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**THE EFFECT OF CLIMATE CHANGES ON WATER RESOURCES  
MANAGEMENT IN IRAQ (CASE STUDY: HADITHA  
RESERVOIR)**

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MANAGEMENT IN IRAQ (CASE STUDY: HADITHA RESERVOIR)

By Sundus Salah Fayyadh FAYYADH

June 2022

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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## ABSTRACT

### THE EFFECT OF CLIMATE CHANGES ON WATER RESOURCES MANAGEMENT IN IRAQ (CASE STUDY: HADITHA RESERVOIR)

Sundus Salah Fayyadh FAYYADH

Master of Science in Civil Engineering

Advisor: Assoc. Prof. Dr. Başak VARLI BİNGÖL

June 2022

Without water life is not possible on this earth, to progress economically and socially water is imperative. Iraq is one of the MENA (the Middle East and North African) countries, currently suffering from serious water scarcity. There are various factors that have contributed to Iraq's water shortage crisis, including shared countries' water policies. Climate change has accelerated in recent years, leading to water shortages due to changing weather patterns, such as droughts, rising pollution, and increasing human demand and usage of water. When the amount of potable and unpolluted water available in river reserves in an area falls below demand, ignoring sanitation systems and pouring rainwater directly into rivers causes pollution and deterioration of river quality, resulting in a water crisis. To address the current water scarcity, the current government should take action and develop a strategic water vision that includes regional cooperation and coordination, research and development, improving agriculture and sanitation, and a variety of public awareness programs to educate the general public. This study looks at the concept of vulnerability and its three characteristics (exposure and adaptive capacity) in the context of climate change and discusses adaptation and mitigation measures that should be considered to respond to climate change.

**2022, 45 pages**

**Keywords:** Climate changes, Reservoir management, Water resources, Hydrologic modeling, Haditha dam,

## ÖZET

# IRAK'TA İKLİM DEĞİŞİKLİKLERİNİN SU KAYNAKLARI YÖNETİMİ ÜZERİNE ETKİSİ (ÖRNEK İNCELEME: HADİTHA REZERVUARI)

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Su olmadan bu dünyada yaşam mümkün değildir, ekonomik ve sosyal olarak ilerlemek için su zorunludur. Irak, şu anda ciddi su kıtlığı çeken MENA (Orta Doğu ve Kuzey Afrika) ülkelerinden biridir. Komşu ülkelerin su politikaları da dahil olmak üzere Irak'ın su sıkıntısı krizine sebebiyet veren çeşitli faktörler vardır. Son yıllarda hızlanarak devam eden iklim değişikliği, kuraklık, artan kirlilik, nüfus artışı ve su kullanımı talebinin çoğalması gibi değişken koşullar su kıtlığına yol açmıştır. Bir bölgede mevcut olan nehir rezervlerinin içilebilir ve kirlenmemiş su miktarı, talebin altına düştüğünde, kanalizasyon sistemlerini göz ardı ederek, yağmur sularını doğrudan nehirlere dökmek, kirliliğe ve nehir kalitesinin bozulmasına neden olur, bu da bir su krizini meydana getirir. Mevcut su kıtlığını gidermek için hükümet harekete geçmeli ve bölgesel işbirliği ile koordinasyon, araştırma geliştirme, tarım ve sanitasyonun iyileştirilmesi ve genel halkı eğitmek için çeşitli kamu bilinci programlarını içeren stratejik bir su vizyonu geliştirmelidir. Bu çalışma, iklim değişikliği bağlamında kırılganlık kavramına ve üç özelliğine (maruz kalma ve uyum kapasitesi) bakmakta ve iklim değişikliğine yanıt vermek için dikkate alınması gereken uyum ve azaltma önlemlerini tartışmaktadır.

**2022, 45 sayfa**

**Anahtar Kelimeler:** İklim değişiklikleri, Rezervuar yönetimi, Su kaynakları, Hidrolojik modelleme, Haditha barajı

## **PREFACE AND ACKNOWLEDGEMENTS**

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**Sundus Salah Fayyadh FAYYADH**

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## LIST OF SYMBOLS

$^{\circ}\text{C}$	Degrees celsius
B	Unknown parameter
E	Average annual volume of Euphrates River
$e_i$	Error terms
f	Function
km	Kilometer
$\text{m}^3$	Cubic meter
R	Average annual volume of rainfall in Iraq
sec	Second
T	Average annual volume of Tigris River
$X_i$	Independent variable
$Y_i$	Dependent variable

## LIST OF ABBREVIATIONS

MENA	The middle east countries
NAO	The north atlantic oscillation
BCM	Billion cubic meters
MODIS	The moderate resolution imaging spectroradiometer
SIWI	Stockholm international water institute
TAWV	The total annual water volume



## LIST OF FIGURES

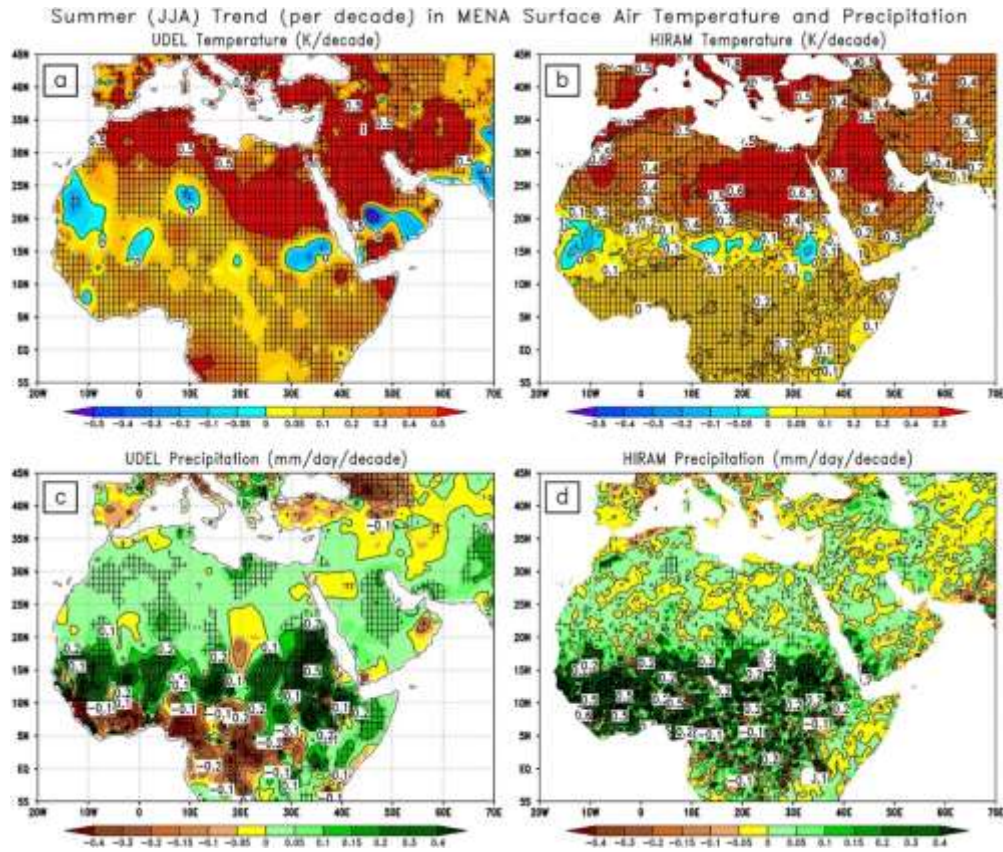
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## 1 INTRODUCTION

Many sociopolitical, economic, and environmental changes have resulted as a result of climate change around the world. As the first and most visible side consequence of climate change, water scarcity, Iraq may be the last country to understand the danger it poses to its own country. Considering the numerous challenges this country is facing, it may not appear to be a very significant or pressing matter. Climate change is rendering Iraq increasingly vulnerable to society, as it threatens water resources and, as a result, the environment and economy, notably in the agricultural sector.

The Middle East Countries (MENA) are considered to be at maximum risk of climate change with significant changes such as rising sea levels, water scarcity, aridity, unpredictable precipitation, and high temperature (Abbas *et al.* 2016).

Figure 1.1 in 2010 and 2018 high temperatures were recorded in 19 countries, among them the MENA region including Iraq (52.0°C), Kuwait (52.6°C), Qatar (50.4°C), Sudan (49.7°C), and Arabia (52.0°C) was at the top.



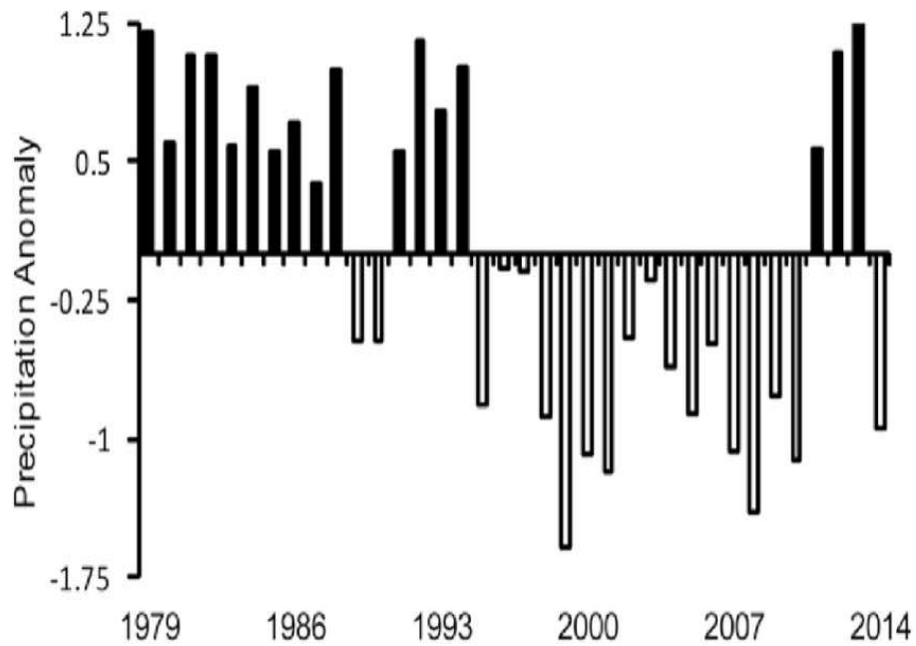
**Figure 1.1** MEAN temperature (El-Samra *et al.* 2018)

One of the major reasons for countries existing in the MENA region to be arid is the very fact that annual rainfall is quite less here, The lack of annual rainfall in the Arab world, with maximum levels of (166 mm), and lower volumes of water flowing from upstream to downstream countries have contributed to the strategic relevance of the Arab world's water scarcity due to its significant economic and development impact. Per maestros, things are already going to worsen in the future and major shortages will be realized both in surface and groundwater resources. Rainfall has decreased, rivers that once used to be the primary source of are getting dried up, and variations in the atmospheric pressure have caused the Tigris and Euphrates rivers to start drying up.

The currents and storm activities in the Mediterranean Sea will also continue to decrease if global warming stays prevalent according to the North Atlantic Oscillation (NAO) pattern (Abdullah 2012) For example, the Greater Zab River present in the

northern region of Iraq is the primary source of water supply and irrigation for the people living in those regions.

