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The Impact of Climate Change on Moisture Balance and Land Degradation in the Region of Southern Iraq

Ahmad S. Muhaimeed[1*], Mohamed Nassar[2] and Basem Katalan[3]
[1]National Environmental Specialist, UN-Habitat, Baghdad, Iraq.
[2]SDS Project Manager, UN-Habitat, Baghdad, Iraq.
[3]GIS Specialist, Land Management Department, ACSAD-Syria.
[*]Corresponding author email id: email: profahmad1958@yahoo.com

***Abstract* – Iraq struggles with rising temperatures while managing a lack of precipitation, increased dry spells, and facing water shortages and land degradation, along with recurring dust storms. Extreme climate changes significantly affect environmental stability, agricultural yield, and overall sustainability maintenance. The research aims to examine climate change in the southern regions of Iraq and its impact on land degradation and vegetation growth. The research uses global meteorological data combined with satellite imagery to study climatic parameter transformations in southern Iraq from 1981 to 2020 and their consequences on water balance, vegetation growth, and land quality. The research analyses MODIS Vegetation Indices (MOD13) together with 20 satellite images throughout Iraq, from 2000 to 2020. Key climatic variables demonstrate time-dependent and geographic changes across Iraq between 1981 and 2020, impacting water balance and vegetation maintenance while leading to land degradation. The research findings demonstrate concerning temperature growth that ranges from o.76 to 1.62°C per decade, because this rapid temperature increase worsens environmental destruction. Rain levels have been decreasing throughout the years, except in the second decade, which shows a slightly higher rainfall rate. Most of the region receives between 105.25 to 110, 13 mm of the mean annual rainfall. The results revealed that the decline in rainfall level causes a loss in water balance of 169.72 million. Cubic meters in the third decade and 169.66 million. Cubic meters in the fourth decade. The reduced precipitation has led to rising evapotranspiration losses that amounted to -50.32 million m^3 in the first decade, followed by 109.35 million m^3 in the second decade, and finally reaching 119.66 million m^3 in the third decade. The increased aridity index forces greater adverse impacts on vegetation density, which leads to faster land degradation and desertification. The widespread destruction of natural lands has reached more than 98% because of desertification processes and water shortages. The rising climate change dangers to the ecosystems require immediate adaptations for combating desertification and enhancing land administration methods.**

***Keywords* – Climate Change, Desertification, Water Balance, Aridity.**

I. INTRODUCTION

Climate change is defined by the International Panel on Climate Change (IPCC) as any change in the climate over time, which is contributed to by natural causes such as changes in the solar cycle, volcanic eruptions, and human causes resulting from human activities in the atmosphere. Climate change ranks as a globally urgent environmental challenge that science identifies as the most formidable issue for our current century (Omenn 2006; Klare 2019). The ecological systems and agricultural productivity, along with water resources and human health and socio-economic development on Earth, face severe impacts from these adverse consequences, which extend beyond their regional boundaries (Tachiiri et al. 2021). Climate exerts influence over dry land vegetation type, biomass, and biodiversity. The Iraqi Ministry of Environment and the United Nations report that Iraq has been severely affected by climate change in recent years, ranking fifth in the world in terms of vulnerability. Official reports indicate that Iraq loses 100,000 acres of land annually due to desertification, and the water crisis has destroyed 50 percent of its agricultural land. Iraq was exposed to the influence of climate change due to the accumulation of carbon dioxide emissions and a significant increase in their percentage during the last three decades (Jassim et. Al, 2013; Al Ansary et al., 2019).

Iraq is already witnessing the effects of climate change and environmental degradation (IOM, 2022). Temperatures are rising, rainfall is decreasing, droughts are more severe, water scarcity is increasing (World Bank Group, 2017), sand and dust storms, and flooding are more frequent. (Sissakian et al, 2013). Strikingly, temperatures in Iraq are soaring up to seven times faster than the global average, while annual rainfall is predicted to decrease by 9 per cent by 2050 (Salem et al. 2017). Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Rainfall is the most important climatic factor in determining areas at risk of land degradation and potential desertification. Rainfall plays a vital role in the development and distribution of plant life, but the variability and extremes of rainfall can lead to soil erosion and land degradation. Rainfall and temperature are the prime factors in determining the world's climate and, therefore, the distribution of vegetation type (Gringof and Mersha 2006).

Evapotranspiration (ET) is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration refers to the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. Evapotranspiration is an important part of the water cycle (Allen et al., 1989). Generally, 57% of precipitation returns to the atmosphere through evapotranspiration, and this amount may reach 90 to 100% in arid and hyper-arid regions (Heidarnejad et al. 2013). Potential evapotranspiration (ETP) is an important factor in the hydrologic cycle, key role in integrated watershed management practices. The increase in temperature as a result of climate change influences hydrologic parameters such as ET (McKenney and Rosenberg, 1993).

Land degradation is one of the most important consequences of climate change that has socioeconomic repercussions worldwide, particularly (IUCN, 2015). Land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system (Barrow 1994). Natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes which are not fully understood. Interactions between the two systems determine the success or failure of resource management programs. This study aims to analyze the changing patterns of annual precipitation, temperature, PET, aridity, and water balance in the hotspot area of the transboundary SDS formation in southern Iraq, for the period 1981-2020.

Iraq is considered as one of the region's most vulnerable countries to climate changes, and it faces a unique set of environmental degradation and increasing frequency and intensity of extreme weather events, especially sand and dust storms (SDS). Unfortunately, Iraq is one of those countries where dust storms hit and last for days. The events of sand and dust storms are either regional or local. Some regions in southern Iraq are considered as the main active sources for the transboundary dust storm formation. These regions (Hotspot) are located within Al Qadysia, Al Muthana, and Thi Qar governorates. This research aims to analyze the changing patterns of annual precipitation, temperature, PET, aridity, and their impacts on water balance and land degradation in the hotspot area for the period 1981-2020.

II. MATERIAL AND METHOD

2.1. *Geographic location of the Hotspot area:*

The study region is located in three governorates: Al-Kadesyia, Al Muthanaa, and Thi Qar, lying between two latitude circles, 37°-29° north and 48°-38° east longitude, southern Iraq (Figure 1). The study area occupies about 1600 km². The dominant climate condition in the region is arid and hyper-arid, with average annual temperatures varying between 24.24 °C in the northern part (Al Qadisia) and 25.81 °C in the southern part-Thi Qar governorate, with mean annual rainfall ranging from 100 mm to 130 mm (Muhaimeed et al., 2025).

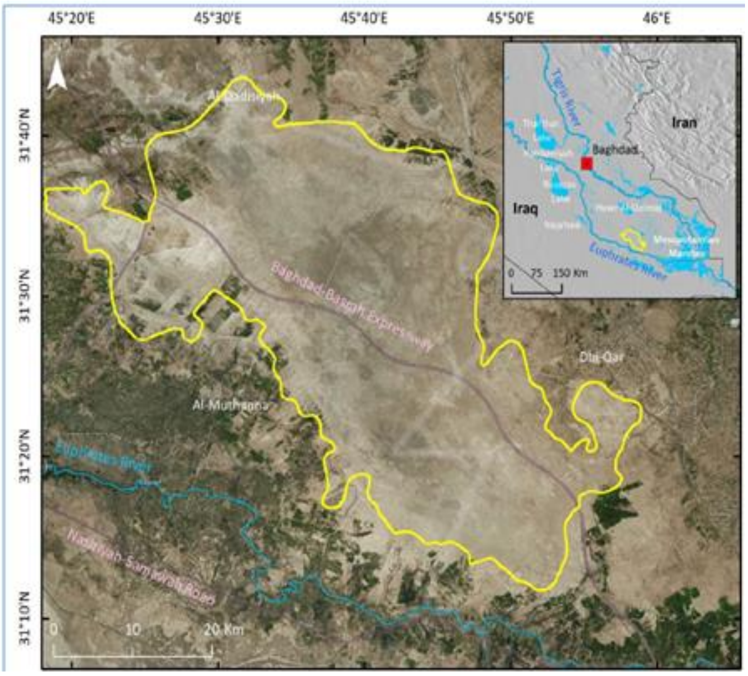


Fig. 1. Location of the study regions.

