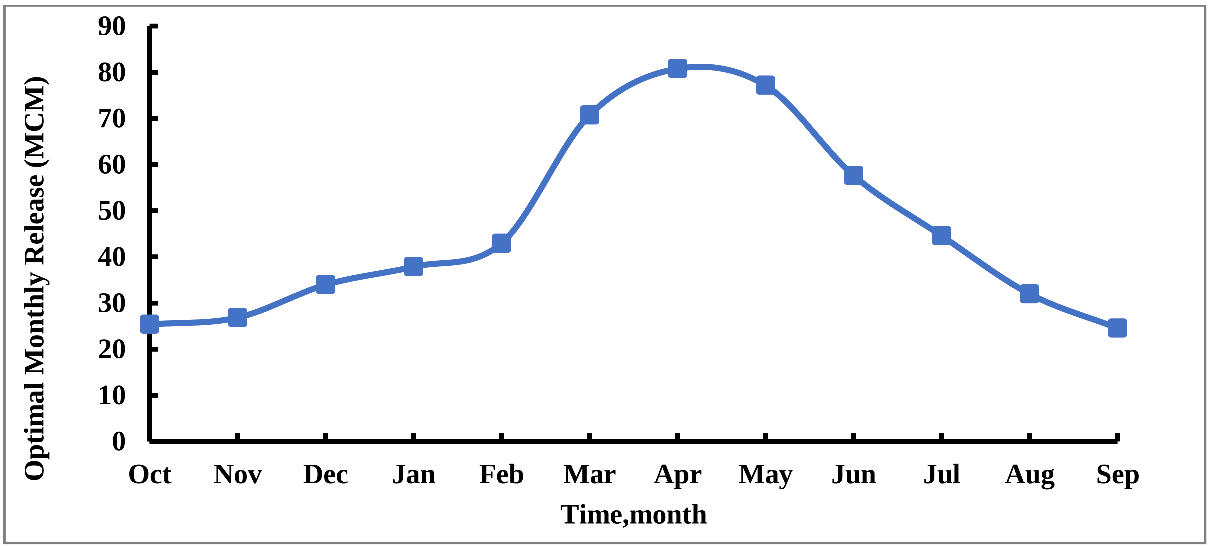

Figure 6.33: Monthly release for operating of Habbaniyah Reservoir

Figure 6.34 compares the current, short-term, and long-term release of the Habbaniyah Reservoir. The current strategy exhibits varying release volumes throughout the year, ranging from 18.58 MCM in September to 68.28 MCM in April. The average release for this strategy is calculated as 38.18 MCM, with a total annual release of 458.21 MCM. In the short-term strategy, the release ranges from 24.57 MCM in September to 86.98 MCM in April. The average release for this strategy is 47.98 MCM, and the total annual release amounts to 575.80 MCM. For the long-term strategy, the release spans from 30.47 MCM in September to 92.88 MCM in April. The average release for this strategy is determined as 53.97 MCM, while the total annual release reaches 647.75 MCM. There is an increase in the release for the short-term and long-term for the current year, equaling 23.5 and 31.2 %.

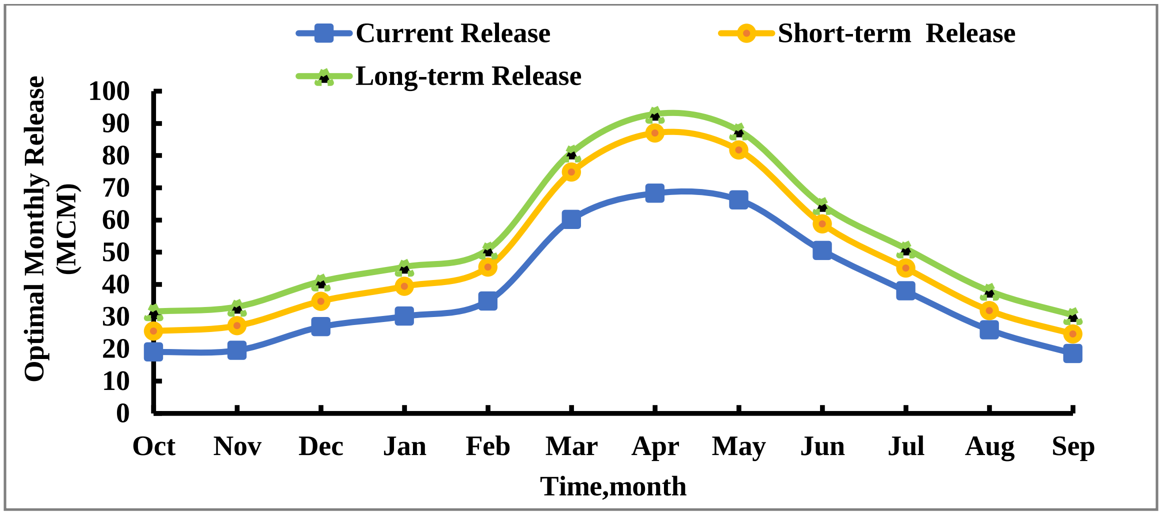

Figure 6.34: Monthly release for operating Habbaniyah Reservoir in the current, short, and long-term strategies.

6.10.3.1 Climate Change Impact on Optimal operating Release Policies

Figure 6.35 represents the enduring optimal operating rules for the release of irrigation water from the Habbaniyah Reservoir. The data in the figure illustrates a continue pattern in the long-term irrigation water releases over the years. In 2022, the TAIWR amounted to 279.4 MCM, reaching a maximum level of 322.4 MCM, which has been sustained until 2059.

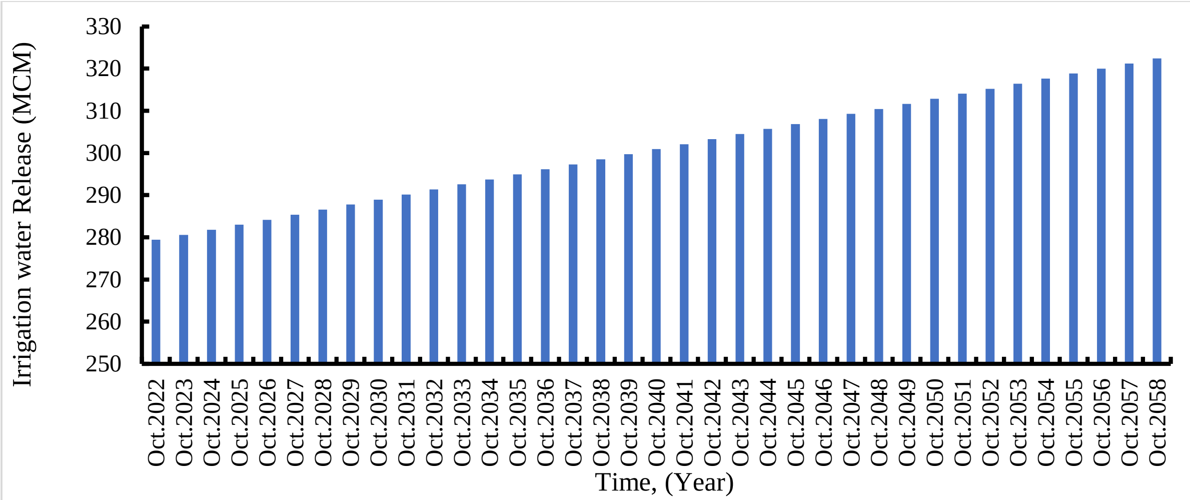

Figure 6.35: Long-term optimal operation rules of irrigation water release from Habbaniyah Reservoir.

6.10.3.2 Population Growth Impact on Optimal Operating Release Policies

Between the years 2022 and 2039, the observed data demonstrates a constant irrigation water release, signifying the existence of a stable and enduring long-term water allocation policy. However, an intriguing trend emerges beyond 2039, as there is a notable surge in the values of water release. This upward trajectory can be primarily attributed to the escalating agricultural water demand that arises from the projected implications of the climate change scenario known as (SSP2-4.5), predicted to manifest between 2040 and 2059.

According to Figure 6.36, a distinct and unwavering pattern of population growth unfolds over the period spanning 2022 to 2059, as evidenced by the continuous expansion in population size. Beginning with an initial count of 2,396,826 Capita in 2022, the population exhibits a consistent annual increase, culminating in a final population size of 4,658,234 Capita at the end of the planning period. This upward trajectory reflects a significant and sustained growth in the overall population throughout the specified timeframe.

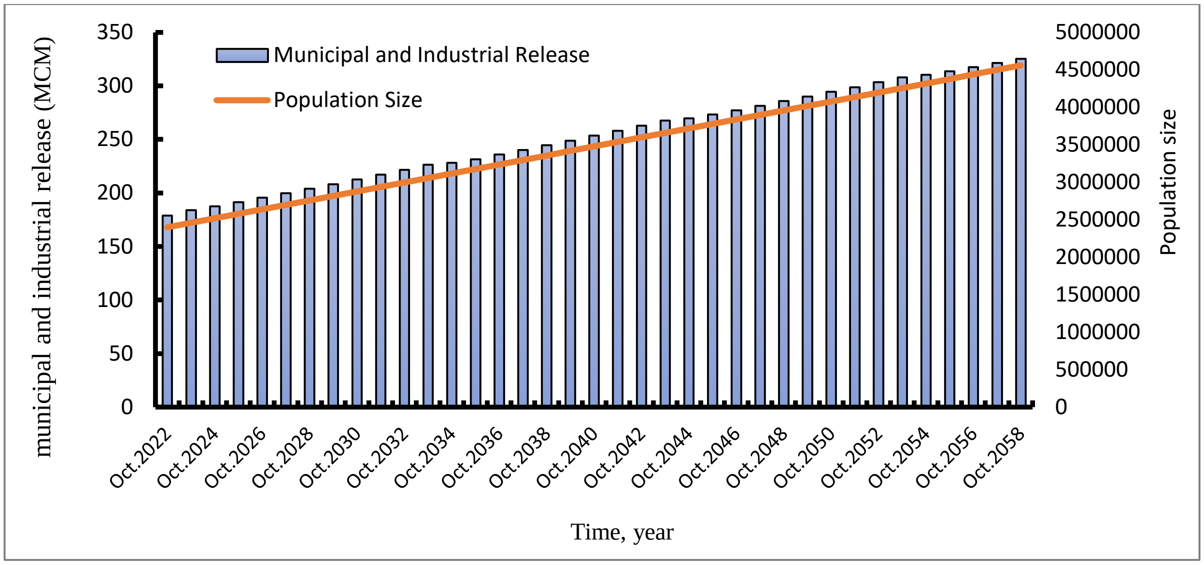

Figure 6.36: Long-term optimal operation rules of municipal and industrial water release from Habbaniyah Reservoir and population size.

Concurrently, there is a discernible upward trend in water release from both the municipal and industrial sectors during the period. Commencing at a value of 178.82 MCM in 2022, the water release exhibits a consistent annual increment, eventually reaching 325.34 MCM by the end of the planned period. This trend underscores the escalating demand for water resources to meet the needs of the municipal and industrial sectors. The average municipal water demand per year, amounting to 253 MCM, corresponds to a population size of approximately 3785987 Capita. This average value represents the collective water consumption of the population over the planning period.

6.10.4 Summary of Predictions and Operating Policies

The analysis presents predictions derived from optimization models for the optimal operation of three reservoirs: Haditha Reservoir, Tharthar Reservoir, and Habbaniyah Reservoir. The models consider various scenarios, incorporating water requirements for agriculture, marshlands, water supply, wetlands restoration, environmental needs, and hydropower release. The objective is to determine safe and efficient operating policies for the reservoirs.

For Haditha Reservoir, two cases are examined. In the first case (H1), the optimization model ensures a safe plan with minimal loss in storage and release. The estimated combined deficit and spillage losses for storage and release are presented, covering the period from October 2022 to September 2059. The optimal total annual release shows different trends in each period, reflecting different climate change scenarios. In the second case (H2), implementing the optimization model leads to a significant maximum deficit in both storage and release throughout the planning period. The cumulative losses in storage and release are presented, and the optimal total annual release gradually increases in both periods.

Similar to Haditha Reservoir, two cases are analyzed for the optimal operation of Tharthar Reservoir. In the first case (TH1), implementing the optimization model results in an unsafe plan with a significant loss in storage capacity and release. The second case (TH2) explores the alternative of drawing water from the reservoir's dead storage, reducing losses in storage and release. The optimal total annual release remains unchanged between the two cases, but there is a notable difference in storage.

The analysis also considers the optimal operation of Habbaniyah Reservoir, which experiences reduced inflow rates. The scenario HB, accounting for water demand for agriculture, is adopted. The optimal total annual release from the reservoir shows a minimum value in 2022 and a maximum value in 2059.

The determination of effective operating policies for the reservoir systems is the focus of the analysis. Monthly releases and rule curves are calculated to illustrate the optimal policies for reservoir management. For the three Reservoir Haditha, Tharthar, and Habbaniyah the monthly release, representing the operational policies, exhibits seasonal variations. The average and total releases show an increasing trend from the current to the long-term strategy, reflecting evolving water management plans and potential changes in water demand and availability. The long-term optimal operating rules for the three Reservoir fluctuate between minimum and maximum values over the planning period.

6.11 Rule Curves for Reservoirs Along River Basin

The Rule Curve for reservoir operation refers to a pre-established guideline or set of rules that dictate the management and release of water from a reservoir. It considers historical data, hydrological conditions, water demand, and other relevant factors. The Rule Curve plays a fundamental role in maintaining the reservoir at desired water levels, optimizing water supply, ensuring effective flood control, and realizing various water management objectives. It offers a systematic framework for making decisions regarding water release from the reservoir, considering different timeframes and varying conditions (Kangrang et al., 2023).

6.11.1 Developing Rule Curves for Haditha Reservoir

The rule curves of optimal storage for Haditha Reservoir depict the recommended storage levels for each month. These curves represent the range of storage values that are considered optimal for efficient reservoir management. The months are listed along with the corresponding minimum, average, and maximum operational storage values.

The rule curves show the fluctuation of storage levels throughout the year, reflecting seasonal variations and water management strategies. The minimum and maximum allowable storage values are also provided, indicating the range within which the reservoir should ideally operate. These values ensure the reservoir's functionality while considering factors such as water supply, demand, and environmental considerations. By following the rule curves, reservoir operators can make informed decisions about water release and storage, ensuring a balance between meeting various water requirements and maintaining reservoir sustainability. Figure 6.37 illustrates the storage zones, where the maximum storage is in March, and the minimum storage is in September. The optimal storage states adopted for first case for the Haditha Reservoir. The average operational storage rule curves increase from 4324.82 MCM in October and steadily increases month by month, reaching its highest point in March at 6517.31 MCM. After March, the storage decreases slightly but remains relatively consistent until September. The maximum and minimum operational storage rule curves behave the same as the average operational storage rule curve. The minimum operational storage rule curve is higher than the minimum allowable storage. From the maximum, minimum, and average rule curves, the wet season for Haditha Reservoir starts from October to March and the dry season from April to September.

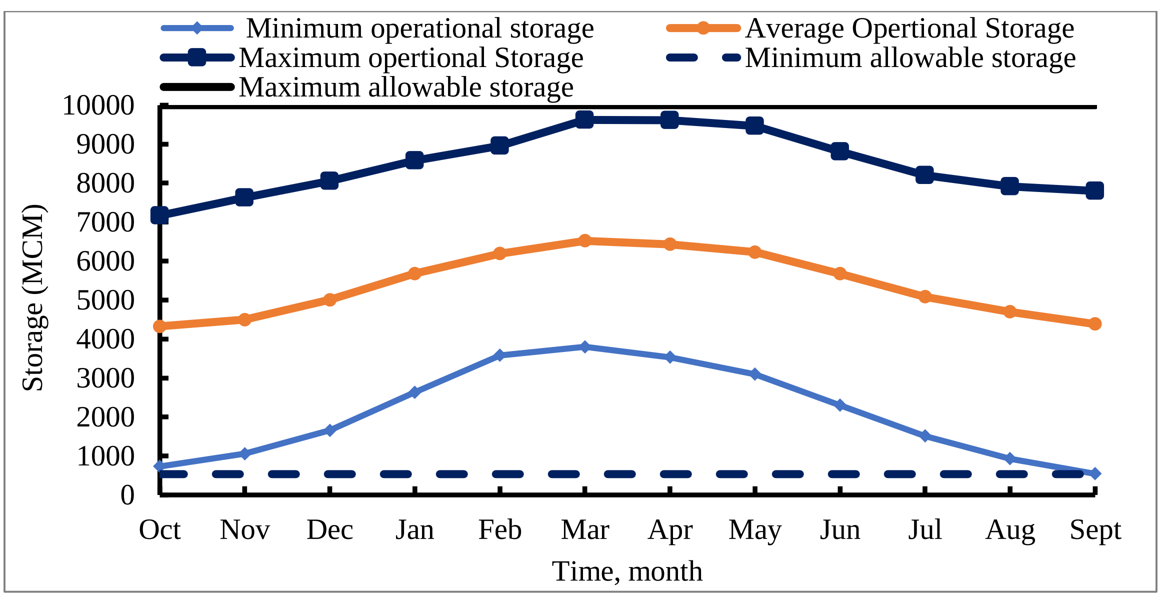

Figure 6.37: Developed rule curves for Haditha Reservoir with respect to the state of optimal storage for the period from October 2022 to September 2059.

6.11.1.1 Rule Curves of the Storage in the Dry and Wet Years

The inflow of the three reservoirs, namely Haditha, Tharthar, and Habbaniyah plays a crucial role in determining the optimal storage states. The analysis of annual inflow rates provides valuable information regarding wet and dry years. Wet years are characterized by inflow rates above the average, indicating a surplus of water entering the reservoirs. In contrast, dry years have inflow rates below the average, indicating a scarcity of water.

Based on Figure 6.38, The range of the maximum operational storage curve values represented is between 7136 MCM in October, and 9623 MCM in March. The range of the average operational storage curve values represented is between 5309 MCM, and 3007 MCM. The range of the minimum operational storage curve values represented is between 530 MCM in September and 3799 MCM in March.

The pattern of the average and maximum operational rule curve as the same.

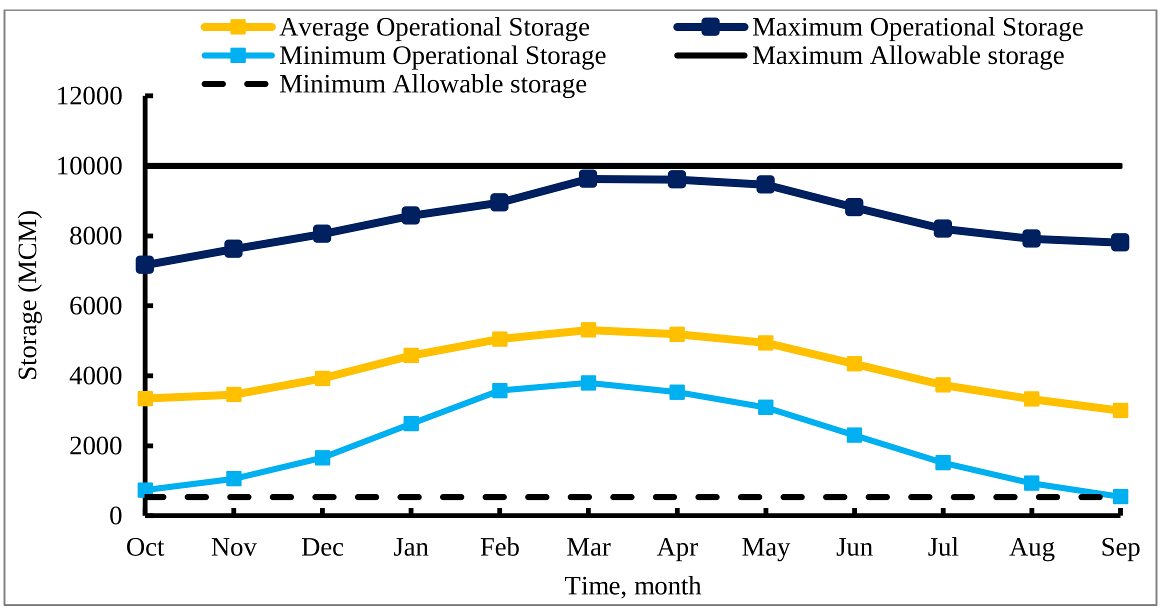

Figure 6.38: Developed dry year's rule curves of the optimal storage of the Haditha Reservoir for the period from October 2022 to September 2059

Figure 6.39 provides insight into the rule curves of the storage zones within the Haditha Reservoir during dry years. The pattern of the average, minimum, and maximum operational rule curve as the same. The maximum operational storage curve values span a range of 7176 MCM in October to 9623 MCM in March. The average operational storage curve values range from 6358 MCM in October to 9033 MCM to a minimum in March. The range of the minimum operational storage curve values represented is between 530 MCM in September and 3799 MCM in March.