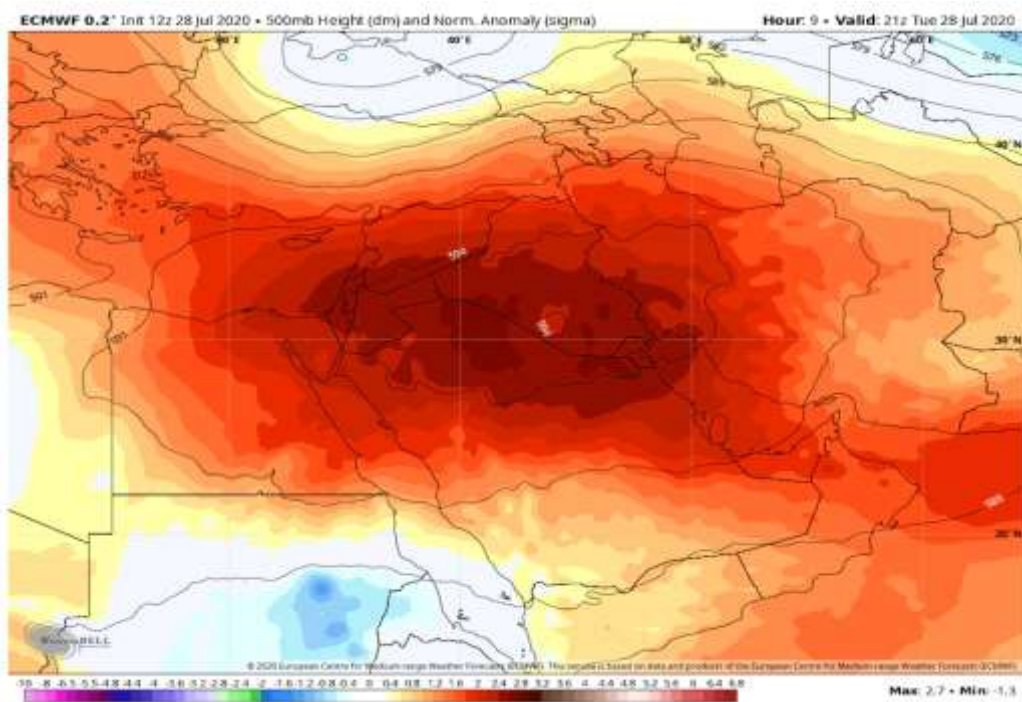
Figure 1.2 The temporal the precipitation over the Upper Zab River Basin during the period between 1979 and 2014



**Figure 1.2** Climate variability impact (Mohammed and Scholz 2019)

It is studied that a change in the precipitation and temperature throughout the world has caused changes in the runoff and water availability across different countries. If there is minimal to no rainfall taking place throughout the year in that region, the river could end up drying eventually leading to a water shortage. Especially, if observed in the Middle East, rainfall has decreased significantly eventually causing problems of water shortage in these countries. It is also observed how the Middle East is prone to be one of the most vulnerable areas in the world to the potential effect of climate change in the future. See the figure below to get more clarity on the temperature effect. It is pivotal to mention here; that till 1970, Iraq never felt an insufficiency of water, thanks to the presence of the Tigris and Euphrates rivers.

Several studies predict how the decreased rainfall and rising temperatures across different cities in the country are already causing larger damage than expected. Higher temperatures in the Middle East are already causing an increase in sea levels and droughts across most countries. The included calamities due to rising temperatures include flooding, droughts, intense cyclones, increase in sea levels, and an increase in waterborne diseases but none of this contributes well to the water shortage that Iraq is already facing. The two rivers that are the primary water security for Iraq – Tigris and Euphrates have been declining extensively as the years pass by. (Figure 1.3)



**Figure 1.3** High pressure brought extreme temperatures to Iraq

There have been some constructions done in Iraq to increase the water flow such as dams and reservoirs to help in preventing any water shortage possible in the country although it is not working very well due to the increasingly high temperatures still prevalent in the Middle East.

The primary goal of recent infrastructure projects in Iraq has been to organize river flow to avoid massive flooding, produce electricity, and irrigation. However, as innovation

and life progressed, water demands increased, and neighboring countries joined in by establishing massive water projects, negatively impacting Iraq's sourced water levels. As a result, the Euphrates experienced a severe reduction in water flow. In addition, the quality of the water has degraded significantly. This drop in quality added to the alarm and necessitated fast action to address the problem. While Iraq has struggled with internal conflicts and external wars for decades, Turkey has constructed multiple dams and water reservoirs on the massive Tigris and Euphrates rivers. Despite all these problems, very little work has been done (Issa *et al.* 2014) to determine detailed future expectations of river flows in the region. The fundamental motive of this study is to comprehend the evaporation losses that have occurred in the dam during the time frame from 1985 to 2015 due to climatic changes. During these years, the reservoir experienced significant water losses as a result of evaporation (Raphaeli 2009).

As a result, the dam shrank significantly, prompting the development of newer methods to avoid deprivation. Its goal in the next years is to examine the existing water status and make an effort to address the causes of water scarcity and disaster. As you may have noticed, dams and lakes are required to regulate the river in large areas. Rain is the primary source of irrigation for three-quarters of agricultural lands, despite changes in rainfall levels from one part of Iraq to the next and from one year to the next. As a result, the Iraqi government had to keep up with the progress. The government's job is to ensure that the adaptation measures are successful. Crop rotation, soil conservation, irrigation, and crop rotation are all examples of farm-position adaptation.



border of Iraq, the Euphrates flows 1000 km and the river Tigris flows 1300 km (Figure 2.2)



**Figure 2.2** Tigris and Euphrates rivers (Yilmaz and Imteaz 2011)

Iraq's surface water is largely contributed by these two rivers, about 98%. In addition, the annual streaming of both the rivers is about 80 to 84.2 BCM (billion cubic meters), out of which 65.7 BCM originates from Turkey, 0.5 BCM from Syria, 11.2 BCM from Iran, and 6.8 BCM from Iraq. This shows that Turkey has 80% control over the water of the Euphrates and Tigris River. As mentioned earlier, Tigris and Euphrates are the major and primary river sources for Iraq, and they are drying up quickly.

These two rivers stream and flow right into the areas where climate change is affecting the most which eventually leads to a decrease in the natural streamflow. Climate change can also be categorized by the continuous pollution of these two rivers due to the

increasing usage of fertilizers, industrial waste, domestic waste, and sewage waste without having any proper treatments in place for the sanitization of the rivers. It can be observed very evidently how water is becoming a scarce and threatened commodity in the regions of Iraq due to the continuous human misuse and climate change aftereffects.

As a result, you can observe changes in the soil properties such as the decrease in the soil water, leaching loss, cut down through lowering soil moisture, and in the regions that experience more than expected rains which cause flooding leading to soil erosion, and loss of the fertile properties of the soil. According to a study, the precipitation and streamflow in regions of Iraq and Syria can be termed the – “Fertile Crescent”.

This study shows us how over the years and in the coming years, the precipitation and stream flows will reduce by a maximum showing an end in the water resources for the Middle East. This can cause the Fertile Crescent to lose its original shape and disappear altogether. Iraq has been observed as the country with the worst irrigation and water storage practices. Due to these two major underlying issues, scientists have predicted the marshes to at least remain their typical size if they do not manage to disappear altogether like the rivers in the country. Considering the factors of the reduced precipitation, drying up of the Tigris and Euphrates rivers, decreasing production land, and poor irrigation practices, it is expected Iraq to become a barren land with extensive deserts spread across.

### **2.1.1 River tigris**

The Tigris River, sometimes known as the Euphrates, is located in southeastern Turkey, primarily on the southern slopes of the Taurus mountain range. It drains an area of 472,606 km<sup>2</sup> and is shared by Turkey, Syria, and Iraq, respectively. The river's overall length is believed to be around 1718 kilometers. A crucial piece of information: the river Tigris is known to mingle with tributaries in the shape of Butman Su, Karzan, and Razuk before it reaches the Turkish/Iraqi border.

Whilst the annual flow of the river at no point goes beyond the range of 64 m<sup>3</sup>/sec, it tremendously augments to 413 m<sup>3</sup>/sec. as it reaches Razuk. Moreover, this water flow paves the way into Iraq at Fiesh Khabur wherein the Khabur tributary is known to integrate into the main river. Talking about the mean annual flow of Khabur, it is somewhere near 68 m<sup>3</sup>/sec. Further, this flow continues driving towards the south to reach the first city by the moniker Mosul. Interestingly, the mean discharge here reaches a surprising figure of 630 m<sup>3</sup>/sec. (Al-Ansari 2016).

Going forward, the Greater Zab River mingles with the Tigris at a distance of around 60 kilometers south of Mosul. This confluence is exactly midway between Mosul and Sharkat cities. Further towards the south, the lesser Zab tributary is known to join the Tigris at Fatha. The enlightenment part is acclaimed to drain an area of approximately 21.476 km<sup>2</sup>. 227 m<sup>3</sup>/sec is the average annual flow. The total annual flow as a result of confluence, on the other hand, is 1340 m<sup>3</sup>/sec. The Tigris is joined by the popular tributary Adhaim in the south of Fatha. This tributary is credited with draining 13.000 square kilometers. The yearly flow is estimated to be 25.5 km<sup>3</sup> at this point. It's also worth noting that this tributary is completely dry from June to November each year. To continue, the final significant tributary, Diyala, is located further south.

Combines with the Tigris in the south of Baghdad. Primarily, this tributary drains an area of 31.846 kilometers/sq. out of which 20% of the share is reaped by the Iranian people. After this water flow reached south of Baghdad, there were no other tributary affiliates with the Tigris. Only a few canals are known to draw water from the river, which is majorly employed for irrigation purposes. Consequently, since no tributary joins hands here, it is the very reason for a significant fall in the annual flow of the river at Baghdad.

### **2.1.2 River euphrates**

his river boasts a length of 2781 kilometers in terms of longevity (Al-Ansari 2016). Further investigation reveals that the rivers Karah Su and Murad Su merge in the southeastern areas of Turkey, resulting in the formation of the Euphrates. Furthermore,

the river's water enters Syria at Jarabis and then travels approximately 675 kilometers to Iraq. The famous Sajor tributary is said to meet the Euphrates after going about 30 kilometers south of Jarabis.

