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# Geomatic Environmental Alteration Monitoring of Climate Change, Socioeconomic Stressors, And Policies Performances In Iraq

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## Abstract

Greenhouse gas emissions that are causing global warming and changing the climate of the planet have already influenced the total environment and its unique ecosystems worldwide. Declining precipitation, increasing temperature and evapotranspiration are a direct reflection of climate change.

Whereas declining surface-water bodies, drought, and decreasing vegetation canopies are consequences of environmental degradation in many countries around the world. A case study from Iraq's environmental alteration, as an extreme example of nature and human interactions, shows the degradation of surface water volumes and the total greenness canopies. However, most of the existing literature has focused on the human impact only, particularly socioeconomic development and wars, as the main cause of the environmental fall of Iraq's ecosystems. Thus, it is a call to establish a balanced understanding of local and regional influences of global warming within such ecosystems at the landscape scale under governmental policies performances. Methods used in this study, include remotely sensed imagery, metrological datasets and related analytic tools and indexes. Analytic indexes including NDVI, SVI, PDSI, SPI and SPEI have been utilized to investigate the existing situation. The results indicated that the country is facing extreme drought and general environmental degradation except for some temporary periods (2003-2007 and 2020). According to the SVI time series, drought was obvious and most of the SVI values were below 0 which indicates dry periods. The NDVI analysis showed a clear increase in overall drought within the study site. Environmental degradation is a symptom of global warming, and population growth has put a strain on natural resources and the environment worldwide. Remote sensing analytic tools have the potential to represent human development and achievable environmental sustainability goals to prevent more harm to the environment.

**Keywords:** Geoinformatics, environmental management, climate change, human settlement, sustainability.

# 1. Introduction

Environmental degradation is a process in which the natural environment is harmed somehow resulting in a reduction in eco-biosystems diversity and the total environmental health (Rice, 2003; van Bruggen et al., 2019; Stonich, 2021; Chen et al., 2022). The main factors that cause environmental degradation is the climate change and the human activities (Xu et al. 2011). Climate change has already occurred, its impact is clearly noticeable, and in several parts of the world this impact is rapidly increasing (Seddon et al., 2020). Consequently, natural disasters are increasingly and aggressively happening due to this impact (Al-Nasrawi et al., 2018b). Drought and water scarcity are among the most significant elements of the environment that have been impacted by climate change (Berbel and Esteban, 2019; Kadhim et al., 2021). Therefore, agriculture, food security and human health are directly impacted due to these changes (Hannah, 2021). On the other hand, since 2018, the concentration of carbon dioxide in the Earth's atmosphere has reached 407.8 parts per million (ppm) (Abdullah, 2021), according to the World Meteorological Organization (WMO). It is roughly 47% higher than in the pre-industrial era, shattering all previous records in human history (Merlone et al., 2019).

According to the Ministry of Agriculture in Iraq, degradation of agricultural land and environmental degradation in Iraq was due to natural causes including drought, desertification, water scarcity and high temperatures caused by climate change. On the other hand, human factors, including inappropriate land management and poorly designed irrigation systems, the construction of dams on the Tigris and Euphrates Rivers, and the government policies that forced farmers to abandon their farmlands, have all added to the problem.

Many previous studies have attempted to explain why agriculture and vegetation cover in Iraq have deteriorated. (Al-Timimi et al.,2013) explored drought frequency in Iraq from 1980 to 2010. The remotely sensed Drought Severity Index (DSI) was used to assess drought trends in Iraq and determine the most vulnerable areas (Jawad, Al-Taai, Al-Timimi, 2018). Price (2018) argued that the strength of evidence regarding environmental degradations in Iraq is uneven.

Therefore, this study aims to monitor and investigate Iraq's environmental degradation issues. Also, finding a reachable geoinformatics dataset can be utilised to discover the environmental degradation factors influenced by natural and artificial environmental stressors.

# 2. Study area

Iraq has historical and geographical importance in the middle east. Iraq has a total area of 438,317 km2 situated between latitudes 29.5° and 37.22° north of the equator, and longitudes 38.45° and 48.45° east of the Greenwich line, astronomically. The Tigris and Euphrates Rivers are the most important sources of freshwater in Iraq, with the world's most important ancient civilizations, such as Sumerian, Assyrian, and Babylonian, located on their banks (see figure. 1).

The desert climate has had an impact on Iraq. Summer is distinguished by high temperatures, which can reach up to 48°C in July and August. A wet period occurs between December and April, and, on average, the country receives about 100-180 mm of precipitation per year. Iraq's mountain regions receive the most rainfall of any region.


**Fig. 1.** *Study area*

The country has three climate zones. A Mediterranean climate affects the mountainous areas in north-eastern Iraq. The coldness and accumulation of snow on the peaks of these mountains are the most distinguishing features of the weather in these areas. The annual rainfall ranges from 400 to 1000 mm. Its summer is moderate, with temperatures not exceeding 35°C. A second climate zone is the semi-arid/steppe climate, which exists between the Mediterranean and desert climate zones. It has an impact on the country's northern and southern regions. The annual precipitation ranges from 200 to 400 mm. The third climate region is the arid/desert climate. This climate affects the sedimentary plain and western plateau regions. It covers 70% of the total land area of the country. It becomes extremely hot in summer, but winters are mild. However, freezing temperatures have been recorded on some winter nights.

# 3. Materials and methods

### *3.1. Data*

A series of metrological and spectral reflectance data for Iraq were used in this study. The metrological data from 01-01-2001 to 01-12-2020, acquired from various sources, were used to derive some metrological and vegetation indices which are widely used for drought monitoring. Data have been accessed and downloaded via the Google Earth Engine (GEE) platform (https://earthengine.google.com) and processed using the R program (https://www.rstudio.com). For example, a time series of daily precipitation (Funk et al., 2015), and a time series of monthly minimum and maximum temperatures were used to calculate a time series of metrological indices including the Precipitation Condition Index (PCI) (Alahacoon and Edirisinghe, 2022), Palmer Drought Severity Index (PDSI) (Huang et al., 2022), the Standardized Precipitation Index (SPI) (Sutanto and Van Lanen, 2022) and the Standardized Precipitation Evapotranspiration Index (SPEI) (Faye, 2022). Furthermore, the Normalized Difference Vegetation Index (NDVI) (Al-Nasrawi et al., 2018a) was used to derive the Standardized Vegetation Index (SVI) (Juntakut, P., 2021) which is used for drought monitoring purposes.

