Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 23 | No. 4 | pp. 2241-2249 | 2024

Original Research Paper

https://doi.org/10.46488/NEPT.2024.v23i04.028

Open Access Journal

Evaluation of the Drought Situation Using Remote Sensing Technology, an Applied Study on a Part of North Wasit Governorate in Iraq

A. J. Dakhil[1], E. K. Hussain[2] and F. F. Aziz[2]†
[1]Department of Road and Transport Engineering, University of Al-Qadisiyah, Collage of Engineering, Al-Diwaniyah, Iraq
[2]Department of Civil Engineering, University of Al-Qadisiyah, Collage of Engineering, Al-Diwaniyah, Iraq
†Corresponding author: F. F. Aziz; fatinalkhuzaai@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 21-03-2024
Revised: 07-05-2024
Accepted: 17-05-2024

Key Words:
Drought
GIS
NDVI
VCI
Remote Sensing

ABSTRACT

Drought presents a substantial threat to both ecological and agricultural systems. Agriculture in Iraq is predicated on precipitation, which is a major contributor to the likelihood of drought resulting from even marginal fluctuations in precipitation. Furthermore, research suggests that Iraq suffers an approximate annual loss of 100,000 acres of arable land due to drought. NDVI and VCI, two significant indices, were utilized in this research to assess and monitor the severity of the drought in the northern region of Wasit province in Iraq. For the period from 1993 to 2023, drought intensity maps were generated utilizing NDVI-based VCI and the Geographic Information System (GIS), an extremely effective spatial data management instrument. NDVI results evidenced that the vegetation cover area was the highest in 1993 and 1998 and declined until it reached the lowest levels in 2023. The vegetation area was concentrated in the southwest parts. In contrast, VCI results demonstrated the extreme drought through the years from 2003 to 2023, which can be attributed to higher temperatures, evaporation, and lower amounts of rainfall. Throughout the thirty-year analysis period, extreme drought conditions were prevalent, especially in the last two decades. Furthermore, this drought should prompt the government to implement preventative measures to avert it. Implementing soil and water conservation measures, such as the establishment of percolation basins, contour bunds, and check dams, can also enhance drought management.

INTRODUCTION

Drought is a costly natural peril that has extensive consequences for the socioeconomic, agricultural, ecological, and water supply sectors. Drought transforms into various forms as it circulates through the water cycle; its effects extend to the human society and biological system (Zhang et al. 2022). Vegetation cover and its type significantly impact the climate in dry regions (Wang et al. 2023, Omuto et al. 2010), it influences the weather and environmental conditions as well as the exchange of energy, water, and carbon between plants, lowering the concentration of carbon in the atmosphere because plants use carbon dioxide and energy in the process of photosynthesis, lowering the concentration of carbon in the atmosphere. This also helps to minimize the consequences of anthropological carbon emissions.

Although vegetation occupies 20% of the earth's surface, growing levels of desertification are having a detrimental influence on climate by interfering with the phenomena mentioned previously (Jones 2013, Pachauri et al. 2014).

Because vegetation cover growing has a significant impact on the ecosystem, with an important consideration in contemporary climate change debates (Jones 2013, Pachauri et al. 2014). By comprehending the correlation between climate change and vegetation, the extent to which vegetation reacts to climate change can be inspected. This knowledge, in turn, furnishes crucial and useful insights for adapting to climate change (Afuye et al. 2021). The proliferation of remote sensing satellites has high accuracy and rapid progress of quantitative remote sensing technology has facilitated the acquisition of various categories of feature information from long-time series and large-scale remote sensing image data (Kattenborn et al. 2021, Pan et al. 2023). Scientists employ remote sensing techniques to observe and quantify vegetation changes at the regional level, which are influenced by both natural climate variability and human activities (Rousvel et al. 2013). Gao et al. (2020) state that dynamic monitoring models that derive changes in vegetation cover from remote sensing image data are crucial to assess and monitor environmental functions and regional ecological quality, including the Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI). Nevertheless, the application of NDVI for such investigations may not be prevalent in other regions of the globe due to the complexity of the growth and distribution of vegetation and the distinctive attributes of various arid regions (Kumar et al. 2022). NDVI is a highly effective technique utilized for the surveillance of ground vegetation conditions, as it genuinely accounts for vegetation biomass, ground cover, and vegetation growth. Monitoring the dynamic alterations of vegetation cover and land use on a regional and global scale is a common application of this technique (Huang et al. 2022). Numerous research on the spatiotemporal distribution of regional vegetation have been conducted, as determined by NDVI values, and have been undertaken by academicians from around the world over the past few decades (Huang et al. 2022). On the other hand, the effectiveness of the VCI derived from the NDVI in monitoring drought conditions has been investigated in numerous regions across the globe. In Kazakhstan, the VCI derived from NDVI has also been compared to measurements of vegetation density, biomass, and field reflectance; this comparison has demonstrated that the VCI is an accurate predictor of the weather's effect on vegetation health (Gitelson et al. 1998). The evaluation of the VCI focuses on monitoring drought during the period of maximum vegetation conditions and the growing season (Tran et al. 2017).

According to NASA and the USGS, vegetation change observations can be reliably conducted using MOD13Q1 products, provided that cloud interference is minimal (source: https://lpdaac.usgs.gov). Given that the majority of the year in Iraq is devoid of clouds, this product is appropriate for this research. So, any part of Iraq serves as a compelling subject of study.