2.2. *Data collecting, Analysis, and Interpretation*

2.2.1. *Metrological Data*

Climate Research Time (CRU-TS) data were used in this study to generate the required meteorological information. The CRU-TS dataset, with its 50 gridded stations operating at a 0.5 degree interval, permitted thorough climate investigations of the study area from 1981 through 2020. A thorough quality control procedure was applied to this dataset, which established data reliability needed for accurate climate modelling, together with trend analysis (Awadh and 3).

Ahmad 2012; Kumar et al. 2024). The researchers obtained essential climate variables, including monthly average maximum temperature, mean rainfall, and potential evapotranspiration (PET) from the CRU-TS dataset during the specific period. The data went through ArcGIS spatial analytical processes that resulted in the creation of yearly averages for each climatic variable.

Results from spatial processing showed each parameter activity, including temperature changes and rainfall patterns, and PET measurements throughout the region over time. The maps generated help scientists under-stand the changes climate change creates across different regions while permitting identification of zones affec-

-ted by droughts and other environmental stressors.

The analysis of climate data through time series evaluation revealed the identification of growing temperatures plus diminishing precipitation, combined with accelerated evapotranspiration water loss.

One essential element of this examination used the Aridity Index (AI) as an established United Nations Development Programme (UNDP) metric to evaluate dryness levels in regional areas (Haugevik et al. 2021). The Aridity Index represents a calculation that measures precipitation (P) against potential evapotranspiration (PET) rates and produces values from zero to one (Table 1).

A region shows greater humidity when its AI value is elevated because precipitation rates surpass evapotrans-piration amounts, which allows for sufficient water resources to exist. A region presents an arid climate with water scarcity when its evapotranspiration exceeds precipitation, resulting in potential desertification according to a lower Aridity Index value.

Table 1. Aridity Index (AI) and its classifications.

Classification	**Aridity Index**
Hyper arid	$AI < 0.05$
Arid	$0.05 < AI < 0.20$
Semi-arid	$0.20 < AI < 0.50$
Dry sub-humid	$0.50 < AI < 0.65$

This study effectively classified Iraq's climate distribution by analyzing AI values, which offered detailed information about its aridity regions. A region with an AI value that exceeds 0.65 belongs to the humid category, which grants enough water resources to support plant life and agricultural growth. Places that have an AI value between 0.50 and 0.65 fall under semi-humid and semi-arid zones, which present average water supply yet still operate under rainfall variability. Arid regions exist within the AI scale of 0.20 to 0.50 because these areas suffer from severe water shortages, which are worsened by intense evapotranspiration rates. Regions show extreme dryness when their AI measurement equals 0.20 or below, thus experiencing extensive desertification along with scarce vegetation cover.

2.1.1. *Satellite Data*

The MODIS Vegetation Indices (MOD13) products were used with 20 satellite images that covered all the study area from 2000 to 2020 to evaluate plant density evolution patterns and land degradation. The analysis tracked vegetation changes throughout a lengthy period necessary for tracking land degradation patterns. NDVI stands as a common remote sensing index that the researchers used to precisely measure vegetation density in the study area. NDVI represents the difference between satellite imagery obtained from near-infrared (NIR) and red bands, which generates numerical values from -1 to +1. The NDVI measurement produces better results in healthy vegetation areas but shows poor values in places where vegetation is absent, and degenerates or land becomes barren. The research examined seasonal together with long-term plant changes via NDVI-based evaluation, which revealed vegetation health deterioration across areas suffering from serious desertification and land degradation. The NDVI is a normalized transformation of the ratio between near-infrared (NIR) and red reflectance, expressed as (Rouse et al. 1974):

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{1}$$

A simple linear trend approach was applied to analyse possible trends in mean annual temperature, rainfall, and potential ETP during the study period. This methodology allows for an assessment of how climatic factors have influenced vegetation dynamics and land degradation over time.

III. RESULTS AND DISCUSSIONS

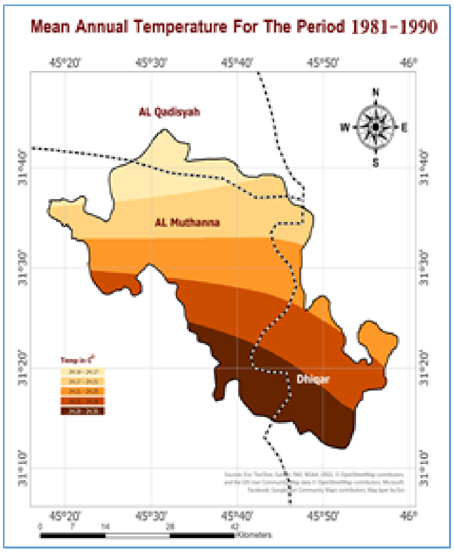
3.1. *Spatial and Temporal Changes of Annual Temperature in Iraq for the period 1981-2020*

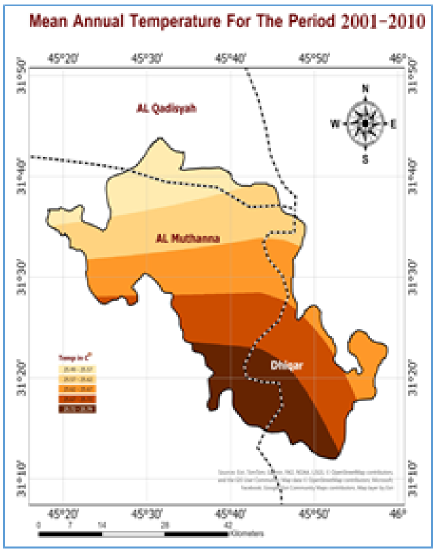
Temperatures in Iraq exhibit substantial daily, seasonal, and long-term variations due to the country's geographical location. This positioning results in pronounced continental climatic conditions, ranging from extreme continental to very arid climates (Adamo et al. 2018). The temperature distribution across Iraq is strongly influenced by topographical features, with elevation playing a significant role in shaping local climate conditions. Additionally, the type of air masses affecting the region contributes to temperature variations, further impacting the country's overall climate dynamics (Iraq IOM, 2022).

Generally, the results indicate a slight increase in the average mean annual temperatures over time for the period 1981-2020. As shown in Table 2, the average annual temperatures for the minimum, maximum, and range have increased gradually over the last four decades. Additionally, temperatures exhibit a spatial trend, increasing from the southern parts to the northern parts of the region. The total area with a high mean annual temperature (above 24°C) decreases from the Southern to the Northern parts of the region (Figure 2).

Table 2. Average Mean annual minimum temperature in Iraq for the period 1981-2020.

Period	Min °C	Max- °C	RANGE	Mean °C
1981_1990	24.10	24.35	0.26	24.24
1991_2000	24.82	25.19	0.37	25.01
2001-2010	25.49	25.79	0.30	25.65
2011-2020	25.63	25.96	0.33	25.81





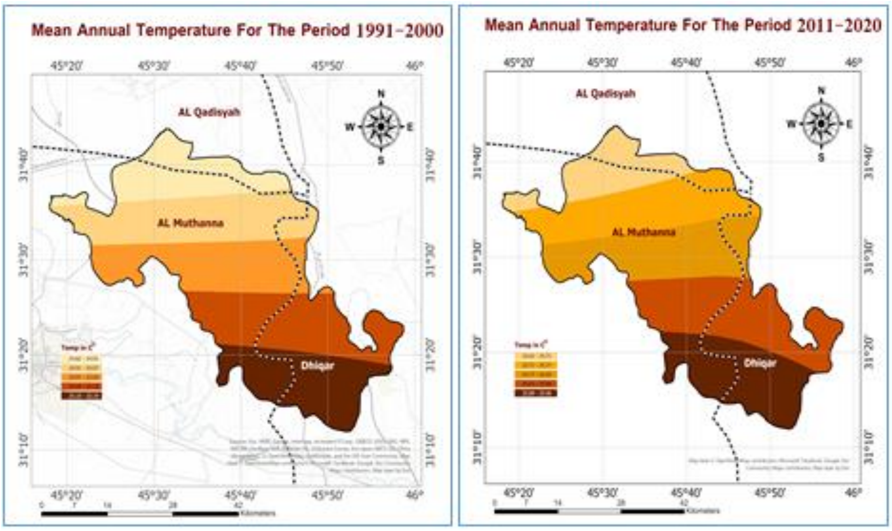


Fig. 2. Spatial and Temporal Distribution of average mean annual Temperature in the Hotspot area for the period 1981- 2020.