### *3.2. Metrological indices*

*The metrological PDSI was developed by (Palmer, 1965) and it uses readily available public data including precipitation, temperature, and the local Available Water Content (AWC) of the soil. It has been widely used for long-term drought monitoring for specific areas over various time intervals. For this study, the time series of monthly PDSI was directly acquired from TerraClimate (Monthly Climate and Climatic Water Balance for Global Terrestrial Surfaces, University of Idaho) at a 4638.3 m spatial resolution for the entire study area via GEE. The PDSI was averaged for the entire study area for each time step and plotted to explore the trend from 2001 to 2020 (figure. 2). It has been reported that the PDSI tends to create exaggerated frequency of extreme wet or dry events. Therefore, the self-calibrating Palmer Drought Severity Index (scPDSI) is an improved version of the PDSI as proposed by Wells et al. (2004). The scPDSI calibrates the behavior of the index automatically for each location to create index values that are comparable between diverse metrological regions (van der Schrier et al., 2013). The scPDSI was also calculated based on monthly precipitation of Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) and monthly potential evapotranspiration (PET) which was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) as a total of eight days PET at a 500 m spatial resolution. The PET was averaged for the entire study area for each month and combined with the monthly precipitation to calculate the monthly scPDSI.*

PCI is another metrological index that reflects drought conditions (Han et al., 2020) (Eq. 1). The PCI was also calculated using CHIRPS data (Funk et al., 2015) which provides an estimate of daily precipitation where the daily precipitation grids were averaged to give monthly precipitation. Then the time series of the monthly precipitation was used to extract the maximum and minimum precipitation that were used to calculate the monthly PCI from 2001 to 2020 (figure. 4).

$$\text{PCI} = \frac{P - P_{min}}{P_{max} - P_{min}} \quad (1)$$

where P is the precipitation, and Pmax and Pmin are the maximum and minimum precipitation, respectively.

The SPI is a widely used index to monitor metrological drought on a range of time scales. The SPI can be calculated using monthly precipitation data. Positive values of SPI indicate wet conditions whereas negative values indicate drought conditions. In this study, the SPI (figure. 5) was calculated for 3 and 12 months to capture drought in the short and long terms, respectively. Daily precipitation data from CHIRPS have been used to calculate the SPI index where the monthly average precipitation has been calculated for the entire study area to calculate the SPI. The SPEI is similar to the SPI, however, it accounts for the evapotranspiration to reflect the changes in surface water balance (Al-Nasrawi et al., 2021; Pei et al., 2020). Similar to the calculation of the SPI, SPEI was calculated for 3 and 12 months.

Furthermore, the SVI was also calculated to evaluate the vegetation dynamics, which can be another indicator of drought. The SVI was calculated based on the EVI, which was acquired from MOD13Q1 at 250 m spatial resolution and 16 days intervals. The SVI is based on a calculation of the z-score deviation from the mean in units of the standard deviation (Eq. 2).

$$\text{SVI} = \frac{EVI_{ijk} - \overline{EVI_{ij}}}{\sigma_{ij}} \quad (2)$$

where $EVI_{ijk}$ is the EVI value for pixel *i* in the period *j* for a year *k*, $\overline{EVI_{ij}}$ is the long term mean of EVI for pixel *i* in the period *j*, and $\sigma_{ij}$ is the standard deviation of EVI in for pixel *i* in the period *j*. Moreover, the mean for 5 years (from 2000 to 2020) of NDVI va lues was calculated for the entire study area to visually assess the impact of long-term drought on the vegetation cover.

# 4. Results

## *4.1. Metrological indices results*

According to the results obtained from the PDSI and scPDSI, there were two peaks for wet periods around 2003 and 2019 (figure. 2). However, the PDSI showed few wet periods before 2005, around 2006, around 2014, and after 2019. Whereas dry periods were mainly between 2007 and 2013 as well as between 2014 and 2019. These wet and dry periods were the results of various climatic and human-made reasons that have happened in Iraq.

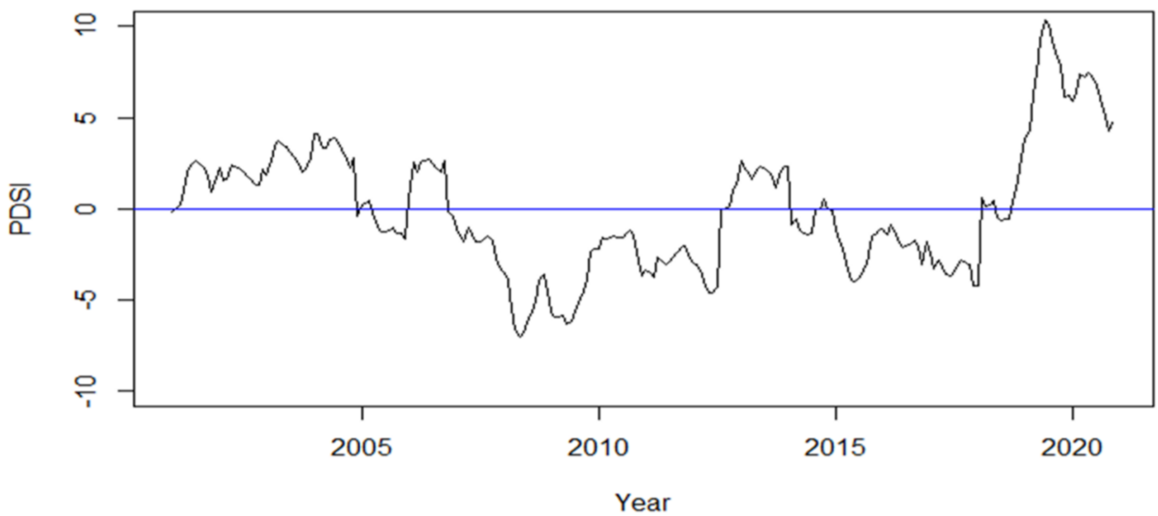


**Fig. 2.** *PDSI for Iraq for the period 2001-2020*

The scPDSI showed similar patterns as the PDSI (figure. 3), however, the scPDSI exhibited a smoother line. Similar to the PDSI, the scPDSI showed that there were wet periods especially after 2002 and after 2019. Whereas the intense drought happened between 2007 and 2013 with a less intense drought between 2015 and 2019.