The Balikh and Khabur tributaries eventually join the Euphrates' water flow, which then legally supersedes the Iraqi boundary at Hasaibah. The average yearly flow of the Euphrates is 909 meters at this point. (Al-Ansari 2016). Because of upstream development on the Tigris and Euphrates Rivers, water depletion in Iraq is predicted to worsen over time, reducing the amount of water entering Iraq from 75% to 27%. (Figure 2.3)

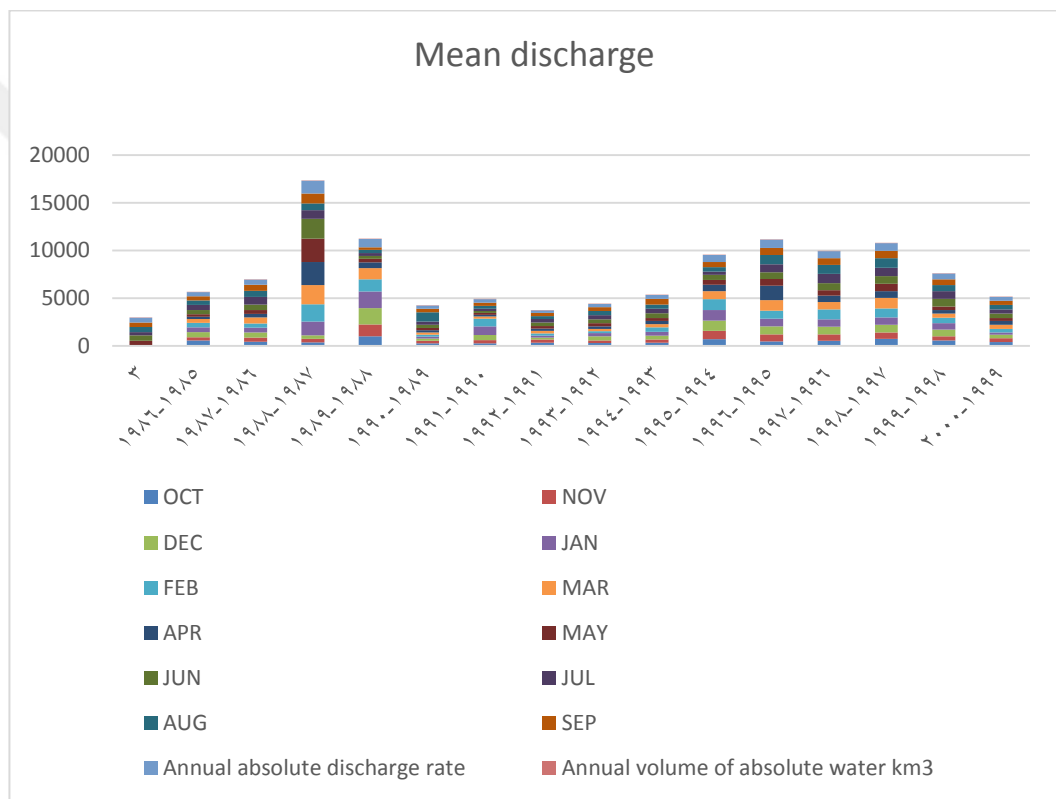
<b>Dam</b>	<b>Storage capacity ( km<sup>3</sup> )</b>	<b>Year of operation</b>
Forat	14.163	1978
Baath	0.09	1989
Teshreen	1.883	2000
<b>Total</b>	<b>16.135</b>	

**Figure 2.3** Dams of the river Euphrates in Syria (Al-Ansari 2016)

Here, some of the water is also distributed to the Habaniya reservoir when the water flow of the river tremendously increases just like during floods. Around 135 kilometers south of Faluja, there is a Hindiya barrage that is responsible for diverting the maximum discharge of the river to further smaller tributaries. To the south of Kifil, the river Euphrates further split into two main channels in the shape of Kufa and Shamiya. What's more, they amalgamate again at Mushkhab. This channel further bisects after progressing for about 25 kilometers south of Shanafiya to rejoin back at Simawa. Then this water enters the Hamar marsh to form additional channels within Hamar marsh.

One of these two channels has been known to team up with the Tigris river water flow at Qurna Orming and the other joins Shat Alarab River at Karma Ali. An important piece of information.

The Euphrates river mean discharge at Hit and Haditha cities till the year 1972 was close to 967 m<sup>3</sup>/sec, which has substantially decreased ever since then to reach the mark of 553 m<sup>3</sup>/sec after 1985. So, if we calculate this depreciation percentage-wise, the decrease is almost 43% (Figure 2.4)



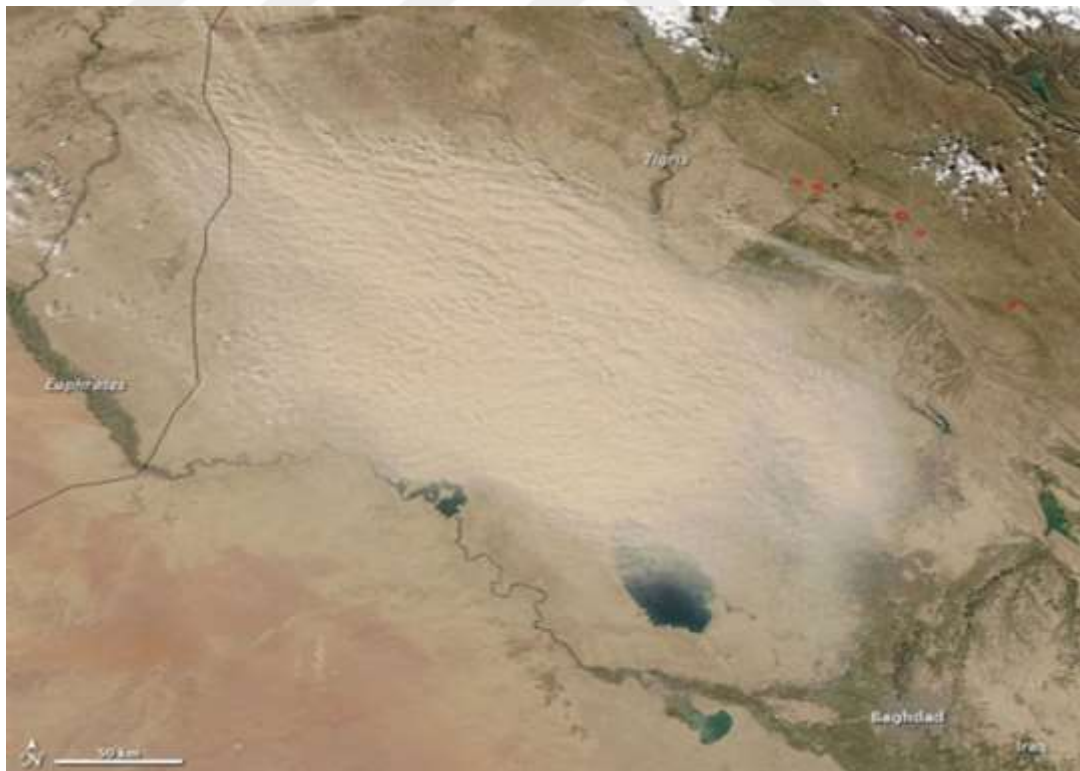
**Figure 2.4** Euphrates river mean discharge at Hit and Haditha cities from 1985 to 2000

### 2.1.3 Shatt al-arab river

The Shatt AL-Arab River, also known as Dijla AL-Awara, is formed by amalgamating the two rivers Euphrates and Tigris in southern Iraq (Sulaiman 2017). The river is 700 m near the city of Basra with the total width of the basin size being 884.000 km<sup>2</sup> and the length being 200 km. Additionally, there are myriad tributaries that join the Shatt AL-

Arab River namely the Karun and the Karkheh Rivers. The annual volumes of water runoff by the prominent four tributaries in Shatt AL-Arab River are Karun account for 24.5 BCM, the Karkheh contributes for 5.8 BCM, the Euphrates for 17.6 BCM, and the Tigris for 25.7 BCM. To add, for irrigation purposes in Iraq the ministry of water resources 2011 announced a plan to build a 129 km channel for water diversion from the Shatt AL-Arab River (Chenoweth *et al.* 2011).

It is predicted that the number can increase to 300 dusty days per year in the next ten years. According to the Global Climate Change Impact, a large part of the Iraqi territory has turned into a potential zone for the occurrence of either dust or sandstorms. Although these problems are huge and it can take years and years to reverse the effects. Figure 2.5 Aerial view of a dust storm. Note it had started just in the northwestern borders of Iraq (The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this natural-color image on March 3, 2011).



**Figure 2.5** Iraq dust storms in 2011 (Adamo *et al.* 2019)

As mentioned above, dust and sandstorms are also natural calamities experienced by Iraq more frequently than usual. This happens due to the obvious aridity present in the climate and the air. This can be seen according to the United Nation report, the country of Iraq has experienced at least 122 dust storms and 283 dusty days alone in 2012. there are a few solutions available that countries can adopt to start the reversal process.

The corrective measures that can be taken by the regional and local people of the country include the creation of wide and large green zones extensively across the country, afforestation of trees and shrubs across the barren land (make sure they have a high tendency towards moisture deficiency), stabilization of the dunes formed because of the sandstorms occurring frequently, practicing better irrigation methods and techniques, applying modern ways for conservation of water, etc.

#### **2.1.4 Iraq's dams**

Dam construction in Iraq dates back to the first half of the twentieth century. The primary motivation for this action was to protect the country's capital, Baghdad, as well as the country's other important cities, from the flood's effects. The first dam on the Lesser Zab River was completed in 1959, bringing a million-dollar smile to the faces of congregating Iraqis (Mohammed and Scholz 2019). However, despite the fact that these operations were running smoothly, the UN halted dam construction in 1990 due to the second Gulf War. As a result, no dams were ever filled to their maximum capacity in the twenty-first century.

Additionally, the Haditha dam also became of no use due to the scarcity of water in the Euphrates. Dams had also been built in the country close to the mid-twentieth century when the major reason for doing so was to protect the capital – Baghdad from getting flooded and eventually for the other low-lying cities also. The first dam was then built over the Lesser Zab River in the year 1959, coming as a promise to millions of Iraqis of a better future. Seeing the great use of the dams, the government decided to build even more for better irrigation and power generation purposes.

The construction took place at a rapid speed and the officials also realized how the build of these dams could also fulfill the water scarcity for the neighboring countries of Turkey and Syria (Wale *et al.* 2009).

As the construction was being carried out flawlessly, the year 1990 was hit with a halt in the construction of dams due to the second Gulf War taking place. Eventually, this halt lasted longer than it should have as the twenty-first century saw none of the dams being filled to their maximum capacity. Therefore, the theory of climate change was again proven against the methods of water storage. Although the Turkish introduced a thing known as the GAP project in the year 1977 to build dams across the country in major cities. This project was estimated to be completed by the year 2010, but due to some political, economic, and financial issues, it was never completed. But the Syrian government managed to build three dams besides the GAP project. It was majorly done for irrigation and power generation purposes.



**Figure 2.6** Analysis of the GAP-Project across the country in major cities. Gaziantep, October 2007

### 3 METHODOLOGY

#### 3.1 Sample Study Haditha Dam

The study was conducted in Iraq's western region. It is about 500 square kilometers in size. The details of position is given as follows,  $41^{\circ}55'$ - $42^{\circ}27'$  east and  $34^{\circ}13'$ - $34^{\circ}40'$  north. The Haditha Dam, located on the Euphrates River, is roughly 7 kilometers from Haditha and 120 km from the Syrian border. (Figure 3.1) (Stockholm International Water Institute 2009). (Appendix 1) (Appendix 2)



**Figure 3.1** Overview of the turbine room inside the Haditha Dam, at Haditha, Iraq, Nov. 17, 2008

Principally, it is an earth-filled dam that has led to the emergence of Lake Haditha (the Haditha Reservoir). It was built with the intent to generate hydroelectricity. What's

more, the dam also served the purpose of modulating the water flow of the Euphrates while also furnishing water supply for irrigation. To the delight of many Iraqis, it produces 660 MW's electricity. This is why; it is termed the second-largest hydroelectric supplier in Iraq, the first one being the Mosul dam. For many who are not aware; Haditha Dam is 9 km and 57 meters tall. The peak is also 20 meters wide and 154 meters high. The reservoir has a surface area of 500 km<sup>2</sup> and the water can reach up to 147 m. Similarly, the storage volume is estimated to be  $\sim 8250 \times 10^6$  m<sup>3</sup>. As far as the maximum height of water is concerned, during floods, it stands at 150.2 m. Consequently, the area at this level is measured at 567 km sq, while the storage volume of the dam stands at 9.8 BCM. the climatic conditions around the reservoir, are indeed quite hot with annual precipitation of only 127 mm (Abobakr Yahya *et al.* 2019).

### **3.1.1 Purpose of the study**

The fundamental motive of the study is to comprehend the evaporation losses that have occurred in the dam during the time frame from 1985 to 2015 due to climatic changes. During these years, the reservoir experienced significant water losses as a result of evaporation (Raphaeli 2009). As a result, the dam shrank considerably, which led to the development of newer modalities to prevent the deprivation.