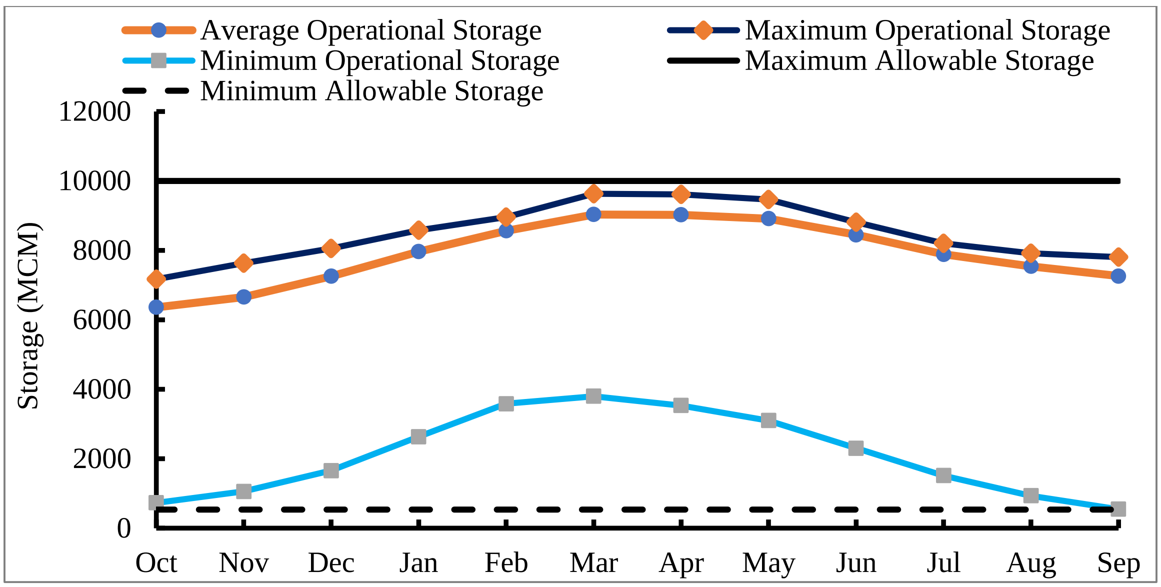

Figure 6.39: Developed wet year's rule curves of the optimal storage of the Haditha Reservoir for the period from October 2022 to September 2059

6.11.2 Developing Rule Curves for Tharthar and Habbaniyah Reservoirs

The operation rule curves of the Tharthar and Habbaniyah Reservoirs can be derived from the optimization model results. The rule curve represents the average of the monthly optimum storage for the period from October 2022 to September 2059. Figure 6.40 shows the rule curve of the optimum storage for the Tharthar Reservoir. The results of the optimal water storage after running the model in which the scenario TH2 is the solution to the problem of the storage deficit for the Tharthar

Reservoir. The maximum and minimum operational rule curves behave the same as the average operational rule curve. The average operational rule curve of reservoir storage initially displays a downward trajectory from October to December, with quantities ranging from 31972.22 MCM to 31065.75 MCM. However, from January to May, there is a consistent rise in storage, reaching its peak in May at 35852.05 MCM. This signifies a substantial accumulation of water during this period. Subsequently, from June to September, a gradual decline in storage is observed, with values ranging from 35246.25 MCM to 31763.15 MCM.

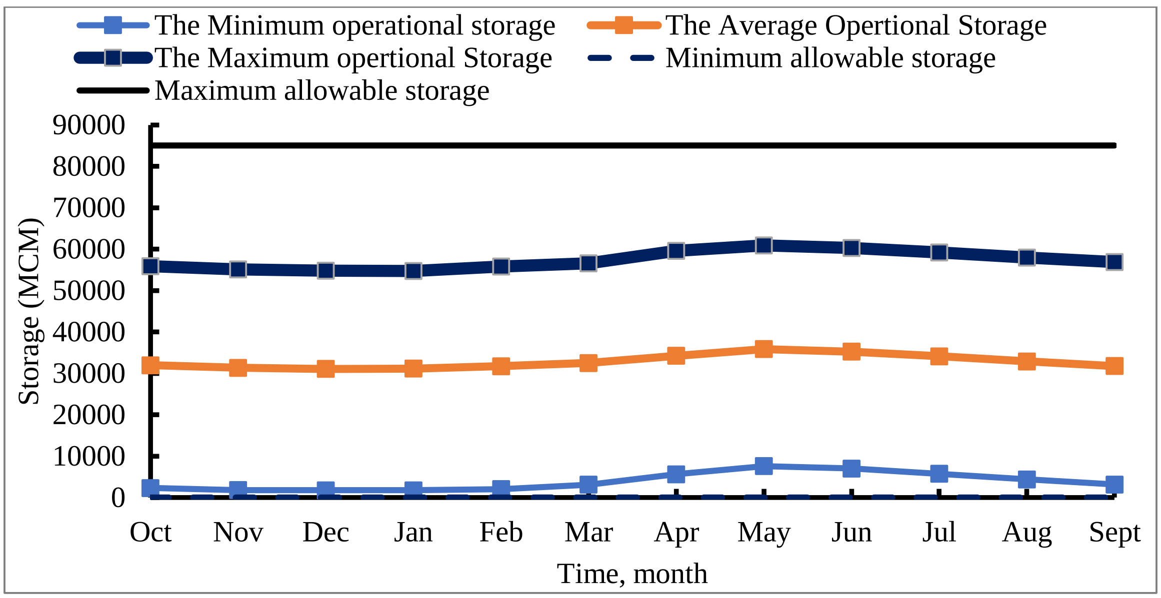

Figure 6.40: Developed rule curves of optimal storage for the Tharthar Reservoir scenario TH2 from the period from October 2022 to September 2059.

Figure 6.41 shows the average operational water storage starting at 2862 MCM in October and increasing until April, peaking at 3111 MCM. From June to September, there is a slight decrease in the average water storage, reflecting a reduction in the stored water volume.

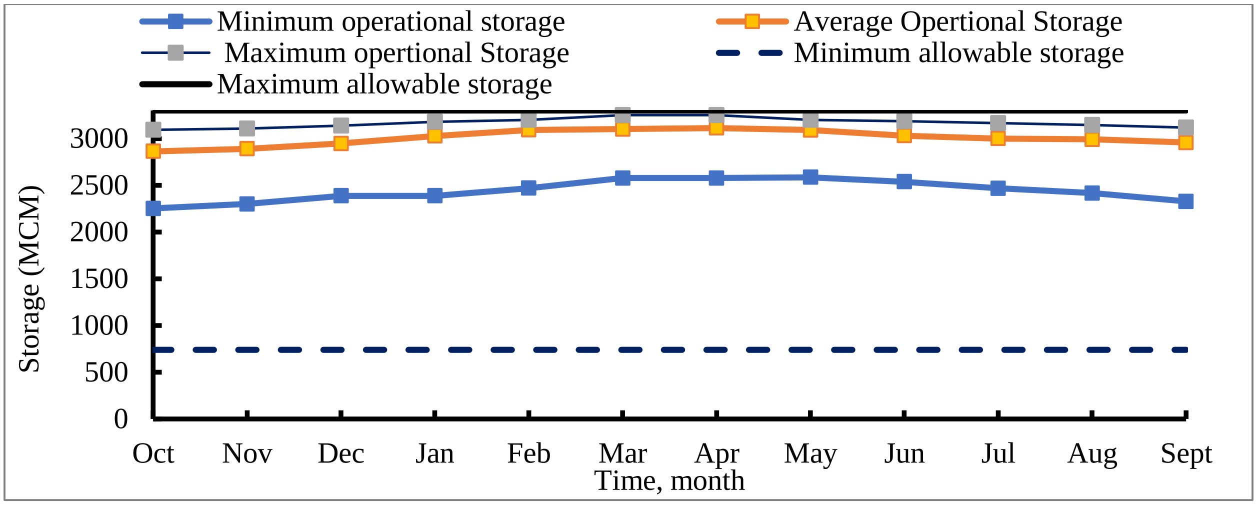

Figure 6.41: Developed rule curves of the optimal storage for the Habbaniyah Reservoir for the period from October 2022 to September 2059

6.11.2.1 Rule Curves of the Storage in the Wet and Dry Years

According to Figure 6.42, the rule curves of the storage zones in the Tharthar Reservoir during wet years are depicted. The average operational storage curve values range from 32843 MCM in December to 37124 MCM in May. According to Figure 6.43, the rule curves of the storage zones in the Tharthar Reservoir during dry years are depicted. The average operational storage curve values range from 13017 MCM in December to 20915 MCM in May.

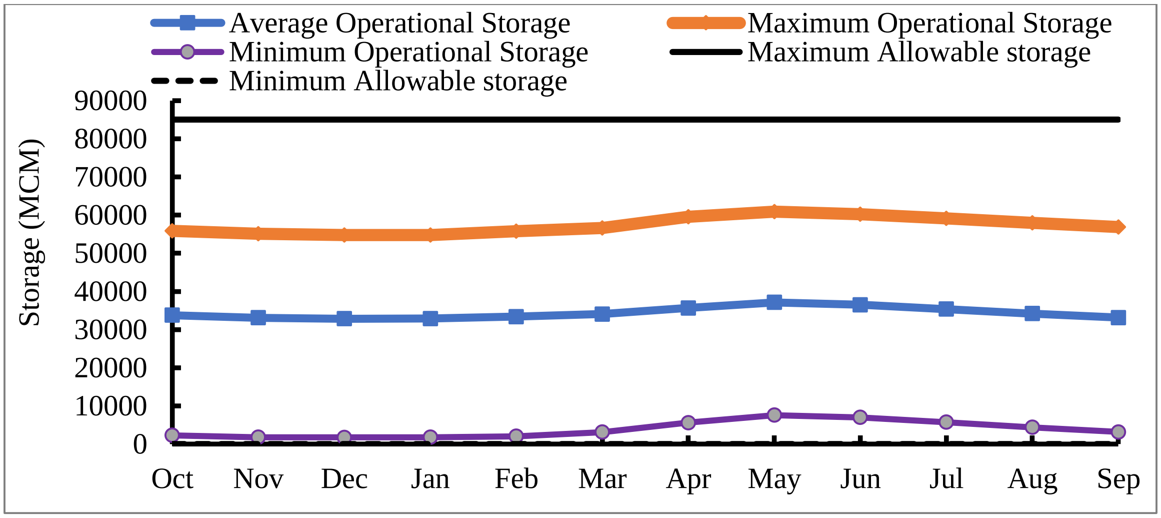

Figure 6.42: Developed rule curve of wet year for Tharthar Reservoir

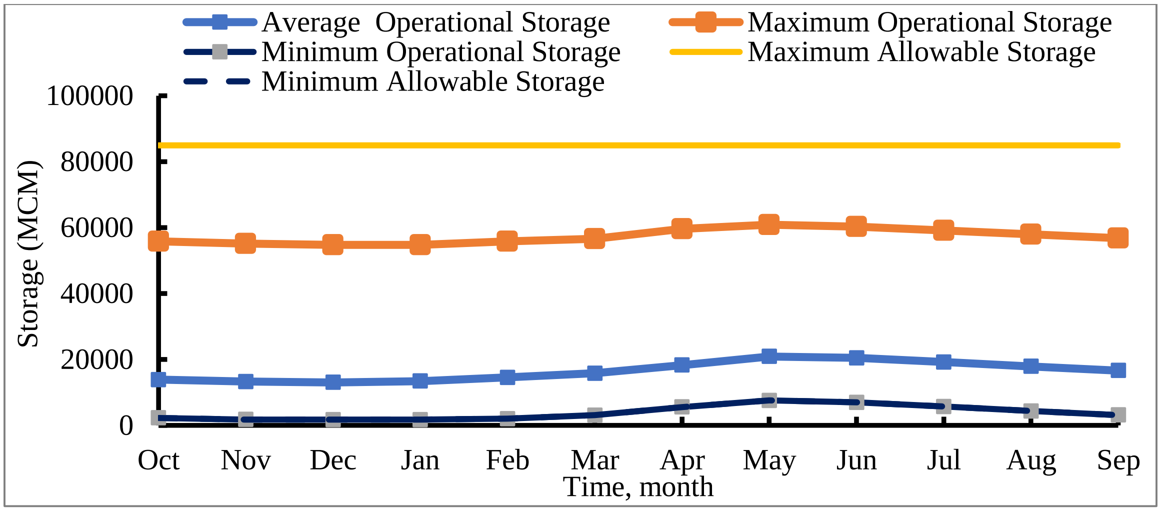

Figure 6.43: Developed rule curve of dry year for Tharthar Reservoir

According to Figure 6.44, the rule curves of the storage zones in the Habbaniyah Reservoir during dry years are depicted. The average operational storage curve values range from 2800 MCM in October to 3250 MCM in April.

According to Figure 6.45, the rule curves of the storage zones in the Habbaniyah Reservoir during wet years are depicted. The average operational storage curve values vary between 2850 MCM in October and 3250 MCM in April.

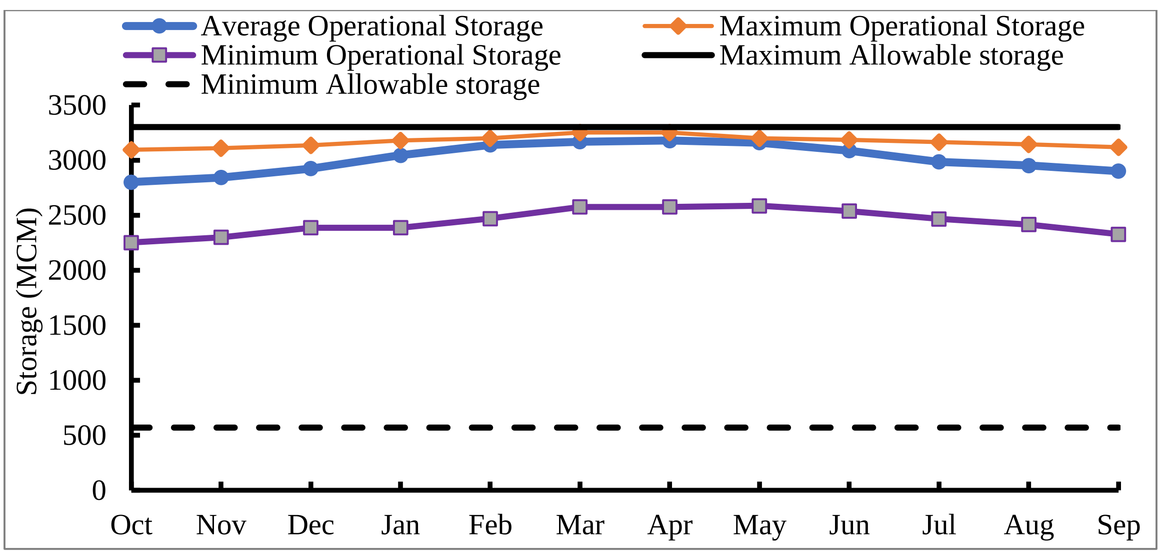

Figure 6.44: Developed rule curve of the dry year for Habbaniyah Reservoir.

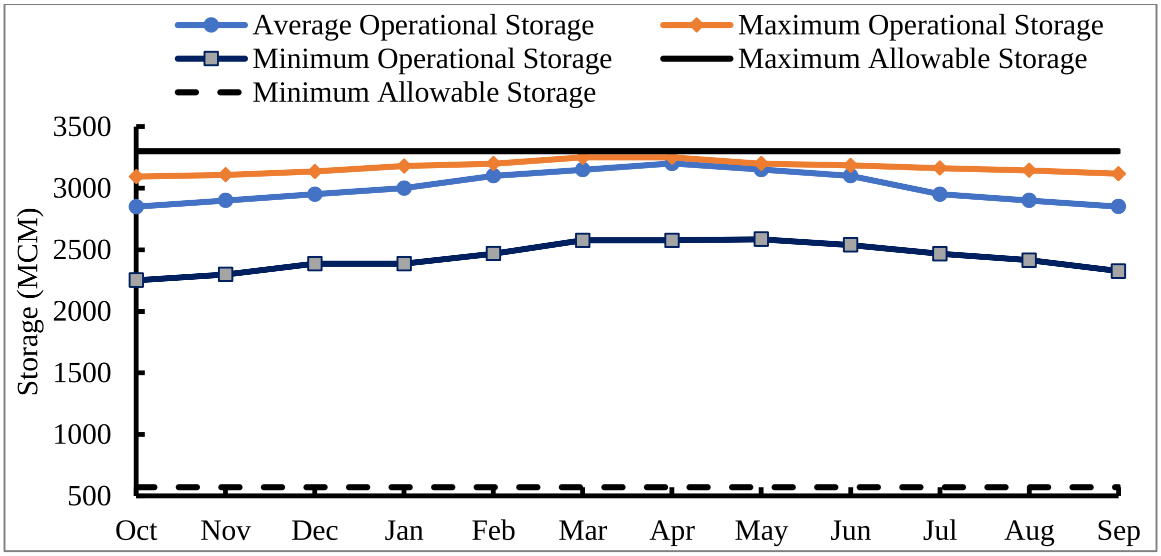

Figure 6.45: Developed rule curve of wet year for Habbaniyah Reservoir

6.12 Estimating the WSE of the Reservoirs

According to the storage results from October 2022 to September 2059, the values of the WSE can be derived from the shifted power equations of the (Elevation - Storage) curve for the three reservoirs. Table 6.3 shows the average operational WSE with related values for storage and zones of storage for Haditha Reservoir.

Table 6.3: Average operational WSE, and storage for Haditha Reservoir (first case)

Date	Average WSE (m.a.s.l)	Average Storage (MCM)
Oct.	139.80	4324.82
Nov.	140.28	4497.73
Dec.	141.62	5004.42
Jan.	143.24	5677.03
Feb.	144.37	6189.41
Mar.	145.05	6517.31
Apr.	144.87	6430.44
May.	144.45	6226.55
Jun.	143.23	5672.92

Jul.	141.82	5083.24
Aug.	140.82	4697.67
Sept.	139.97	4385.98

Based on Table 6.3, the reservoir is divided into different zones, and the table presents information on the elevation of the reservoir meters above sea level (m.a.s.l) and the volume of water storage. In October, the elevation is recorded as 139.80 m.a.s.l, which gradually increases in November (140.28 m.a.s.l) and December (141.62 m.a.s.l). This upward trend continues until reaching its peak in March at 145.05 m.a.s.l. After March, the elevation slightly decreases but remains relatively stable until September. Table 6.4 shows the average operational WSE and storage of the Tharthar Reservoir (second case).

Table 6.4: Average operational WSE, and storage for Tharthar Reservoir (second case)

Date	Average WSE (m.a.s.l)	Average Storage (MCM)
Oct.	28.71	31972.22
Nov.	28.24	31319.27
Dec.	28.06	31065.75
Jan.	28.13	31158.97
Feb.	28.54	31727.97
Mar.	29.10	32511.93
Apr.	30.32	34224.07
May.	31.47	35852.05
Jun.	31.04	35246.25
Jul.	30.24	34103.48
Aug.	29.36	32879.93
Sept.	28.56	31763.15

The examination of Table 6.4 uncovers a gradual decline in the elevation of the Haditha Reservoir from October to December, with values ranging from 28.71 (m.a.s.l.) to 28.24 (m.a.s.l.). This downward trend is followed by a slight increase in January (28.13 m.a.s.l.) and February (28.54 m.a.s.l.). However, starting from March, a significant gap in elevation becomes evident, reaching its peak in May at 31.47 m.a.s.l. Subsequently, there is a moderate decrease in June (31.04 m.a.s.l.) and July (30.24 m.a.s.l.), followed by a further decline in August (29.36 m.a.s.l.) and September (28.56 m.a.s.l.). Table 6.5 shows the average operational WSE and storage of Habbaniyah Reservoir.