To calculate the average increase in mean annual temperature from 1981 to 2020, meteorological data from 1981 to 1990 were used as the baseline for comparison. This approach enabled an assessment of temperature variations over the four decades. Overall, the rate of increase in mean annual temperature indicates both temporal and spatial differences, ranging from 0.3°C to 1.7°C, with variations observed across different decades (Table 3).

The results (Figure 3) show a consistent decline in mean annual temperature from the southeast to the northwest. This trend is primarily due to higher relative humidity levels in northwestern Iraq, which is influenced by its proximity to the Mediterranean Sea and the related climatic conditions. The analysis confirms significant variations in both space and time regarding the rate of temperature increase throughout the study period, with notable differences observed among the three decades examined.

The most recent decade (2011-2020) shows the highest temperature increase, ranging from 1.2°C to 1.7°C. In contrast, the period from 1991 to 2000 experienced the lowest increase, ranging from 0.3°C to 1.0°C. These findings emphasise the combined effects of natural and human-related factors that contribute to global warming and rising temperatures across Iraq.

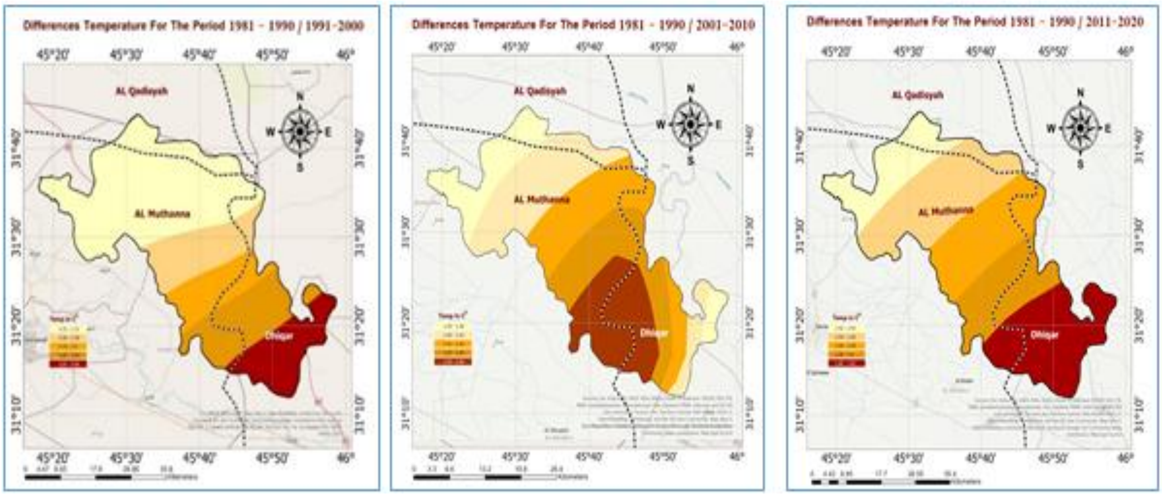


Fig. 3. Temporal and Spatial distribution of temperature rise rate in the hotspot area during the period of 1981-2020.

Table 3. Temporal and spatial temperature rising rate for the last three decades.

1991-2000		2001-2010		2011-2020	
Rising Rate °C	**Area %**	**Rising Rate °C**	**Area %**	**Rising Rate °C**	**Area %**
0.76	47.51	1.40	20.42	1.54	14.74
0.78	13.67	1.41	19.88	1.56	25.74
0.80	10.25	1.42	20.99	1.58	19.95
0.83	15.47	1.43	18.56	1.60	15.57
0.86	13.10	1.45	20.14	1.62	24.00
	100.00		100.00		100.00

A straightforward statistical analysis shows both positive and negative trends in the increasing mean annual temperature over time (Figure 4). Some periods display a consistent rise in temperature, while others show only minor fluctuations. These trends reflect the impact of regional climatic factors and the larger dynamics of global climate change on Iraq's temperature patterns. Additionally, projections from the World Meteorological Organization (Abtew and Melesse 2012) suggest that global mean near-surface temperatures for the period from 2024 to 2028 are expected to be between 1.1°C and 1.9°C above the 1850-1900 baseline. This reinforces the urgent need for climate adaptation and mitigation strategies in the region. Given these trends, Iraq is likely to continue experiencing intensified heatwaves, prolonged droughts, and desertification. Therefore, it is essential to implement policy interventions, adopt sustainable land-use practices, and invest in climate resilience.

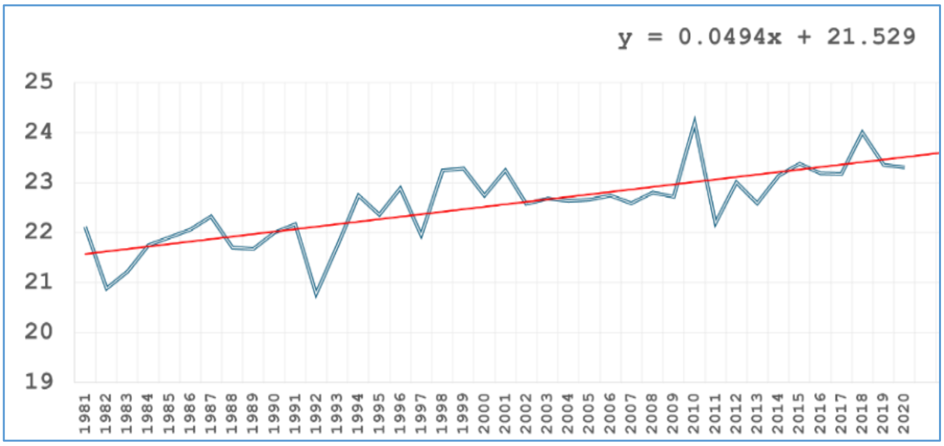


Fig. 4. Statistical trend in mean annual temperature changes with time in Iraq during the period 1981-2020.

Iraq has experienced a rising annual mean temperature pattern that matches worldwide temperature increases during the past four decades (Salman et al. 2019). According to the Intergovernmental Panel on Climate Change (IPCC 2021), global warming develops from atmospheric greenhouse gas buildup that triggers extensive climate-related disruptions. The MENA region, alongside vulnerable areas including South Asia and sub-Saharan Africa, has demonstrated similar warming patterns, which resulted in reduced crop production, together with increased water loss through evapotranspiration and serious water shortages (Alrteimei et al. 2022; Moisa et al. 2025). The speed of temperature growth that Iraq experiences displays a clear southern bias, which expresses wider regional trends influenced by landforms and water bodies, plus atmospheric movements.

3.2. *Analysis of the Spatial and Temporal Distribution of Mean Annual Rainfall from 1981 to 2020*

Precipitation levels in Iraq, including the study region, display considerable variability both spatially and temporally, primarily due to the Mediterranean climate. Rainfall typically starts in October, reaching its peak in December, January, and February. The results presented in Table 4 indicate a declining trend in the mean annual minimum, maximum, and average rainfall in the study regions from 1981 to 2020, except for the second decade, which shows an increase in the rainfall with time. The mean annual rainfall increased from 110.13 mm in the first decade to 122.07 mm in the second decade, and decreased to 105.30mm and 105.28mm in the third and the last decades, respectively. In contrast, the mean annual minimum and maximum rainfall show the same trend as the mean annual rainfall. These findings underscore the ongoing changes in Iraq's precipitation patterns, which have important implications for water resource management, agriculture, and efforts to control desertification. Additional research is needed to identify the main factors driving these changes, including climate change, shifts in regional atmospheric circulation, and human-induced environmental alterations.

Table 4. Changes in average annual rainfall in the study region from 1981 to 2020.