Based on the findings of the Global Environment Outlook 1 by the United Nations Environment Program, Iraq is identified as the fifth most susceptible nation globally in relation to the decline in the availability of food and water, adverse climatic conditions, and associated health concerns. Moreover, it is estimated that Iraq experiences an annual loss of around 100,000 acres of agricultural land. Furthermore, it has been highlighted that Iraq has the greatest population growth rate among all countries in West Asia. This demographic trend is expected to exacerbate the aforementioned predicaments to a greater extent. Iraq ranks 39th globally in terms of water stress and is among the top five countries experiencing significant adverse effects from climate change. In 2021, the annual precipitation reached a historically minimal level, mostly attributed to unsustainable farming methods, a reduction in vegetative coverage, and the occurrence of the second-most arid season during the preceding four decades. The insufficiency of rainfall throughout the annual cycle, in conjunction with these ecological elements, has resulted in the occurrence of water scarcity, desertification, and soil degradation. The protracted battle in Iraq has resulted in detrimental effects on the nation's water and land resources, leading to an exacerbation of soil erosion and pollution. The study aims to assess and monitor the spatial and temporal drought conditions and variation in vegetation cover in the northern part of Wasit Governorate, Iraq, using drought indices such as NDVI and VCI based on Landsat 5, 7 and 8 satellite images of agricultural drought and determine the extent to which it is affected by rainfall rates and temperature changes. Study results can help government planners formulate and manage drought impacts.

MATERIALS AND METHODS

Describing the Study Area

Wasit Governorate is located within a central part of Iraq, occupying the northeastern part of the alluvial plain. It is bordered to the east by Iran, to the north by Diyala and Baghdad governorates, to the west by Babel and Diwaniyah governorates, to the southwest by Nasiriyah Governorate, and to the southeast by Maysan governorate. The area of Wasit Governorate is (17,153) km^2, which constitutes 3.94% of the total area of Iraq, which amounts to (435,052) km^2 (Central Bureau of Statistics, 7162, p. 6). The study area is located astronomically between latitudes 32°30' N and longitudes 44°46' E, as indicated in Fig. 1. The governorate is considered one of the agricultural governorates; its agricultural arable land is about 4 km^2. This investigation focused on the northern part of Wasit Governorate in Iraq, which covered an area of approximately 10196.94 km^2 and lies between latitudes 32°30' N and longitudes 44°46' E. Fig. 1. The climatic conditions of the study region are characterized by a spectrum from arid to semiarid. The climate in this region is characterized by extremely cold winters and arid, scorching summers. In this particular geographic area, the onset of precipitation often occurs in October and lasts until May, as the annual rainfall amounts range between 103 and 195 mm, and the evaporation-transpiration amounts range between 1669 and 2235 mm.

Datasets

To monitor the status of agricultural distress in the area of study, the particular agricultural drought indices were developed using satellite images of Landsat 5, Landsat 7, and Landsat OLI 8 and 9. Fig. 2 shows how one Landsat image completely encapsulates the research area (Path 168, Row 37). In the scope of the study, satellite images of Landsat-5 and Landsat-8 for January and February of 1993 1998, 2003, 2013, 2018, and 2013 were obtained when plants were in their growing season. Table 1 lists the attributes of the satellite images utilized. A remotely sensed data set with visible and near-infrared bands and a 30-meter spatial resolution was utilized to analyze the drought conditions in the study area. The study utilized annual precipitation data obtained from the General Directorate of Meteorology and satellite images obtained from the USGS.

Normalized Difference

Both agricultural drought indices, which utilize spectral analysis, were employed in the study.