Table 6.5: Average operational WSE and storage of Habbaniyah Reservoir

Date	Average WSE (m.a.s.l)	Average Storage (MCM)
Oct.	49.68	2968.16
Nov.	49.78	2997.46
Dec.	49.97	3052.01
Jan.	50.25	3131.43
Feb.	50.48	3195.29
Mar.	50.60	3231.55
Apr.	50.64	3242.62
May.	50.68	3252.61
Jun.	50.55	3215.84
Jul.	50.36	3162.45
Aug.	50.22	3121.20
Sept.	49.99	3056.88

In Table 6.5, the WSE starts at 49.68 m.a.s.l in October and exhibits a gradual increase, reaching its highest point of 50.68 m.a.s.l in May. From June to September, there is a slight decrease in the average WSE, reflecting a decline in the water levels during the dry season.

6.13 Optimum Operation for Haditha Reservoir regarding Generation of Hydropower

The water sourced from the Haditha Reservoir serves a dual purpose. Firstly, it is utilized for electricity generation, harnessing the reservoir's potential as a hydropower resource. Secondly, the released water plays a crucial role in meeting the diverse requirements of cities situated in the ERB.

According to Figure 6.46, The analysis focuses on the impact of climate change scenarios on these variables, particularly the release and hydropower generation under the SSP1:2.6 scenario from 2022 to 2039, as well as the significant increase in release and hydropower electricity observed after 2039 because of the SSP2:4.5 scenario. From 2022 to 2039, the discharge from the outlet shows a gradual increase. Starting at 384.94 in 2022, it rises to 411 in 2059. This suggests a consistent trend of increased release from the outlet during this period, likely influenced by climate change factors specified in the scenario.

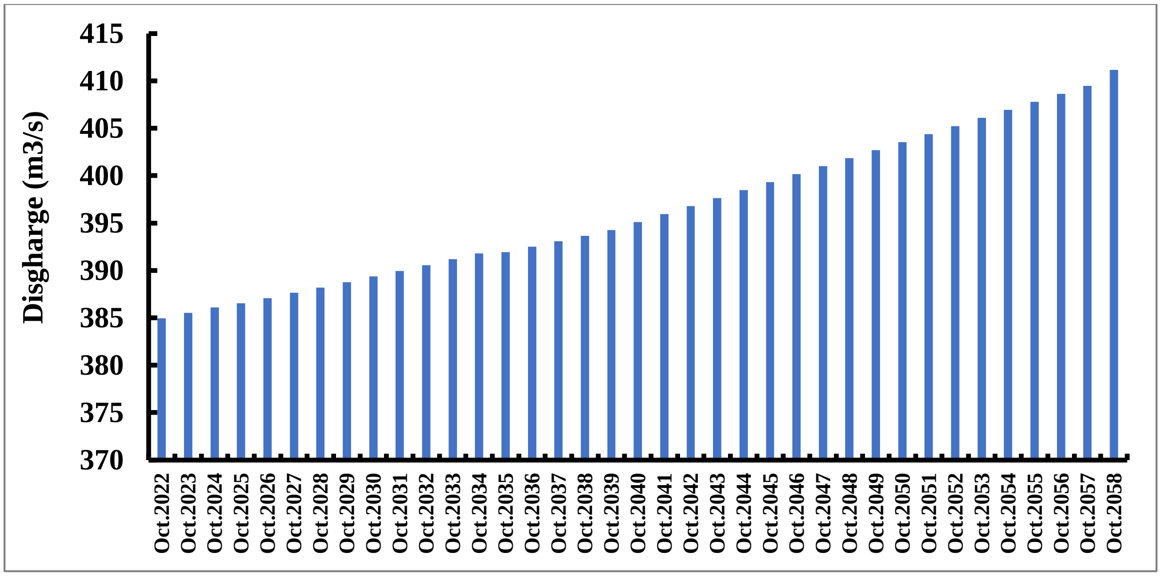

Figure 6.46: Annual discharge from the power generating outlets of Haditha Reservoir

Figure 6.47 shows the annual hydro-power electric of the Haditha Reservoir. Under the SSP1:2.6, and 4.5 scenarios, the total hydropower generation exhibits a gradual increase from 2022 to 2059. Starting at 698.29 MW in 2022, it rises to 739 MW in 2059. This indicates a consistent upward trend in hydropower generation during this period, influenced by the climate change factors specified in the scenario.

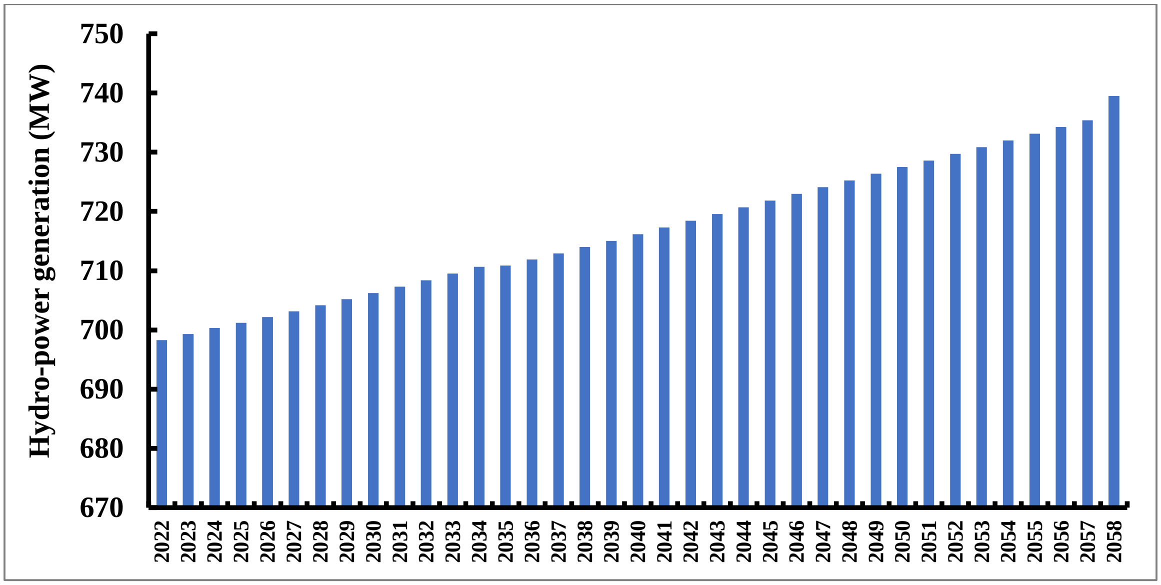

Figure 6.47: Total annual hydro-power electric of the Haditha Reservoir

6.14 Validation of the Results of the Optimization Model

The validation process for the optimization model results in this research involved assessing the accuracy and reliability of the obtained results. Various techniques were employed to verify the validity of the optimization model, ensuring that the results align with real-world conditions and provide significant insights for water resource development strategies in the Euphrates River Basin.

6.14.1 Validation of the Haditha Reservoir Storage Results

The validity of the results obtained for the Haditha Reservoir's optimization model has been assessed using data from 2000 to 2020. The model's performance was evaluated through the coefficient of determination (R^2), which was 0.9377, indicating a good correlation between predicted and measured storage. Furthermore, the model's performance was evaluated using two additional metrics: the Nash-Sutcliffe efficiency coefficient (NSE). The NSE value was 0.94, indicating a high level of accuracy in the model's performance. A positive PBIAS suggests a systematic overestimation of the predicted values. In this case, a PBIAS value of 0.12 indicates a relatively small bias between the predicted and observed values. Overall, these findings suggest that the optimization model for the Haditha Reservoir is reliable and capable of accurately forecasting reservoir storage. Figure 6.48 shows the chronological changes in the Haditha reservoir's storage by comparing the predicted values with the measured values over 2000-2020.

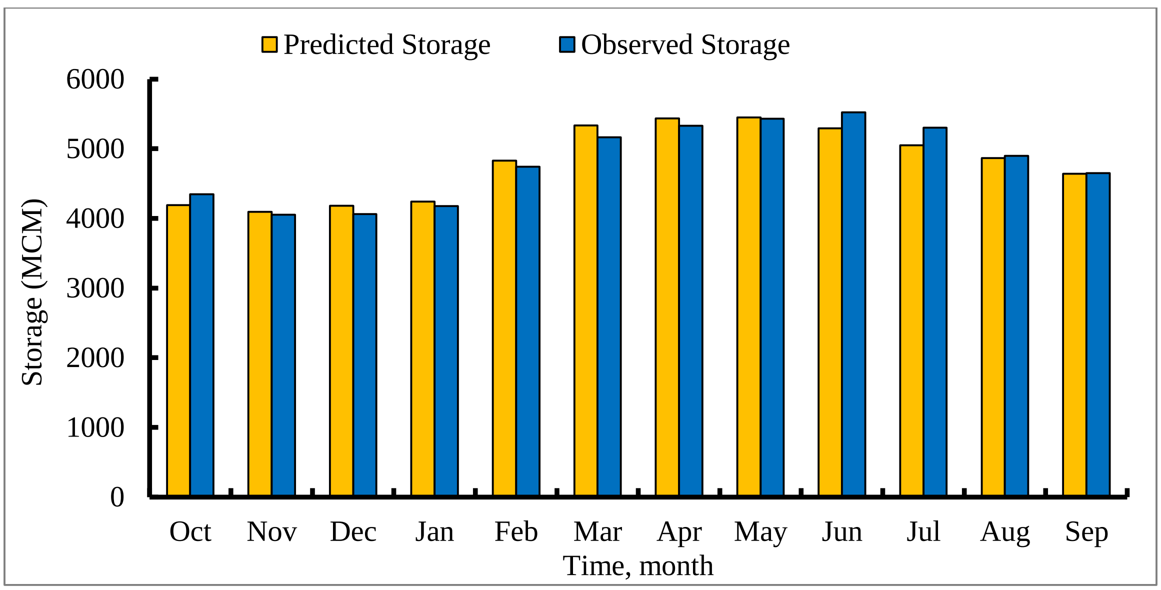

Figure 6.48: Chronological changes in the Haditha reservoir's storage by comparing the predicted values with the measured values over 2000-2020.

6.14.2 Validation of the Results Derived for the Tharthar and Habbaniyah Reservoirs

The performance of the models has been evaluated using the coefficient of determination (R^2), the Nash-Sutcliffe efficiency coefficient (NSE). For the Tharthar Reservoir, the R^2, and NSE, were 0.7083 and 0.68, respectively. PBIAS is a metric used to assess the overall tendency of the predicted values to be consistently higher or lower than the observed values, expressed as a percentage. A PBIAS (Percent Bias) value of - 0.58 indicates the bias or systematic error between the predicted and observed values. A PBIAS value of -0.58 suggests a systematic underestimation of the predicted values compared to the observed values. In other words, the predicted values tend to be lower than the observed values by approximately 0.58.

Figure 6.49 shows the chronological changes in the Tharthar reservoir's storage by comparing the predicted values with the measured values over 2000-2020. For the Habbaniyah Reservoir, the R^2, and NSE, values are 0.8143, and 0.69, respectively. However, it's important to note that a PBIAS value of 0.18 indicates a relatively small bias. The magnitude of the bias is quite low, suggesting that the model or system is reasonably accurate overall, with only a minor tendency to slightly overestimate the observed values. This indicates a lower level of error or discrepancy between the predicted and observed values in the dataset. These results suggest that models for both Tharthar and Habbaniyah Reservoirs have moderate correlations between the predicted and measured storage. Figure 6.50 shows the chronological changes in the Habbaniyah reservoir's storage by comparing the predicted values with the measured values over 2000-2020.

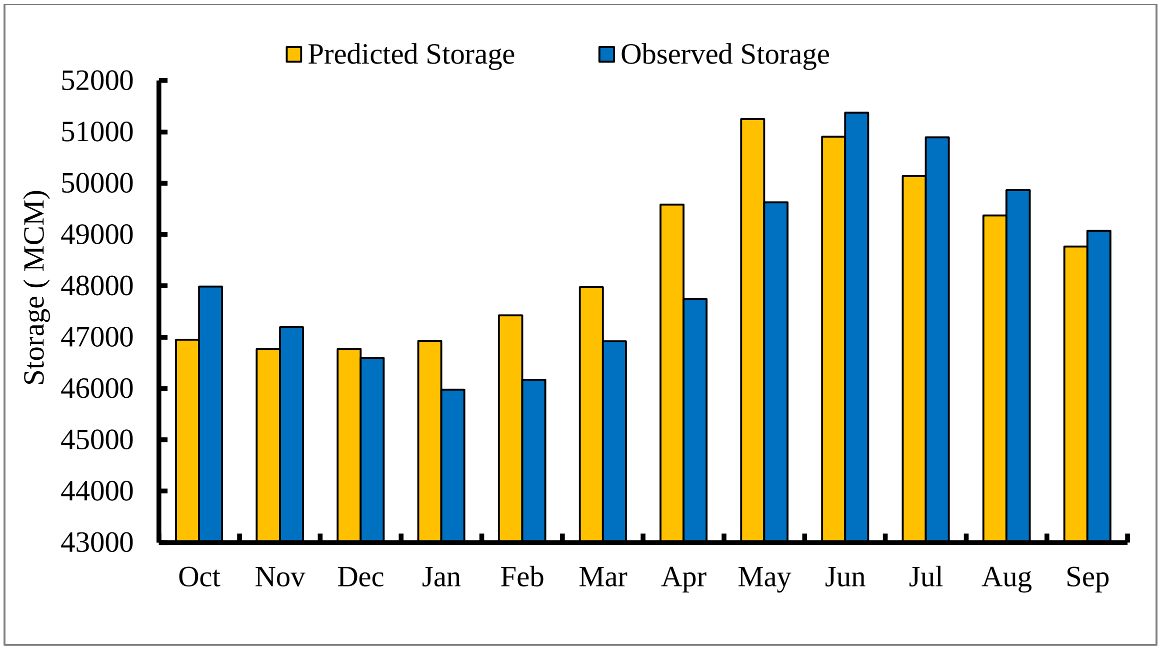

Figure 6.49: Chronological changes in the Tharthar reservoir's storage by comparing the predicted values with the measured values over 2000-2020.

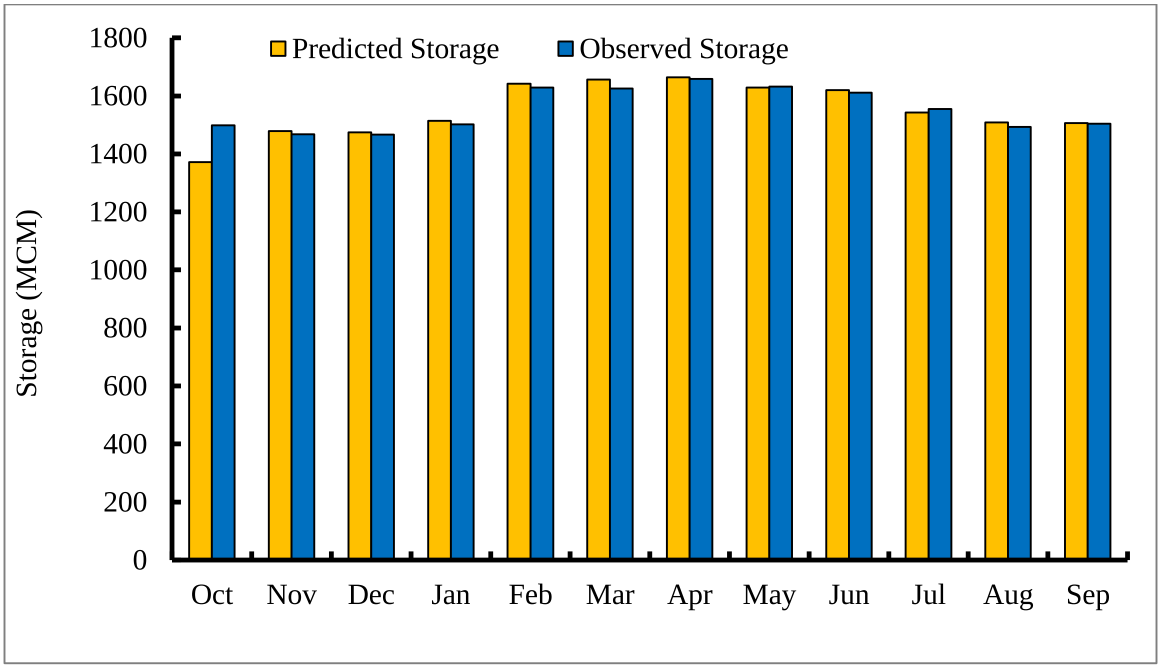

Figure 6.50: Chronological changes in the Habbaniyah reservoir's storage by comparing the predicted values with the measured values over 2000-2020.

6.15 Simulation of Euphrates River Basin Based on WEAP Model

Once the data for the study area is inputted, the WEAP model can conduct monthly simulations and provide projections for various aspects of the system. These include demand site requirements, satisfaction of instream flow requirements, reservoir storage, evaporation, and transmission. The results view serves as a versatile reporting tool, allowing for the examination of scenario calculations in the form of charts, tables, or schematic displays. Monthly or yearly results can be generated for any period within the study timeframe.

Figure 6.51 shows the water release for the provinces provided from the Haditha reservoir. Anbar demonstrates the highest average water release, while Baghdad exhibits the lowest water release, equivalent to 651, and 48 MCM, respectively. The water release of the Muthanna province is higher than that of Thi-Qar province, where the main reason is that the irrigated areas in Muthanna are larger than in Thi-Qar.

Figure 6.52 shows the Monthly water release of the provinces that are fed by Tharthar Reservoir. The water release for both provinces, Babil and Diwaniyah, shows an increasing trend over the years. In February, the water release values were 205.33 for Babil and 146.72 for Diwaniyah. From March to September, the water release values fluctuated between 220 to 227.33 MCM. Throughout the entire period, the water release from Babil province consistently remains higher than that of Diwaniyah province due to the irrigated areas in Babil province are larger than in Diwaniyah province. The average difference between the water release values of the two provinces remains relatively consistent, with Babil's water release being approximately 63.67 MCM higher than Diwaniyah's release.