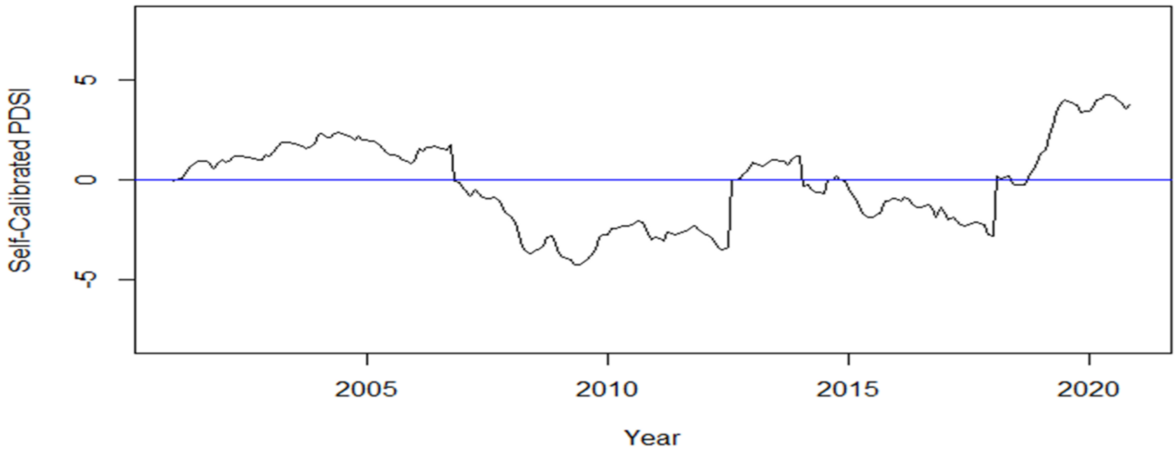


**Fig. 3.** *Self-calibrated PDSI (scPDSI) for Iraq from 2001-2020*

According to the SPI and SPEI indices, Iraq has experienced some wet and dry events along the 19 years (figure. 4). It seemed that the drought was not contributed by the precipitation (figure. 5) even though that climate in Iraq is relatively dry. In contrast, Iraq has experienced wet conditions after 2003 and these conditions were related to changes in the surface water including surface water of marshlands (Al-Ansari et al., 2012; Al-Nasrawi et al., 2021) and rivers (Abdullah et al., 2015; Yousuf et al., 2018). Furthermore, dry conditions have happened before 2003 and between 2015 and 2020, and these dry periods have happened due to the shortage of surface water as mentioned earlier. The SPI and SPEI, which were calculated based on a 3-months window, might not be suitable for monitoring vegetation and agricultural drought clearly, however, the 12-month SPI and SPEI might be more suitable to show those conditions. According to the 12-months SPEI and 12-months SPI, two major wet periods have occurred in 2003-2005 and in 2020 in Iraq which were caused by releasing water in the marshes (Abbas et al., 2020), and probably the increased wet conditions in the catchment area during these periods (Al-Ansari, 2019; Jawad and Qasim, 2021).