### **3.1.2 The study area's location**

In terms of location, the research area is typically found in Iraq's western regions, which are entirely under the control of the AI-Anbar Governorate. It mainly covers an area of 500 square kilometers and is located at 41°55'-42°27'E, 34°13'-34°40' N.

### **3.1.3 The climate of the study area**

The climate in the reservoir's immediate vicinity is hot and dry, where the rain average, per year, is expected to be around  $127 \times 10^{-3}$  m. In fact, it might spans the values from

$45 \times 10^{-3}$  m up to  $200 \times 10^{-3}$  m. The rainy season runs from November to April, and the dry season runs from May to October. (Abobakr Yahya *et al.* 2019)

#### **3.1.4 Geological setting of the study area**

The reservoir is located on the northern slope of the Arabian-African platform, as revealed by the map. They underlined the site's complicated geological circumstances, as revealed by prior investigations. The location is anticipated to have limestone and dolomites, as well as karst and a variety of diverse kinds.

### **3.2 Evaporation Data Between 1985-2015**

The transformation of a liquid into a vapor is known as evaporation. Water molecules are constantly moving, and some of them are promoted to excited levels of energies, which in turn suffer a phase transition from water to vapor. Through the hydrological cycle, the water-vapour phase transition contributes to considerable losses from water bodies and helps to regulate the global water balance. Controlling the water-vapour transformation, from land-based water bodies, is considered as one of the critical component of water conservation measures. It is particularly critical in dry areas where water scarcity is already a problem. The Haditha Reservoir faced a serious water shortage from 1985 to 2015. The average monthly evaporation, as well as the amount of vapour, in cubic meters, was computed by the means of Meyer's formula, the power-law, and S.O.Sulaiman methodologies. Many different approaches and modalities are used to estimate evaporation. This procedure employs evaporimeters in addition to a well established equations that estimate the water-vapour transformation imperically. Moreover, the methodology considered in this study utilies methods that comopute water-vapour transformation rates analytically.

### 3.2.1 Evaporimeters

There are many types of instruments that measure the rate of evaporation such as, the Class A Evaporation Pan in addition to the Colorado Sunken Pan. Another type is the US Geological Survey Floating Pan. Evaporation pans, on the other hand, are not identical replicas of enormous reservoirs. They have the following significant flaws in particular: 1. They differ in terms of heat storage capacity and heat transfer from the pan's edges and bottom. (Both the submerged and floating pans are designed to address this problem.) As a result, the rate of evaporation from a pan is influenced by its size. 2. The wind activity across the surface of an evaporation pan is affected by the height of the rim. 3. The pan material has different heat-transfer properties than the reservoir.

### 3.2.2 Empirical evaporation equations

Meyer's Formula, Fitzgerald's Formula, Rower's Formula, and Wind velocity are some of the empirical formulae used to check for evaporation (Issa *et al.* 2014). Equation (3.1)

$$\text{Meyer's Formula: } E = Km(ew - ea) (1 + Ua)^{16} \quad (3.1)$$

According to Meyer's formula, the evaporation is defined by  $E$  and measured in millimetres. On the other hand, the pressure of saturated vapour is referred to as  $ew$  and measured in (mmHg) at the water surface temperature. The other significant factor that appears in Meyer's formula is the actual vapor pressure and referred to as  $ea$  where (mmHg) is the measuring units. The other parameter included in the formula is  $Ua$ , which represents the wind speed, where the measurements are conducted at 9 meters relative to the surface of the ground. The coefficient  $Km$  is a metric that takes into account other elements including the size of the water body; it's usually 0.36 for huge lakes and 0.50 for tiny ones. Equation (3.2)

$$\text{Formula Fitzgerald: } E = (0.4 + 1.24u_0)(ew - ea). \quad (3.2)$$

Here,  $u_0$  is the wind speed at the ground level. Equation (3.3)

$$\text{Formula for Rowers: } E = 0.771(1.465 - 0.000732p_a)(0.44 + 0.0733u_0)(e_w - e_a) \quad (3.3)$$

In formula for Rowers, the average atmospheric pressure is called  $p_a$ , where the mmHg is the units used in the measurements. The wind speed rate is included in the formula as  $u_0$ , where (km/h) is the measurement unit. The measurements are conducted at 600 mm away from the ground.

### **Wind velocity:**

The wind velocity obey The 1/7th power law, up to  $5 \times 10^2$  m away from the ground. This occurs at the lower atmosphere. The power-law represents a straightforward formula which can be used to compute the speed of wind at a wind-generator hub at a given height relative to data at a reference point, and it can be written in a compact form as follows:  $u_2 / u_1 = (h_2 / h_1)^p$ , where  $u_1$  and  $u_2$  represent the average of the wind speed measured  $h_1$  and  $h_2$ . Here,  $p = 1/7$ .

### **3.2.3 Estimating evaporation using analytical methods**

Evaporation can be calculated using the water-budget, energy-budget, and mass-transfer equations, as well as Penman, Priestly-Taylor, and De Bruin. (Abbas *et al.* 2016). The energy-budget and mass-transfer approaches need expensive instrumentation, which is why the water-budget method is extensively employed.

#### **Water-budget method**

This approach represents a straightforward method for calculating water-vapour transformation, and it is usually employed in lakes related research. In fact, it usually returns correct data. Mathematically, the method is written in the following form Equation (3.4):

$$\Delta \text{ storage} = \text{Input} - \text{Output} \text{ or } \Delta S = (I+P) - (O+E+GW). \quad (3.4)$$

In the same spirit, Equation (3.5)

$$E = -\Delta S + I + P - O - GW \quad (3.5)$$

The incoming is measured in centimetres and referred to as I. P represents the precipitation and is measured in centimetres. The outflow is measured in centimetres and referred to as O. As usual, E is the amount of evaporation and measured in centimetres. Moreover, GW is the groundwater seepage (cm). The estimation of groundwater seepage and the estimation of precipitation limit the accuracy of this procedure.

**Energy-transfer method:**

The energy available for evaporation is calculated using this method by taking into account the incoming, departing, and finally, the energy kept in the water for a definite time interval. The equation of conservation of energy is used in this procedure. The energy budget equation is as follows Equation (3.6):

$$Q_n = Q_h + Q_e + Q_g + Q_s + Q_i \quad (3.6)$$

In the above equatin, the net heat energy meausred at the water surface is refered to as  $Q_n$ . On the other hand the heat transfer is represented by  $Q_h$ .  $Q_e$  is the amount of energy lost by evaporation,  $Q_g$  is the rate of heat transfer into the ground,  $Q_s$  is the heat stored in the body of water, and  $Q_i$  is the energy advected. We utilize Bowen's ratio to calculate  $Q_h$ , which is defined as follows Equation (3.7):

$$\beta = \frac{Q_h}{Q_e} = 6.1 \times 10^4 \rho a (T_w - T_a) (e_w - e_a) \quad (3.7)$$

Here,  $p_a$  is the pressure in the atmosphere (mmHg),  $e_w$  is the saturated pressure (mmHg),  $e_a$  is the vapor pressure at the moment (mmHg),  $T_w$  is the water's surface temperature (°C), and  $T_a$  is the air temperature (°C)

**Mass-transfer method:**

The turbulent movement of vapour out of the evaporating surface toward the outer environment, represent the main essence of the this approach. Evaporation is aided by two factors. First, the gradient of the vapor pressure and second is the speed of the wind.

The evaporation is computed using the following formula Equation (3.8):

$$E = (a + bu)(e_s - e_a) \tag{3.8}$$

Here,  $u$  is the wind speed at a certain height away from ground, and  $a$  and  $b$  are empirical constants. To calculate the amount of water-vapour transformation toward the atmosphere from a surface of the lake. Thornthwaite and Holzman (1939) proposed the following Equation (3.9):

$$E = 0.000119(e_1 - e_2)(u_2 - u_1) p \times [\ln(h_2 / h_1)]^2 \tag{3.9}$$

Here,  $u_1$  and  $u_2$  are wind velocities (m/s) at heights  $h_1$  and  $h_2$ , respectively,  $e_1$  and  $e_2$  represent equivalent vapour pressure and it is measured in Pa units. Here  $p$  is the ambient air pressure.

**Method of Penman:**

In evaporation research, the Penman method is likely the most used. It falls under the genre of combination methods, which combine characteristics of energy budgeting and mass transfer methods. Mathematically, the formula is given as follows Equation (3.10):

$$E = \Delta \Delta + \gamma (Q_m - Q_t) \rho_w L_v + \gamma \Delta + \gamma f(u)(e_s - e_d) \quad (3.10)$$

The change saturation pressure of vapour, as a slope, in the air temperature graph and measured in  $\text{mbar}^\circ\text{C}^{-1}$  units.  $e_s$  at ambient air temperature is the saturation vapor pressure (mbar), and  $Q_m$  is the radiation net Equation (3.11)

$$(\text{cal cm}^{-2} \text{ day}^{-1}): Q_m = Q_s - Q_{sr} + Q_a - Q_{ar} - Q_{br} \quad (3.11)$$

$Q_{sr}$  and  $Q_{ar}$  are fixed sections of  $Q_s$  and  $Q_a$ , respectively, and  $Q_{br}$  is derived using the Stefan Boltzmann formula and the lake's surface temperature. The Penman formula comprises a factor that represent the energy. Another important factor that appears in the formula is the aerodynamic one.

The energy factor represent the consumed amount Whereas the aerodynamic one represents the wind speed in addition to vapour-pressure shortfall during th evaporation operation.

Penman provides an initial wind function of is Equation (3.12)

$$f(u) = 0.26(1 + 0.536u^2) \quad (3.12)$$

Later on, Penman reconsidered the  $f(u)$  and reformulated it as follows Equation (3.13):

$$f(u) = 0.26(0.5 + 0.536u^2) \quad (3.13)$$

which is significantly better, in comunity, to compute the water-vapour transformation from big open-water areas.

### **Method of Priestley–Taylor:**

A simplified variant of the Penman formula is the Priestley–Taylor formula. Priestley and Taylor (1972) calculate evaporation using Penman equation's energy component, claiming that the aerodynamic term can be approximated as a fixed fraction of total evaporation over a suitable average period. This is how the Priestley–Taylor Equation (3.14) is written:

$$E = \alpha \Delta \Delta + \gamma (Q_m - Q_t) \rho_w L_v \quad (3.14)$$

where  $\alpha$  is a parameter with an average value that was derived empirically.  $\alpha = 1.26$ . This is the same as thinking of aerodynamic factor to represent up to 21% of total evaporation. When using the Priestley–Taylor technique, neither data are required of the wind-speed nor the wind function is needed.

#### **De Bruin's Method:**

De Bruin approach the problem using Penman equation. Moreover, De Bruin considered Priestley–Taylor factor instead of the Priestley–Taylor method. As a result De Bruin managed to devise a formula to compute the evaporation only in terms of the aerodynamic factor in the Penman Equation (3.15):

$$E = \alpha \alpha^{-1} \gamma \Delta + \gamma f(u)(e_s \alpha - e_d) \rho_w L_v \quad (3.15)$$

Interestingly, the radiation data is not required as an input in the computation of the change in the reservoir's thermal content to use the De Bruin approach.

### **3.3 Mathematical Analysis**

The data collected is used for mathematical analysis to obtain the total annual water volume (TAWV) that comprises total water flow from Tigris River (T), Total water flow from Euphrates River (E), and yearly volume of water from rainfall in Iraq (R). The results are made with regression and statistical analysis.