Period	**Min, mm**	**Max.mm**	**Range**	**Mean mm**
1981-1990	103.98	116.25	12.27	110.13
1991-2000	116.21	130.50	14.29	122.07
2-01-2010	100.75	110.14	9.39	105.30
2011-2020	99.57	110.67	11.10	105.28

Meteorological data (Table 5 and Figure 5) show the spatial distribution of average mean annual rainfall for the baseline period of 1981 to 1990, highlighting slight regional variations. During this time, the mean annual rainfall in the study region varied between 104 mm and 116 mm, with rainfall levels increasing as one moves north and northeast. Generally, the average mean annual rainfall in the area decreases with time, except for the second decade, which shows a slight increase in the mean annual rainfall, with precipitation levels increasing toward the north and northeast. These findings parallel a general trend of rainfall distribution in Iraq (Muhaimeed et al. 2025). According to NUPI (2022), Iraq’s precipitation is highly variable both seasonally and regionally. The north and northeast receive the highest amount of rainfall. These findings highlight the slight differences in precipitation patterns across regions, emphasizing the challenges water scarcity poses in the southern regions of Iraq. According to Running et al. (2017), Iraq's rainfall is highly variable both seasonally and regionally. These findings highlight the significant differences in precipitation patterns across Iraq, emphasizing the challenges of water scarcity faced by the central and southern regions.

Table 5. Mean annual rainfall and total amount of water in the region during the period of 1981-2020.

1981-1990			**1991-2000**			**2001-2010**			**2011-2020**		
Rainfall mm/y	**Total Amount (m.m^3)**	**Area (km^2)**	**Rainfall mm/y**	**Total Amount (m.m^3)**	**Area (km^2)**	**Rainfall mm/y**	**Area (km^2)**	**Total Amount (m.m^3)**	**Rainfall m.m^3**	**Total Amount (m.m^3)**	**Area (km^2)**
104	0.001	0.01	118	13.65	115.7	102	68.1	6.94	100	1.76	17.6
106	12.67	119.5	120	35.79	298.3	104	400.3	41.63	102	20.11	197.2
108	28.98	268.3	122	48.19	395.0	106	525.1	55.66	104	30.54	293.6
110	44.76	406.9	124	46.74	377.0	108	426.1	46.02	106	47.92	452.1

1981-1990			1991-2000			2001-2010			2011-2020		
Rainfall mm/y	**Total Amount (m.m³)**	**Area (km²)**	**Rainfall mm/y**	**Total Amount (m.m³)**	**Area (km²)**	**Rainfall mm/y**	**Area (km²)**	**Total Amount (m.m³)**	**Rainfall m.m³**	**Total Amount (m.m³)**	**Area (km²)**
112	40.22	359.2	126	33.78	268.1	110	177.0	19.47	108	37.79	349.9
114	32.68	286.7	128	13.62	106.4				110	31.48	286.2
116	18.10	156.0	130	4.68	36.0						
	177.41	1596.6		196.47	1596.5		1596.5	169.72		169.60	1596.5

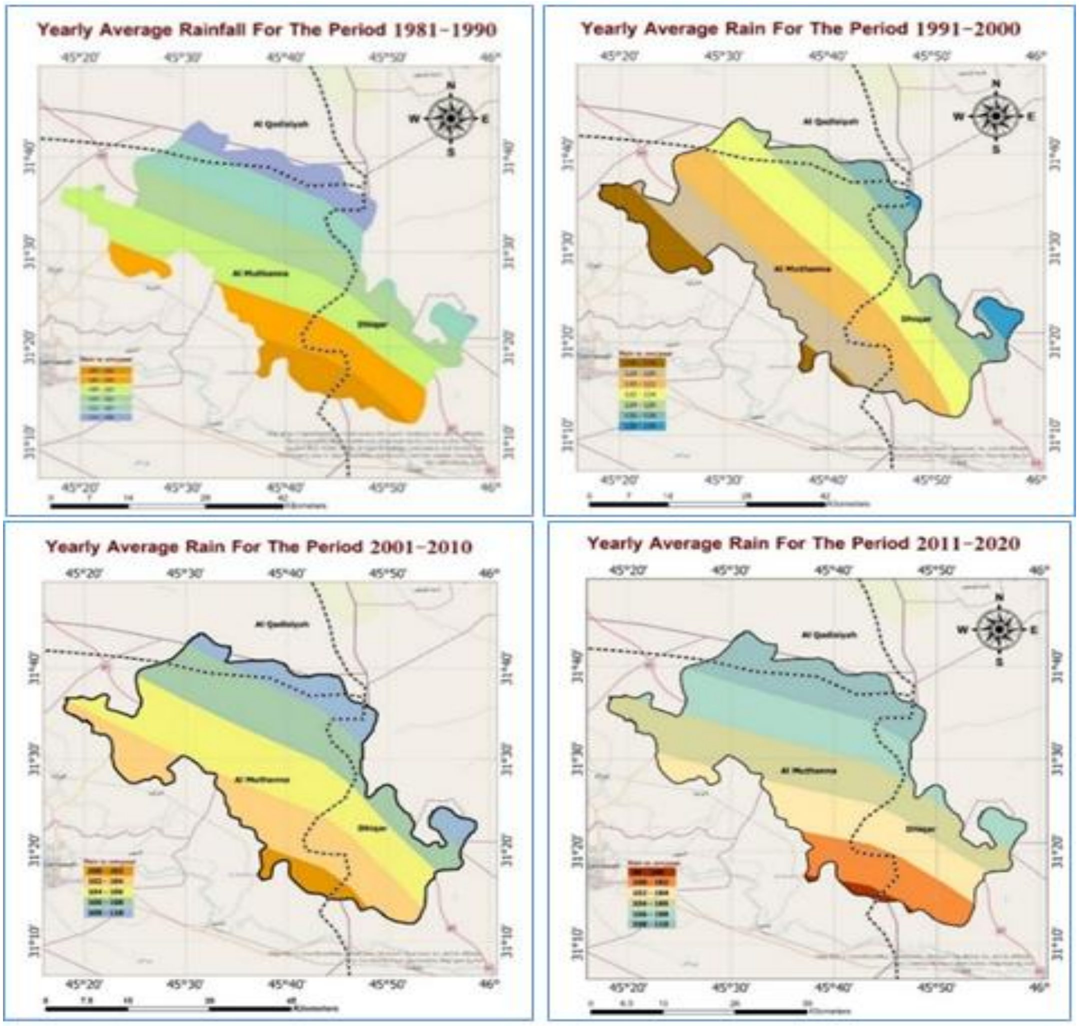

Yearly Average Rainfall For The Period 1981-1990
Yearly Average Rain For The Period 1991-2000
Yearly Average Rain For The Period 2001-2010
Yearly Average Rain For The Period 2011-2020

Fig. 5. Spatial and Temporal change of the average mean annual Rainfall in the Hotspot area during the period 1981-2020.

An analysis of rainfall data compared to the baseline (1981-1990) with subsequent decades shows temporal and spatial variations in rainfall. The rates of change range from -7 mm per year in the last decade to +17 mm per year in the second decade. Additionally, the results indicated the spatial and temporal variations from decade to decade throughout the period from 1991 to 2020 (Table 6 and Figure 6). The decline in rainfall during the last two decades has caused a loss of about 35.45 million cubic meters of water.

The results of statistical analyses (Figure 7) illustrated the negative relationship between the mean annual rainfall and time for the period 1981-2020. It can be noted that some periods display a consistent decline in rainfall, while others show only minor fluctuations. These trends reflect the impact of regional climatic factors and the larger dynamics of global climate change on Iraq's temperature patterns. The supplementary impacts of climate change have led to reduced precipitation because of changing weather patterns. Iraq faces additional difficulties in rainfall predictions because its geography consists of desert regions and semi-arid areas combined with various land altitudes. Located in the Middle East region, which shows maximum vulnerability to climate change, Iraq faces precipitation changes that affect different parts of the country at different levels. The decline of precipitation in certain areas leads to dual effects of diminished agricultural yields while intensifying water resource demand, which impacts all communities, including farmers and urban residents.

Table 6. Differences in the average annual rainfall for the period 2011-2020/1981-1990.