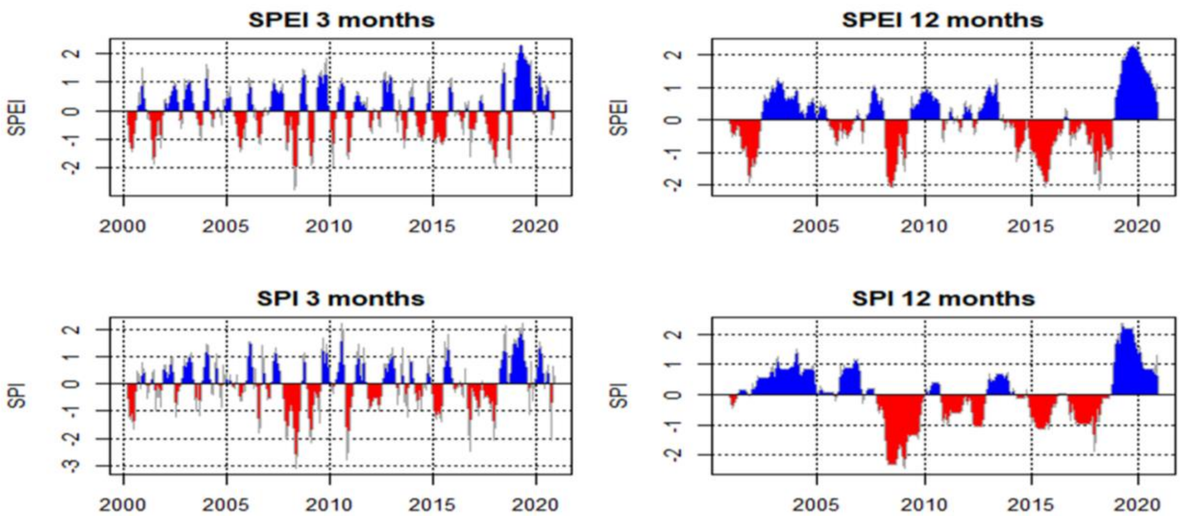


**Fig. 4.** *SPI and SPEI calculated for 3- and 12-month intervals*

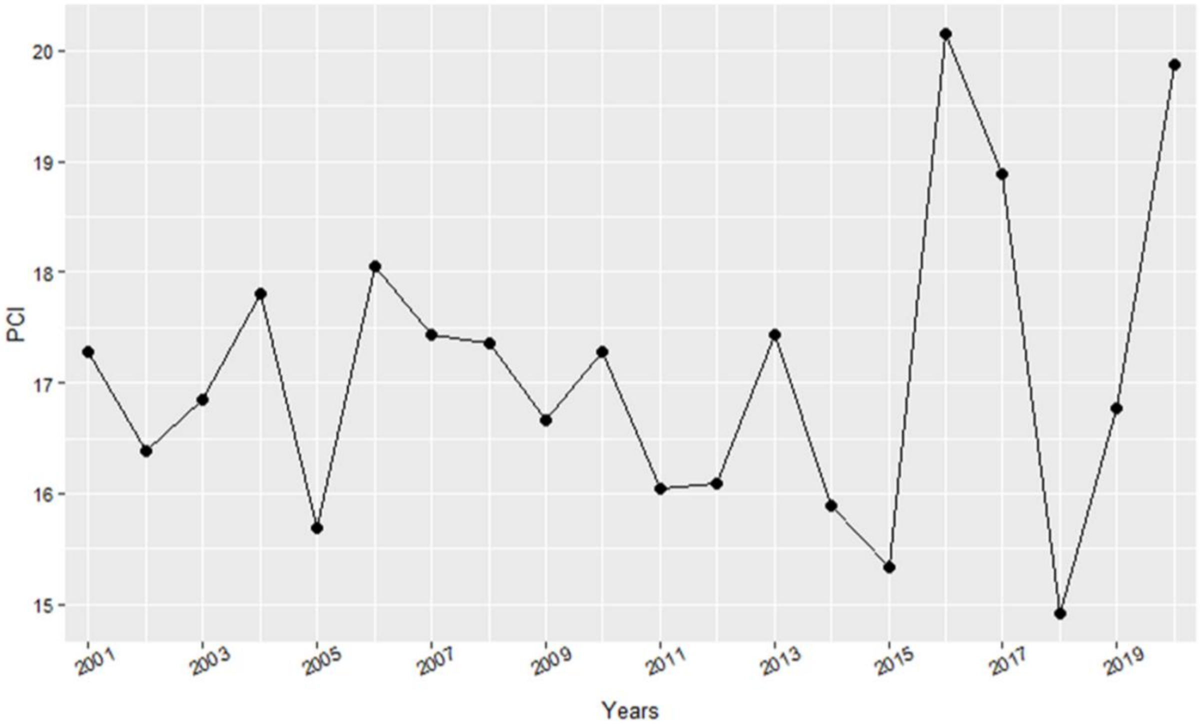


**Fig. 5.** *Annual PCI values for Iraq*

According to the SVI time series (figure. 6), wet periods have occurred in 2014 and 2019. In the other years, drought was obvious and most of the SVI values were below 0 which indicates dry periods.

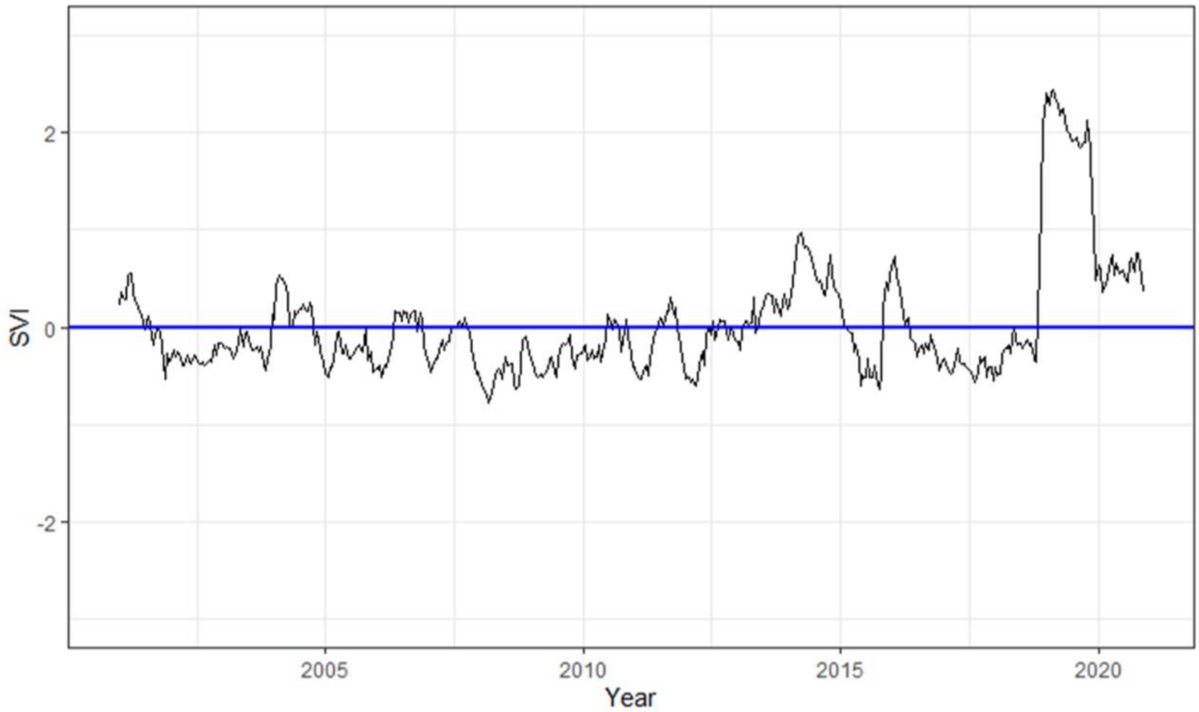


**Fig. 6.** *SVI values for Iraq from 2001-2020*

The NDVI showed a general drought over the study site with periods between 2001-2005 and 2015-2020 that showed more greenness than the period between 2005-2015 (figure. 7). This was expected since the SPEI and SPI showed wet periods during 2001-2005 and 2015-

2020. However, even though the SPEI and SPI showed some wet periods around 2010 and 2015 (figure. 4), drier vegetation cover can be seen between 2005 and 2015 and this was due to the long-term average NDVI shown in Figure 7.