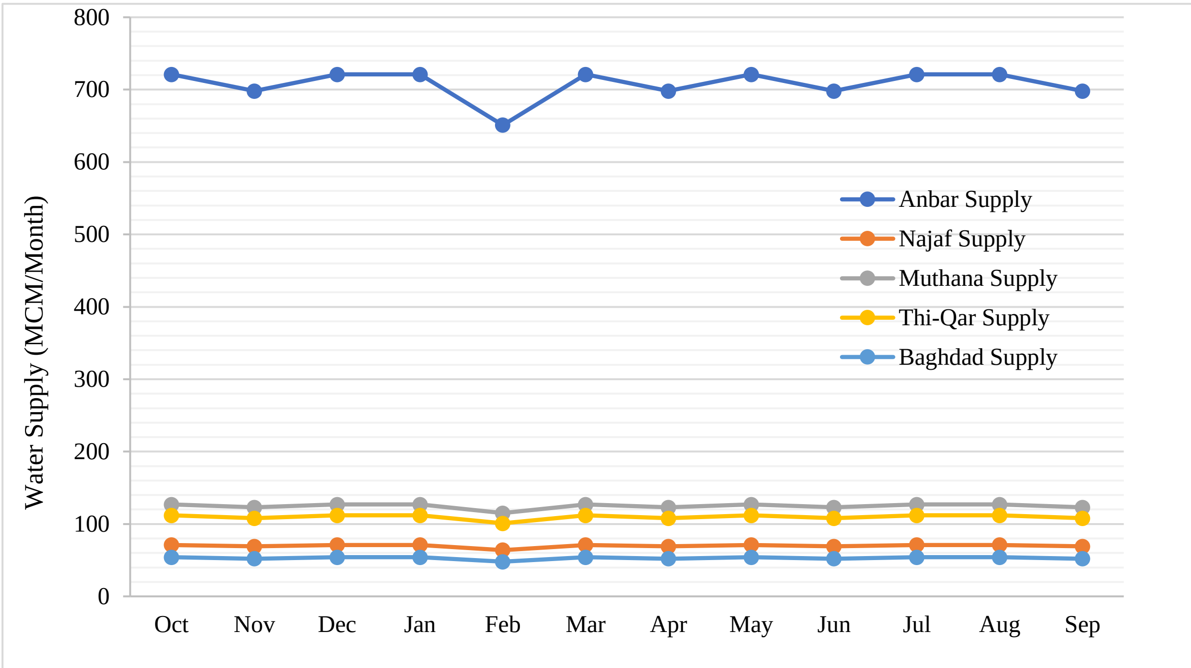

Figure 6.51: Water release of the provinces that feeding by Haditha Reservoir

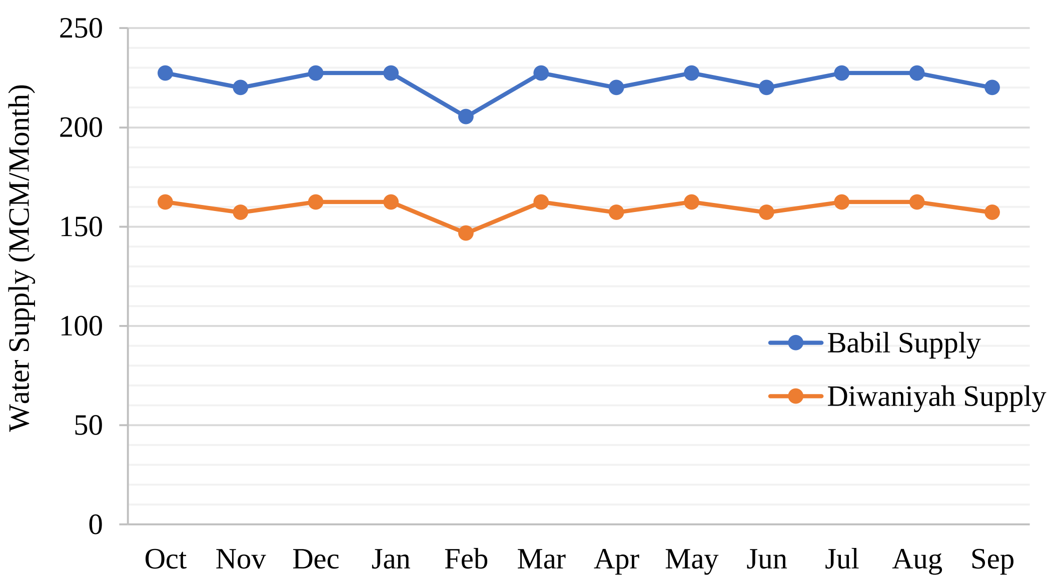

Figure 6.52: Water release of the provinces that feeding by Tharthar Reservoir

Figure 6.53 shows the water release of the provinces that are fed by Habbaniyah Reservoir. The water release for Karbala province shows a generally increasing trend over the years. In February, the water release value was 66 MCM. From March to September, the water release values fluctuated between 71 to 73. MCM.

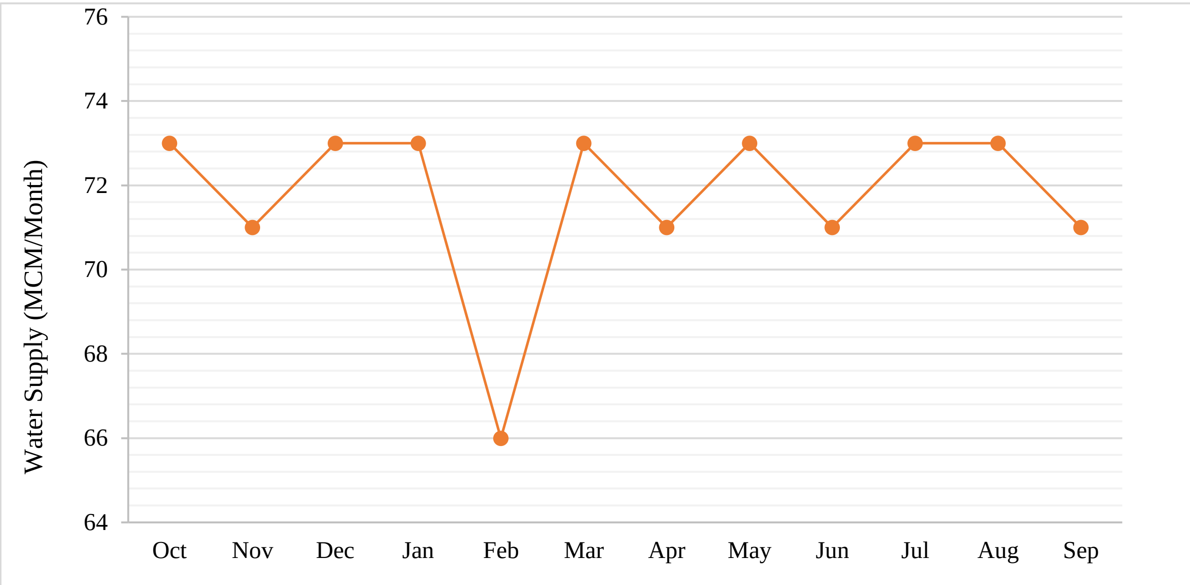

Figure 6.53: Water release of the provinces that feeding by Habbaniyah Reservoir

6.16 Comparison of the Simulated Water Release

6.16.1 Comparison of the Water Release from Haditha Reservoir

The comparison of results from the optimization model DDDP, predicting annual water release, with the simulated annual water release by the WEAP Model is considered an important step in the simulation process.

Figure 6.54 shows the comparison between the predicted annual water release of the DDDP Model and the simulated annual water release by the WEAP Model for Haditha Reservoir. In general, the predicted by the WEAP Model and simulated water release by the WEAP Model values are relatively close, but there are some differences between the two models. For the initial years, the predicted and simulated values are relatively consistent, with minor variations. As the years progress, the differences between the predicted and simulated values become more noticeable.

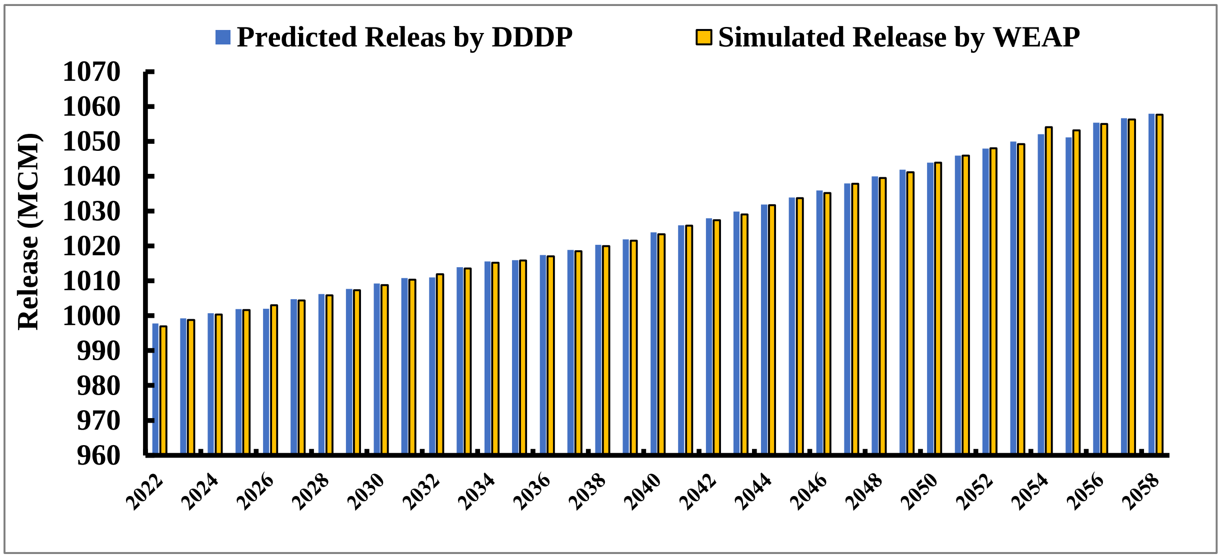

Figure 6.54: Comparison between the predicted annual water release by DDDP and the simulated annual water release by WEAP model of Haditha Reservoir.

6.16.2 Comparison of the Water Release for Tharthar and Habbaniyah Reservoirs

Figures 6.55 and 6.56 show the comparison between the predicted annual water release by DDDP and simulated water release WEAP model for Tharthar and Habbaniyah Reservoirs. In general, the predicted annual water and simulated water release values are relatively close for both Tharthar and Habbaniyah Reservoirs.

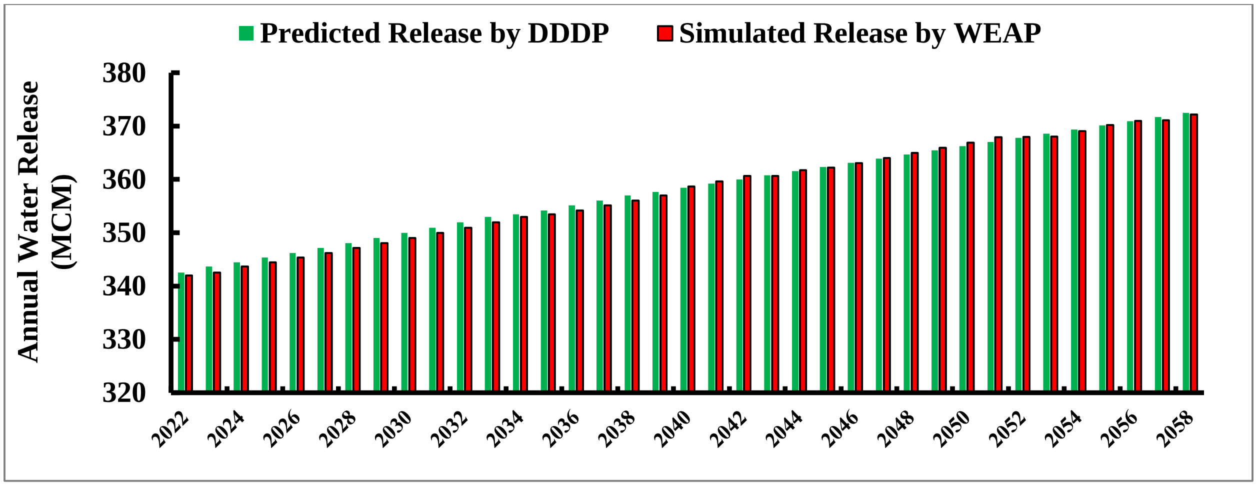

Figure 6.55: Comparison between the predicted annual water release by DDDP and the simulated annual water release by WEAP model of Tharthar Reservoir

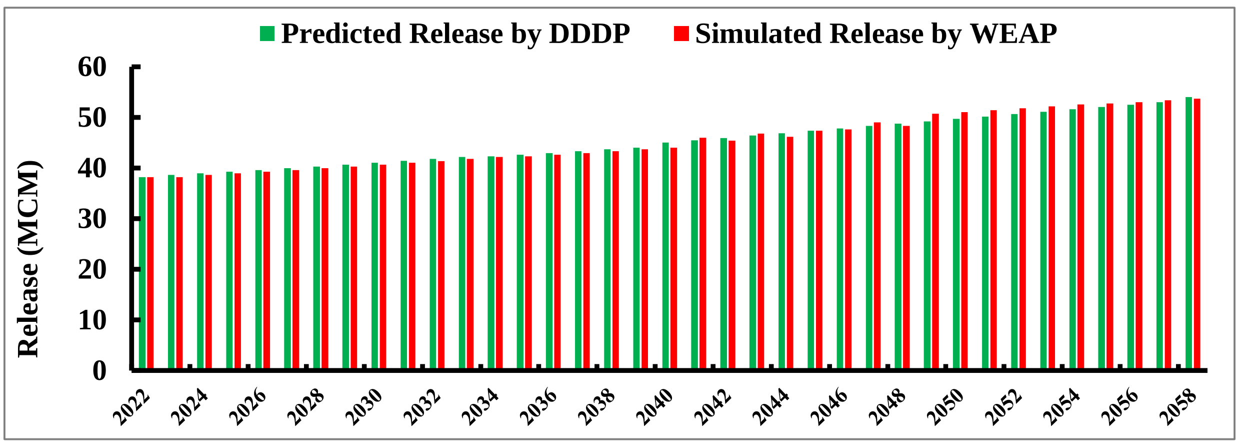

Figure 6.56: Comparison between the predicted annual water release by DDDP and the simulated annual water release by WEAP model of Habbaniyah Reservoir.

6.17 Different Operation Challenges of the Euphrates River Basin: Scenarios of Management

The Euphrates River Basin presents various operation challenges that require careful management. In order to address these challenges effectively, it is essential to explore different scenarios of management. These scenarios offer valuable insights into the diverse factors influencing the basin's operation, enabling to development of long-term strategies and approaches that can ensure sustainable and efficient management of the Euphrates River Basin. By considering these scenarios, we can better understand the complexities involved and work towards a harmonious and balanced utilization of this vital water resource.

6.17.1 Applying First Case for Tharthar Reservoir

Creating the balance between the water supply and demand for the overall ERB has to consider the operation scenarios of the three reservoirs. This balance depends on the main scenarios of the Tharthar Reservoir for both cases.

To take advantage of the excess water storage during wet years and to compensate for shortages during dry years in the three reservoirs (Haditha, Tharthar, and Habbaniyah) an equation can be created to balance the supply and demand for the ERB. This equation can be expressed as:

$$Total\ Net\ Available\ Water = \sum_{t=1}^{T} Supply - \sum_{t=1}^{T} Demand \tag{6.1}$$

Where The *Total Net Available Water* is a difference between the $Total\ Supply$ and demand, $Total\ Supply$ or the Total Release is the cumulative supply for the three reservoirs Haditha, Tharthar, and Habbaniyah, and the $Total\ Demand$ is the cumulative demand for the three reservoirs. $Total\ Supply$ And $Total\ Demand$ can be expressed as:

$$Supply = S_i + Q_t + Pr_t - Ev_t - S_{t+1} \tag{6.2}$$

The total supply for ERB from October 2022 to September 2059 is 624835 MCM, and the total demand is 646666 MCM after applying first case or scenario TH1 for the Tharthar Reservoir. The net available water is -21830 MCM. The negative sign refers to the deficit in supply.

Figure 6.57 shows the total supply and demand for the ERB For Tharthar Reservoir. The trend of the demand increases in the slope after 2039 because of increases in the water requirement especially agricultural water demand. The supply fluctuation is the succession of dry and wet years for reservoirs, where if the year is wet, the supply is higher than the Demand, and if it is wet, the supply is lower than the need, and so on. One possible interpretation of Figure 6.57 is that the supply of water from the three reservoirs is not sufficient to meet the increasing demand over time. This could be due to a variety of factors, such as changes in weather patterns leading to wetter or drier years and resulting in higher or lower levels of water availability in the reservoirs.

Figure 6.58 shows the Net Available Water after applying first case. The surplus of water to the top with a positive sign and the deficit to the down with a negative sign. The maximum surplus in 2032 equals 2643 MCM and the maximum deficit in 2053 equals 8495 MCM. The minimum surplus in 2051 equals 160 MCM in 2052 and the minimum deficit in 2047 equals 1030 MCM.

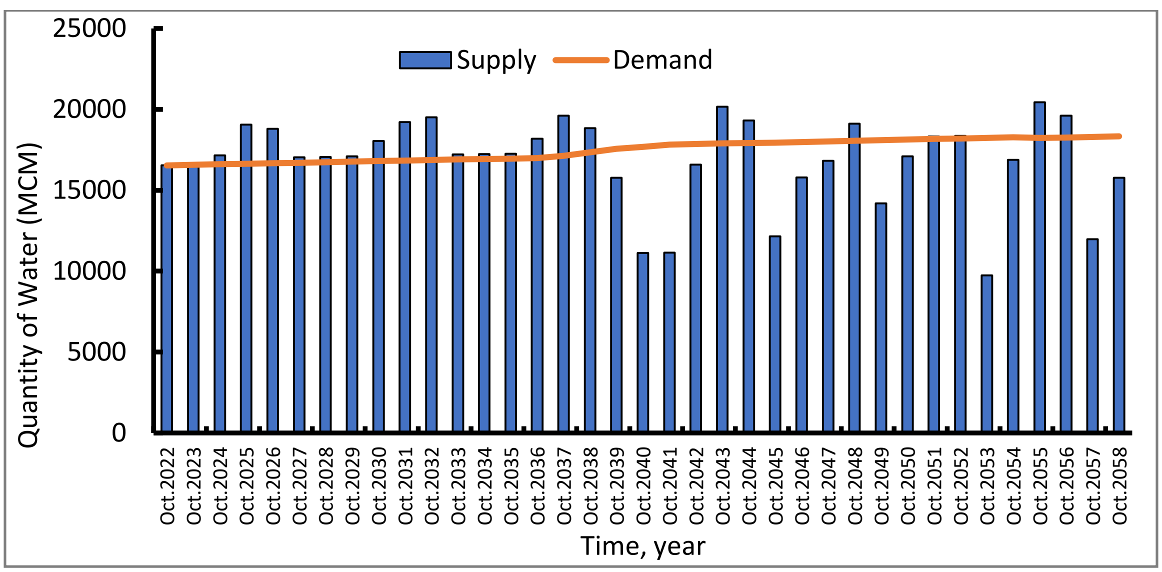

Figure 6.57: Water supply and demand after applying the first case for Tharthar Reservoir.

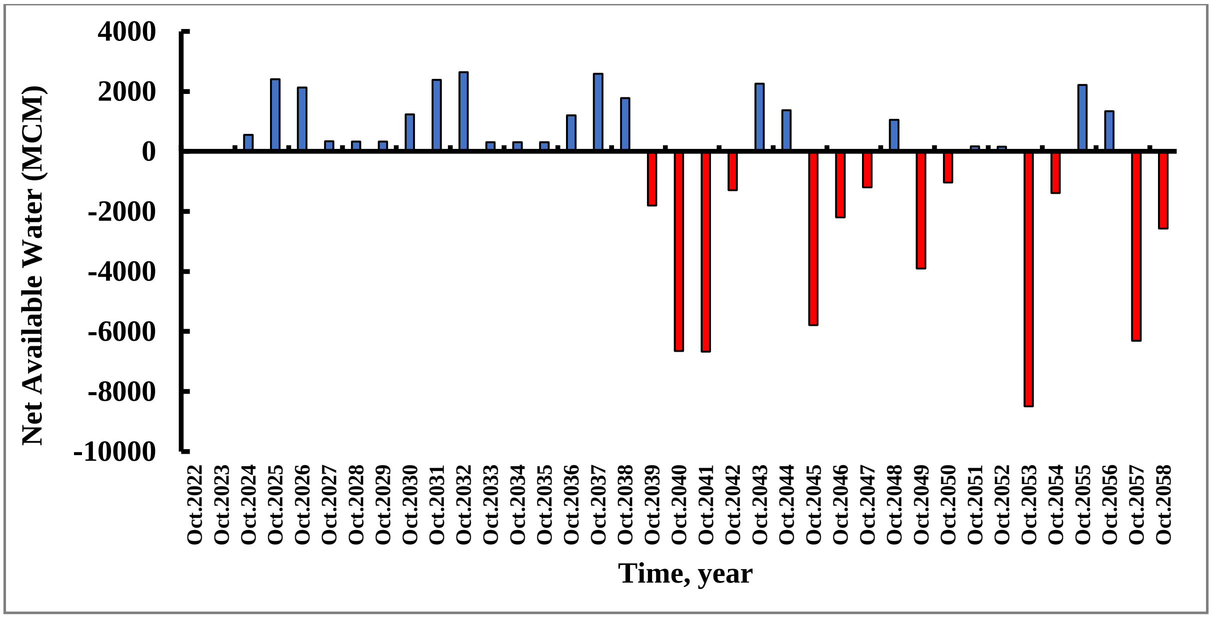

Figure 6.58: Net available water after applying the first case for Tharthar Reservoir.