1991 -2000			**2001 -2010**			**2011 -2020**		
Rainfall Changes mm/y	**Area (km)**	**Water Balance m.m³**	**Rainfall Changes mm**	**Area %**	**Water Balance m.m³**	**Rainfall changes mm/y**	**Area %**	**Water Balance m.m³**
8	11.01	0.09	-6	183.33	-1.10	-7.00	21.27	-0.15
9	99.21	0.89	-5	549.28	-2.75	-6.00	606.01	-3.64
10	253.82	2.54	-4	507.60	-2.03	-5.00	861.75	-4.31
11	212.14	2.33	-3	341.10	-1.02	-4.00	107.56	-0.43
12	259.58	3.12	-2	15.26	-0.03			
13	267.53	3.48						
14	179.47	2.51						
15	146.76	2.20						
16	138.34	2.21						
17	28.67	0.49						
T: 125	1596.53	19.86	- 20	1596.58	-6.93	- 21	1596.59	- 8.52

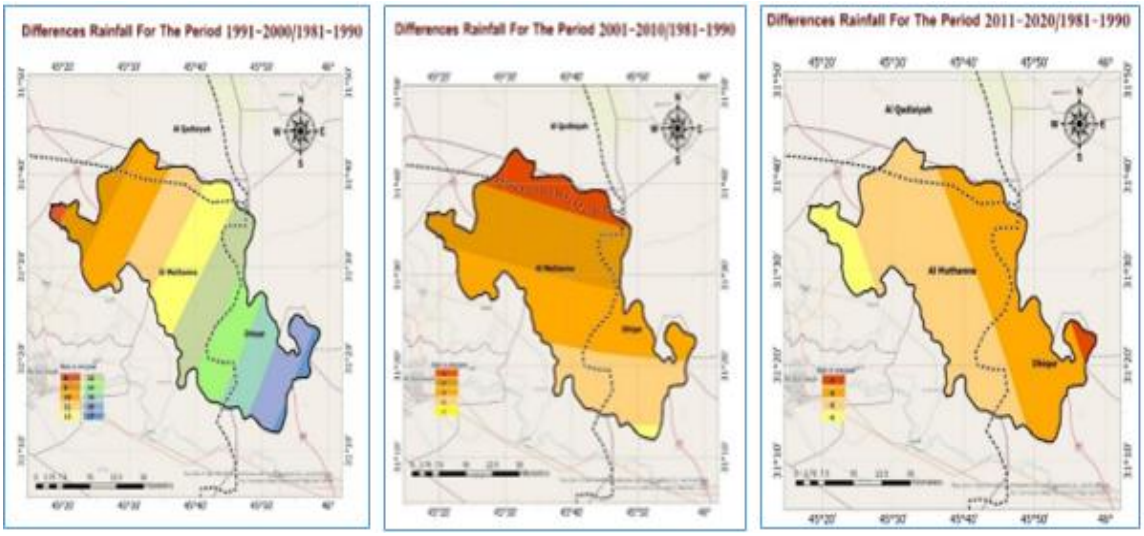


Fig. 6. Spatial and Temporal change of the average mean annual rainfall in the region during the period 1981-2020.

A straightforward statistical analysis (Figure 9) shows a positive trend in the decreasing mean annual rainfall over time (Figure 3). Some periods display a consistent rise in rainfall, while others show only minor fluctuations. These trends reflect the impact of regional climatic factors, mainly temperature and vegetation, and the larger dynamics of global climate change on Iraq's temperature patterns. Precipitation variability serves as a crucial factor in this study, which strengthens the worries regarding hydrological stability in the region.

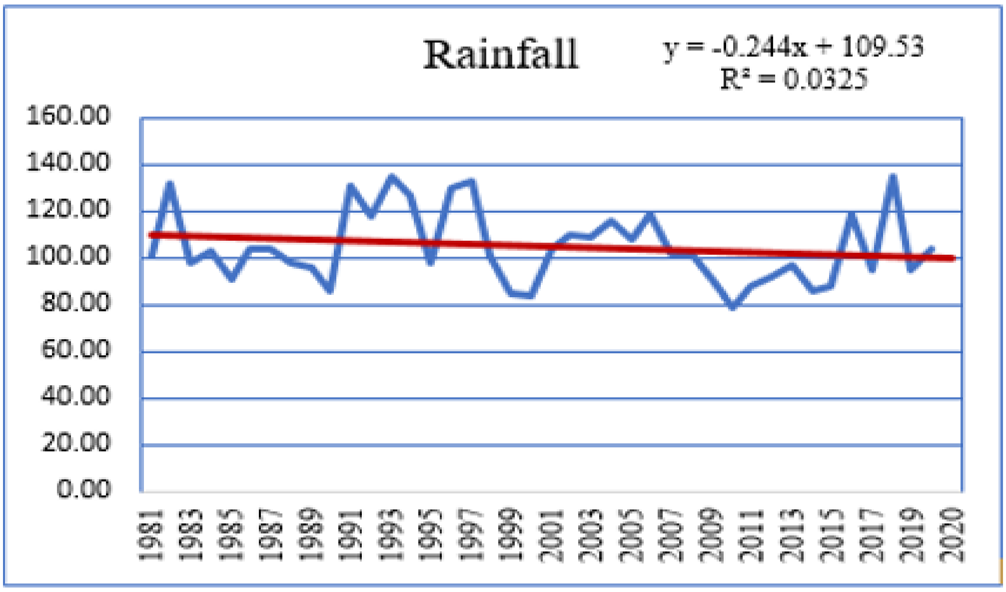


Fig. 7. Statistical trend in mean annual rainfall changes with time in Iraq during the period 1981-2020.

3.3. *Analysis of the Spatial and Temporal Distribution of Mean Annual PET from 1981 to 2020*

Evapotranspiration (ET) contributes to the loss of a substantial amount of rainfall globally, with the percentage of loss varying by location (Agnew and Anderson 2024). ET refers to the total evaporation that results from soil evaporation and vegetation transpiration (Huang et al. 2017). It is essential for the energy and mass exchange among soil, water, plants, and the atmosphere, making it a critical factor in the hydrogeological budget (Alam et al. 2020). The main climatic factors that influence evapotranspiration (ET) are solar radiation, wind speed, relative humidity, and temperature. Additionally, the type of vegetation and soil moisture levels play significant roles in determining ET rates (MacPherson 2019). Evapotranspiration leads to the loss of water and moisture from water bodies, soil, and vegetation surfaces. As such, it is a crucial component of the water balance and essential for irrigation planning in any region.

The results indicate that the average mean annual potential evapotranspiration (PET) in the study region has consistently increased over four decades (Table 7). Specifically, the average mean annual PET rose from 2395.33 mm during the first decade (1981-1990) to 2472.52 mm in the third decade (2011-2020). This increase is primarily attributed to the rise in the mean annual temperature, as previously discussed. Moreover, the rise in the evapotranspiration (ET) is affected by the growth of vegetation cover and surface water during hotter seasons, especially summer, when elevated temperatures lead to increased water loss.

Table 7. Changes in average annual PET in the study region from 1981 to 2020.

Period	**Min_ mm**	**Max_ mm**	**Mean mm**
1981_1990	2362.56	2424.11	2395.33

Period	Min_ mm	Max_ mm	Mean mm
1991_2000	2394.74	2455.51	2426.32
2001_-2010	2440.68	2502.58	2472.52
2011-20_20	2439.25	2495.61	2469.30

The results presented in Table 8 and Figure 8 indicate a variation in the rate of increase in the average mean annual of ETP and the total amount of water lost by ETP for the four decades from 1981 to 2020. The total amount of water lost increased from 3832.4 million cubic meters in the first decade to 3950.5 million cubic meters for the last decade. Less than 3.2% of the total area of the study region had a potential evapotranspiration (PET) value below 2370 mm, and this area decreased over time. In contrast, more than 95% of the region's total area had PET values ranging from 2380 mm to 2,420 mm during the same period. Additionally, areas with PET values exceeding 2,420 mm accounted for 3.1% of the total land area in 1981-1990, which increased to 5.5% in the last decade.