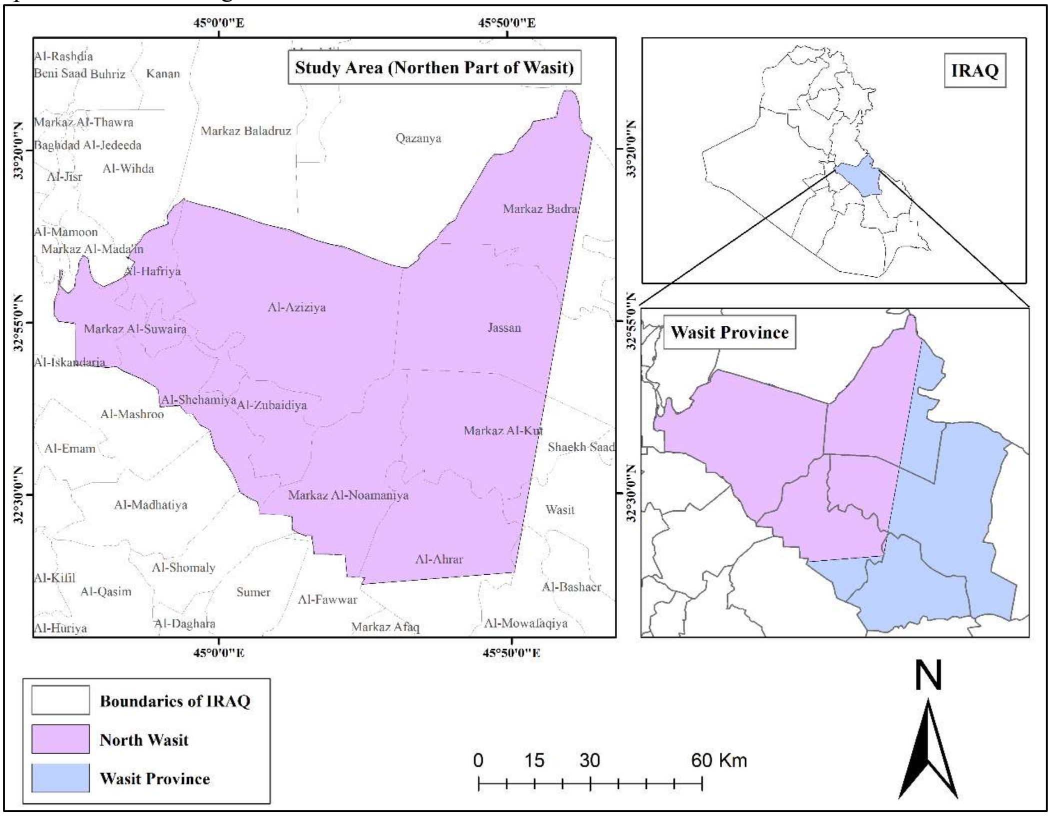
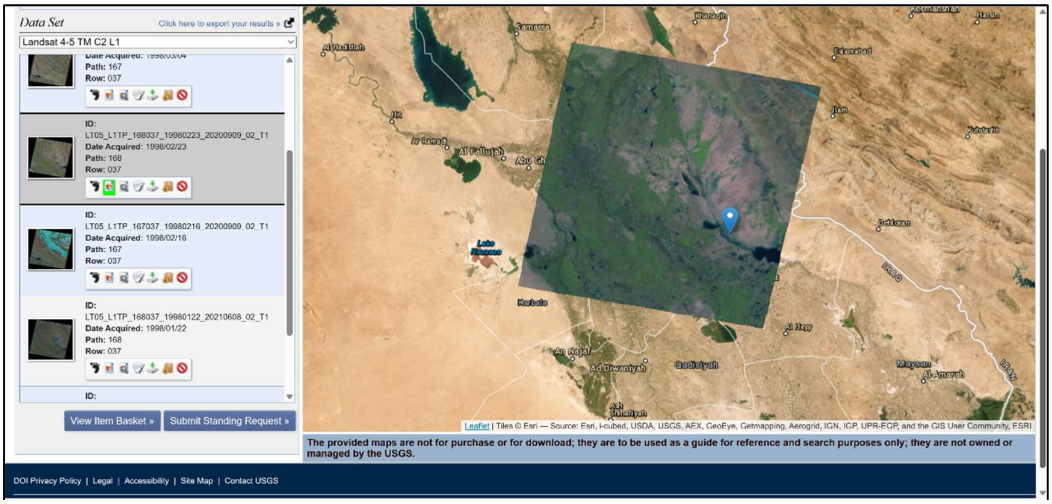


Fig. 1: Geographical map of study area showing Wasit Provence and studied area.



Date Acquired: 1998/03/04
Path: 167
Row: 037

ID:
LT05_L1TP_168037_19980223_20200909_02_T1
Date Acquired: 1998/02/23
Path: 168
Row: 037

ID:
LT05_L1TP_167037_19980216_20200909_02_T1
Date Acquired: 1998/02/16
Path: 167
Row: 037

ID:
LT05_L1TP_168037_19980122_20210608_02_T1
Date Acquired: 1998/01/22
Path: 168
Row: 037

ID:

Leaflet | Tiles © Esri — Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, UPR-EGP, and the GIS User Community, ESRI

The provided maps are not for purchase or for download; they are to be used as a guide for reference and search purposes only; they are not owned or managed by the USGS.

DOI Privacy Policy | Legal | Accessibility | Site Map | Contact USGS

Fig. 2: Landsat images of the study area.

Table 1: Satellite data specifications.

Landsat	Path/Row	Date	Bands	Resolution (m)
LT05 ETM	168/37	1993/01/24	Multispectral	30
LT05 ETM	168/37	1998/03/11	Multispectral	30
LT07 ETM	168/37	2003/01/3	Multispectral	30
LT07 ETM	168/37	2013/02/24	Multispectral	30
LT08 OLI	167/37	2018/01/29	Multispectral	30
LT08 OLI	167/37	2023/02/05	Multispectral	30

*Data Source (USGS website) https://www.usgs.gov/

Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is a vegetation index widely used in environmental research. The calculation involves the use of wavelengths throughout the red and near-infrared spectrums. The formula utilized in the determination procedure is as follows (Borowik et al. 2013).

The Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing index that quantifies:

$$NDVI = ((\rho Nir - \rho Red))/((\rho Nir + \rho Red)) \quad \ldots(1)$$

Where:

Nir: used to denote the near-infrared reflectance.

Rid: used to denote the red reflectance band.