6.17.2 Applying Second Case for Tharthar Reservoir

The summation supply is the cumulative supply for the three reservoirs, Haditha, Tharthar, and Habbaniyah, and the summation demand is the cumulative demand for the three reservoirs. The total supply for ERB from October 2022 to September 2059 equals 664436 MCM, and the total demand is 646666 MCM after applying second case or scenario TH2 for the Tharthar Reservoir. The net available water is a difference between the total supply and demand, equal to 17770 MCM.

Figure 6.59 shows the total supply and demand for the ERB For Tharthar Reservoir. The supply fluctuates around the demand curve, where the demand curve approaches a linear curve. The demand trend increases in the slope after 2039 because of increased water requirements, especially agricultural and municipal water demand. The supply fluctuation is the succession of dry and wet years for reservoirs, where if the year is wet, the supply is higher than the demand, and if it is dry, the supply is lower than the need, and so on. One possible interpretation of Figure 6.59 is that the water supply from the three reservoirs is insufficient to meet the increasing demand over time. The fluctuation of the supply curve around the demand curve indicates that there are times when the supply can meet demand, but there are also times when the demand is not fully met. This fluctuation could be due to various factors, such as changes in weather patterns leading to wetter or drier years and resulting in higher or lower levels of water availability in the reservoirs.

Figure 6.60 shows the Net Available Water after applying the second case. The maximum surplus in 2032 equals 2644 MCM, and the maximum deficit in 2057 equals 6315 MCM. The minimum surplus in 2051 equals 160 MCM, and the minimum deficit in 2047 equals 1191 MCM.

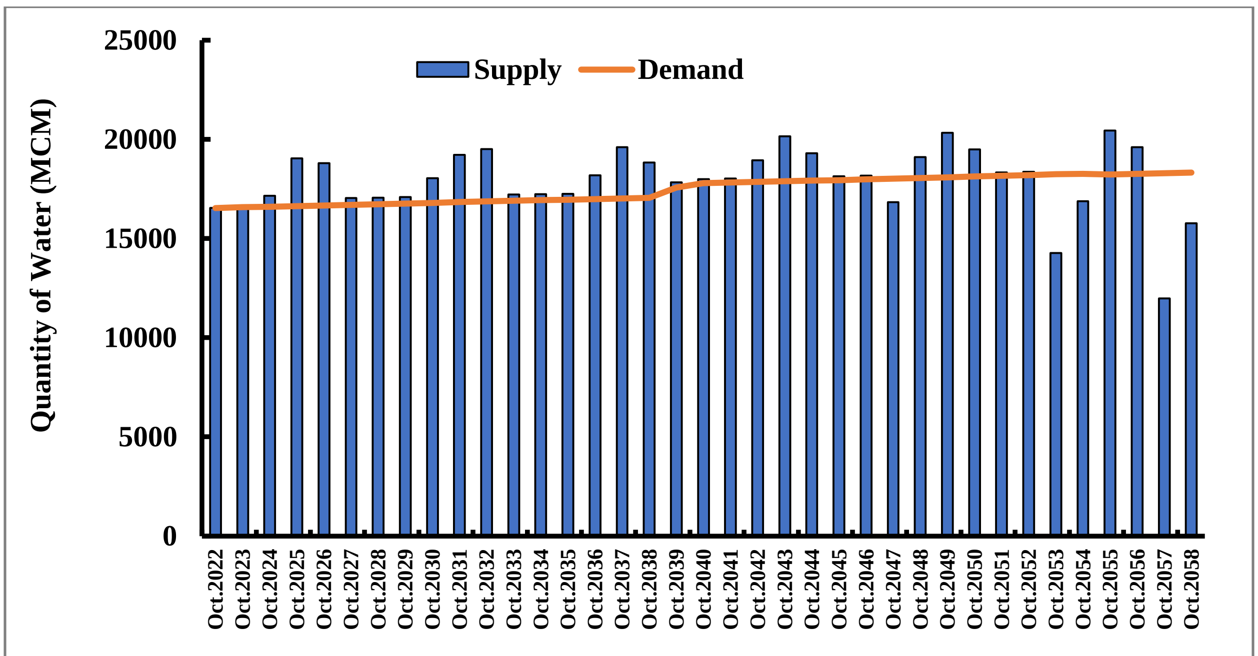

Figure 6.59: Water supply and demand after applying second case for Tharthar Reservoir.

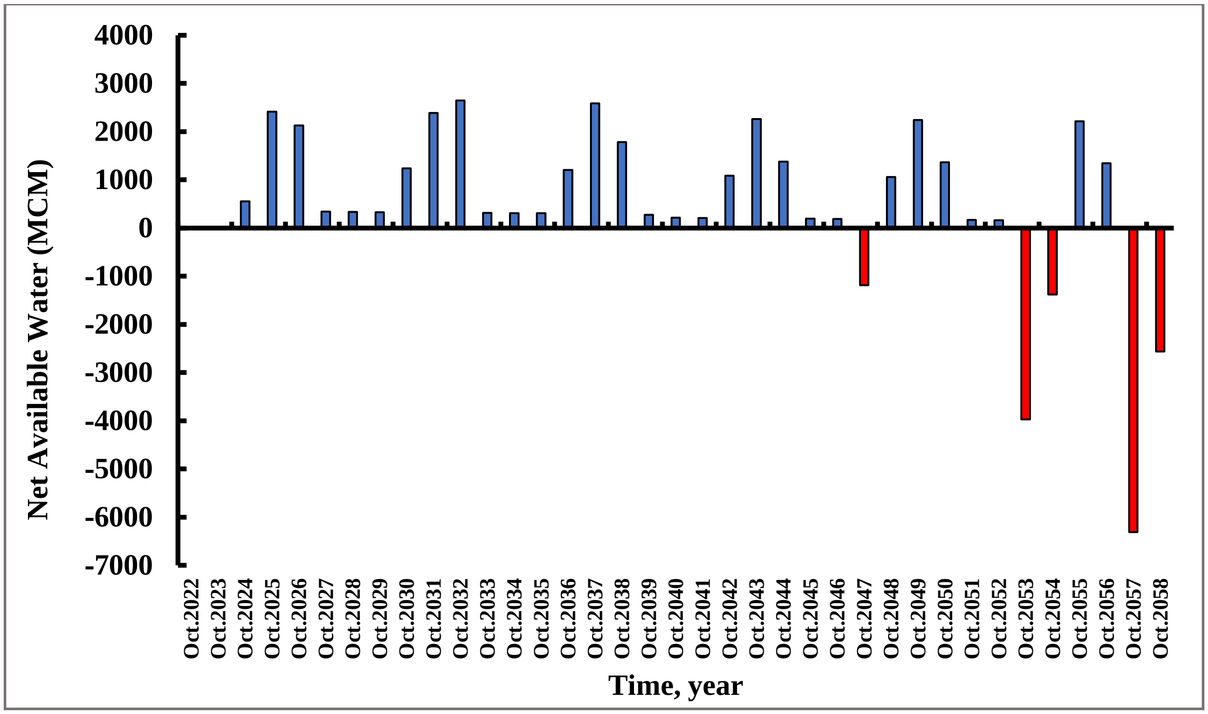

Figure 6.60: Net available water after applying second case for Tharthar Reservoir.

6.18 Identifying Weaknesses in the ERB Management Under the Challenges

The effective management of the Euphrates River Basin (ERB) system is vital for ensuring sustainable water resource utilization, energy generation, and ecosystem preservation in Iraq. However, the ERB system faces multiple challenges, including climate change, demand growth, and the violation of Iraq's water rights by neighboring countries. Climate change brings about environmental and meteorological changes that directly impact water availability and quality within the basin. Demand growth reflects the increasing water and energy requirements of a growing population and expanding industries in the region. Additionally, the violation of Iraq's water rights further exacerbates the challenges faced by the ERB system.

6.18.1 Climate Change Effects on the Management ERB System

Climate change significantly affects the management of the ERB system. Alterations in evaporation rate, precipitation patterns, increased temperatures, and extreme weather events directly impact the basin's hydrological cycle and water resources. Changes in water availability influence the operation of water infrastructure, affecting water supply for various purposes, including irrigation water release.

In comparison to the water year 2022, the cumulative increases in irrigation water release by the end of 2059 for the three reservoirs (Haditha, Tharthar, Habbaniyah) are 5%, 13%, and 15% respectively. This poses a challenge for the management of the system as it requires ensuring a sustainable and efficient allocation of water to meet the increasing needs.

On the other hand, the cumulative increases in evaporation rates by the end of 2059 for the same reservoirs are 32%, 30%, and 26% respectively. However, the cumulative increases in evaporation rates for the same reservoirs pose a significant weakness. The higher evaporation rates result in increased water loss from the reservoirs, reducing the overall availability of the water in the reservoirs effect on the hydropower generation, and irrigation purposes.

In terms of precipitation rates, the cumulative decreases by the end of 2059 for the three reservoirs are 30%, 36%, and 29.5% respectively. Furthermore, the cumulative decreases in precipitation rates by the end of 2059 for the three reservoirs further compound the weaknesses in the system. The reduced precipitation leads to a decrease in water replenishment, making it even more challenging to meet the growing demand for irrigation water release.

6.18.2 Demand Growth Effects on the Management ERB System

The rapid growth in water demand poses significant challenges for the management of the ERB system. Increasing population and expanding industrial activities within the basin contribute to rising water requirements. Meeting this escalating demand strains the existing water infrastructure, leading to inefficiencies in water allocation. Moreover, the extraction of water resources for various purposes can have adverse impacts on the ecological balance within the basin. Identifying weaknesses in the ERB system management under demand growth is essential for developing strategies that ensure reliable and sustainable water supply to meet the increasing needs of the municipal and industrial of the ERB.

In comparison to the water year 2022, the cumulative increases in municipal and industrial water release by the end of 2059 for the three reservoirs (Haditha, Tharthar, Habbaniyah) are 83.8 %, 86.8 %, and 81.9 % respectively.

6.18.3 Violation of Iraq's water rights Effects on the Management ERB System

The violation of Iraq's water rights by neighboring countries represents a significant challenge for the management of the ERB system. Disputes over water allocation and construction of dams and infrastructure upstream can result in reduced water flows downstream, negatively impacting water availability and ecosystem health within Iraq. This violation undermines the equitable distribution and utilization of water resources, further straining the management of the ERB system. Addressing weaknesses arising from the violation of Iraq's water rights is crucial for developing diplomatic and legal solutions to ensure the fair and sustainable management of water resources within the ERB. During the period from 2000 to 2021, the inflow into the reservoirs can be categorized into wet and dry years. For the Haditha Reservoir, approximately 38% of the years were characterized as wet, with a higher inflow of water, while 62% of the years were classified as dry, indicating lower inflow. Similarly, for the Tharthar Reservoir, approximately 47.6% of the years were wet, while 52.4% were dry. As for the Habbaniyah Reservoir, around 43.7% of the years were wet, and 56.3% were dry. The higher occurrence of dry years underscores the challenges faced by Iraq in securing sufficient water supply for various purposes, including irrigation, municipal, and industrial needs. These imbalances in inflow can lead to water scarcity, reduced agricultural productivity, and increased strain on the ecosystem and overall water management in the region.

6.19 Long-term Solutions of the ERB Management Problem

The long-term solutions for the ERB management problem involve developing alternative scenarios to address uncertainties and achieve sustainable water allocation. Scenarios provide insights into potential outcomes considering factors like water availability, conservation projects, and climate change. Socio-economic development goals, including access to safe drinking water, irrigation, and industrial supply, are prioritized for Iraq. Here are the key points:

1. Reduction in Demand: Implement strategies to reduce the water demand in various sectors. The targets for optimal operation aim to achieve a percentage reduction in demand, particularly in the agriculture sector. To manage drought until 2060, a strict operating plan is required, involving reduced consumption across sectors except for municipal, environmental, and industrial demand. To implement the proposed solution, operational scenarios H1, TH1 and HB need to be adopted for the Haditha, Tharthar and Habbaniyah Reservoirs, respectively.

2. Utilizing Dead Storage: Scenario TH2 involves drawing water from the Tharthar reservoir's dead storage. The Ministry of Water Resources (MoWR) has installed floating pumping stations on the dead storage to take advantage of water availability during drought conditions. When the storage in the conservation zone is depleted, the Tharthar Reservoir's dead storage, amounting to 39600 MCM, will fill the shortage in water supply.
3. Achieving Balance in Water Supply and Demand: To ensure a sustainable water management system in the ERB, it is crucial to establish a balance between water supply and demand. This requires careful consideration of the operational scenarios for all three reservoirs, with a particular focus on implementing the second case scenario (TH2) for the Tharthar Reservoir. By adopting TH2, which results in an additional cumulative net water supply of 17770 MCM, steps can be taken to optimize the utilization of available water resources and meet the growing demands within the region. These operational scenarios play a pivotal role in achieving equilibrium and addressing the challenges posed by water scarcity and increasing water needs.

Chapter Seven

Conclusions and Recommendations

An approach to water planning and decision-making in the ERB was introduced. Long-term strategies and a plan that provides comprehensive integration of water resource development in the ERB over a 37-year planning period were presented in this study. This chapter provides the main conclusion points that can be drawn from the findings obtained.

7.1 Conclusions

1. Research findings indicate that future irrigation water requirements will increase due to rising temperatures, reduced rainfall and humidity, and increased evaporation.
2. The average values of reference evapotranspiration (ETo) and net irrigation water requirements (NIWR) vary throughout a crop's growth cycle and across seasons, depending on the weather. These results emphasize the importance of scientifically planning irrigation to optimize water usage effectively.
3. The evaporation rates from the reservoirs increase under different future scenarios of climate change. The SSP1:2.6 scenario showed slightly higher evaporation rates compared to the RP, while the SSP2:4.5 scenario indicated higher evaporation rates. The increase in evaporation rates from reservoirs under different future scenarios of climate change, such as SSP1:2.6 and SSP2:4.5, is likely attributed to the rise in temperature associated with global warming.
4. Based on optimization model results, during the planning period from October 2022 to September 2059, the Hadith Reservoir receives cumulative inflow of

484,922 MCM of water. Additionally, the Tharthar Reservoir receives an inflow of 301,209 MCM from the Tigris River, while the Habbaniyah Lake receives 83,420 MCM from the Euphrates River. Within the Euphrates River Basin, the Haditha Reservoir supplies 69% of the water requirements, while the Tharthar reservoir and Habbaniyah Lake contribute 23% and 8% respectively.

5. By implementing scenario TH1 for the Tharthar Reservoir, the total water supply for the Euphrates River Basin (ERB) from October 2022 to September 2059 reaches 624,835 MCM, while the total water demand amounts to 646,666 MCM. On the other hand, when scenario TH2 is applied to the Tharthar Reservoir, the total water demand for the ERB is 646,666 MCM, and the total water supply is 664,436 MCM.
6. The strategy maintains its resilience throughout the planning process as scenarios H1 and TH2 are applied to optimize the operation of the Haditha and Tharthar Reservoirs, leveraging the optimization model from October 2022 to September 2059.
7. The evaporation rates from the reservoirs are as follows: The Haditha Reservoir has a total evaporation rate of 33,886 MCM, accounting for 7% of the reservoir's total inflow. The Tharthar and Habbaniyah Reservoirs have respective evaporation rates of 193,546 MCM and 29,536 MCM, representing 64% and 35% of their total inflows. In terms of water supply and demand in the second case, the Haditha Reservoir has a total water supply of 455,593 MCM and a total water demand of 457,218 MCM. The Tharthar Reservoir has a total water supply of 155,854 MCM and a total water demand of 168,926 MCM. The Habbaniyah Reservoir has a total water supply and demand of 52,987 MCM and 20,987 MCM, respectively.

8. The balancing equations between demand and supply for ERB showed that in the first case of the Tharthar Reservoir operation, there would be a deficit in supply equals (-21830) MCM. In the second case, the surplus amount equals 17770 MCM.
9. The performance metrics R2, NSE, and PBIAS were assessed for Haditha Reservoir, Tharthar Habbaniyah Reservoirs. The evaluation revealed varying degrees of agreement between the storage values derived from the DDDP and the measured values, ranging from good agreement for Haditha Reservoir to moderate agreement for Tharthar and Habbaniyah, respectively.

7.2 Recommendations

These recommendations aim to provide a comprehensive framework for long-term water resource development in the Euphrates River Basin in Iraq, considering sustainable practices, collaboration, adaptation to climate change, and the preservation of water resources for the well-being of the region.

1. Developing and implementing efficient water management practices and technologies, such as water recycling and conservation techniques, to optimize water usage within the ERB.
2. In order to avoid storage deficits and release issues in the ERB, the Ministry of Water Resources in Iraq should complete the operation of floating pumps on the dead storage of the Tharthar reservoir.
3. Establish effective monitoring and surveillance systems to track water quality and ensure the protection of the ERB's water sources from pollution and contamination. Strategically place monitoring stations at key locations across the ERB, considering factors such as proximity to pollution sources, representative sampling, and coverage of critical water bodies. Also, Integrate GIS technology

to spatially map and analyze water quality data. This helps identify patterns, hotspots, and areas requiring targeted intervention.

4. With the projected increase in temperatures and fluctuations in precipitation patterns, the development of adaptation strategies becomes crucial to mitigate the impacts of climate change on the Euphrates River Basin. These strategies should involve the implementation of measures aimed at reducing water consumption and fostering sustainable agricultural practices that can withstand the challenges posed by changing climatic conditions.