The rising trend in water loss due to PET (Potential Evapotranspiration) spans from the northern regions to the southern parts of the region. This variation is influenced by several factors, including temperature, vegetation density, soil moisture, wind speed, and the availability of surface water. Each of these parameters plays a significant role in determining the total water loss through soil evaporation and vegetation transpiration. As temperatures increase, evapotranspiration also goes up. In recent years, human activities have induced an increase in atmospheric carbon dioxide (CO2), which leads to global warming and climate change (IPCC, 2001; IPCC, 2007).

Table 8. Average mean annual values for PET in the study region during the period 1981-2020.

1981-1990			1991-2000			2001-2010			2011-2020		
PET mm/y	**Total Amount of Water Lost (m.m³)**	**Area %**	**PET mm/y**	**Total Amount of Water Lost (m.m³)**	**Area %**	**PET mm/y**	**Total Amount of Water Lost (m.m³)**	**Area %**	**PET mm/y**	**Total Amount of Water Lost (m.m³)**	**Area %**
2370	102.6	3.1	2400.0	53.36	1.4	2450	163.12	4.2	2440	1.43	0.01
2380	496.3	13.2	2410.0	492.46	12,8	2460	684.14	17.4	2450	245.1	6.3
2390	851.8	22.1	2420.0	894.36	23.1	2470	946.86	24	2460	811.3	20.7
2400	890.5	23.1	2430.0	852.82	22	2480	904.02	22.8	2470	1006.3	25.5
2410	773.3	25.3	2440.0	778.66	19.9	2490	714.36	18	2480	945.8	239
2420	598.0	15.2	2450.0	609.92	15.6	2500	490.86	12.3	2490	722.4	18.2
2430	119.9	3.1	2460.0	200.25	5.2	2510	52.20	1.3	2500	218.2	5.5
Total	3832.4			3881.8			3955.6			3950.5	

A straightforward statistical analysis (Figure 9) shows a positive trend in the increasing mean annual ETP over time. Some periods consistently rise in ETP, while others show only minor fluctuations. These trends reflect the impact of regional climatic factors, mainly temperature and vegetation, and the larger dynamics of global climate change on Iraq's ETP patterns. The study reveals elevated evapotranspiration levels as the key indicator of worsening water balance deficit that scientists worldwide have started to recognise as a common pa-

-ttern among affected regions.

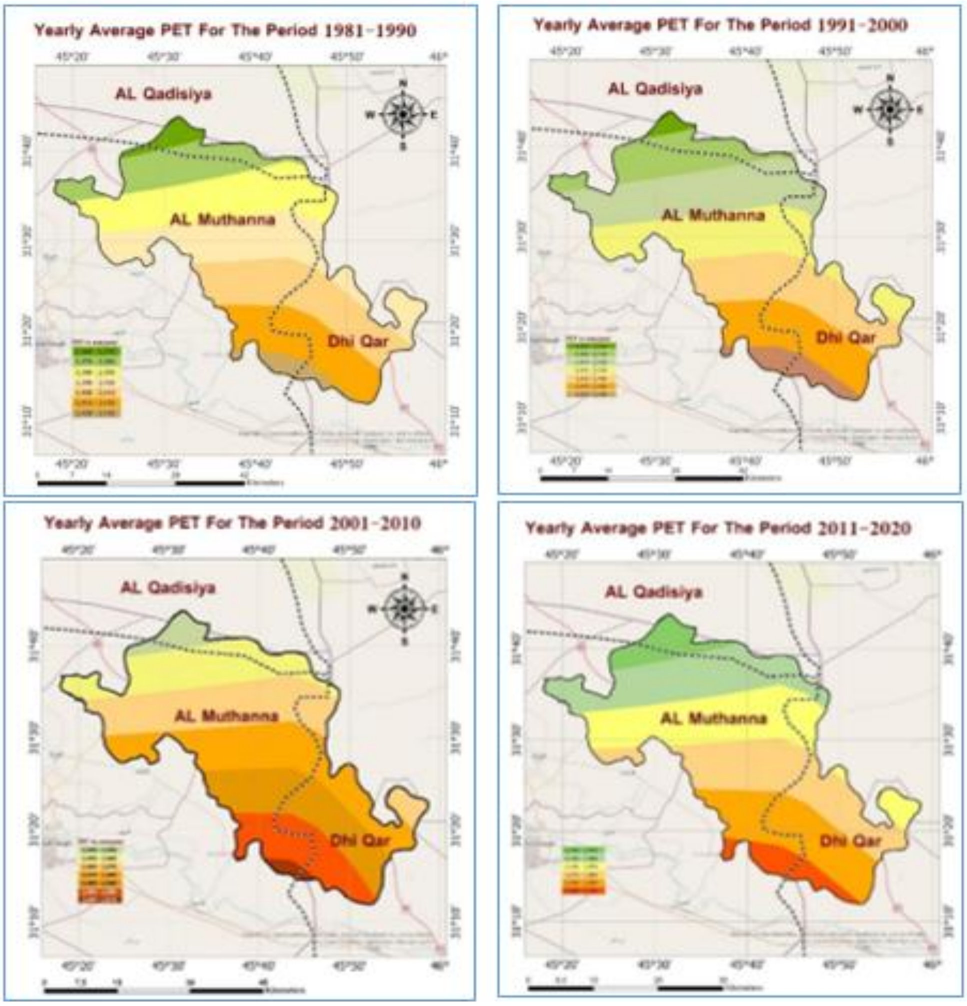


Fig. 8. Spatial and Temporal distribution of the average mean annual PET in the study region during the period 1981- 2020.

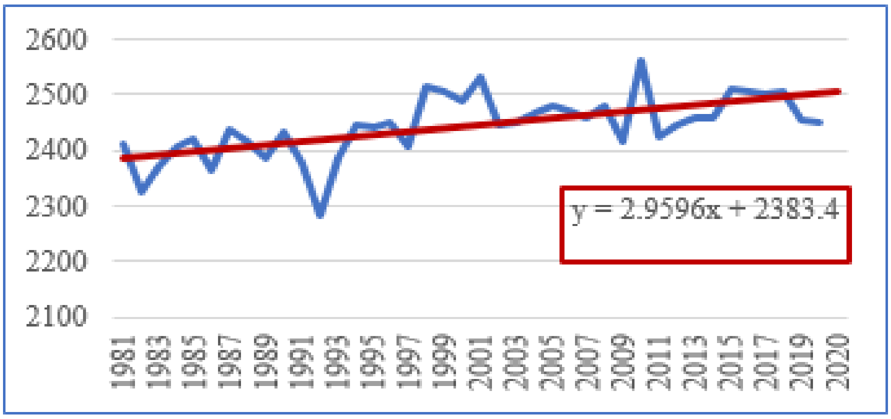


Fig. 9. Statistical trend in mean annual ETP changes with time in Iraq during the period 1981-2020.

The results (Table 9 and Figure 10) illustrate the differences in the mean annual PET from 1991 to 2020 compared to the first decade. Generally, the differences in the total amount of water lost by ETP increased from the second to the third, then decreased in fourth decade (50.32, 124.38, and 119.66 million cubic meters for the last three decades, respectively). These findings are mainly due to the increase in the mean annual temperature with time.

Table 9. Differences in the mean annual PET from 1991 to 2020 compared to 1981-1990.