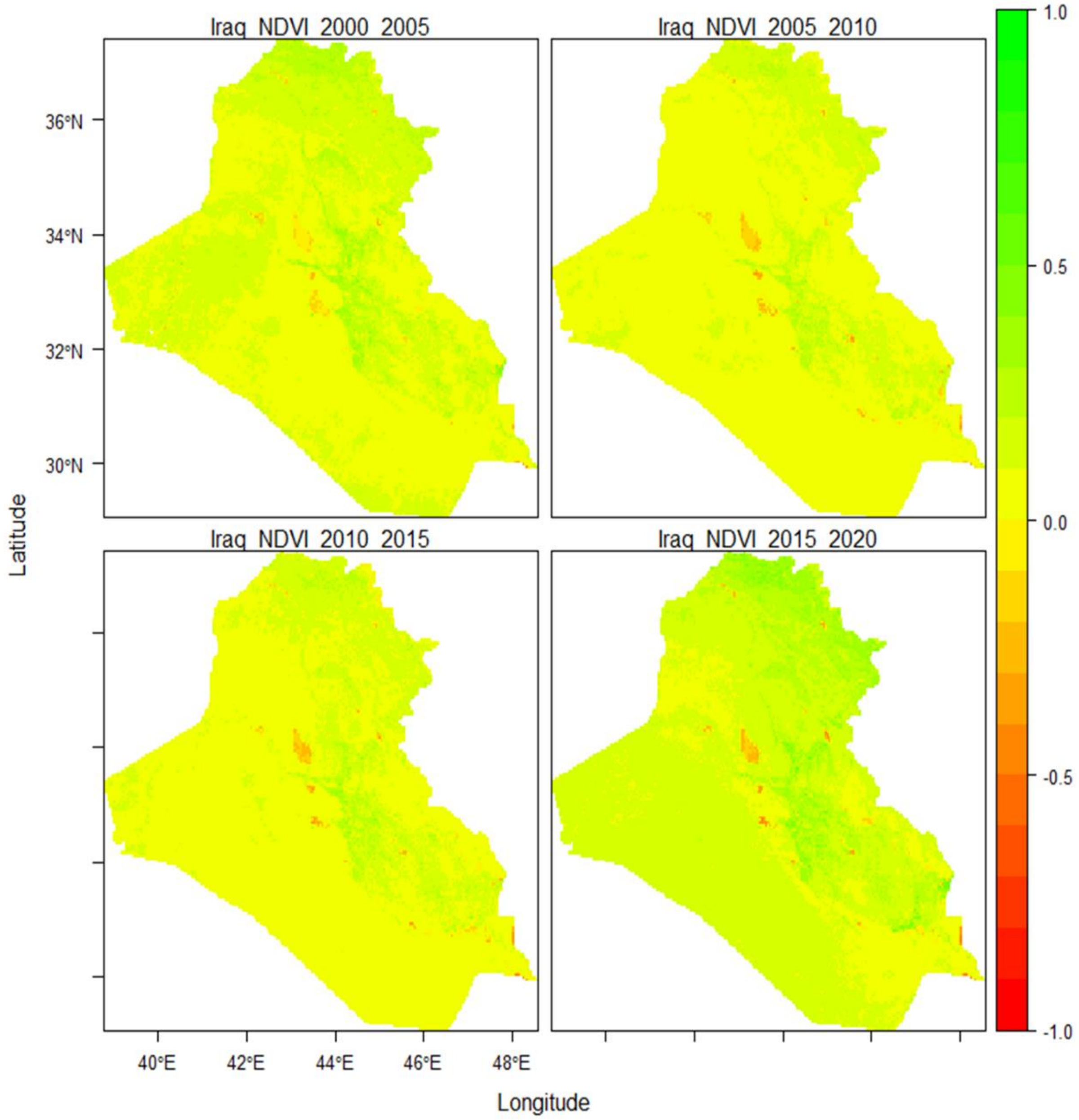


**Fig. 7.** *Long term average NDVI from 2000 to 2020*

### *4.2. Rainfall is decreasing*

Agriculture in Iraq has been weakened due to rising temperatures, declined precipitation, desertification, severe droughts, salinization, and the growing frequency of dust storms (Hassan et al., 2018). Rising temperature (figure. 9), declining in precipitation especially between 2008 and 2011 (figure. 8), and increased water scarcity, have long-term consequences on the natural system productivity in Iraq.

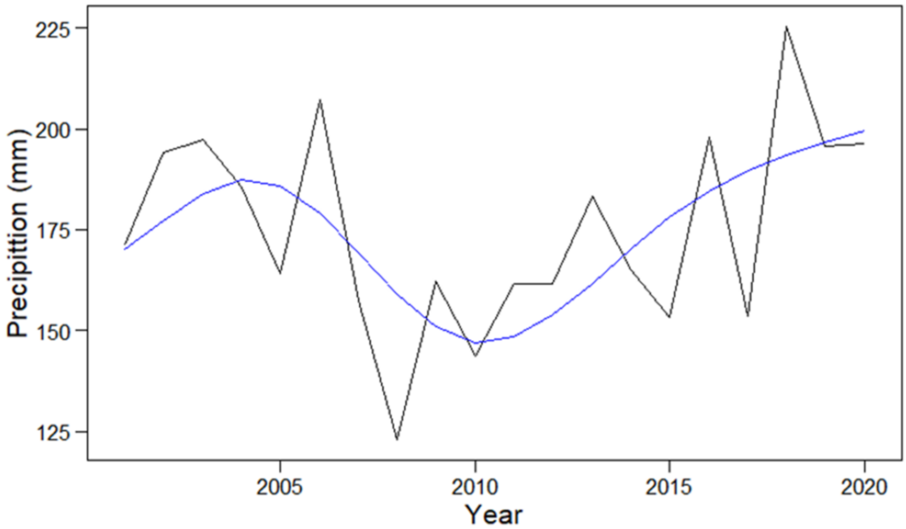


**Fig. 8.** *Time series of annual precipitation in Iraq between 2001 and 2020. Blackline represents the time series of annual precipitation, while the blue line represents smoothed time series of precipitation*