### 3.3.1 Regression analysis

Regression analysis is a type of analysis of the correlation between the dependent and independent variable, i.e. the value of the dependent variable changes when one or more independent variables change due to many factors. The most often used linear model relates a variable Y to one variable X by the Equation (3.16).

$$Y_i = f(X_i, B) + e_i \quad (3.16)$$

- $Y_i$  = Dependent variable
- $f$  = Function  $X_i$  = Independent variable
- $B$  = Unknown parameter
- $e_i$  = error terms

For this study, there are three independent variables ( $X_i$ ) used to relate to the dependent variable.

- The volume of water discharge of the Tigris River in BCM is denoted as  $x_1$
- The volume of water discharge of the Euphrates river in BCM denoted as  $x_2$
- The volume of annual rainfall in Iraq is denoted as  $x_3$ .
- Total Annual water volume (TAWV), denoted as  $Y$ .

So, according to the linear equation, the Total Annual water volume can be written as Equation (3.17):

$$\log Y_i = b_0 + b_1 \log X_1 + b_2 \log X_2 + \dots + b_n \log X_n + e_i \quad (3.17)$$

The value of  $b_0$ ,  $b_1$ , and  $b_3$  can be calculated using the regression analysis least-square principles. It is a statistical procedure to obtain the best result for a set of data points. The pivotal function of the principle of least squares is minimizing the sum of the

squares. that can be retransformed to the original units by using an anti-logarithm Equation (3.18):

$$Y_i = 10^{b_0} * (X_1^{b_1}) * (X_2^{b_2}) \dots (X_n^{b_n}) * 10^{e_i} \quad (3.18)$$

### 3.3.2 Statistical analysis

The vital three parameters are obtained i.e. TAWV (Total Annual water volume), Average annual volume of Tigris River (T), Average annual volume of Euphrates River (E), and Average annual volume of rainfall (Figure 3.2).

The Equation (3.19) used in this method (Ries and Friesz 2000, Perry *et al.* 2004, Risley *et al.* 2008) follows:

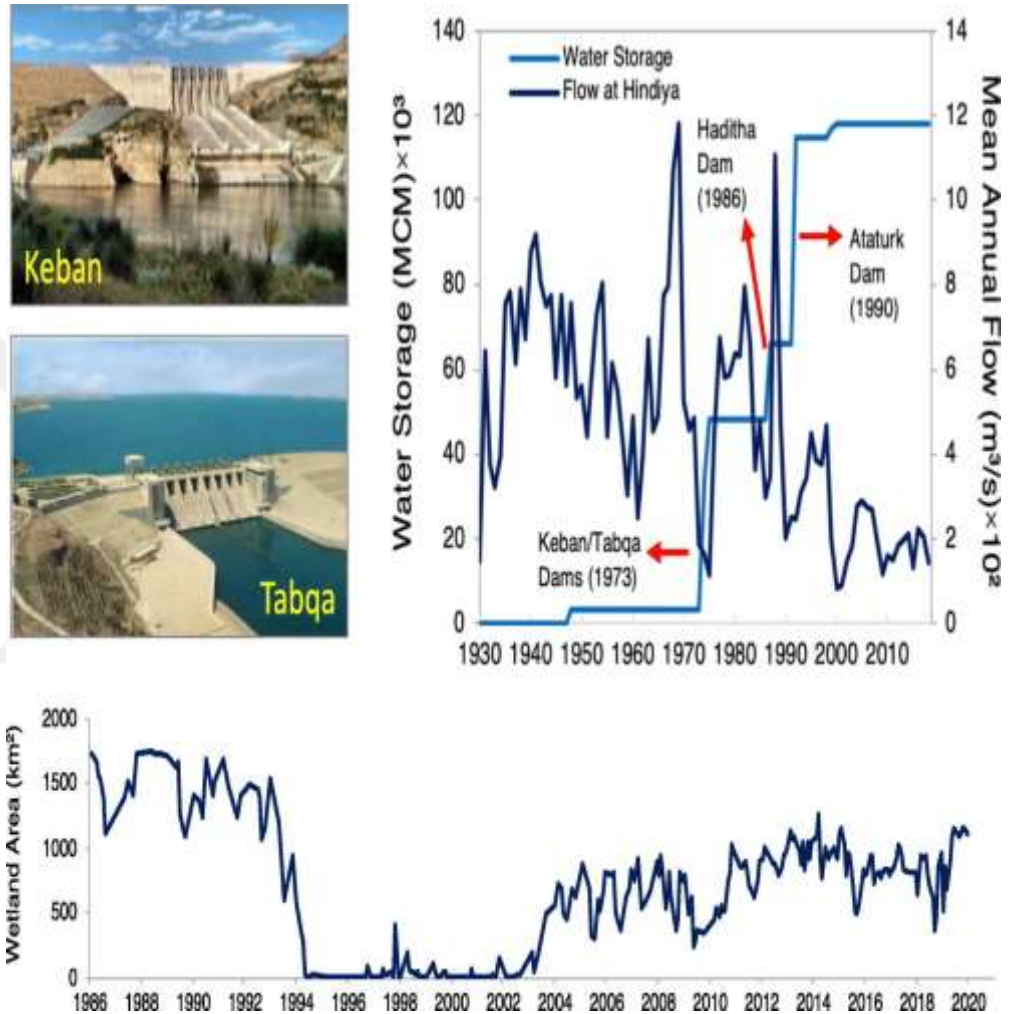
$$Q_s = [DAs / DA_g] * Q_g \quad (1) \quad (3.19)$$

where  $Q_s$  is the low-flow statistic of the ungaged site, in cubic feet per second;  $DA_s$  is the drainage area of the ungaged site, in square miles;  $DA_g$  is the drainage area of the gaging station (upstream or downstream) in square miles, and  $Q_g$  is the low-flow statistic of the gaging station (upstream or downstream) in cubic feet per second. The drainage-area ratio method can be used by weighting the average ratios of drainage areas at the gaging stations to the ungaged site drainage area if the ungaged location is between two gaging stations by the following Equation (3.20):

$$Q_s = [Q_{gu} (DA_{gd} - DA_s) + Q_{du} (DA_s - DA_{gu})] / (DA_{gd} - DA_{gu}) \quad (2) \quad (3.20)$$

where  $Q_{gu}$  is the flow statistic at the upstream gaging station, in cubic feet per second;  $Q_{du}$  is the flow statistic at the downstream gaging station, in cubic feet per second;  $DA_{gu}$  is the drainage area of the upstream gaging station, in square miles;  $DA_{gd}$  is the drainage area of the downstream gaging station, in square miles. The method generally is reliable if the drainage-area ratio of the two sites is between 0.5 and 1.5 (Risley *et al.*

2008). Where an ungaged location meets these criteria for gaged streams with known effects from regulation, irrigation, and urban change, this method can be used to estimate flow statistics as long as the record from the gaging station is used to compute the statistic also is affected by the same condition.



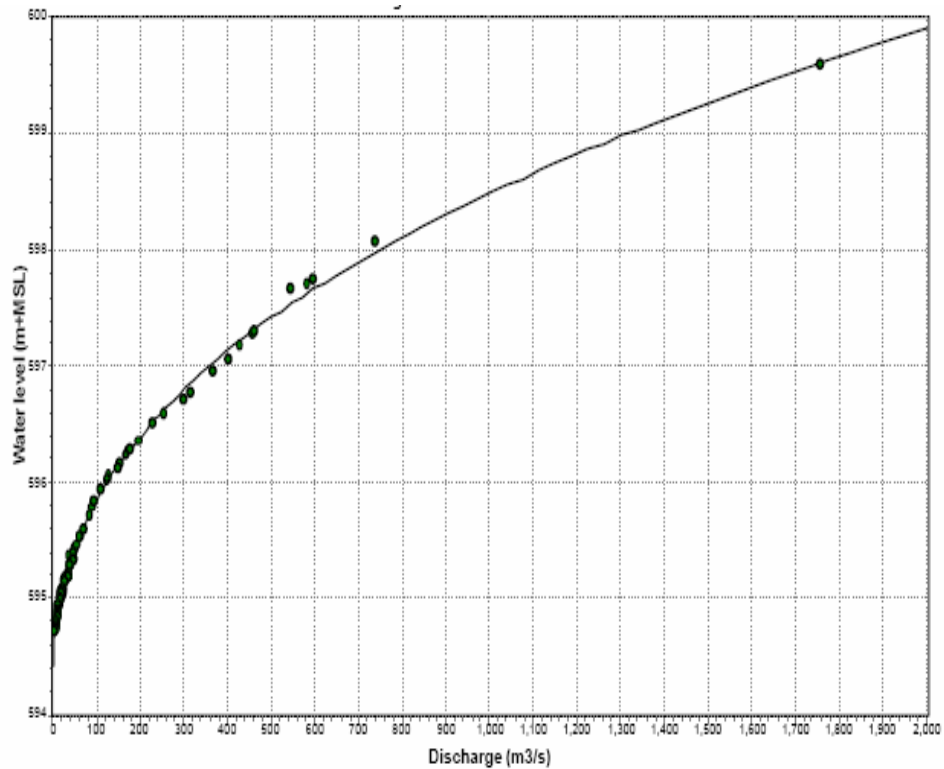
**Figure 3.2** Average annual volume of Tigris River (Ali 2016)

### 3.4 The Statistical Program Used in the Measurements

#### 3.4.1 Incoming water to the tank

The water entering the reservoir in the Al-Qaim area is monitored at the beginning of the Euphrates River entering the Iraqi border in the Al-Qaim area by using rulers to

measure the river level as shown in the figure below and the corresponding discharge through a pre-prepared curve (RATING CARVE) and this curve is prepared by taking The real expenditures by electronic devices. This Curve shows the relationship between the level and the discharge as shown below, the expenditures can be estimated through it by taking the river's ratio and then interrupting it with the curve where it gives us the corresponding discharge (Figure 3.3).

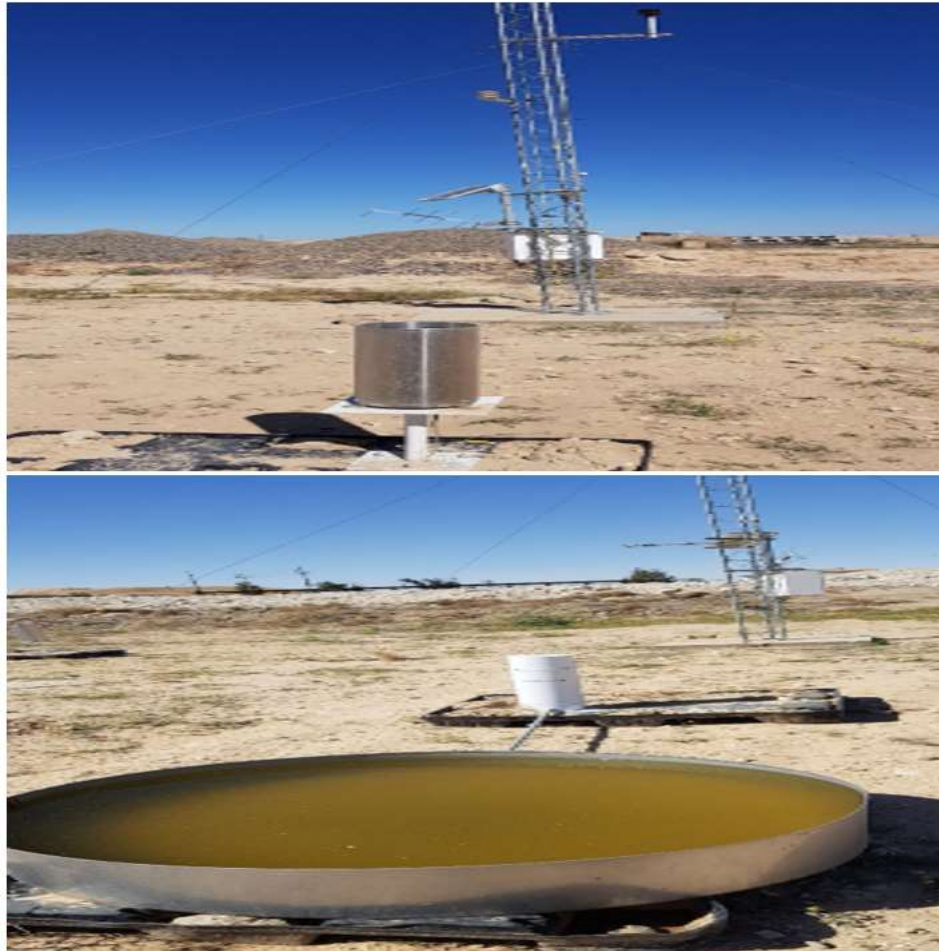


**Figure 3.3** Curved model for measuring discharge through river level readers

### 3.4.1.1 Water consumption of incoming water

There is water consumption in the incoming water, as the river travels a distance of about 160 km until it reaches the Haditha Dam reservoir, where it passes through many cities and villages, and it is represented in consumption for domestic, human, industrial, and agricultural uses, in addition to leakage, and there is a large consumption of incoming water represented by evaporation due to the distance between River and large reservoir area. Evaporation is measured through an integrated weather station that

measures, in addition to evaporation, maximum, minimum, and normal temperatures, wind speed, and relative humidity the measurement is done by Class A Pan (Simon-Gáspár *et al.* 2021) (Figure 3.4).