The non-dimensional vegetation index, commonly referred to as NDVI is a radiometric measurement used to assess the differential response of various plant species to radiation in the red and near-infrared (NIR) spectra. The use of the Normalized Difference Vegetation Index (NDVI) has been widely employed in agricultural and drought-related research due to its ability to establish a correlation between the index and the proportion as well as the overall health of green vegetation. This phenomenon can be attributed to the significant utility of the Normalized Difference Vegetation Index (NDVI). Examples of studies falling under this area include the computation of seasonal variations, the categorization of land cover types, and the evaluation of plant conditions (Jurecka et al. 2016), The NDVI values can vary within a range from negative to positive. A decrease in the Normalized Difference Vegetation Index (NDVI) signifies a reduced presence of vegetation within the given region, while an increase in the NDVI value suggests a larger concentration of vegetation in the area (Singh et al. 2016). The NDVI values utilized in this study were obtained through the analysis of photos acquired by the Landsat satellite throughout January for each respective year.

Vegetation Condition Index (VCI)

The Vegetation Condition Index (VCI) is a method utilized to evaluate the spatial attributes, duration, and intensity of drought. Furthermore, it exhibits a strong correlation with precipitation patterns and compares the present range of values of the Normalized Difference Vegetation Index (NDVI) for the same period in previous years to determine the health of the vegetation (Ainembabazi 2022). It is denoted in percentage form and indicates the observed value's position relative to the minimum and maximum values from the preceding years. Decreased and increased values correspond to unfavorable and favorable conditions of vegetation, respectively.

VCI can be classified into five categories, according to (Bhuiyan et al. 2006) as shown in Table 2.

According to Kogan (1995), the Vegetation Condition Index (VCI) can be calculated as follows:

$$VCI = ((\mathrm{NDVI}j - NDVI\,min))/((NDVI\,max - NDVI\,min)) * 100. \quad ..(2)$$

Where:

NDVI_i: the NDVI of the current year.

NDVI max: the maximum NDVI of multiyear studied.

NDVI min: the minimum NDVI of multiyear studied.

RESULTS AND DISCUSSION

Variation in Normalized Difference Vegetation Index (NDVI)

Table 2: Drought classification by VCI according to (Bhuiyan et al. 2006) definition.

VCI Level	Drought -Severity
<10%	Extreme Drought
10% - 20%	Severe Drought
20%-30%	Moderate Drought
30%-40%	No Drought
40%-100%	Wet