1991 -2000		2001 -2010		2011 -2020	
ETP Changes mm/y	**Water Balance m.m^3**	**ETP Changes mm**	**Water Balance m.m^3**	**ETP Changes mm/y**	**Water Balance m.m^3**
30.00	4.61	74.00	4.21	72.00	11.98
31.00	25.85	76.00	11.65	74.00	45.56
32.00	10.79	78.00	77.77	76.00	53.49
33.00	5.87	79.00	30.730	78.00	8.64
34.00	3.20				
Total	50.32		124.38		119.66

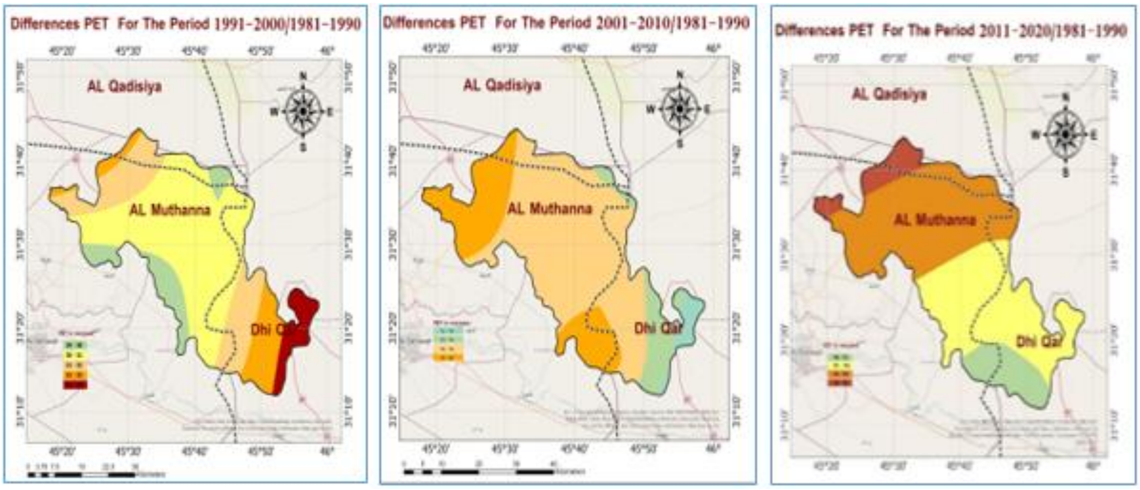


Fig. 10. Spatial distribution for Differences in the Rising Rate of PET compared to the baseline 1981-1990.

The study reveals elevated evapotranspiration levels in the study region as the key indicator of worsening water balance deficit that scientists worldwide have started to recognize as a common pattern among affected regions. The Murray-Darling Basin of Australia and the United States share the same finding that increasing PET leads to lower soil moisture storage and causes agricultural harm through crop damage and worsening land conditions (Al-Kaisi et al. 2013; Dadzie et al. 2023). The situation in Iraq demands urgent attention regarding these changes since the country depends on scarce water supplies, which will worsen due to increased PET rates and reduced precipitation levels.

IV. ARIDITY INDEX CHANGES FOR THE PERIOD 1981-2020

Iraq is one of the countries significantly impacted by increasing aridity. Aridity is defined as a lack of moisture, often accompanied by a consistent shortage of rainfall (Agnew and Anderson, 1992). It describes a situation in which a region experiences a severe lack of available water, particularly due to the permanent absence of rainfall or extreme dryness resulting from insufficient precipitation. Aridity is measured by the Aridity Index (AI), which quantifies the level of dryness in a specific location. Recently, aridity events, exacerbated by climate change, have emerged as significant socio-environmental challenges. These events harm ecosystems and human livelihoods across various regions worldwide. Aridity continues to present a major and persistent challenge for many global regions (Huang et al. 2017).

Generally, the result indicated that the most dominant aridity classes in the study region are the hyper-arid class (Figure 11) identified using gridded climatic data to calculate the Aridity Index (AI) for the period from 1981 to 2020, following the methodology outlined by (12). The results (Figure 9) indicate that Iraq predominantly experiences a Hyper-Arid climate, except for the second decade, which shows the presence of Arid and Hyper-Arid climates in the study region. These findings align with those reported by (Al-Awadi and Ahmad, (2012).

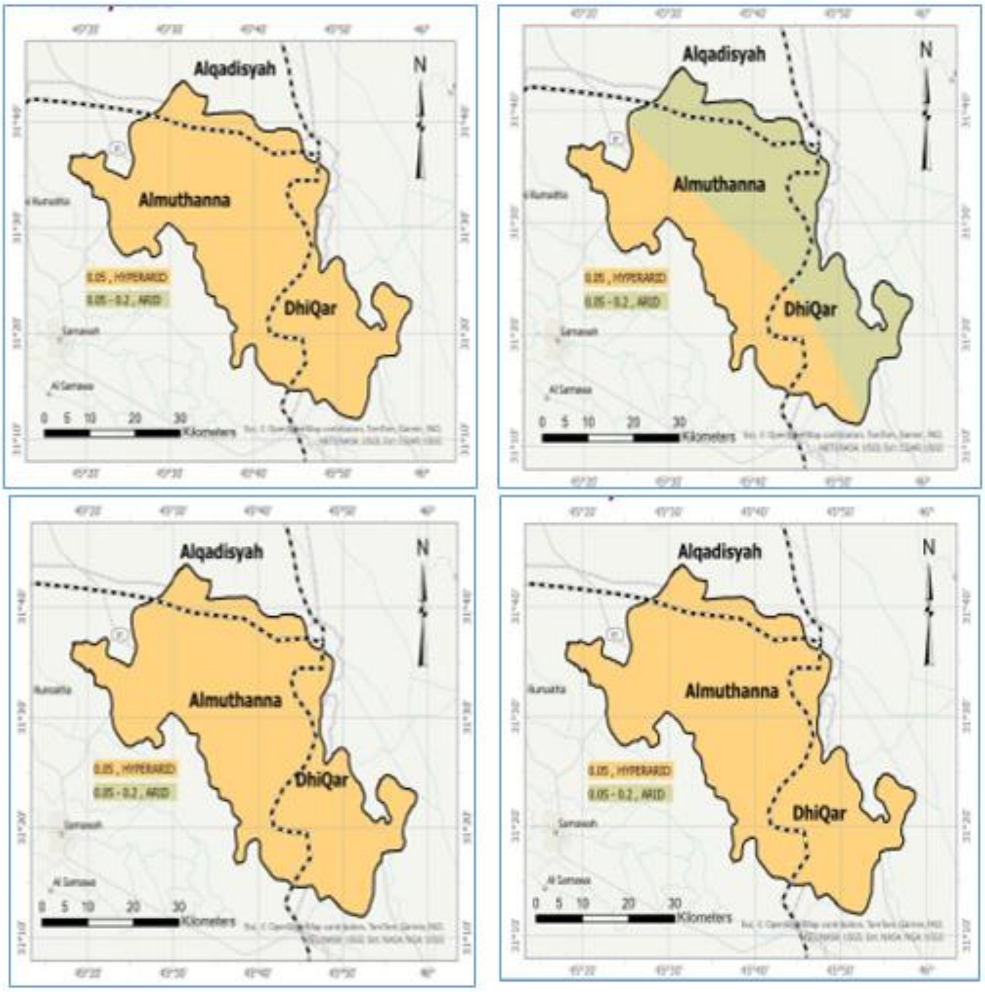


Fig. 11. Spatial distribution of Aridity index in Iraq for the period 1981-2020.

The United Nations Convention to Combat Desertification (UNCCD) identifies the widespread expansion of drylands as an acute and continuing effect of climate change, which endangers food systems alongside biodiversity and livelihood sustainability (Jain et al. 2024). Multiple studies have identified the same arid to hyper-arid environmental transition, which affects large Iraqi territories as well as North African regions and Central Asian territories (Lioubimtseva et al. 2005; Huang et al. 2016). The ecological situation in Iraq has become dangerous because the baseline remains weak despite previous damage from grazing animals and tree clearing, and ill-advised land management activities.

V. WATER BALANCE

The study region, suffering from extremely dry climatic conditions characterized by high temperatures, low rainfall, and significantly high evapotranspiration, has experienced water shortages. The results confirmed the negative impact of climate change on water availability in the region. This has significantly impacted vegetation health. The result in Table 10 confirms that Evapotranspiration (ET) highly contributes to the loss of a substantial amount compared to rainfall for all decades, with loss varying by location in the study region. The total amount of water lost by rainfall decline, and the increase in ETP is 299.15 million cubic meters during the last three decades compared to the first decade (baseline). Additionally, the total amount of water lost increased from 70.18 m.m³ in the second decade (1991-2000) to 117.51 and 111.52 m.m³ for the third and fourth decades, respectively. These findings revealed that increasing PET leads to lower soil moisture storage, land degradation, desertification, and causes agricultural harm through crop damage and worsening land conditions (Al-Kaisi et al. 2013; Dadzie et al. 2023). The study region, suffering from extremely dry climatic conditions characterized by high temperatures, low rainfall, and significantly high evapotranspiration, has experienced water shortages.