Appendix-A1

Table A1-1: Physical properties of water (After Chow et al.,1988)

Temperature T	Density ρ_w	Specific weight γ	Dynamic viscosity μ	Kinematic viscosity ν	Vapor pressure P_V
	kg/m^2	N/m^3	N·s/m	m^2/s	N/m^2
0°C	1000	9810	1.79×10^{-3}	1.79×10^{-6}	611
5°C	1000	9810	1.51×10^{-3}	1.79×10^{-6}	872
10°C	1000	9810	1.31×10^{-3}	1.79×10^{-6}	1230
15°C	999	9800	1.14×10^{-3}	1.79×10^{-6}	1700
20°C	998	9790	1.00×10^{-3}	1.79×10^{-6}	2340
25°C	997	9781	8.91×10^{-5}	8.94×10^{-7}	3170
30°C	996	9771	7.96×10^{-5}	7.99×10^{-7}	4250
35°C	994	9751	7.2×10^{-5}	7.24×10^{-7}	5630
40°C	992	9732	6.53×10^{-5}	6.58×10^{-7}	7380
50°C	988	9693	5.47×10^{-5}	5.54×10^{-7}	12.300
60°C	983	9643	4.66×10^{-5}	4.74×10^{-7}	20.000
70°C	978	9594	4.04×10^{-5}	4.13×10^{-7}	31,200
80°C	972	9535	3.54×10^{-5}	3.54×10^{-7}	47,400
90°C	965	9467	3.15×10^{-5}	3.26×10^{-7}	70.100
I00°C	958	9398	2.82×10^{-5}	2.94×10^{-7}	101.300

Table A1-2: Maximum and minimum discharge of the major gauge station and barrages (Saleh, 2010; Abdullah and Al-Ansari, 2021)

No	Description	Max. Discharge (m^3/s)	Mini. Discharge (m^3/s)
1	Husaybah Gauge Station	2760	186
2	Hit Gauge Station	5779	71
3	Al-Hindiya Barrage	3382	43
4	Al-Ramady Barrage	1279	247.5
5	Al-Falluja Barrage	3600	104.5

Table A1-3: Maximum discharge of the miner barrages and regulators (Abdullah, and Al-Ansari, 2021)

No	Description	Maximum Discharge (m^3/s)
1	Warrar Regulator	3600
2	Dhiban Regulator	800
3	Samara -Tharthar Regulator	9000
4	Tharthar Regulator	1100
5	Shat-Al-Hilla Regulator	245
6	Shat-Al-Diwaniyah Regulator	96
7	Abbasiya Regulator	1100
8	Shamiya Regulator	1100
9	Khawarnaq Regulator	1100
10	Kufa Barrage	1400
11	Meshkhab Barrage	750
12	Abu Ashera Regulator	50
13	Husseinia Regulator	55
14	Bani Hassan Regulator	45
15	Saqlawiyah Regulator	26
16	Abu Ghraib Regulator	28

17	Radwaniyah Regulator	7.2
18	Yousifia Regulator	24.4
19	Eskandariah Regulator	8
20	Greater Mussaiyab Regulator	40
21	Kifil Regulator	18.5
22	Hammar Marsh Regulator	40
23	Central Marsh Regulator	30

Table A1.4: Maximum and minimum monthly values of the decision and state variables and water inflow of the three reservoirs (Haditha, Tharthar, and Habbaniyah) (NCFWRM, 2022; Abdullah and Al-Ansari, 2022)

Description	Haditha Reservoir	Tharthar Reservoir	Habbaniyah Reservoir
Maximum inflow (m^3/s)	1598	4026	495
Minimum inflow (m^3/s)	111	0	0
Maximum storage (MCM)	10000	85000	3300
Minimum storage (MCM)	530	39600	760
Maximum outflow (m^3/s)	4730	500	800
Minimum outflow (m^3/s)	70	0	0

Table A1.5: Maximum, minimum, and average of the monthly inflow data for Haditha Reservoir (NCFWRM, 2022)

Time	Max. Inflow (m^3/s)	Min. Inflow (m^3/s)	Average Inflow (m^3/s)
Oct	729	183	353.0
Nov	670	200	439.3
Dec	840	174	522.9
Jan	990	280	593.5
Feb	1150	230	599.2

Mar	1598	180	489.7
Apr	735	136	362.4
May	820	123	347.8
Jun	777	63	322.4
Jul	696	111	320.1
Aug	742	111	380.1
Sept	811	105	352.5

Table A1.6: Maximum, minimum, and average of the monthly inflow data for Tharthar Reservoir (NCFWRM, 2022)

Time	Max. Inflow (m^3/s)	Min. Inflow (m^3/s)	Average Inflow (m^3/s)
Oct	100	0	5
Nov	240	0	31
Dec	822	0	106
Jan	800	0	184
Feb	1463	0	360
Mar	1794	20	406
Apr	4026	0	754
May	3530	0	788
Jun	812	0	153
Jul	152	0	21
Aug	100	0	5
Sept	100	0	5

Table A1.7: Maximum, minimum, and average of the monthly inflow data for Habbaniyah Reservoir (NCFWRM, 2022)

Time	Max. Inflow (m^3/s)	Min. Inflow (m^3/s)	Average Inflow (m^3/s)
Oct	334	0	73
Nov	236	0	84
Dec	280	0	79
Jan	282	0	111
Feb	465	0	134
Mar	348	5	84.5
Apr	178	0	49.9
May	118	0	37.8
Jun	192	0	54.4
Jul	495	0	95.3
Aug	301	0	120.9
Sept	290	0	120

Appendix-A2

Table A2.1: The maximum temperature of the three scenarios (CCKP,2022)

Maximum Temperature For the reference period Scenario (1995 - 2014) °C								
Province	Baghdad	Babil	Najaf	Diwaniyah	Muthanna	Karbala	Anbar	Thi-Qar
Jan	15.69	16.25	16.51	16.46	17.25	15.87	14.42	16.92
Feb	18.98	19.56	19.63	19.85	20.53	19.03	17.17	20.36
Mar	24.28	24.85	24.9	25.18	25.83	24.27	22.25	25.73
Apr	30.42	30.97	30.81	31.26	31.78	30.34	28.07	31.9
May	36.82	37.25	36.86	37.57	37.9	36.46	33.96	38.33
Jun	43.42	43.63	42.69	43.87	43.79	42.67	39.96	44.75
Jul	46.37	46.53	45.4	46.61	46.22	45.52	42.8	47.14
Aug	46.2	46.32	45.24	46.38	45.98	45.36	42.68	46.79
Sep	40.92	41.2	40.44	41.31	41.24	40.4	37.98	41.93
Oct	33.13	33.52	33.12	33.79	34.03	32.75	30.49	34.39
Nov	23.72	24.14	24.02	24.33	24.85	23.52	21.74	24.85
Dec	16.81	17.46	17.74	17.75	18.45	17.11	15.62	18.27
Maximum Temperature for the SSP1-2.6 Scenario (2020 - 2039) °C								
Jan	16.77	17.26	17.52	17.45	18.18	16.91	15.47	17.9
Feb	20.05	20.69	20.64	20.92	21.52	20.12	18.13	21.45
Mar	25.29	25.84	25.88	26.21	26.88	25.19	23.14	26.75
Apr	31.68	32.22	31.89	32.45	32.87	31.53	29.23	33.11
May	38.04	38.54	38.23	38.8	39.05	37.84	35.47	39.23
Jun	44.79	44.96	43.98	45.15	45.07	44.05	41.28	46.03
Jul	47.56	47.64	46.52	47.73	47.3	46.62	44.04	48.3
Aug	47.99	48.07	46.96	48.18	47.68	47.04	44.22	48.53
Sep	42.21	42.5	41.81	42.65	42.58	41.73	39.33	43.25
Oct	34.06	34.44	34.04	34.79	35.03	33.64	31.48	35.48
Nov	24.88	25.12	24.98	25.33	25.81	24.39	22.78	25.88
Dec	16.81	17.46	17.74	17.75	18.45	17.11	15.62	18.27
Maximum Temperature for the SSP2-4.5 Scenario (2040 - 2059) °C								
Jan	17.03	17.7	17.95	17.94	18.69	17.33	15.64	18.34
Feb	20.52	21.08	21.24	21.37	22.03	20.58	18.85	21.79
Mar	25.77	26.41	26.49	26.78	27.45	25.84	23.84	27.42
Apr	32.22	32.64	32.51	32.97	33.49	31.91	29.59	33.57
May	38.56	39.1	38.61	39.39	39.58	38.28	35.77	40
Jun	45.38	45.6	44.75	45.82	45.77	44.74	42.17	46.6
Jul	48.8	49.05	47.81	49.05	48.59	48.04	45.09	49.53
Aug	48.46	48.49	47.5	48.6	48.22	47.65	45.06	48.99
Sep	43.55	43.79	43.09	43.99	43.91	42.93	40.56	44.5
Oct	35.42	35.82	35.42	36.04	36.39	35.05	32.66	36.61

Nov	25.22	25.74	25.82	26.09	26.74	25.19	23.38	26.7
Dec	18.46	18.86	18.99	19.13	19.88	18.45	17.07	19.72

Table A2.2: Monthly minimum temperature of the three scenarios (CCKP,2022)

Monthly Minimum Temperature For the reference period Scenario (1995 - 2014) °C								
Province	Baghdad	Babil	Najaf	Diwaniyah	Muthanna	Karbala	Anbar	Thi-Qar
Jan	3.04	3.45	3.63	3.97	4.63	3.03	1.98	4.86
Feb	5.04	5.51	5.62	6.03	6.7	4.9	3.64	6.91
Mar	9.37	9.92	10.03	10.47	11.22	9.31	7.58	11.44
Apr	14.73	15.41	15.42	15.95	16.74	14.71	12.69	16.98
May	20.52	21.15	20.99	21.72	22.38	20.37	18.16	22.75
Jun	26.08	26.85	26.24	27.25	27.62	25.83	23.36	28.22
Jul	29.02	29.44	28.49	29.67	29.6	28.65	26	30.67
Aug	28.53	28.88	27.85	29.13	28.99	27.8	25.45	30.13
Sep	24	24.53	24.04	24.87	25.02	23.78	21.65	25.76
Oct	17.29	17.85	17.97	18.47	19.25	17.2	15.47	19.41
Nov	9.83	10.49	10.65	11.03	11.87	9.84	8.41	12.03
Dec	4.1	4.61	5.06	5.34	6.06	4.22	3.42	6.07
Monthly Minimum Temperature for the SSP1:2.6 Scenario (2020 - 2039) °C								
Jan	3.71	4.19	4.21	4.72	5.26	3.72	2.59	5.7
Feb	5.81	6.31	6.54	6.95	7.59	5.77	4.38	7.73
Mar	10.18	10.9	10.81	11.4	12.11	10.19	8.39	12.27
Apr	15.63	16.37	16.34	16.96	17.61	15.6	13.53	17.89
May	21.37	21.93	21.82	22.48	23.12	21.26	18.97	23.41
Jun	27.23	27.86	27.18	28.22	28.55	26.96	24.41	29.21
Jul	29.88	30.26	29.42	30.65	30.62	29.45	26.99	31.56
Aug	29.75	30.12	29.04	30.31	30.21	29.24	26.75	31.08
Sep	25.01	25.56	25.23	26.07	26.2	24.86	22.72	26.99
Oct	18.44	19.36	19.21	19.81	20.42	18.59	16.59	20.65
Nov	10.53	11.04	11.37	11.64	12.66	10.44	9.18	12.68
Dec	4.97	5.62	5.89	6.23	7.04	5.15	4.11	7.15
Monthly Minimum Temperature for the SSP2:4.5 Scenario (2040 - 2059) °C								
Jan	17.65	18.27	18.11	18.75	19.3	17.56	15.67	19.64
Feb	4.07	4.57	4.72	5.09	5.72	4.41	3	6.09
Mar	6.11	6.87	6.99	7.42	8.27	6.21	4.86	8.36
Apr	10.81	11.46	11.5	11.97	12.74	10.75	9.04	12.84
May	16.36	16.98	17.09	17.65	18.36	16.24	14.33	18.58
Jun	21.96	22.67	22.53	23.27	23.99	21.9	19.66	24.17
Jul	28.14	28.78	28.18	29.16	29.49	27.65	25.34	30.18

Aug	31.17	31.58	30.64	32	31.81	30.93	28.07	32.66
Sep	30.68	31.09	30.19	31.31	31.33	29.75	27.68	32.15
Oct	26.37	26.91	26.41	27.21	27.32	26.02	23.84	28
Nov	19.64	20.32	20.28	20.85	21.47	19.4	17.74	21.66
Dec	11.47	12.12	12.3	12.68	13.62	11.43	9.87	13.72

Table A2.3: Monthly precipitation of the three scenarios (CCKP,2022)

Monthly precipitation for the reference period Scenario (1995 - 2014) mm								
Province	Baghdad	Babil	Najaf	Diwaniyah	Muthanna	Karbala	Anbar	Thi-Qar
Jan	8.9	5.96	3.62	5.28	3.97	5.29	7.14	5.6
Feb	6.43	5.48	3.7	4.7	3.64	4.91	6.34	5.36
Mar	9.1	7.68	5.28	6.72	5.35	7.31	7.57	6.91
Apr	10.51	9.67	8.14	9.84	8.72	8.7	9.09	10.07
May	6.76	6.91	6.86	6.86	6.92	6.6	7.34	7.38
Jun	0.84	0.61	0.86	0.67	0.74	0.78	1.46	0.52
Jul	0.02	0.03	0.02	0.02	0.02	0.02	0.06	0.02
Aug	0.01	0.01	0.03	0.02	0.03	0.02	0.05	0.02
Sep	0.24	0.15	0.16	0.12	0.11	0.17	0.26	0.09
Oct	6.52	5.1	4.82	5.51	6.58	4.86	5.99	6.35
Nov	12.25	10.72	8.11	10.75	9.89	9.03	8.67	11.76
Dec	9.65	7.35	4.85	6.82	6.06	6.61	7.98	8.06
Monthly Mean Minimum for the SSP1:2.6 Scenario (2020 - 2039) mm								
Jan	9.03	6.99	4.87	6.42	5.37	6.48	7.92	6.82
Feb	6.52	4.88	3.68	4.93	4.1	4.11	6.19	5.44
Mar	8.34	6.73	5.02	6.58	5.45	6.62	7.82	7.16
Apr	12.25	9.26	8.57	9.46	10.46	8.79	9.72	10.92
May	8.68	7.69	7.41	7.97	7.25	8.06	9.49	7.96
Jun	0.67	0.75	0.8	0.66	0.71	0.79	1.22	0.59
Jul	0.02	0.03	0.02	0.02	0.02	0.02	0.05	0.04
Aug	0.01	0.02	0.02	0.02	0.03	0.02	0.04	0.02
Sep	0.07	0.02	0.05	0.03	0.03	0.04	0.1	0.02
Oct	5.37	5.02	4.25	5.06	5.01	4.12	5.38	5.81
Nov	12.45	11.12	9.34	11.53	11.61	10.14	9.79	13.85
Dec	9.59	9.1	6.03	8.43	7.55	7.61	7.83	9.44
Monthly precipitation for the SSP2:4.5 Scenario (204 - 2059) mm								
Jan	8.69	6.39	4.15	6.07	4.46	5.77	7.81	6.1
Feb	6.03	4.6	3.78	4.8	3.9	4.45	6.21	5.28
Mar	8.26	6.31	5.04	6.18	5.65	6.23	7.4	6.72
Apr	11.77	11.29	8.22	10.04	9.66	9.64	9.4	11.16
May	11.85	10.81	10.56	11.41	10.79	10.6	11.23	10.74

Jun	0.88	0.75	0.73	0.77	0.71	0.82	1.57	0.83
Jul	0.02	0.02	0.01	0.01	0.02	0.02	0.05	0.02
Aug	0.01	0.01	0.02	0.01	0.02	0.01	0.04	0.02
Sep	0.06	0.07	0.11	0.07	0.06	0.08	0.1	0.05
Oct	7.31	5.17	4.47	4.97	4.74	5.25	5.72	5.95
Nov	12.65	11.22	7.65	9.54	9.7	9.53	8.58	12.15
Dec	9.87	7.97	5.29	7.45	6.29	7.2	8.48	8.18

Table A2.4: Monthly relative humidity of the three scenarios (CCKP,2022)

Monthly Relative Humidity For the reference period Scenario (1995 - 2014) %								
Province	Baghdad	Babil	Najaf	Diwaniyah	Muthanna	Karbala	Anbar	Thi-Qar
Jan	60.99	57.3	55.09	54.31	52.63	58	61.09	53.21
Feb	52.85	48.57	45.28	45.56	42.87	48.66	52.85	43.57
Mar	41.82	37.79	35.78	35.38	33.89	38.04	42.17	33.82
Apr	34.71	31.5	28.83	28.87	27.46	31.65	33.93	27.77
May	29.91	26.55	24.99	24.39	23.59	27.02	28.82	23.1
Jun	20.22	20.04	18.06	17.74	16.73	18.98	21.03	15.51
Jul	17.61	15.61	15.34	13.58	14.25	15.7	17.39	11.95
Aug	17.07	15.91	16.49	14.1	15.37	16.39	18.68	12.85
Sep	19.29	17.5	17.38	15.37	16.16	18.46	20.4	14.08
Oct	34.11	31.72	32.76	29.3	31.35	32.33	35.74	28.59
Nov	54.02	50.36	49.29	47.68	48.32	50.69	53.79	47.25
Dec	62.32	57.98	56.35	55.88	54.46	57.99	61.51	54.32
Monthly Relative Humidity for the SSP1:2.6 Scenario (2020 - 2039) %								
Jan	60.5	57.14	54.57	65.07	55.26	52.62	57.73	59.9
Feb	51.78	48.22	45.06	59.1	44.44	42.49	48.94	52.96
Mar	40.15	36.74	34.79	46.16	34.35	32.79	37.81	41.25
Apr	34.82	32.18	29.18	39.15	29.75	27.88	33.01	34.35
May	29.17	25.58	25.26	32.6	23.32	23.83	27.49	28.33
Jun	20.35	20.3	16.81	21.79	18.8	16.21	19.29	21.42
Jul	16.94	15.32	15.05	17.2	13.29	13.61	13.91	17.09
Aug	15.15	14.74	14.92	14.2	13.35	13.21	12.86	16.67
Sep	18.33	16.44	17.05	19.29	14.65	15.86	17.04	20.29
Oct	31.8	30.14	29.73	33.94	27.17	29.19	30.1	34
Nov	52.72	48.86	48.32	56.64	46.59	47.7	49.56	53.5
Dec	60.61	55.85	55.62	65.7	54.11	53.08	56.89	61.44
Monthly Relative Humidity for the SSP2:4.5 Scenario (2040 - 2059) %								
Jan	36.19	36.76	33.92	32.45	31.79	31.14	34.03	36.4
Feb	59.82	59.57	55.19	52.69	52.21	50.52	55.55	59.6
Mar	52.64	50.81	47.13	44.86	44.39	42.55	47.6	51.74

Apr	42.45	40.63	36.86	35.02	34.52	33.8	36.9	40.4
May	35.17	34.51	30.69	29.17	28.51	27.94	30.4	32.35
Jun	29.05	30.32	26.83	25.3	24.41	24.24	26.62	28.23
Jul	19.25	20.5	19.25	18.2	16.67	16.71	19.48	21.06
Aug	14.85	17.15	15.3	14.8	13.02	13.91	15.44	16.56
Sep	15.31	16.86	15.74	16.36	13.99	15.22	16.23	18.23
Oct	17.17	18.18	16.75	16.99	15.03	16.43	17.89	19.86
Nov	32.62	33.7	29.86	31	28.45	29.79	31.58	35.21
Dec	51.88	52	48.74	48.53	46.95	47.73	50.34	52.68

Appendix-A3

Table A3.1: Coefficients crops and maximum crop heights (Allen et al., 1998)

Crop	Kc-ini	Kc-mid	Kc-end	Maximum Crop Height (m)
Barley	0.3	1.15	0.25	1
Broad Bean	0.5	1.15	1.1	0.8
Cabbage	0.7	1.05	0.95	0.4
Cauliflower	0.7	1.05	0.95	0.4
kidney Beans	0.5	1.05	0.9	0.4
onion	0.7	1.05	0.75	0.3
potato(spring)	0.5	1.15	0.75	0.6
wheat	0.7	1.15	0.25	1
cotton	0.35	1.2	0.6	1.5
cucumber	0.6	1	0.75	0.3
eggplant	0.6	1.05	0.9	0.8
groundnut	0.4	1.15	0.6	0.4
Maize(spring)	0.7	1.2	0.6	2
Okra	0.4	1	0.9	2
sweet pepper	0.6	1.05	0.9	0.7
Rise	1.1	1.2	1.05	1
sesame	0.35	1.1	0.25	1
sorghum	0.3	1	0.55	2
soya bean	0.4	1.15	0.5	1
sunflower	0.35	1.15	0.35	2
tomato	0.6	1.15	0.7	0
tobacco	0.5	1.15	0.8	1.2
watermelon	0.4	1	0.75	0.4
alfalfa	0.4	1.2	1.15	0.7
citrus	0.7	0.65	0.7	4
date palm	0.9	0.95	0.95	8
Grape	0.3	0.85	0.45	2
Olives	0.65	0.7	0.7	5
sugarcane	0.4	1.25	0.75	3
pomegranate	0.6	0.95	0.75	3
stone fruit trees	0.4	0.9	0.65	3
green gram	0.5	1.05	0.9	0.4

Table A3.2: Lengths of crop development stages for various planting periods (days) (Allen et al., 1998)

Crop	initial	development	Midseason	late season	total
Barley	24	55	73	48.48	202
Berseem	46	69	69	45.8	229
Broad Bean	84	43	38	0	165
Cabbage	52	78	65	19.53	217
Cauliflower	41	59	48	18.15	165
kidney Beans	16	27	27	10.53	81
onion	25	43	132	53.13	253
potato	28	33	33	32.76	126
wheat	21	63	74	32.3	190
cotton	23	39	47	42	150
cucumber	21	30	42	16.5	110
eggplant	25	38	34	21.24	118
groundnut	44	56	44	31.5	175
Mung bean	19	43	29	18.7	110
Maize	23	36	40	26.25	125
Okra	22	30	83	22.4	160
sweet pepper	20	29	38	28.75	115
Rise	19	38	42	18.88	118
sesame	21	39	50	32.89	143
sorghum	20	30	60	25.84	136
soya bean	27	36	52	26.6	140
sunflower	29	39	39	24.7	130
tomato	30	25	35	25.3	115
tobacco	17	33	33	49.4	130
watermelon	21	41	41	20.91	123
alfalfa	all seasons	all seasons	all seasons	all seasons	all seasons
citrus	all seasons	all seasons	all seasons	all seasons	all seasons
date palm	all seasons	all seasons	all seasons	all seasons	all seasons
Grape	all seasons	all seasons	all seasons	all seasons	all seasons
Olives	all seasons	all seasons	all seasons	all seasons	all seasons
pomegranate	all seasons	all seasons	all seasons	all seasons	all seasons
stone fruit trees	all seasons	all seasons	all seasons	all seasons	all seasons

Table A3.3: Irrigated area for 28 Projects (JICA,2016)

ID	Project Name	Gouvernante	Total Area (Hectar)
1	Small farms to Haditha dam	Anbar	14750
2	Small farms from the Haditha dam up to the boundary of the Ramadi project	Anbar	11750
3	Ramadi-Habbaniyah	Anbar	33750
4	Faluja-amreah	Anbar/Baghdad	14000
5	Saqlawiyah	Anbar/Baghdad	35000
6	Abu-Ghraib	Anbar/Baghdad	51500
7	Radhwaniyah	Baghdad	7000
8	Yousifia	Baghdad	31250
9	Latifia	Baghdad/Babil	27000
10	Iskandariyah	Baghdad/Babil	12750
11	Faluja Al-Muahada	Anbar/Baghdad/Babil	13500
12	Small farms from the boundary of the Anbar Muhafadha up to the Hindiyah barrage	Babil	6250
13	Jarf Al Sakhr & Ruwaiyah	Anbar/Baghdad/Babil/Karbala	9500
14	Greater Mussaiyab	Babil	77500
15	Husainaia	Babil/Karbala	25500
16	Bani – Hasan	Babil/Karbala/Najaf	36250
17	Small farms from the Hindiyah barrage up to Kifil	Muthana	1000
18	Iskandariyah - Mehaweel & Gadwel AlNasir	Babil	45500
19	Hilla-Hashimiyah	Babil	60000
20	Hurriyah-Dahgharah	Babil/Diwaniyah	158750
21	Hilla-Diwaniah	Babil/Diwaniyah/Najaf	70500
22	Diwaniah-Shafi'iyah	Diwaniyah/Muthana	95000
23	Rumaitha	Muthana	36000
24	Hilla – Kifil	Babil/Karbala/Najaf	43250
25	Kifil – Shnafiyah	Babil/Diwaniyah/Najaf	123500
26	Muthanna	Muthana	10250
27	Shnafiyah - Nasiriya	Diwaniyah/Thi-Qar/Muthana	65000
28	Suq Al Shoyokh	Thi-Qar	18750

Table A3.4: Hydraulic information of Haditha Dam (After Li et al.,2018).