The NDVI for the period 1993-2023 was calculated every

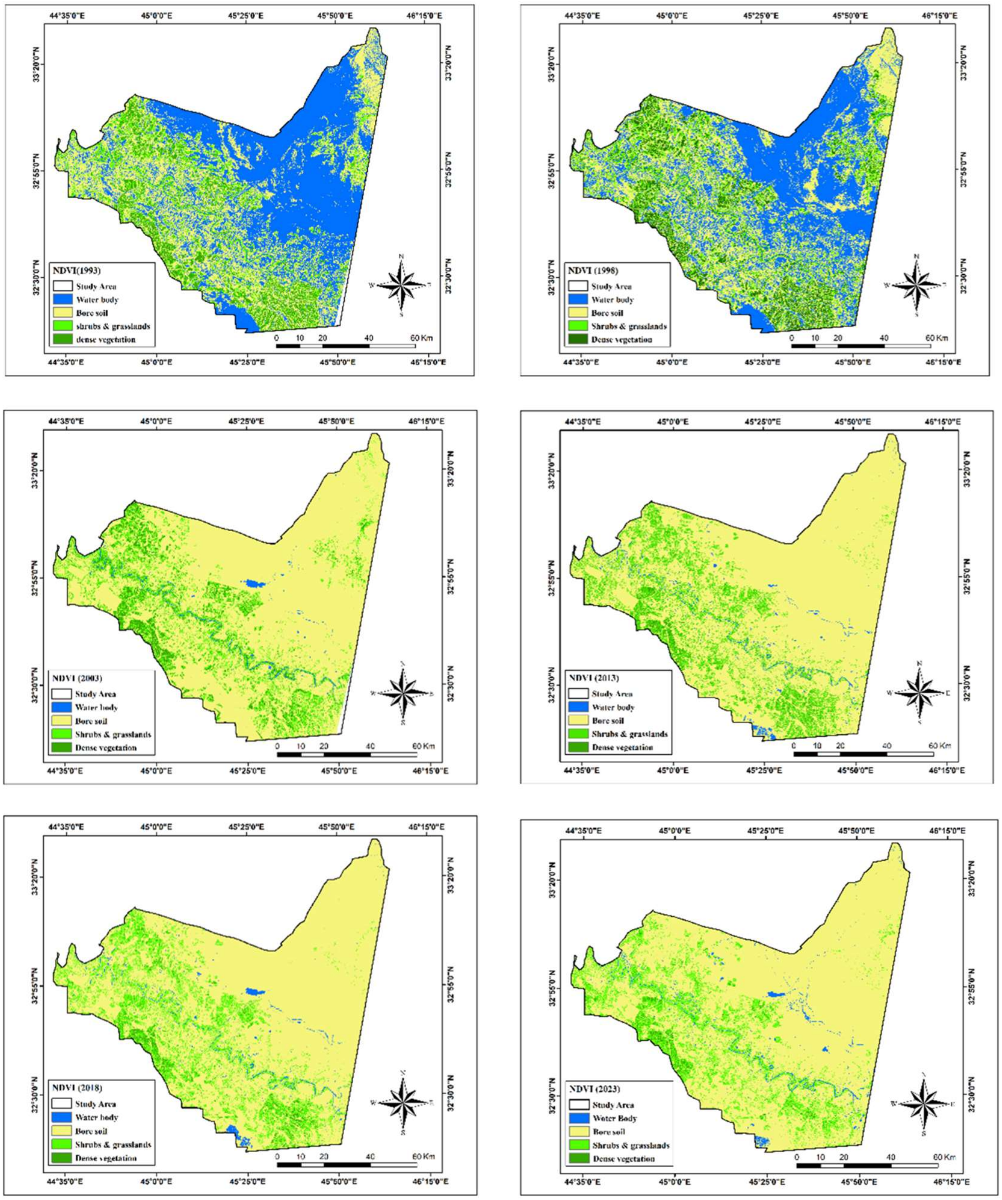


Fig. 3: NDVI raster for the years (A) 1993; (B) 1998; (C) 2003; (D) 2013; (E) 2018; and (F) 2023.

three years. This was done using Landsat-5, Landsat-7 and Landsat-8 satellite images acquired from the USGS for January and Feb. Then the Difference Vegetation Index (NDVI) was calculated via Arc Map 10.8 software. Fig. 3 shows the NDVI raster class distribution for the six years studied. These images were analyzed to determine how drought and vegetation cover have changed in the study area. Spatiotemporal analysis showed a significant change due to drought for NDVI images; yellow areas were unhealthy, areas with buildings, or bore soil, while green showed healthy, moist vegetated areas; in addition, blue areas demonstrate marshes and swamps (water bodies) (Rousta et al. 2020). In general, NDVI values for green parts ranged between 15.443% and 21.976% in 2023 and 1998, respectively. Extract vegetation coverage data as shown in Table 3 and calculate the area and vegetation layer percentage in each year.

The vegetation condition increased between 1993 and 1998 by 3.6%. The values returned to decrease in subsequent years until 2023 to some extent in the plant area. The spatiotemporal of the NDVI plot for the northern part of Wasit shown in Fig. 3 also indicated a similar evolution

Table 3: The area and percentage of vegetation for the study area over the period 1993 to 2023.

Year	Vegetation Area (km^2)	Percent (%)	Variation (±)
1993	1813.437	18.371	-0.011
1998	2169.226	21.976	3.594
2003	1922.537	19.477	1.095
2013	1720.794	17.433	-0.949
2018	1736.517	17.592	-0.790
2023	1524.371	15.443	-2.939
Average (6 years)	1814.480	18.382	
Total study Area 9871 km^2			

and a tendency for a decrease in the NDVI during the years 2003 to 2013 and a return to increase in 2018 and then a decrease in 2023, due to severe or extreme drought years that hit the region, the highest percentage of vegetation cover was recorded in 1998. On the other hand, the NDVI results showed that the northern Badra district recorded the highest decline. The area located in the southwest of the study area has the densest vegetation coverage, as shown in Fig. 3. Fig. 4 shows the relationship of vegetation cover percentage (NDVI) with precipitation.

Variation in Vegetation Condition Index (VCI)

The VCI-based agricultural drought intensity maps from 1993 to 2023 are shown in Fig. 5 during January and February. VCI varies considerably in vegetation phenology is 0 -100 in the study area over the period 1993-2023 (Fig. 6). For example, in 1993 and 1998, larger parts of the agricultural land recorded a low VCI (VCI<20), reaching 67% of the total studied area. From Fig. 5, it can be observed that the highest VCI in 2003 may be affected by the low precipitation in this year. The following years 2013, 2018, and 2023 recorded high VCI values, which occupied an area larger than the study area which gradually decreased with the increase in the amount of rainfall, as can be seen in Figs. 5 and 6.

This increasing level of drought can be attributed to the fact that Wasit Governorate, like other regions in central and southern Iraq, is now suffering from water shortages as a result of a combination of factors, including historically low levels of rainfall, and inadequate water resource management practices and reduced water inflow from upstream regions that share borders with the Tigris and Euphrates rivers. The decrease in water flow from upstream is the primary factor contributing to this shortage. In addition to the enormous urban sprawl that exists in the study region and the governorates that are located nearby.

The wetted area occupied around 5690.98 km^2, 4500.728 km^2, 471.32 km^2, 1084.44 km^2, 1132.21 km^2 and 1359.4 km^2 for the years 1993, 1998, 2003, 2013, 2018, and 2023, respectively, from the total area (9871 km^2).