**Figure 3.4** Haditha dam air anwaa station

#### **3.4.1.2 The levels of the reservoir and the amount of water stored in the lake**

The levels of the reservoir are read on a daily basis by the devices in the hydroelectric station or through the level measuring rulers installed in the front of the dam at the reservoir. Every half an hour and throughout the day (Figure 3.5).



**Figure 3.5** Tank level gauge

### **3.4.1.3 The water level in the back and Sheikh Hadid area**

#### **A - The water level at the back of the dam:**

The water level at the back of the dam near the hydroelectric station is measured by an automatic electronic device installed on the bank of the river at the back of the dam (Figure 3.6), (Figure 3.7)



**Figure 3.6** The electronic device used for water level measurement



**Figure 3.7** The bank of Euphrates River

**B - The water level in the Sheikh Hadid area:**

It is the area where the real discharge is measured by means of special devices for measuring the discharge into the river for the purpose of verifying the absolute discharge from the hydroelectric station. The levels are read through an automatic electronic device installed in that area to measure the levels

#### 3.4.1.4 True discharge

The actual discharge is made by a specialized cadre in the project using the **SONTEK M9 (RIVERSURVEYOR® S5 AND M9)** device shown in the pictures below to verify the incoming and absolute discharge in the Al-Qaim area, in the Sheikh Hadid sub-district. (SonTek. 2010). (Figure 3.8)

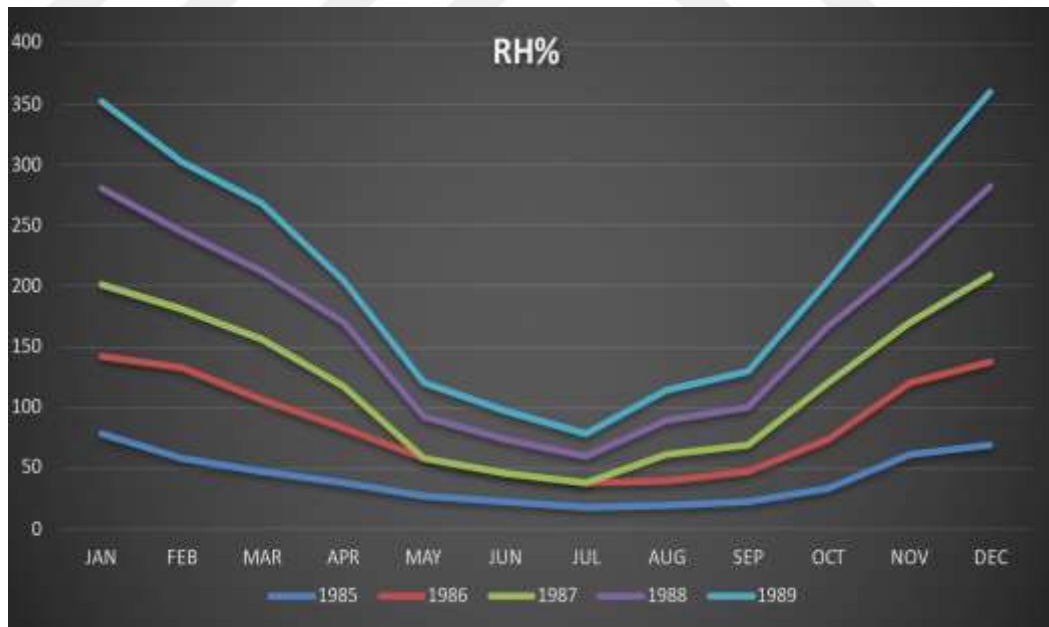


**Figure 3.8** Verify the incoming and absolute discharge in the Al-Qaim area

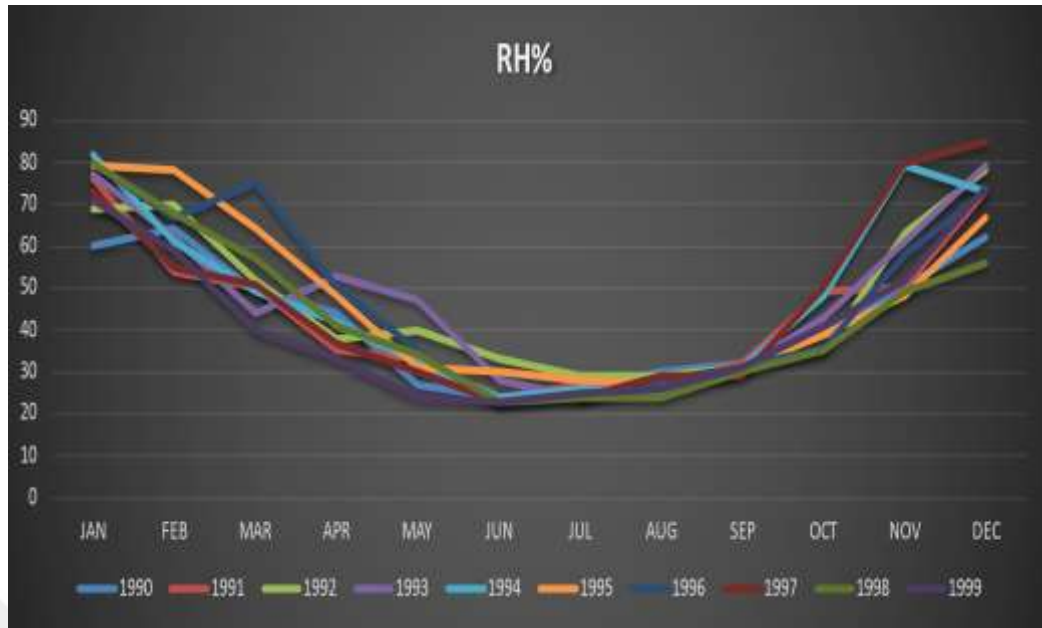
#### 4 RESULTS AND DISCUSSION

The meteorological stations at Haditha and Ana gave meteorological data by providing daily values of water temperature, temperature, humidity RH, and wind velocity to calculate evaporation volume. The evaporation rate was not checked using all of the methods. Meyer's and the power-law were the most accurate and square methods used by professionals to determine the evaporation rate.

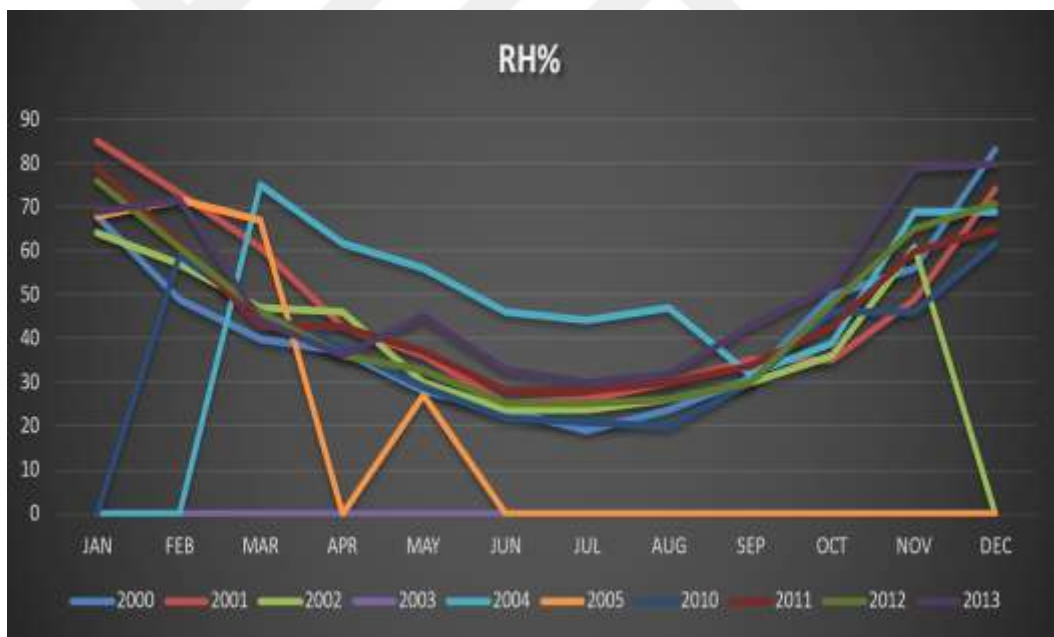
Figure 4.1 depicts the fluctuation in the water body during the three stages to show the change in the water surface area stored by Haditha Dam using classification figures (Figure 4.2), (Figure 4.3). The water body's status before the building of Haditha Dam is shown in April 1985, and the water body's status after the dam's first operation is shown in June 1985. The water body variation after the first operation of the hydroelectric unit, which demands a greater level of the Dam's water, is shown from the 25th of April to the 9th of June 1986



**Figure 4.1** Indicate the value of humidity between 1985 to 1989



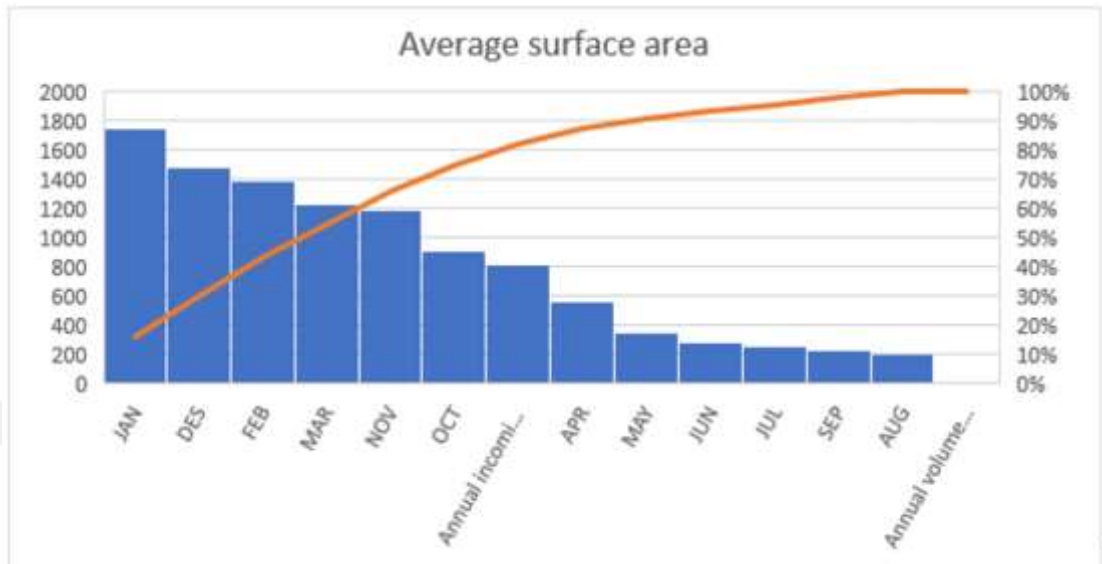
**Figure 4.2** Indicate the value of humidity between 1990 to 1999