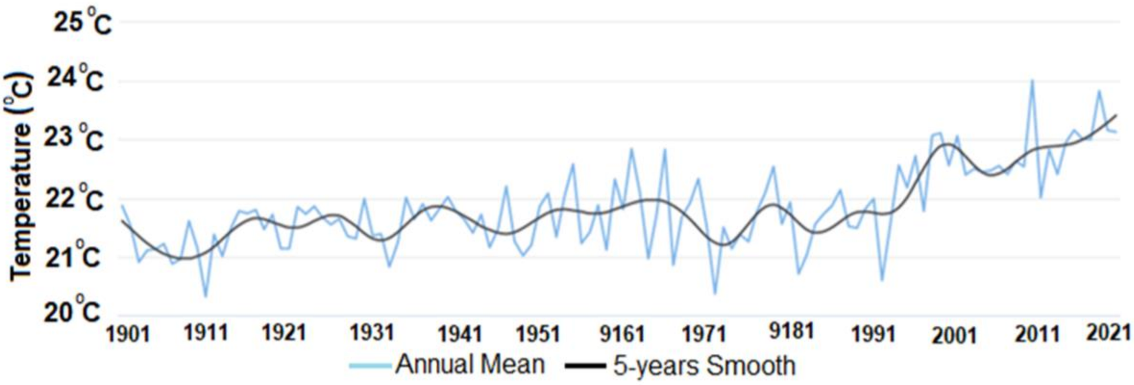


**Fig. 9.** *The annual mean temperature in Iraq from 1901 to 2020*
**Source:** *https://climateknowledgeportal.worldbank.org/country/iraq/climate-data-historical*

Surface temperature rises gradually as vegetation declines. Consequently, declining vegetation canopy exposes more of the Earth's surface to direct sun radiation, which leads to increase surface temperature accumulation (Field et al., 1995). Figure 9 shows the annual mean temporal temperature in Iraq, which ranges between 20-24°C. Figure 9 is showing a clear temporal temperature increase in Iraq. The increasing annual mean temperature used to range between 20-22°C for the period of 1901 to 1995. In 1995, and for the first time in recent history the annual mean temperature has climbed up over the 22°C zone (figure. 9) to start a new era. Although the new records (after 1995-present) have a major drop from 22.92°C in 2000 to 22.39°C in 2005, the whole records from 1995 to 2022 are placed within a new-ever zone of 22-24°C. The overall trend is clearly increasing rapidly, particularly after 1989 (see figure 9), and seems to be continuing.

Between November and April, especially December and March, nearly 90 percent of the annual rain falls. Rain is uncommon in the remaining months, particularly those with high temperature, such as June, July, and August. Except for the north and northeast, data from stations in the foothills of the mountains, the plains of the south, and areas to the southwest of the mountains indicate that the average annual precipitation for these region ranges between 1500- and 2000mm. Precipitation is more abundant in the mountains, possibly up to 2600 mm per year in some places, but the terrain prevents extensive cultivation. In unirrigated land, agriculture is limited primarily to mountain valleys, foothills, and steppes that receive 700 mm of rain or more per year. Even in this region, only one crop can be grown per year, and increased rainfall frequently causes crop failure.

There is a spatiotemporal correlation between precipitation (figure. 8) and vegetation cover (figure. 7). We can see an increase in vegetation cover in the north-eastern regions of Iraq, which receive most of the rain, as well as around riverbanks that rely on rain and snowmelt in the Tigris and Euphrates basins. On the other hand, in the arid areas, as in the western and northern regions, we see a decrease in vegetation cover. As a result, we discover that droughts have a significant impact on the regional and temporal distribution of vegetation cover. This indicates that drought, as a manifestation of climatic extremism in Iraq, plays a significant influence on ecological degradation.

### *4.3. The Influence of Human Activities*

An additional source that worsens drought is human activities. It is known that climate change is one of the most difficult and intractable concerns we face nowadays, and it continues to be a puzzling subject. The Intergovernmental Panel on Climate Change (IPCC, 2021), a collection of 1,300 independent scientific experts from around the world, stated in its 5th Edition that there is a more than 95% possibility that human activities during the last 50 years caused global warming (IPCC, 2014). Better water, land, food and energy management will reduce production cost and increase benefits for human and the environment. However, we still need to learn more about the complex dynamics of these systems and their feedback mechanisms. Human-made greenhouse gases have contributed significantly to the observed increase in Earth's temperatures during the last 50 years (IPCC, 2021).

At the same time, one of the major issues that the globe, as well as Iraq, faces is the continuing increase in population. The problem of rapid population increase is the root cause of all other environmental problems, and this rapid population expansion is ascribed to environmental developments in a variety of disciplines. Massive growth that is out of proportion to available natural resources leads to the collapse of agriculture, resulting in a downturn and challenges in controlling economic and social development. Population expansion will certainly have an impact on environmental damage due to the constant strain on basic services and the continued increase in natural resource exploitation (Bartlett, 1994). Therefore, Iraq's environmental degradation is being exacerbated by the following two major human-caused issues.