CONCLUSION

In this investigation, Mapper (TM) photos and operational images (OLI) were used to identify changes in vegetation

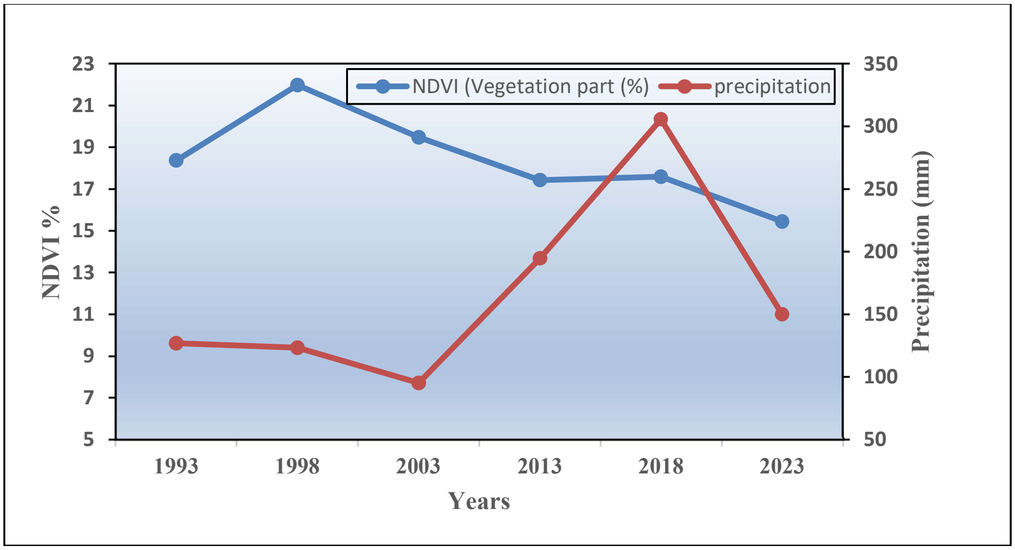


Fig. 4: Relationship of vegetation cover percentage (NDVI) with precipitation.

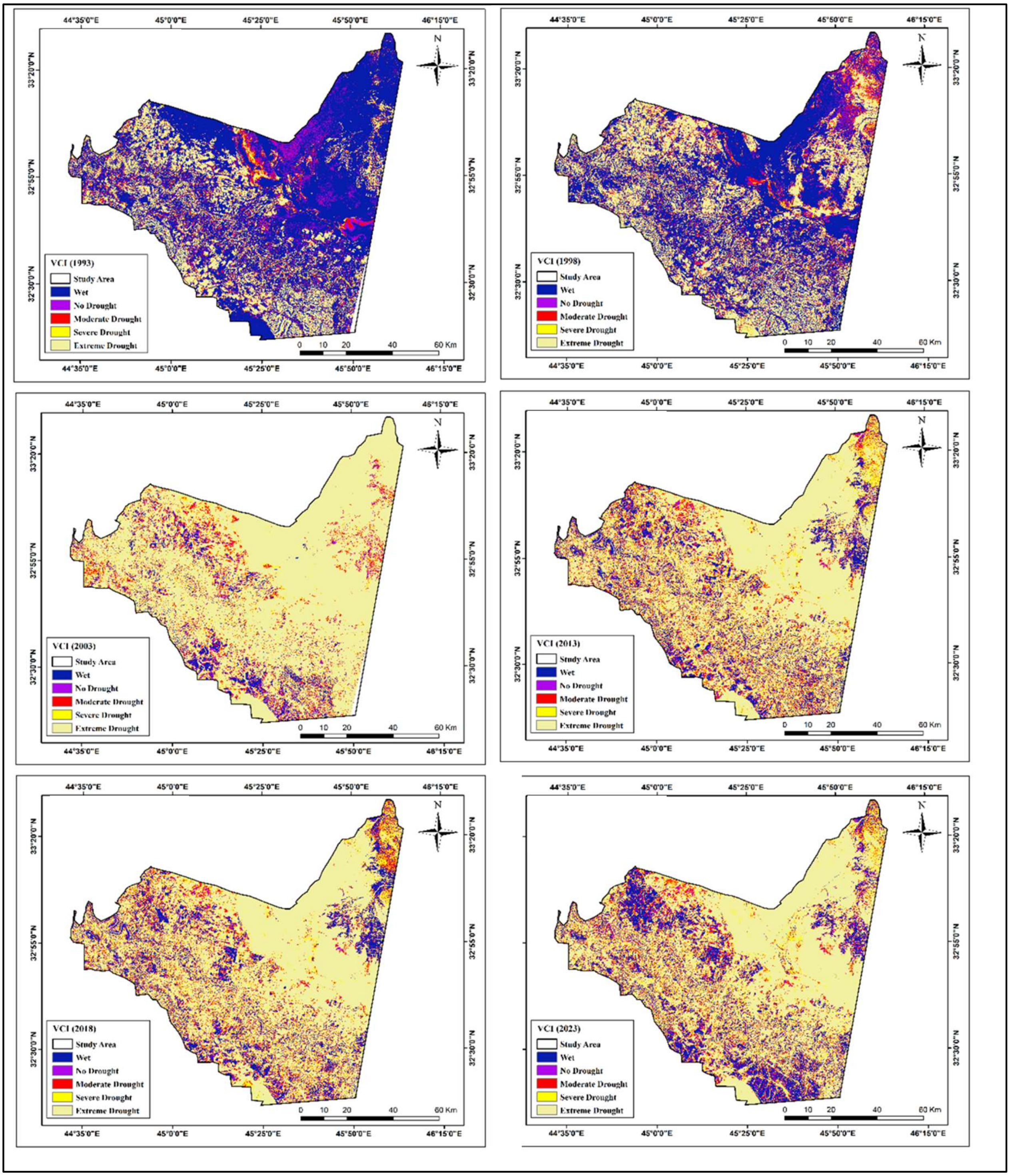


Fig. 5: VCI raster for the years (A) 1993; (B) 1998; (C) 2003; (D) 2013; (E) 2018; and (F) 2023.