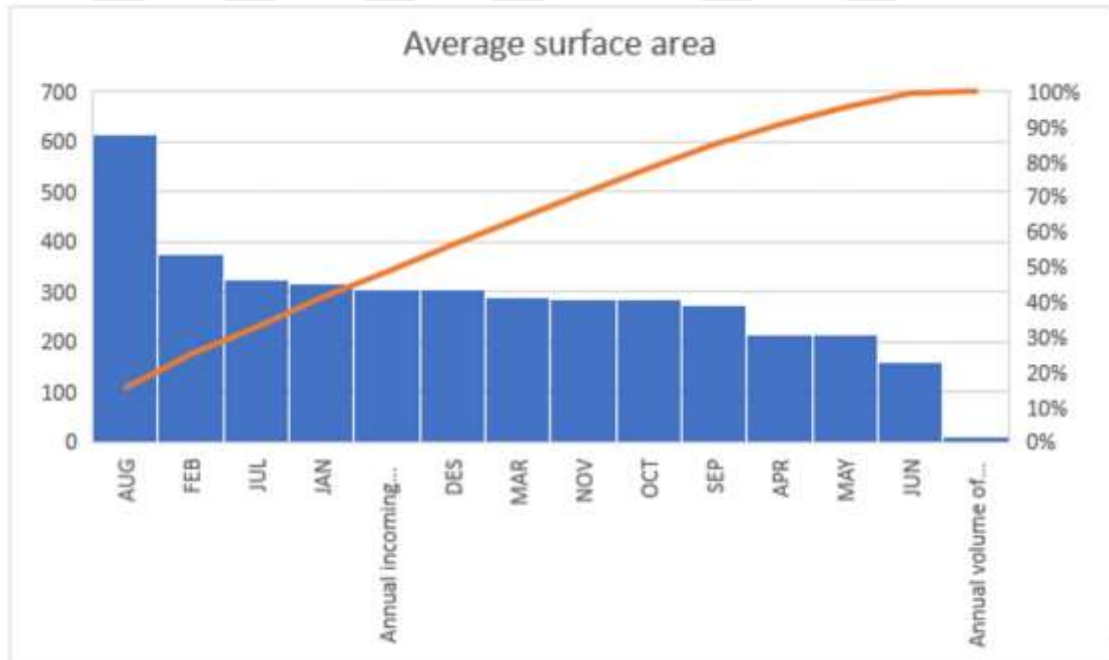
**Figure 4.3** Indicate the value of humidity between 2000 to 2013

The second stage of the study period covers the years from 1988 (the year the dam was completed and put into service) to 2000, when the reservoir's surface area was rather stable. Due to the relative stability in the amounts of annual water revenues and other secondary factors, the average surface size of the lake during this period was 418 km<sup>2</sup>,

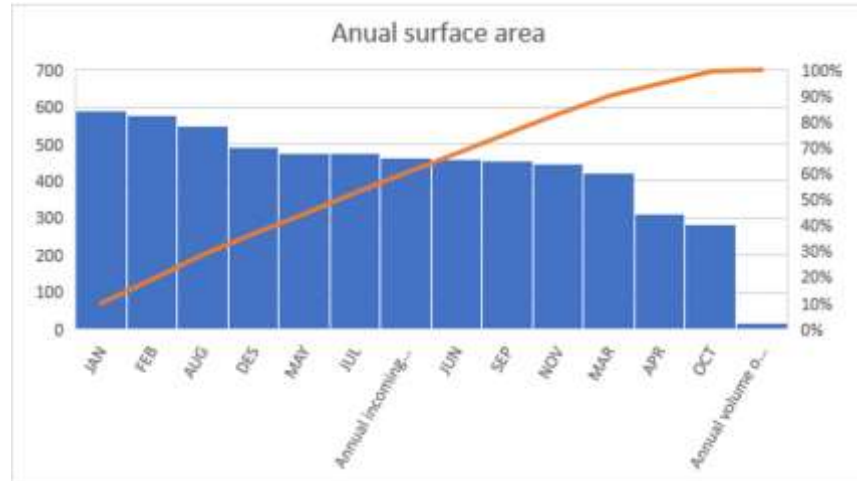
and this area can be used as a credible reference for comparing the change in the surface area of the lake in later years (Figure 4.4), (Figure 4.5), (Figure 4.6).



**Figure 4.4** That the average surface area of the lake from 1988 to 2000

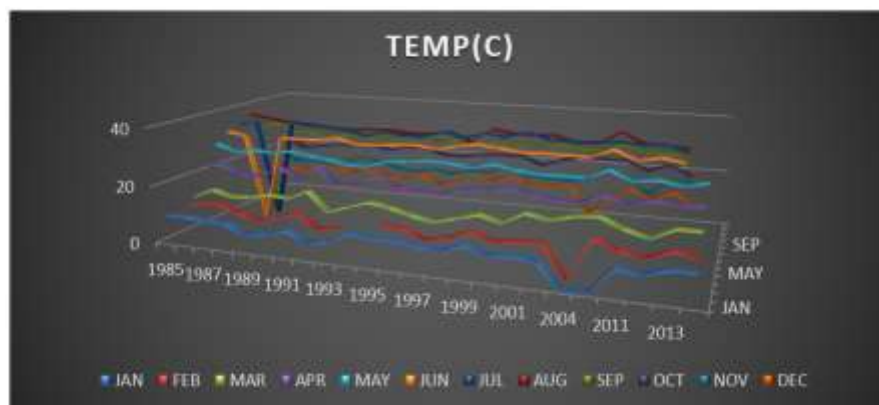


**Figure 4.5** That the average surface area of the lake from 2001 to 2010



**Figure 4.6** That the average surface area of the lake from 2011 to 2020

The years 2000 to 2014 make up the third stage. Figure 4.5 shows that there was a considerable change in the water surface area in 2001, with a drop of roughly 64% of the average area compared to the prior period. Thereafter, there was a fluctuation in inclination and declination for the rest of the period, except for a sudden abrupt reflection decline point in 2015, when the area decreased by nearly 65 percent from 427 km<sup>2</sup> in 2014 to 148 km<sup>2</sup> in 2015. There were two key explanations for the decrease. Firstly, From February to September 2015, the Euphrates' water resources were disrupted by Turkey. Second, the takeover of the Tabqa Dam in Syria by armed groups and the closure of its Gates (Figure 4.7).



**Figure 4.7** Comparative change of temperature of Haditha lake, 1985-2014

## 5 CONCLUSIONS AND RECOMMENDATION

Finally, it is demonstrated that the primary cause of Iraq's water dilemma is current climate change during the previous several years, as well as mismanagement of water resources within Iraq. Iraq faces various obstacles in handling the water issue, including rising demand for water due to tremendous population expansion, increased sedimentation affecting dam storage capacity and not separating it from rains, and excessive water usage at all levels. (Zubaidi *et al.* 2020). The study's modification methods are based on focus groups conducted in the Iraqi region to examine farmers' attitudes toward climate change and their responses to its negative effects. Planting trees, crop modification, changing planting dates, and soil conservation are among the key modification policies identified by farmers as appropriate for rain-fed plants, according to their responses. Because climate change affects a wide range of industries, including agriculture and water, the consequences are widespread, threatening national food security and farmers' livelihoods. To deal with the projected effects of climate change, each country must create mitigation and adaptation plans. Agricultural sector changes are required to provide food security and protect the poor's main source of income, which is farming. This evaluation looked at agricultural and government-level modification measures. To continuously negotiate and deliberate with the Turkish side, as well as manage water flows to ensure Iraq's water needs are met, establish a higher committee comprised of an association linked to the Prime Minister, an administrative group from the Ministry of Water Resources, and experts in information systems, GIS, and remote sensing. Iraq should focus on a long-term strategy for managing its water resources

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## **APPENDICES**

**APPENDIX 1. Main causes of the water problem in Iraq**

**APPENDIX 2. Prolific ways to control the existing problem of water scarcity in Iraq**



## APPENDIX 1. Main causes of the water problem in Iraq

**STATION: Haditha annual absolute discharge rate m<sup>3</sup>/s and annual volume of absolute water km<sup>3</sup> from 1985 to 2020**

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual absolute discharge rate	Annual volume of absolute water
													m <sup>3</sup> /s	km <sup>3</sup>
3								533	569	349	507	502	492	10.29
-1985 1986	572	339	523	508	473	381	260	268	420	555	455	452	434	13.58
-1986 1987	446	435	512	527	433	642	369	391	569	807	647	611	532	16.12
-1987 1988	367	366	383	1422	1811	2035	2401	2451	2090	881	713	1036	1330	49.43
-1988 1989	1003	1244	1706	1735	1291	1182	599	369	293	303	316	294	861	18.69
-1989 1990	263	265	235	202	202	227	230	237	359	319	978	378	325	11.23
-1990 1991	278	332	510	926	804	217	195	188	205	225	304	342	377	11.34
-1991 1992	344	318	219	204	230	259	233	260	374	367	311	314	286	9.36
-1992 1993	291	279	431	329	223	218	264	347	406	437	432	408	339	10.91
-1993 1994	347	325	403	399	470	346	325	304	485	494	440	572	409	12.2
-1994 1995	688	893	1063	1100	1163	815	679	504	523	339	465	564	733	21.41
-1995 1996	478	725	829	825	838	1088	1519	691	715	837	988	732	855	26.8
-1996 1997	521	688	790	783	1044	777	643	593	722	990	918	704	764	24.58
-1997 1998	734	684	783	787	930	1123	683	769	830	855	1019	746	829	24.9
-1998 1999	576	441	697	673	574	429	353	366	813	797	655	606	582	17.01
-1999 2000	400	405	380	233	370	423	386	332	444	458	447	442	393	12.2
-2000 2001	415	460	219	174	262	296	160	209	289	329	360	327	292	8.98
-2001 2002	411	387	211	134	185	233	161	130	223	326	386	290	256	7.43
-2002 2003	255	290	237	559	543	515	338	367	446	457	470	320	400	12.85
-2003 2004	258	292	330	272	344	1127	577	633	587	512	538	537	501	17.48
-2004 2005	501	472	537	706	654	571	531	407	486	629	598	472	547	16.45
-2005 2006	401	400	398	365	882	506	401	399	557	664	685	631	524	17.71
-2006 2007	636	609	433	639	666	443	438	569	555	633	700	684	584	18.58
-2007 2008	615	609	527	416	409	419	353	400	459	600	612	650	506	14.92
-2008 2009	546	414	371	300	300	276	250	205	278	372	400	398	343	9.87
-2009 2010	370	360	240	211	300	202	200	200	283	363	437	488	305	10.62
-2010 2011	468	516	400	384	241	338	293	256	351	439	446	561	391	12.53
-2011 2012	513	500	438	443	505	564	371	370	658	650	692	663	531	17.03
-2012 2013	597	541	408	315	600	442	296	315	523	481	450	450	452	14.09
-2013 2014	450	450	376	359	373	461	395	374	782	1154	836	647	555	17.76
-2014 2015	533	413	400	400	330	211	251	211	144	103	73	45	260	7.13
-2015 2016	252	350	350	350	381	350	350	350	380	400	386	478	365	12.05
-2016 2017	408	478	408	372	538	434	286	302	514	550	550	502	445	14.3
-2017 2018	519	462	418	351	258	273	193	173	267	353	311	300	323	8.46
-2018 2019	311	255	174	172	177	200	188	220	433	388	489	752	313	13.62
-2019 2020	714	653	783	888	760	985	589	429	359	394	400	425	615	16.2
-2020 2021	460	593	518										524	