	Unit	
Location of Haditha dam		34º 12′ 25" N 42º 21' 18" E
Dam Dimensions		
Dam height	m	57
Length	m	9000
Hydraulic Information's		
Type of Turbines		Vertical Kablan
Number of unite		6
Install capacity	Mw	6 × 110 = 660
Length of unit	m	67.35
Flood level	m	150.2
Maximum drawdown in upstream water level	m	129
Downstream water level	m	107.3
Maximum powerhouse discharge	m^3/s	6 × 339 = 2034

Table A3.5: Hydraulic data of Haditha powerhouse turbine (After Li et al.,2018).

No.	U/S.W. L (m)	Net Head (m)	N_{QE}	Q(m^3/s)	$V_{e\ inlet}$ (m/s)	N (rad/s)
Haditha Turbine						
1	129	18.5	0.6779	100	1.5038	3.3520
2	134.3	25.5	0.5800	118	1.7744	3.3586
3	139.6	32.5	0.5155	136	2.0451	3.3353
4	144.9	39.5	0.4689	151	2.2707	3.3326
5	150.2	46.5	0.4331	169.5	2.5489	3.2839

Appendix-B1

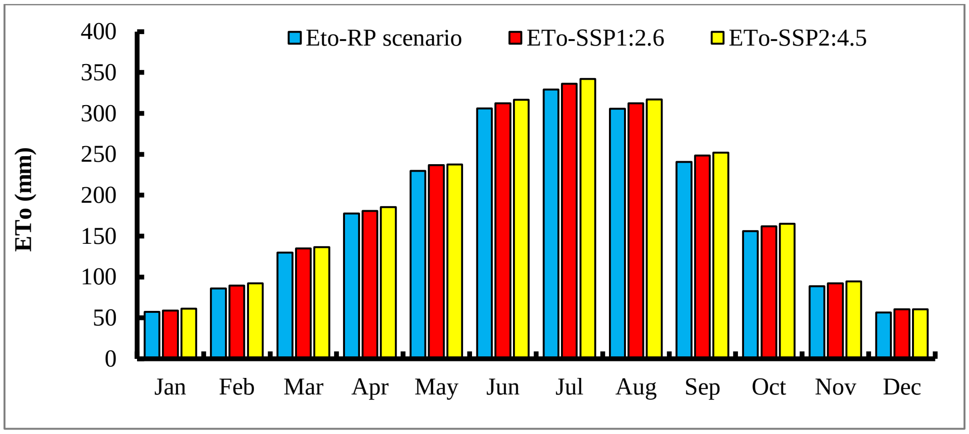

Figure B1.1: Estimated ETo for Baghdad province.

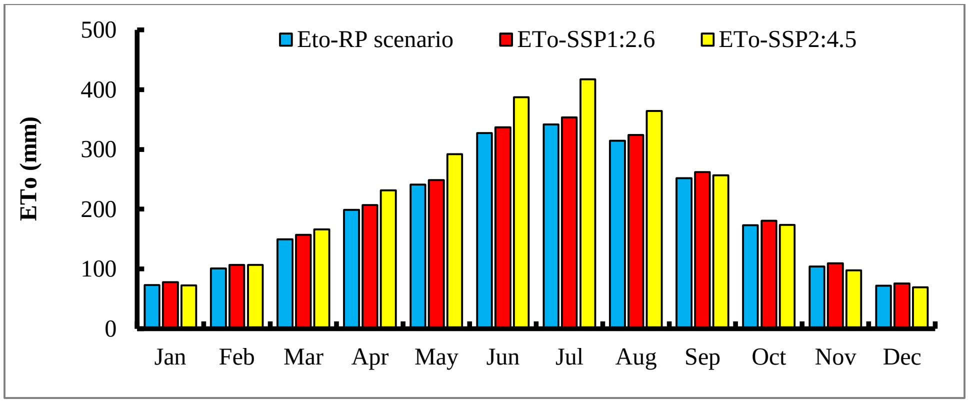

Figure B1.2: Estimated ETo for Diwaniyah province.