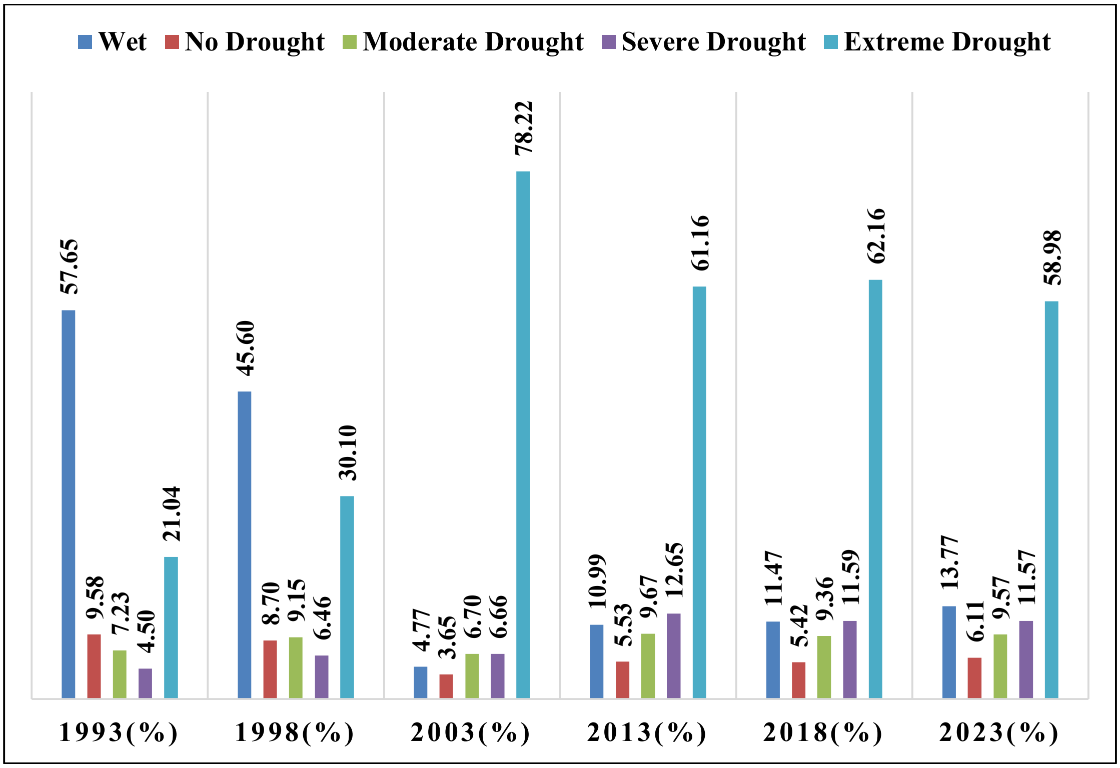


Fig. 6: Variation in Drought Severity Level (VCI) in the Northern Part of Wasit for the study years.

and drought conditions via GIS 10.8, which led finally to the following facts:

1. During this period, the vegetation pattern was continuously declining. According to the NDVI, the peak vegetation cover was 2,169.22 km^2 in 1998, and it reached 1,524.37 km^2 in 2023. The reduction accounted for 6.5% of the total area. While the overall rate of decreasing vegetation cover is 1,814.48 km^2.
2. For the variation in vegetation condition index (VCI), extreme drought areas in 2003 were the largest with an area of about 7721 km^2. It found that the wet area was large in most of the districts in 1993 and 1998, as noticed in the districts of Badra, Al-Aziziya, and Jassan.
3. The reductions in vegetation cover during periods of drought can be ascribed to the scarcity of water resources and irrigation water. In addition to the extensive urban development that encompasses the study area and the neighboring governorates. Conversely, the scarcity of precipitation throughout the study period contributed to the severe drought in the area. Following this, the reduction in precipitation caused a substantial depletion of the studied area's surface and groundwater resources, including lakes, rivers, and groundwater; as a result, the soil moisture content decreased.
4. Finally, it can be concluded that the utilization of geographic information systems (GIS) and remote sensing data can be instrumental in the investigation and surveillance of land cover changes. They can provide information that is more precise, economical, and timely.

REFERENCES

Afuye, G. A., Kalumba, A. M. and Orimoloye, I. R., 2021. Characterisation of vegetation response to climate change: A review. *Sustainability*, 13(13), pp.7265. https://doi.org/10.3390/su13137265

Ainembabazi, S., 2022. Comparison of standardized precipitation index (SPI) and vegetation health index (VHI) in drought monitoring in Isingiro District (Doctoral dissertation). http://hdl.handle.net/20.500.12281/14299

Bhuiyan, C., Singh, R. P. and Kogan, F. N., 2006. Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. *International Journal of Applied Earth Observation and Geoinformation*, 8(4), pp.289-302. https://doi.org/10.1016/j.jag.2006.03.002

Borowik, T., Pettorelli, N., Sönnichsen, L. and Jędrzejewska, B., 2013. Normalized difference vegetation index (NDVI) as a predictor of forage availability for ungulates in forest and field habitats. *European Journal of Wildlife Research*, 59, pp.675-682. https://doi.org/10.1016/j.jag.2006.03.002

Gao, L., Wang, X., Johnson, B.A., Tian, Q., Wang, Y., Verrelst, J., Mu, X. and Gu, X., 2020. Remote sensing algorithms for estimation of fractional vegetation cover using pure vegetation index values: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 159, pp.364-377.