#### *a. Limited supply of water in Iraq*

Climate change, while not the only cause of water shortage, it causes less rain for agriculture and a deterioration of the quality of freshwater reserves due to the inflow of saline water from the Arabian Gulf into freshwater aquifers and higher pollutant concentrations. Iraq's water security is predicated on the Tigris–Euphrates Rivers system, which is deteriorating. The 2020-2021 season in Iraq was the second driest in the last 40 years (M.W.R.I, 2022), resulting in a 29% and 73% decline in water flow in the Tigris and Euphrates, respectively. Unsustainable resource construction projects (such as hydroelectric dams, and water diversion systems in the river basins) have a direct impact on Iraq's hydrological systems. Additionally, excessive increase and improper use of water from natural sources in traditional agriculture in Iraq have led to the destruction of various streams and wetlands.

The Euphrates-Tigris basin is shared by Turkey, Iran, Syria, and Iraq (as shown in Figure 10), and the basin's connections have been strained by unilateral irrigation plans that impact river flows, dam development, and political disagreements between countries. Disputes have made it impossible for the four countries to successfully co-manage the basin's rivers. Despite increasing cooperative efforts in the 2000s, no official agreement on basin water management has been reached (climate-diplomacy.org, 2021).

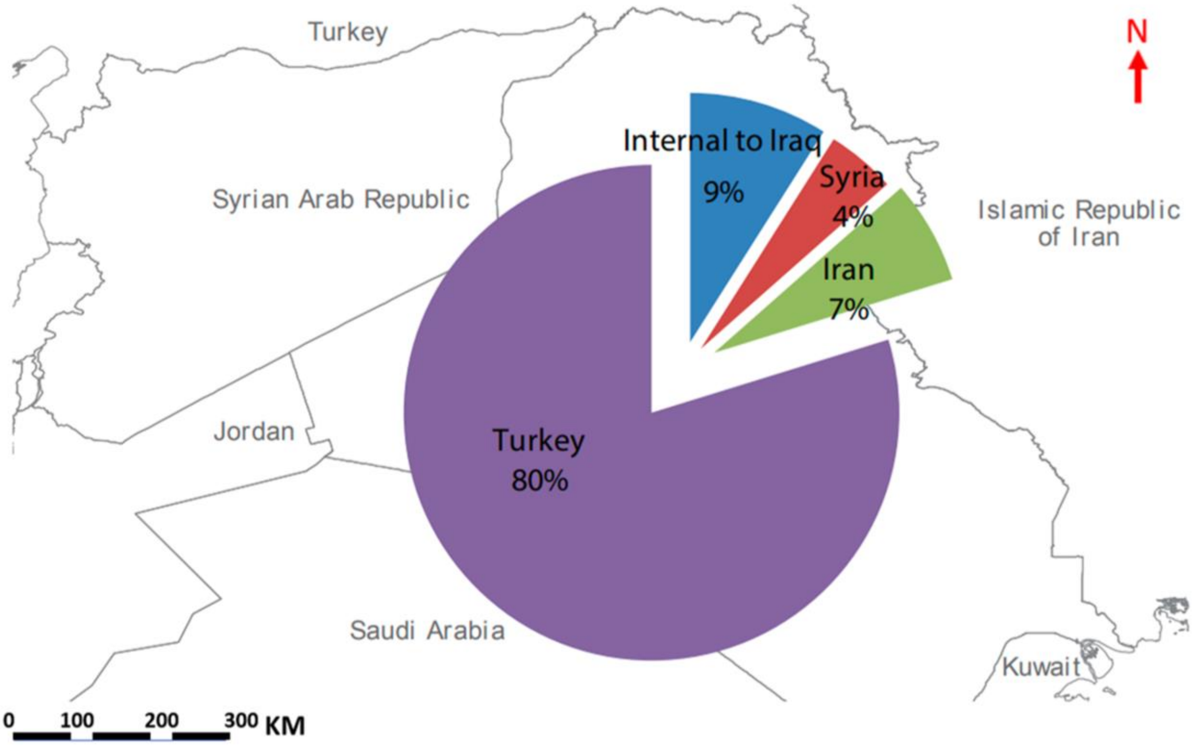


**Fig. 10.** *Iraq's water supply by countries*
**Source:** *Source Ministry of water resources Iraqi*

***b. Iraq's political and administrative accomplishments***

The performance of the Iraqi government had an adverse impact on the environment (World Bank,2019) including difficulties of policies and legislation, exemplified by a high volume of imports at the expense of domestic products, and a lack of investment in the agricultural sector, particularly for infrastructure projects and qualitative issues which are illustrated using rudimentary agricultural technologies and the lack of rivalry between local food commodities and their imported counterparts.

## 5. Discussion

The degradation of Iraq's environment and agricultural land is caused by a combination of natural and human factors, including drought, retreating water volumes, high temperatures, climate shifts, and bad land-policies, which have all combined with weak governmental management and legislation performance. The deterioration of Iraq's habitat and its ecosystems are the result of land degradation in a semi-arid climate zone.

There are slight changes and decreasing in the greenness canopy as the figure 7 of NDVI is showing. Figure 7 is showing a slight greenish reduction from 2000-2015. However, 2020 is showing a bit healthier vegetation cover over the study site for a temperate period, because of the more rainfall occurred during 2016 and 2020.

The precipitation was fluctuated and has been calculated through the PCI that is represented the precipitation concentration index and has illustrated that there is a significant and clear precipitation decline in overall trend with some exempted enhancement in 2016 and 2020.

Results have proven a clear drought is increasing within the study site. The SPI and SPEI were calculated, and they are showing a significant drought in most years. Furthermore, when drought within the study site is occurred for such a long period of time (e.g., the five years 2000-2013), it is going to impact the vegetation (reducing the greenness canopies) and the total environment at multi-levels. A huge environmental degradation will be gathered in place within this period of drought, resulting in destroying most of plants and all other sort of small vegetation canopies and its associated communities. Only the big plants or/and the arid-adaptable-vegetation will resist to be destroyed during such tough five years of drought. In the other words, “The Strongest Survivor”!