## APPENDIX 2. Prolific ways to control the existing problem of water scarcity in Iraq

### STATION: Haditha Annual incoming discharge rate m<sup>3</sup>/s and Annual volume of incoming water km<sup>3</sup> from 1985 to 2020

Year	OCT	NOV	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual incoming discharge rate m <sup>3</sup> /s	Annual volume of incoming water km <sup>3</sup>
-1988 1989	913	1191	1482	1752	1383	1234	565	344	278	260	201	232	820	18.45
-1989 1990	284	328	207	191	243	191	246	224	359	519	393	331	293	10.29
-1990 1991	295	351	562	510	399	381	192	427	387	410	430	348	391	12.07
-1991 1992	276	279	544	499	548	352	300	298	329	280	250	221	348	11.35
-1992 1993	340	405	477	411	358	391	337	497	401	408	368	256	387	12.67
-1993 1994	433	427	526	486	624	439	459	334	353	418	516	733	479	20.22
-1994 1995	956	1150	1231	1285	1270	861	705	351	288	379	512	528	793	23.35
-1995 1996	638	1119	990	1142	1389	1416	1593	838	497	695	743	667	977	30.22
-1996 1997	750	873	903	1054	1345	1127	1068	735	771	815	584	489	876	28.54
-1997 1998	713	989	1220	1132	1350	1443	817	869	580	587	675	644	918	28.06
-1998 1999	698	832	1047	1013	945	623	429	370	310	263	258	303	591	16.36
-1999 2000	355	612	751	933	1188	802	366	344	343	339	262	250	545	14.98
-2000 2001	285	287	303	317	377	290	214	213	159	326	615	275	305	10.18
-2001 2002	238	247	613	616	391	216	290	236	303	335	273	287	337	12.26
-2002 2003	348	582	825	663	635	789	548	367	288	282	308	457	508	16.17
-2003 2004	515	742	547	710	1214	1789	665	1207	554	349	569	650	793	26.12
-2004 2005	648	700	903	925	859	665	493	358	465	495	525	339	615	18.42
-2005 2006	625	731	537	934	1331	623	512	574	603	809	873	679	736	23.22
-2006 2007	382	643	958	1173	751	581	555	621	379	716	821	584	680	19.82
-2007 2008	386	374	532	879	758	436	343	307	355	403	542	548	489	14.68
-2008 2009	296	312	402	310	278	259	225	263	293	310	288	305	295	9.59
-2009 2010	349	386	385	351	405	288	337	314	315	461	756	333	390	12.51
-2010 2011	282	446	493	592	577	423	312	475	457	475	551	455	462	16.75
-2011 2012	464	686	919	819	937	806	428	560	735	636	728	480	683	20.05
-2012 2013	383	495	629	622	422	282	330	622	509	356	369	396	451	13.74
-2013 2014	377	377	397	545	666	691	661	559	401	370	406	346	483	14.96
-2014 2015	355	331	364	299	323	257	216	166	114	97	102	155	232	8.83
-2015 2016	454	565	604	752	627	549	554	481	372	387	357	417	510	15.57
-2016 2017	338	530	573	867	946	545	166	286	572	311	361	329	485	14.17
-2017 2018	352	344	351	404	428	280	297	320	279	210	214	299	315	9
-2018 2019	234	225	248	335	355	401	858	696	919	891	880	868	576	22.3
-2019 2020	750	716	801	818	818	880	778	634	423	311	411	527	656	19.63
-2020 2021	652	634	600											

**Station: Haditha element: Mean wind speed M/S from 1985 to 2013**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	2.1	4.1	3.4	4.4	3.8	5.7	6.3	4.7	4.2	2.8	2.2	2.2
1986	2.7	3.1	3.9	3.9	4.6	6.1	6.7	4.9	3.5	3.5	3.2	2.2
1987	2.2	2.8	0		3.9			5.2	3.6	3.1	3.9	2.9
1988	3.1	2.9	4	3.2	4.5	5.4	6.3	5.6	4	3.1	3.3	3.3
1989	3.6	4.3	4.6	4	4.4	5.8	6.2	5.2	2.4	1.8	1.7	2.4
1990	3.6	4.3	4.6	4	4.4	5.8	6.2	5.2	2.4	1.8	1.7	2.4
1991	1.1			3.9	7.1	5.6	7.7	5.5	3.7	2	2	2.5
1992	3.6	3.8	3.5	4.3	4.6	4.9	6.5	5	3.5	2.8	3	2.7
1993	3	2.7	3.5	3.1	4.1	5.5	6.2	4.6	3.4	2.5	2.7	2.1
1994	2.9	3.1	3.9	4.2	3.6	6.2	6.9	5.6	3.2	2	2.6	3
1995	1.8	2.9	2.2	3	3.3	5.2	5.6	4.8	3.5	3.2	2.5	1.9
1996	2.8	3.4	3.7	4.1	3.6		0	4.3	3.7	3.2	2	2.1
1997	3.2	2.5	3.6	3.6	3.6	4.4	6.5	5.1	2.4	2.1	2.1	2.1
1998	2.3	3.1	3.1	2.5	2.9	4.3	4.6	2.8	3.3	3.1	1.6	2.3
1999	2.1	2	3.4	3.2	4.3	4.2	4.8	3.8	3.4	2.4	2.7	1.6
2000	2.1	2.7	3.4	3.7	3.6	4.7	4.9	3.8	3.8	2.2	1.8	2.6
2001	2.4	2.5	2.4	3.4	4.6	5.8	5.1	3.8	3.2	2.9	2.9	1.9
2002	2.9	2.5	2.8	3.9	4	5	4.3	4.8	3.5	2.3	2.4	miss
2004	miss	miss	2.9	3.1	3.8	3.4	2.9	2.3	2.2	2.2	2.1	1.6
2010	miss	2.4	2.1	1.8	1.9	2.4	3	1.8	1.8	1.8	1.6	1.5
2011	1.3	2.3	2.8	2.6	2.4	3.3	2.5	2.7	2	2.4	2.2	1.8
2012	1.5	2.2	2.7	2.3	2.8	2.8	2.4	2.6	1.9	1.7	1.6	1.7
2013	1.8	1.8	2.5	2.4	2.4	3.2	3.2	2.5	2	2.2	1.7	2.1

**Station: Haditha element: mean air temp (c) from 1985 to 2014**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	9.3	9	12.2	22	28.7	32	33.7	36.1	30	22	17.2	8.9
1986	9.4	12.6	15.4	22.7	26.3	30.8	34.8	35.1	32.2	24.8	13.2	7.9
1987	8.8	12.7	13.5	20.1	27.4	0	0	34.2	29.4	21.1	14.1	11
1988	8.3	10.5	14	19.7	26.9	31.1	35.4	33.9	29.3	22.3	13	9.9
1989	5.4	8.3	15.5	23.5	28	30.9	34.6	33.3	28.6	23.4	15.5	8.7
1990	6.2	10.3	14.9	20.5	27	31.5	34.7	32.5	29.3	23.6	16.7	10.5
1991	8.6	12.4	18.2	24.6	26	32.4	33.8	33	28.9	23.7	16	8.2
1992	5	7.6	11.5	19.6	24.8	30.6	32.4	33.3	28.7	22.8	13.6	7.8
1993	6.6	8.8	14.1	19.7	24.7	30.8	34.1	33.6	29.3	24.5	13.1	10.3
1994	10		16.3	23.6	27.1	31.6	33.5	32.8	30.6	24.5	14.4	6.8
1995	9.3	11.4	15.1	20.1	27.6	31.9	33.3	33.3	28.9	22.3	13.3	8.5
1996	9.1	11.1	13.2	19.5	28.4	31.1	35.9	34.1	29.6	22.5	15.1	12.1
1997	8.5	7.8	11.8	19.4	28.2	32.6	34	31.4	28.5	23.5	14.9	10.3
1998	7.5	9.6	13.8	21.5	27.2	33.7	36.1	36.4	30.4	24	18.1	12.2
1999	10.2	12.5	15.8	22.2	29	32.9	35.3	35.2	30	24.1	14.8	9.9
2000	7.9	10	13.8	23	27.6	32	37.4	35	29.6	21.2	14.5	10
2001	8.5	11	17.7	22.1	26.7	32.2	35.4	35.6	30.8	23.8	14.1	10.8
2002	7.6	11.3	16.3	20.7	26.9	32.2	35.2	33.4	30.3	25.3	15.2	miss
2004	miss	miss	18.2	20.4	26.8	32	35.4	33.6	30.1	25.2	20.6	7.2
2010	miss	14.4	18.9	23.7	30.1	35.1	36.2	38.1	32.7	25.2	16.9	11.4
2011	8.3	11.2	15.7	21.4	26.9	32.1	35.6	34.6	30.3	22.1	11.6	8.1
2012	7.4	9.9	13.6	23.3	28	33.5	36.1	34.4	30.4	24.6	17.4	11.2
2013	9.6	12.9	17.2	22.5	26.6	32.2	34.1	33.8	29.3	21.2	16.9	7.7
2014	9.6	11.2	17.2	22.7	28.3							

**Station: Haditha element mean RH% from 1985 to 2014**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	79	58	47	38	28	22	18	19	23	33	62	69
1986	64	75	59	46	31	24	20	21	24	41	58	68
1987	58	49	50	34				21	23	46	50	72
1988	80	63	56	52	33	28	22	28	30	48	52	73
1989	72	57	57	35	28	24	19	26	30	37	63	79
1990	60	64	49	44	27	24	26	30	32	40	50	62
1991	76	54	50	35	33	24	27	28	32	49	50	73
1992	69	70	52	38	40	33	29	29	31	35	63	78
1993	77	62	44	53	47	28	24	27	31	43	61	79
1994	82	61	49	42	32	24	26	25	31	48	79	73
1995	79	78	64	48	31	30	28	27	31	39	48	67
1996	80	67	75	50	35		24	28	31	36	58	73
1997	73	55	51	37	30	23	24	29	29	50	80	85
1998	80	68	57	41	34	23	24	24	30	35	49	56
1999	71	59	40	33	24	23	25	26	31	41	52	74
2000	68	49	40	37	28	24	19	24	31	50	56	83
2001	85	73	61	43	36	25	26	30	35	35	49	74
2002	64	57	47	46	30	24	24	26	30	36	61	miss
2003	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss
2004	miss	miss	75	62	56	46	44	47	32	39	69	69
2005	68	72	67	miss	27	miss	miss	miss	miss	miss	miss	miss
2006	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss
2007	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss
2008	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss
2009	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss	miss
2010	miss	59	46	38	29	22	21	20	30	46	46	62
2011	79	62	43	43	37	28	28	30	34	43	60	65
2012	76	61	46	36	33	25	25	26	30	48	65	71
2013	69	72	44	36	45	33	30	32	43	52	79	80
2014	85	67	60	49	38							

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