Gitelson, A.A., Kogan, F., Zakarin, E., Spivak, L. and Lebed, L., 1998. Using AVHRR data for quantitative estimation of vegetation conditions: Calibration and validation. *Advances in Space Research*, 22(5), pp.673-676. https://doi.org/10.1016/j.isprsjprs.2019.11.018

Huang, J., Ge, Z., Huang, Y., Tang, X., Shi, Z., Lai, P., Song, Z., Hao, B., Yang, H. and Ma, M., 2022. Climate change and ecological engineering jointly induced vegetation greening in global karst regions from 2001 to 2020. *Plant and Soil*, pp.1-20.

Jones, H. G., 1992. *Plants and microclimate: A quantitative approach to environmental plant physiology*.

Jurecka, F., Hlavinka, P., Lukas, V., Trnka, M. and Zalud, Z., 2016. Crop yield estimation at the field level using vegetation indices. In: *Proceedings of International PhD Students Conference*. Czech Republic Phd MENDELNET, pp.90-95.

Kattenborn, T., Leitloff, J., Schiefer, F. and Hinz, S., 2021. Review on Convolutional Neural Networks (CNN) in vegetation remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, 173, pp.24-49. https://doi.org/10.1016/j.isprsjprs.2020.12.010

Kogan, F. N., 1995. Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, 15(11), pp.91-100. https://doi.org/10.1016/0273-1177(95)00079-T

Kumar, B. P., Babu, K. R., Anusha, B. N. and Rajasekhar, M., 2022. Geo-environmental monitoring and assessment of land degradation and desertification in the semi-arid regions using Landsat 8 OLI/TIRS, LST, and NDVI approach. *Environmental Challenges*, 8, 100578. https://doi.org/10.1016/j.envc.2022.100578

Omuto, C. T., Vargas, R. R., Alim, M. S. and Paron, P., 2010. Mixed-effects modelling of time series NDVI-rainfall relationship for detecting human-induced loss of vegetation cover in drylands. *Journal of Arid Environments*, 74(11), pp.1552-1563. https://doi.org/10.1016/j.jaridenv.2010.04.001

Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P. and Dubash, N.K., 2014. *Climate change 2014: synthesis report*. *Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change: 151*. IPCC. https://hdl.handle.net/10013/epic.45156

Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P. and Dubash, N.K., 2014. *Climate Change*.

Pan, J., Chen, L., Shu, Q., Zhao, Q., Yang, J. and Jin, S., 2023. Spatiotemporal imagery selection for full coverage image generation over a large area with HFA-Net based quality grading. *Geo-spatial Information Science*, pp.1-18. https://doi.org/10.1080/10095020.2023.2270641

Rousta, I., Olafsson, H., Moniruzzaman, M., Zhang, H., Liou, Y. A., Mushore, T. D. and Gupta, A., 2020. Impacts of drought on vegetation assessed by vegetation indices and meteorological factors in Afghanistan. *Remote Sensing*, 12(15), 2433. https://doi.org/10.3390/rs12152433

Rousvel, S., Armand, N., Andre, L., Tengeleng, S., Alain, T. S. and Armel, K., 2013. Comparison between vegetation and rainfall of bioclimatic ecoregions in central Africa. *Atmosphere*, 4(4), pp.411-427. https://doi.org/10.3390/atmos4040411

Singh, R. P., Singh, N., Singh, S. and Mukherjee, S., 2016. Normalized difference vegetation index (NDVI) based classification to assess the change in land use/land cover (LULC) in Lower Assam, India. *International Journal of Advanced Remote Sensing and GIS*, 5(10), pp.1963-1970. https://doi.org/10.23953/cloud.ijarsg.74

Tran, H. T., Campbell, J. B., Tran, T. D. and Tran, H. T., 2017. Monitoring drought vulnerability using multispectral indices observed from sequential remote sensing (Case Study: Tuy Phong, Binh Thuan, Vietnam). *GIScience & Remote Sensing*, 54(2), pp.167-184. https://doi.org/10.1080/15481603.2017.1287838

Wang, X., Liu, G., Xiang, A., Xiao, S., Lin, D., Lin, Y. and Lu, Y., 2023. Terrain gradient response of landscape ecological environment to land use and land cover change in the hilly watershed in South China. *Ecological Indicators*, 146, 109797. https://doi.org/10.1016/j.ecolind.2022.109797

Zhang, X., Hao, Z., Singh, V. P., Zhang, Y., Feng, S., Xu, Y. and Hao, F., 2022. Drought propagation under global warming: Characteristics, approaches, processes, and controlling factors. *Science of the Total Environment*, 838, 156021. https://doi.org/10.1016/j.scitotenv.2022.156021

ORCID DETAILS OF THE AUTHORS

A. J. Dakhil: https://orcid.org/0000-0002-3598-261X
E. K. Hussain: https://orcid.org/0000-0002-2228-2817
F. F. Aziz: https://orcid.org/0009-0002-7744-1712