At this point, the lost vegetation and all its associated communities (most habitats and certain ecosystems) will not be restorable with the next wet-five years period. With respecting of the recoverability possibilities by some vegetation/ plants, grass and other communities, the normal canopies in place will need a longer period of certain environmental conditions to recover and not to be whipped with another followed drought period. For example, the wetlands of Mesopotamia have got gained a clear water extension after 2003 of intensive governmental restoration plans. However, the ecosystems yet to be recovered in thousands of years (Richardson and Hussain, 2006; Al-Nasrawi et al., 2021)

Having that said, yet generally there are so many other associated factors to be gathered in this argument. Including two main factors that could strongly contribute to vegetation reduction as a response to the drought periods, particularly within this study site. First, within such agricultural countries as this case study (Iraq), drought of five years caused migration of many farmers that left with no water resources to feed their crop lands, animals or even themselves. The followed wet-period and then drought left them with uncertainty, which has added another forced on them to be resettled elsewhere especially nearby cities, and start changing their lifestyle, occupation, and thousands of years of unique culture. That resulted in leaving their lands for more degradation vulnerabilities. The second important factor is the soil salinity and soil degradation. When vegetation canopies are destroyed and agricultural activities discontinued for a certain time, they will be converted to bare lands/salty land. Thus, restoration plans for such situation will not be easy by getting more precipitation or any other water resources, it's more complicated than that and it will take longer than it took for deteriorating.

According to recent studies, degradation has affected 39% of Iraq's area, with the remaining 54% under threat. Climate change mitigation and transnational water management will be difficult because of national and regional political uncertainties. Figures 11 show the spatial and temporal environment degradation in Iraq. The agricultural areas that were harmed by 46 to 56% are those where agriculture and vegetation rely on rainfall, or what is known as rainfed agriculture in Iraq. The incidence of damage in places that rely on irrigation agriculture on the banks of the Tigris and Euphrates Rivers ranges from 31 to 46%. That means climate change, human activity, and water management policies all play a role in the deterioration of the environment in Iraq. Iraq's environmental difficulties pose a serious threat to the country's environment. Addressing them is the responsibility of all executive and legislative state entities, not just the Ministry of Agriculture and Environment.

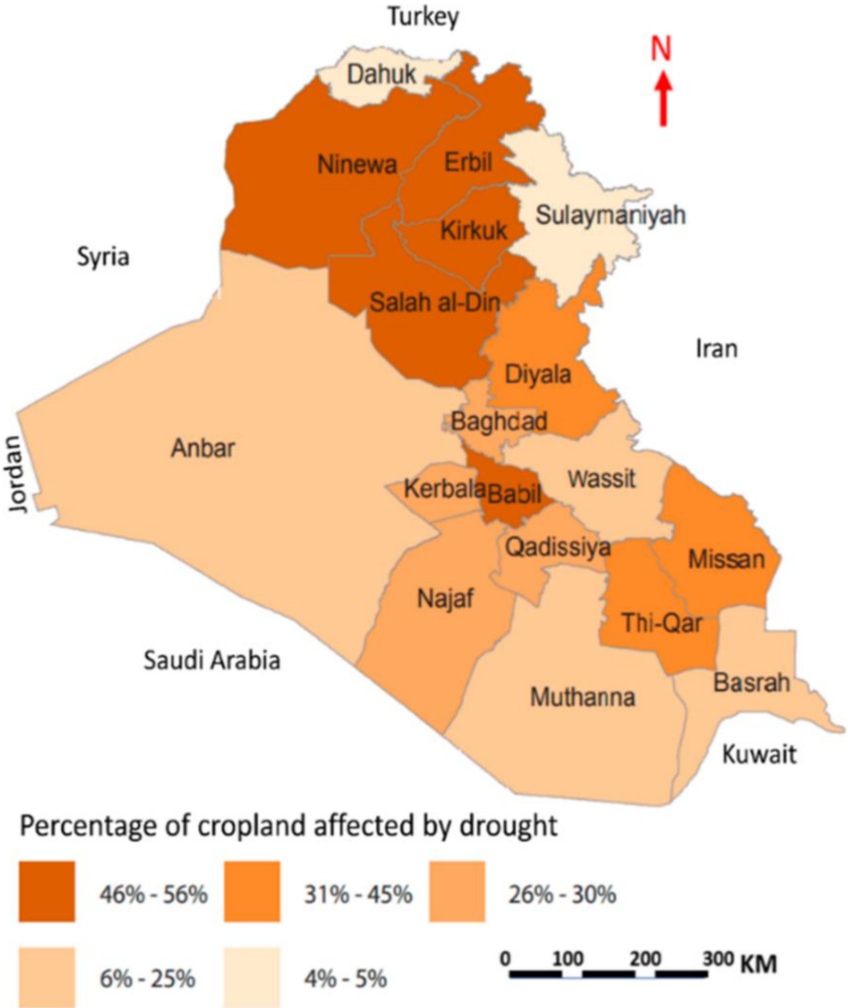


**Fig. 11.** *Percentage of cropland affected by drought in Iraq regions*
**Source:** *FAO, IAU*

# 6. Conclusion

The environmental degradation once occurred over even a short period of time that caused by drought conditions will not be recoverable by the same equative period. Many ecosystems including vegetation canopies will need a longer time to recover, whereas some others may extinct forever! As they may no longer adaptable to this new level of environmental challenges and climate changes. In this study, some key issues related to environmental degradation have been highlighted. Firstly, environmental degradation is a symptom of global processes that endanger the globe, such as desertification and drought caused by global warming and climate change. Secondly, Iraq's rising population expansion has put a strain on natural resources and the environment. Thirdly, exacerbation of the salinity and water scarcity problem as a result of neighboring countries' policies, particularly Turkey's, of constructing massive dams in contravention of international law. Finally, environmental degradation is the result of current and prior regime practices such as draining marshes and water bodies, chopping down millions of palm trees, and burning oil wells in the south.

Future studies should give more attention to the possible effects of human activities, such as farming patterns, crop types, water demand, and drought tolerance. Future climate change study in Iraq may broaden the causes for the drying of oasis and natural lakes, as well as its ramifications for the Iraqi desert ecosystem.

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