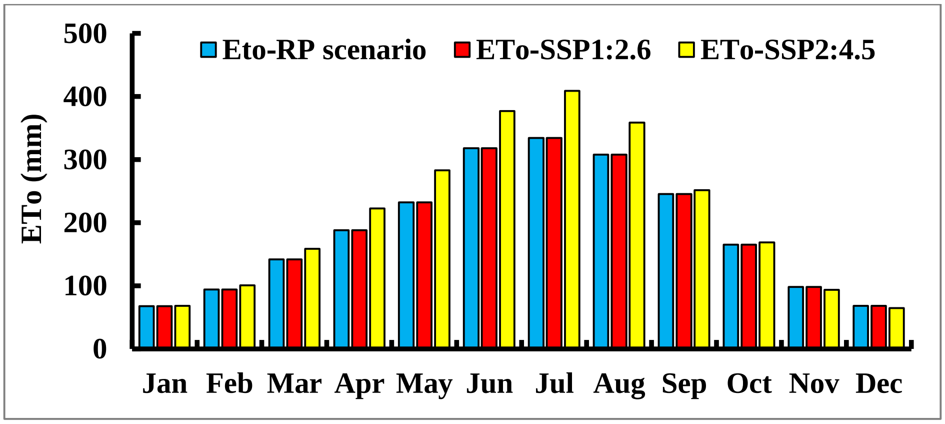

Figure B1.3: Estimated ETo for Karbala province

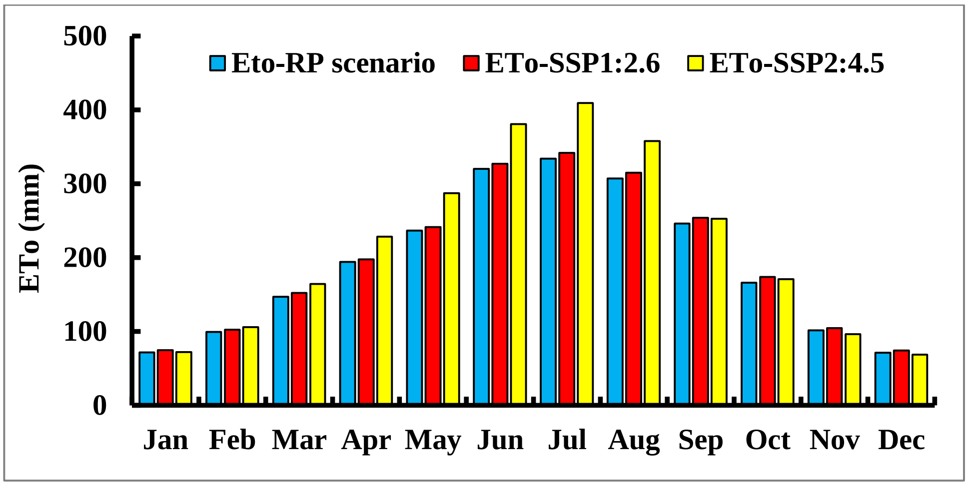

Figure B1.4: Estimated ETo for Najaf Province

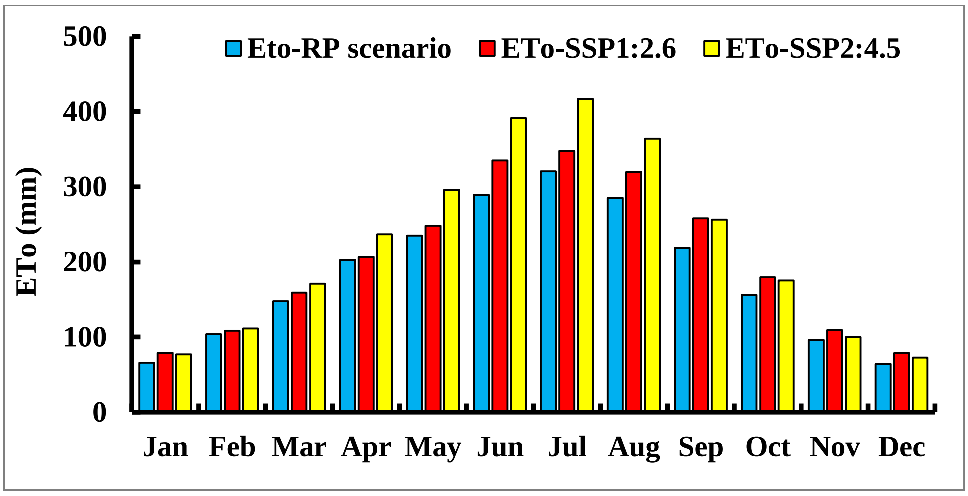

Figure B1.5: Estimated ETo for Muthanna province

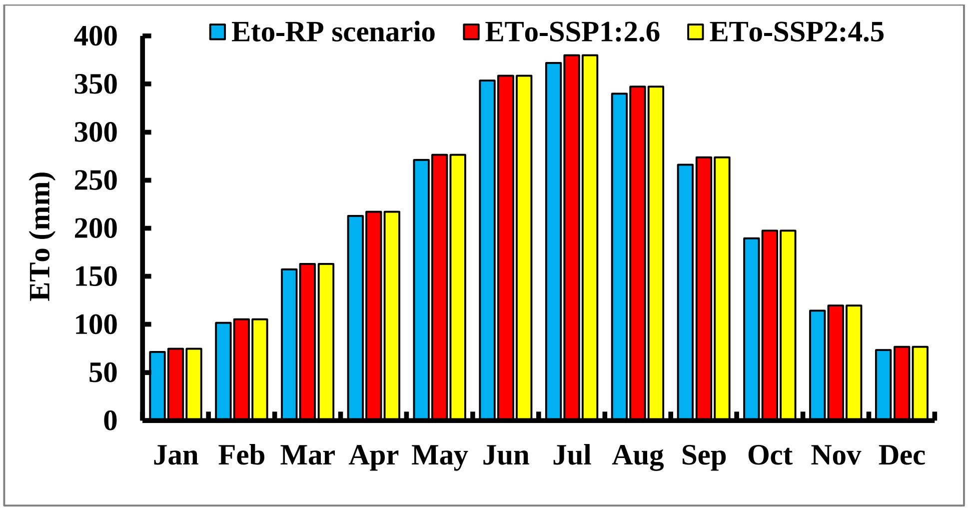

Figure B1.6: Estimated ETo for Thi-Qar Province

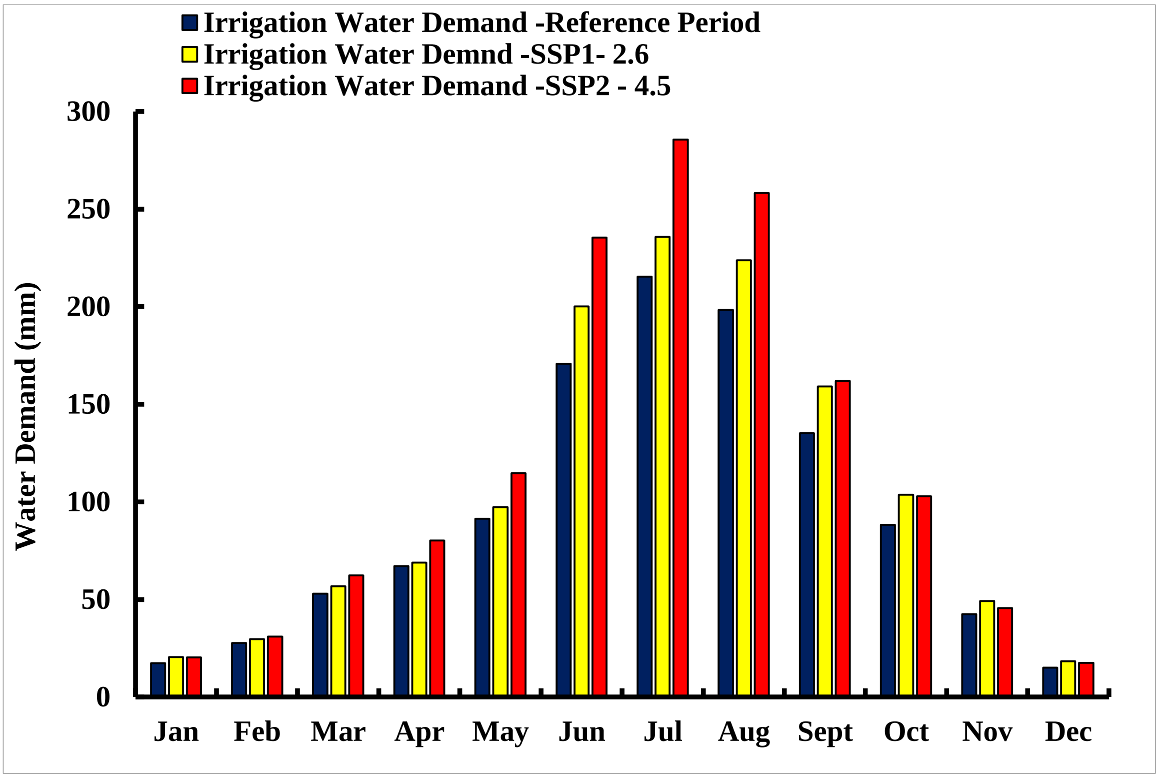

Figure B1.7: Estimated irrigation water demand for Muthanna Province

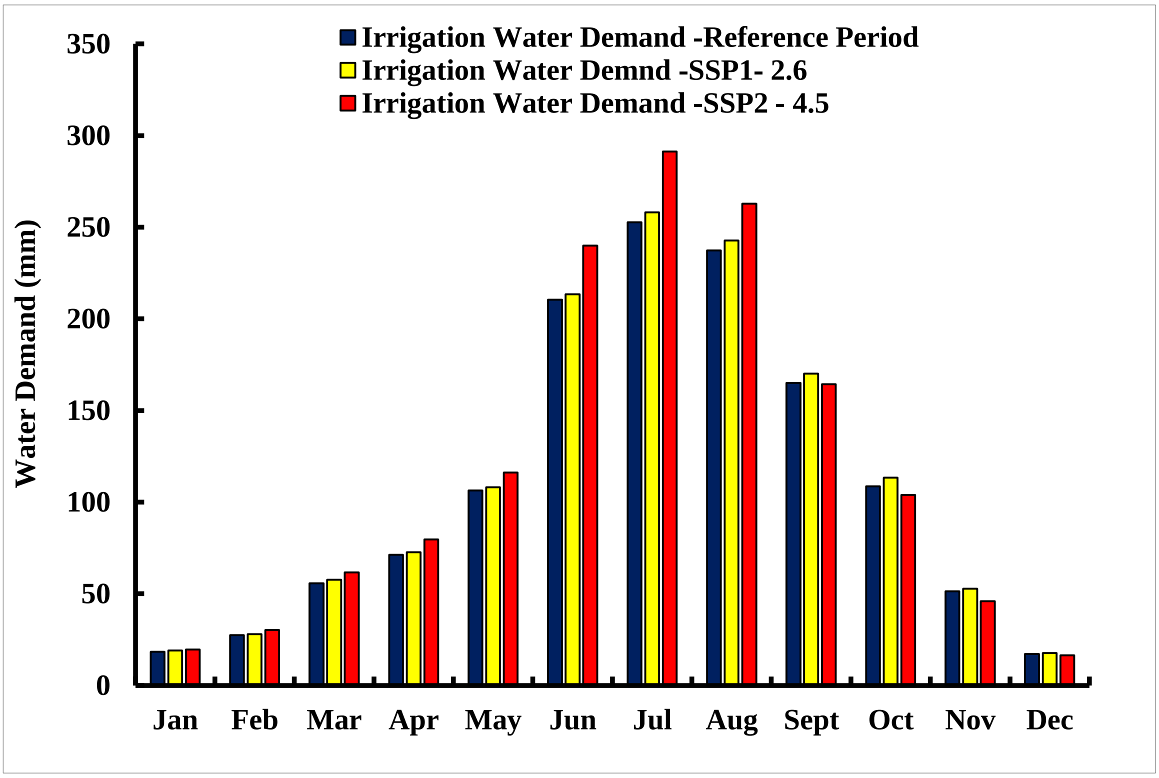

Figure B1.8: Estimated irrigation water demand for Thi-Qar Province

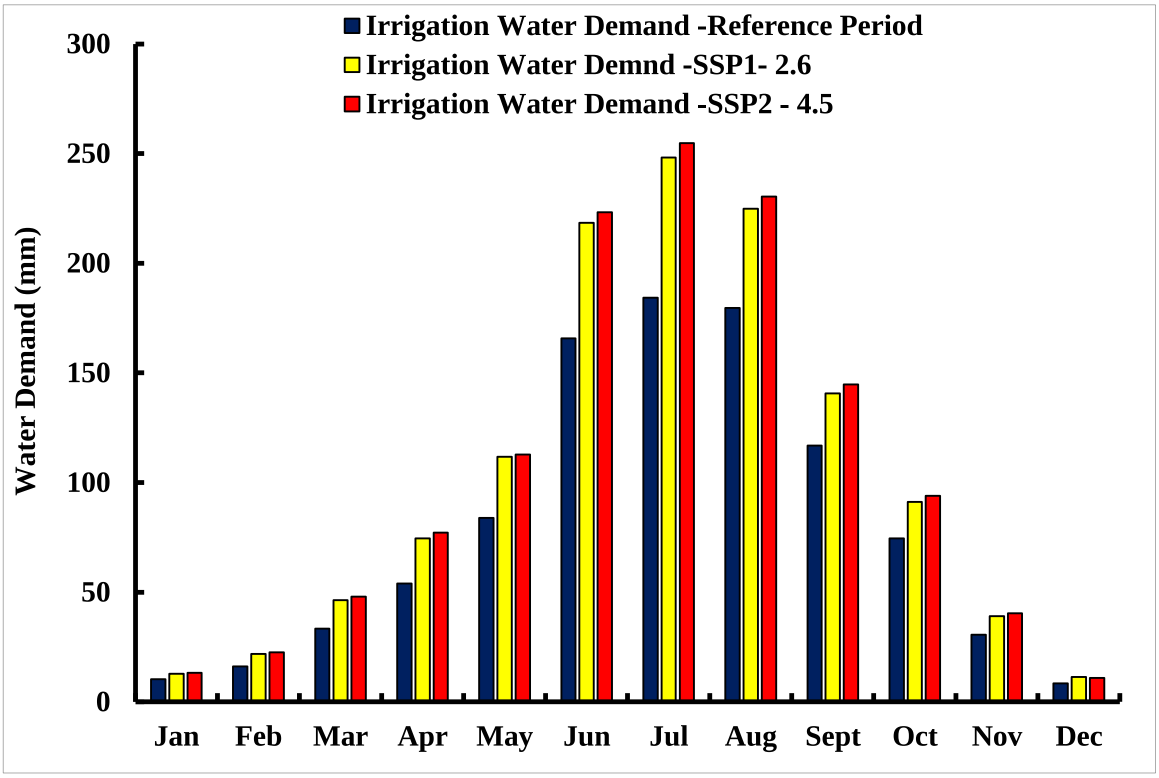

Figure B1.9: Estimated irrigation water demand for Najaf Province

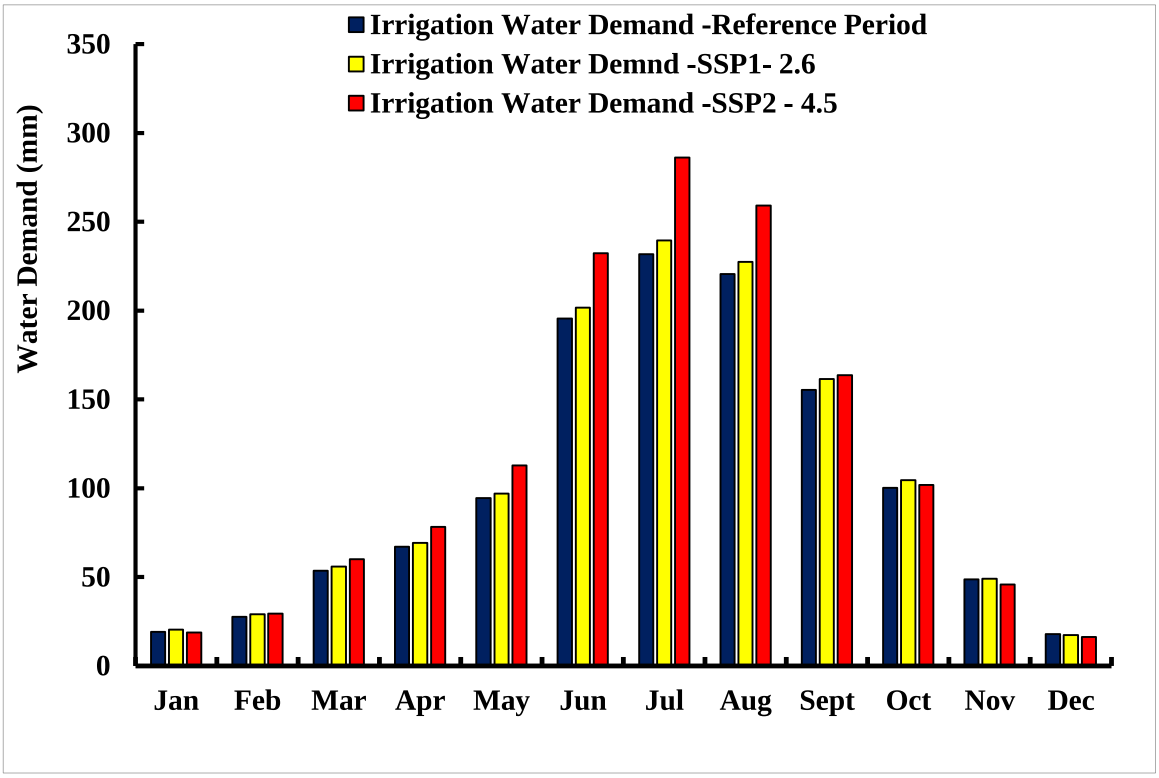

Figure B1.10: Estimated irrigation water demand of Diwaniyah Province

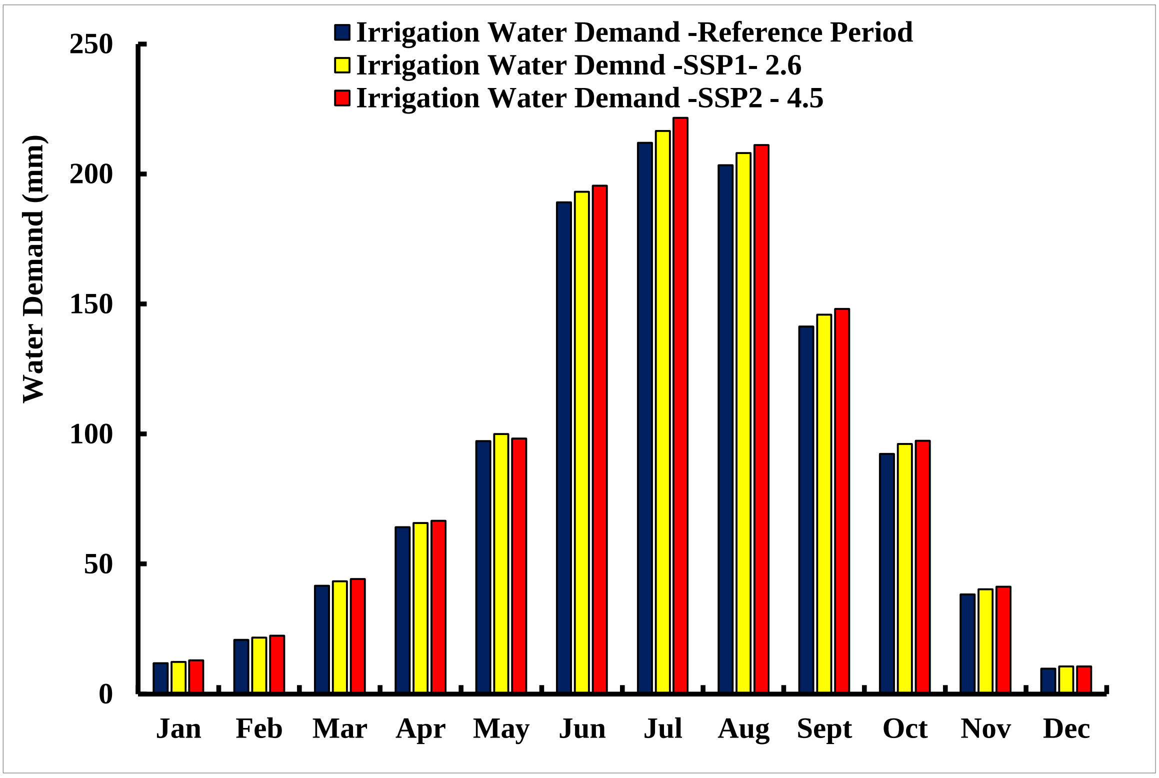

Figure B1.11: Estimated irrigation water demand of Baghdad Province

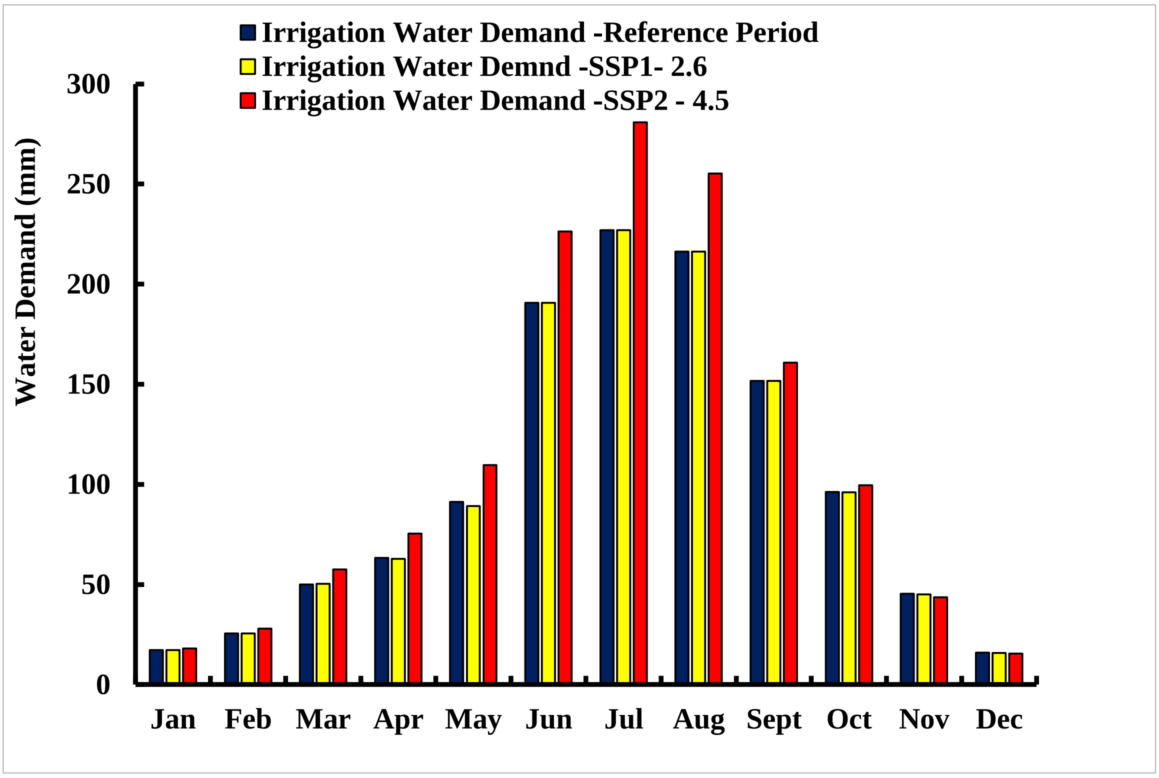

Figure B1.12: Estimated irrigation water demand of Karbala

Appendix-C1

Codes of Haditha Reservoir

```
Sub Hadithacode()
If Range("C3").Value = 1 Then
Range("D3").Value = "=4340+O3-P3+Q3-T3"
End If
If Range("C4").Value > 1 Then
Range("D4").Value = "=I3+O4-P4+Q4-K3"
End If
Range("D4:D446").FillDown
For C = 3 To 446
If Cells(C, "D") <= 10000 And Cells(C, "D") >= 530 Then
Cells(C, "E") = Cells(C, "D")
ElseIf Cells(C, "D") > 10000 Then Cells(C, "E") = 10000
ElseIf Cells(C, "D") < 530 Then Cells(C, "E") = 530
End If
Next C
If Range("C3").Value = 1 Then
Range("F3").Value = "=4340+O3+Q3-P3-E3"
End If
If Range("C4").Value > 1 Then
Range("F4").Value = "=I3+O4-P4+Q4-E4"
End If
Range("F4:F446").FillDown
For C = 3 To 446
If Cells(C, "F") <= 0 Then
Cells(C, "G") = Cells(C, "T")
```

```
Else
Cells(C, "G") = Cells(C, "T")
End If
Next C
If Range("C3").Value = 1 Then
Range("H3").Value = "=4340+O3-P3+Q3-T3"
End If
If Range("C4").Value > 1 Then
Range("H4").Value = "=I3+O4-P4+Q4-G4"
End If
Range("H4:H446").FillDown
For C = 3 To 446
If Cells(C, "H") <= 10000 And Cells(C, "H") >= 530 Then
Cells(C, "I") = Cells(C, "H")
ElseIf Cells(C, "H") > 10000 Then Cells(C, "I") = 10000
ElseIf Cells(C, "H") < 530 Then Cells(C, "I") = 530
End If
Next C
If Range("C3").Value = 1 Then
Range("J3").Value = "=4340+O3+Q3-P3-I3"
End If
If Range("C4").Value > 1 Then
Range("J4").Value = "=I3+O4-P4+Q4-I4"
End If
Range("J4:J446").FillDown
For C = 3 To 446
If Cells(C, "J") <= 0 Then
Cells(C, "K") = Cells(C, "T")
Else
```

```
Cells(C, "K") = Cells(C, "T")
End If
Next C
For C = 3 To 446
If Cells(C, "L") > 1500 Then
Cells(C, "M") = 0
Else
Cells(C, "M") = Cells(C, "K")
End If
Next C
For C = 3 To 446
If Cells(C, "M") <= 0 Then
Cells(C, "N") = 0
Else
Cells(C, "N") = Cells(C, "T")
End If
Next C
For C = 3 To 446
If Cells(C, "H") <= 530 Then
Cells(C, "U") = Cells(C, "H") - 530
Else
Cells(C, "U") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "H") > 10000 Then
Cells(C, "V") = Cells(C, "H") - 10000
Else
Cells(C, "V") = 0
```

```
End If
Next C

For C = 3 To 446
If Cells(C, "J") < Cells(C, "T") Then
Cells(C, "W") = Cells(C, "J") - Cells(C, "T")
Else
Cells(C, "W") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "J") >= Cells(C, "T") Then
Cells(C, "X") = Cells(C, "J") - Cells(C, "T")
Else
Cells(C, "X") = 0
End If
Next C
End Sub
```

Codes of Tharthar Reservoir

```
Sub Tharthar code()
If Range("C3").Value = 1 Then
Range("D3").Value = "=47303+O3-P3+Q3-R3"
End If
If Range("C4").Value > 1 Then
Range("D4").Value = "=D3+O4-P4+Q4-F3"
End If
Range("D4:D446").FillDown
For C = 3 To 446
If Cells(C, "D") <= 85000 And Cells(C, "D") >= 0 Then
Cells(C, "E") = Cells(C, "D")
ElseIf Cells(C, "D") > 85000 Then Cells(C, "E") = 85000
ElseIf Cells(C, "D") < 0 Then Cells(C, "E") = 0
End If
Next C
If Range("C3").Value = 1 Then
Range("F3").Value = "=47303+O3+Q3-P3-E3"
End If
If Range("C4").Value > 1 Then
Range("F4").Value = "=E3+O4-P4+Q4-E4"
End If
Range("F4:F446").FillDown
For C = 3 To 446
If Cells(C, "F") <= 0 Then
Cells(C, "G") = 0
Else
Cells(C, "G") = Cells(C, "R")
End If
```

```
Next C
If Range("C3").Value = 1 Then
Range("H3").Value = "=47303+O3-P3+Q3-G3"
End If
If Range("C4").Value > 1 Then
Range("H4").Value = "=I3+O4-P4+Q4-G4"
End If
Range("H4:H446").FillDown
For C = 3 To 446
If Cells(C, "H") <= 85000 And Cells(C, "H") >= 0 Then
Cells(C, "I") = Cells(C, "H")
ElseIf Cells(C, "H") > 85000 Then Cells(C, "I") = 85000
ElseIf Cells(C, "H") < 0 Then Cells(C, "I") = 0
End If
Next C
If Range("C3").Value = 1 Then
Range("J3").Value = "=47303+O3+Q3-P3-I3"
End If
If Range("C4").Value > 1 Then
Range("J4").Value = "=I3+O4-P4+Q4-I4"
End If
Range("J4:J446").FillDown
For C = 3 To 446
If Cells(C, "J") <= 0 Then
Cells(C, "K") = 0
Else
Cells(C, "K") = Cells(C, "R")
End If
Next C
```

```
For C = 3 To 446
If Cells(C, "L") > 1250 Then
Cells(C, "M") = 0
Else
Cells(C, "M") = Cells(C, "K")
End If
Next C
For C = 3 To 446
If Cells(C, "M") <= 0 Then
Cells(C, "N") = 0
Else
Cells(C, "N") = Cells(C, "R")
End If
Next C
For C = 3 To 446
If Cells(C, "H") <= 0 Then
Cells(C, "S") = Cells(C, "H") - 0
Else
Cells(C, "S") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "H") > 85000 Then
Cells(C, "T") = Cells(C, "H") - 85000
Else
Cells(C, "T") = 0
End If
Next C
For C = 3 To 446
```

```
If Cells(C, "J") < Cells(C, "R") Then
Cells(C, "U") = Cells(C, "J") - Cells(C, "R")
Else
Cells(C, "U") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "J") >= Cells(C, "R") Then
Cells(C, "V") = Cells(C, "J") - Cells(C, "R")
Else
Cells(C, "V") = 0
End If
Next C
End Sub
```

Codes of Habbaniyah Reservoir

```
Sub Habbaniyahcode()
If Range("C3").Value = 1 Then
Range("D3").Value = "=1477.7+O3-P3+Q3-R3"
End If
If Range("C4").Value > 1 Then
Range("D4").Value = "=D3+O4-P4+Q4-F3"
End If
Range("D4:D446").FillDown
For C = 3 To 446
If Cells(C, "D") <= 3300 And Cells(C, "D") >= 740 Then
Cells(C, "E") = Cells(C, "D")
ElseIf Cells(C, "D") > 3300 Then Cells(C, "E") = 3300
ElseIf Cells(C, "D") < 740 Then Cells(C, "E") = 740
End If
Next C
If Range("C3").Value = 1 Then
Range("F3").Value = "=1477.7+O3+Q3-P3-E3"
End If
If Range("C4").Value > 1 Then
Range("F4").Value = "=E3+O4-P4+Q4-E4"
End If
Range("F4:F446").FillDown
For C = 3 To 446
If Cells(C, "F") <= 0 Then
```

```
Cells(C, "G") = 0
Else
Cells(C, "G") = Cells(C, "R")
End If
Next C
If Range("C3").Value = 1 Then
Range("H3").Value = "=1477.7+O3-P3+Q3-G3"
End If
If Range("C4").Value > 1 Then
Range("H4").Value = "=I3+O4-P4+Q4-G4"
End If
Range("H4:H446").FillDown
For C = 3 To 446
If Cells(C, "H") <= 3300 And Cells(C, "H") >= 740 Then
Cells(C, "I") = Cells(C, "H")
ElseIf Cells(C, "H") > 3300 Then Cells(C, "I") = 3300
ElseIf Cells(C, "H") < 740 Then Cells(C, "I") = 740
End If
Next C
If Range("C3").Value = 1 Then
Range("J3").Value = "=1477.7+O3+Q3-P3-I3"
End If
If Range("C4").Value > 1 Then
Range("J4").Value = "=I3+O4-P4+Q4-I4"
End If
```

```
Range("J4:J446").FillDown
For C = 3 To 446
If Cells(C, "J") <= 0 Then
Cells(C, "K") = 0
Else
Cells(C, "K") = Cells(C, "R")
End If
Next C
For C = 3 To 446
If Cells(C, "L") > 1250 Then
Cells(C, "M") = 0
Else
Cells(C, "M") = Cells(C, "K")
End If
Next C
For C = 3 To 446
If Cells(C, "M") <= 0 Then
Cells(C, "N") = 0
Else
Cells(C, "N") = Cells(C, "R")
End If
Next C
For C = 3 To 446
If Cells(C, "H") <= 0 Then
Cells(C, "S") = Cells(C, "H") - 0
```

```
Else
Cells(C, "S") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "H") > 3300 Then
Cells(C, "T") = Cells(C, "H") - 3300
Else
Cells(C, "T") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "J") < Cells(C, "R") Then
Cells(C, "U") = Cells(C, "J") - Cells(C, "R")
Else
Cells(C, "U") = 0
End If
Next C
For C = 3 To 446
If Cells(C, "J") >= Cells(C, "R") Then
Cells(C, "V") = Cells(C, "J") - Cells(C, "R")
Else
Cells(C, "V") = 0
End If
Next C
```

References

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