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Table 10: Impact of Climate Change on Water Balance for the period 1981-2020.

	Amount of Water Lost (Million Cubic Meters)			
	1991-2000	**2001-2010**	**2011-2020**	**Total**
Rainfall	19.86	-6.93	- 8.52	4.41
ETP	50.31	124.38	119.66	294.35
Total	70.18	117.45	111.52	**299.15**

VI. IMPACT OF CLIMATE CHANGE ON VEGETATION DENSITY AND LAND DEGRADATION (2001-2020)

The Normalized Difference Vegetation Index (NDVI) is the most used method to assess vegetation cover, serving as an indicator of green biomass. The interaction between the Land surface and the atmosphere involves multiple processes and feedback mechanisms, all of which can vary simultaneously. Precipitation and temperature influence the potential distribution of terrestrial vegetation, play a crucial role in soil formation and evolution, and affect the timing of grazing, which historically supports a nomadic lifestyle. The study utilised NDVI measurements from the MODIS sensor to study vegetation densities and land degradative patterns throughout Iraq. A thorough examination of the study region's vegetation development was achieved through satellite data acquisition from 2001 to 2020, monthly. Mean NDVI values between 2001 and 2020 confirmed that the region has a weak and limited vegetation cover in some locations that constitute 2% of the total area of the study area, represented by the cultivation area. Bare lands are the dominant type of land use which occupying about 98% of the total area due to water security. The bare land mostly consists of sand dunes (main-

-ly in the eastern part), sand sheets, and some saline soils.

The results indicated that some vegetation changes occurred across different years through the data presented in Figure 12 and Table 11. The seasonal agricultural methods employed by farmers create in very small area that affects vegetation development alongside land condition degradation. The NDVI ranges from 0.0 to 0.7. Most of the region is non-vegetated land areas, accounting for 93% of the total land territory, even though they exist within the NDVI range of 0.0 to 0.15. The areas without substantial vegetation occur naturally because of dry climatic conditions, sequences of Aeolian erosion and deposition, desertification, sand dunes, sand sheet, along with human-caused bare land and water-filled regions. Most of the region (98%) constitutes a degradation over a wide extent because land degradation runs rampant within these regions. The area containing weak agricultural and natural vegetation amounts to less than 6% of the region's total landmass and falls within NDVI ranges from 0.30 to 0.70. The dominant natural vegetation consists of drought and salt-tolerant types, including Tamarix and Shokalsham.

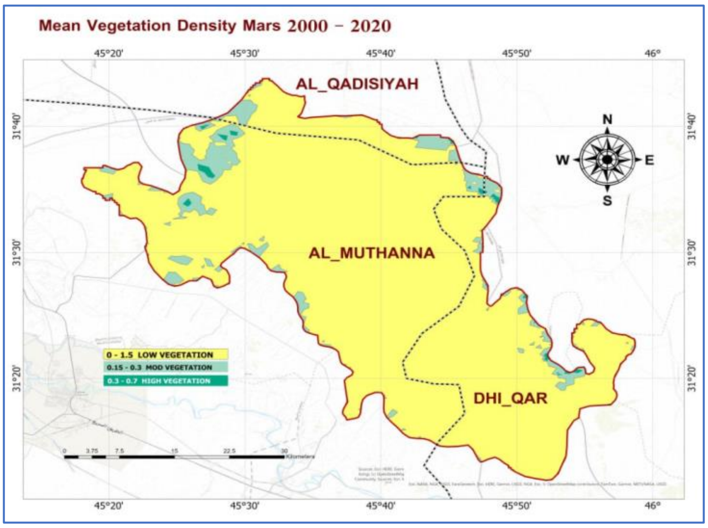

Fig. 12. The average mean NDVI values for March during the period 2000-2020.

Table 11. The average mean annual NDVI for the study region from 2001-2020.

Mean NDVI	Area (km)	Area %
0.15	1485.17	93.02
0.30	103.93	6.51
0.70	7.45	0.47
Total	1596.56	100.00

VII. CONCLUSIONS AND RECOMMENDATIONS

The study area, Southern Iraq, is facing rapid climate change, with annual temperature increases ranging from 0.68°C to 1.72°C per decade. This temperature rise, combined with reduced rainfall and increased soil moisture loss due to rising potential evapotranspiration (PET), has led to a significant decline in water availability, severely affecting vegetation health and reducing vegetation cover density. These climatic conditions are further accelerating desertification and land degradation, with disruptions to regional water cycles intensifying the environmental challenges. Variability in rainfall patterns and increasing temperatures have disrupted the balance between water inflow and outflow, resulting in higher rates of evaporation and evapotranspiration, thereby exacerbating the effects of water scarcity and land degradation across the country. To counter these challenges, preserving and restoring vegetative cover is essential. Greenbelt projects aimed at preventing soil erosion and land degradation are critical in maintaining soil fertility and ecosystem integrity. Moreover, the creation of oases in desert and arid regions can play a pivotal role in mitigating the impacts of climate change on biodiversity by establishing microenvironments that support both vegetation and wildlife. Supporting farmers in areas vulnerable to desertification is also a key strategy to combat rural migration through the provision of drought-resistant crops, advanced irrigation technologies, and financial support to improve agricultural resilience.

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AUTHOR'S PROFILE

First Author

Prof. Dr. Ahmad Salih Muhaimeed, received B.S degree in Soil Science from Baghdad University in 1974, and M.S in Soil Survey and Classification from the University of Nebraska-Lincoln, USA in 1978. Have Ph.D. in Soil Survey from Colorado State University, USA in 1981. He served as lecturer of soil survey and land management in the following universities: Salahaldeen, Mosul and Baghdad. He worked as Head of soil science and water resources and the Desertification Combat Department, college of Agriculture at Baghdad University as well as the Council Secretariat of Agriculture College. Having 35 years of experience in academics. Presented Many papers in national and international conferences. Published five text books and more than 125 papers. He served as supervisor for more than 30 graduate students in the area of Soil Survey and land management using GIS and Remote Sensing. He was nominated as a soil sciences expert member in FAO-ITPS, 2015-2018, and a National consultant with FAO-Iraq. He worked at the Arabic Center-ACSAD as an expert in land classification and management and the director of the Land Management and Water Uses Dept, 2018-2022. He joined the work with UN-Habitat -IRAQ as a National Environmental Specialist in 2022.

Second Author

Mohamed Nassar, is a climate change specialist and Programme Management Officer with the United Nations Human Settlements Programme (UN-Habitat), focusing on sustainable land and water management in climate-vulnerable and conflict-affected regions. With advanced degrees in Sustainable Energy Policy, Project Management, and Engineering, and certifications including PMP, CEM, and LEED Green Associate, he brings a multidisciplinary approach to climate resilience. As UN-Habitat Iraq's climate change focal point, he leads initiatives that integrate adaptation into rural development, particularly in southern Iraq and Kuwait. He manages a USD 13.1 million project on transboundary sand and dust storm mitigation, supporting climate-resilient agriculture, early warning systems, and water access. His work bridges climate science with scalable, low-carbon solutions and advances nature-based strategies, sustainable resource management, and net-zero goals. He focuses on translating global climate commitments into local action that enhances both livelihoods and ecological resilience.

email id: Mohamed.nassar@un.org.

Third Author

Engineer Mohammed Basem Qatlan, a Geographic Information Systems (GIS) expert, holds a BA in Agricultural Sciences from Damascus University in 1984, a postgraduate diploma in Geographic Information Systems from Vrije Universiteit Amsterdam, the Netherlands, in 1997, and a Master's degree in Geographic Information Systems from the University of Salford, England. He is Head of the Geographic Information Systems Unit, Remote Sensing and Geographic Information Systems Laboratory, at the Arab Center for Strategic Studies (ACSAD). He worked in the Ministry of Agriculture in Syria in the field of land survey and classification from 1987 to 1991, and in the agricultural ecosystems project in Syria. He has more than 10 published scientific papers. He served as a national consultant for the United Nations Convention to Combat Desertification (UNCCD) in preparing the National Drought Strategy for Syria. He has conducted numerous training courses in several Arab countries. email id: bkatlan80@gmail.com