Drought Hazard Mapping Methods in Iraq's Southern Marshes: A Review

Evaluating Methods for Mapping Water Stress in Wetland Ecosystems

Fadhaa Turki Dakhil
School of Civil Engineering, University Sains Malaysia, Nibong Tebal, Penang, Malaysia
eng.fadha@gmail.com

Nuridah Binti Sabtu
School of Civil Engineering, University Sains Malaysia, Nibong Tebal, Penang, Malaysia
nsabtu@usm.my (corresponding author)

Alaa G. Khalaf
Space Research and Technology Center, Scientific Research Commission, Ministry of Higher Education and Scientific Research, Iraq
dr_alaaspace1@mohesr.edu.iq

Received: 19 April 2025 | Revised: 19 May 2025 and 12 June 2025 | Accepted: 15 June 2025

 DOI: https://doi.org/10.48084/etasr.11610

ABSTRACT

In recent years, the southern Iraqi marshlands have undergone multiple restoration efforts aimed at reversing ecological degradation caused by extensive human intervention. Studies report a 60% decline in open water coverage and up to a 40% reduction in vegetation during prolonged droughts between 2000 and 2015, compared to pre-drought conditions. This review evaluates the effectiveness of marshland restoration and land use dynamics by employing Remote Sensing (RS), Geographic Information Systems (GIS), and field surveys, with a particular focus on drought periods and subsequent recovery initiatives. This work offers a strategic framework to support decision-makers in combating land degradation and fostering ecological resilience. Despite some progress, significant challenges remain, underscoring the need for coordinated national and international efforts to achieve sustainable restoration outcomes.

Keywords-drought; remote sensing; GIS; marshlands; Iraq

I. INTRODUCTION

Iraq's southern wetlands, primarily the Al-Hawizeh, Central, and Al-Chibayish marshes, are located near the confluence of the Tigris and Euphrates rivers. These ecosystems possess high ecological and cultural value, supporting rich biodiversity and sustaining traditional livelihoods such as fishing and agriculture [1–4]. However, prolonged droughts, water scarcity, and habitat degradation have severely impacted these wetlands, posing threats to both wildlife and local communities [5, 6]. In conjunction with climate change and fluctuating water temperatures, these challenges underscore the urgent need for the implementation of sustainable management practices [7]. To address these issues, Geographic Information Systems (GIS) and Remote Sensing (RS) have become essential tools for assessing ecosystem dynamics and guiding wetlands restoration efforts. GIS enables the visualization and spatial analysis of georeferenced data for environmental and engineering decision-making, while RS provides satellite-derived insights into land use, vegetation cover, and surface water extent [8–10]. Studies using advanced RS and GIS techniques have identified major environmental shifts between 1990 and 2000, including increased desertification and reduced water bodies. These changes have impaired traditional agricultural systems and soil fertility, with up to 76% of southern wetlands classified as highly vulnerable to desertification [11].

In this study, we investigate the environmental transformations in Iraq's southern marshlands by examining land cover changes, the consequences of desiccation, and the effectiveness of restoration efforts. The research aims to deliver a comprehensive assessment of the wetlands' ecological status and evaluate the success of ongoing rehabilitation using advanced RS and GIS methodologies. The primary objectives of the study are:

- Historical analysis: To document historical land cover changes in the southern Iraqi marshlands over recent decades, with particular focus on periods of ecological decline and subsequent recovery.

- Impact assessment: To assess the environmental consequences of desiccation, including its effects on ecosystem health, biodiversity loss, and Water Quality (WQ) degradation.
- Restoration evaluation: To evaluate the effectiveness of post-2003 restoration programs, particularly their impact on reviving native flora and fauna and reestablishing ecological functions.
- Identification of challenges: To identify key economic, social, and political barriers that hinder full ecological recovery of the marshes.
- Policy recommendations: To propose strategies for enhancing the sustainability of restoration initiatives and protecting the marshlands' unique biological and cultural heritage.

II. METHODOLOGY

This review paper focuses on three key methodological approaches: RS, GIS, and field surveys. These techniques have been widely adopted in various countries for environmental monitoring applications, including drought and flood assessment. Their use has enabled the generation of two- and three-dimensional land cover and land use maps, as well as the detailed analysis of specific target areas. Figure 1 presents a schematic diagram of the overall methodological framework, illustrating the interactions and workflow among RS, GIS, and field survey techniques as implemented in the reviewed studies.

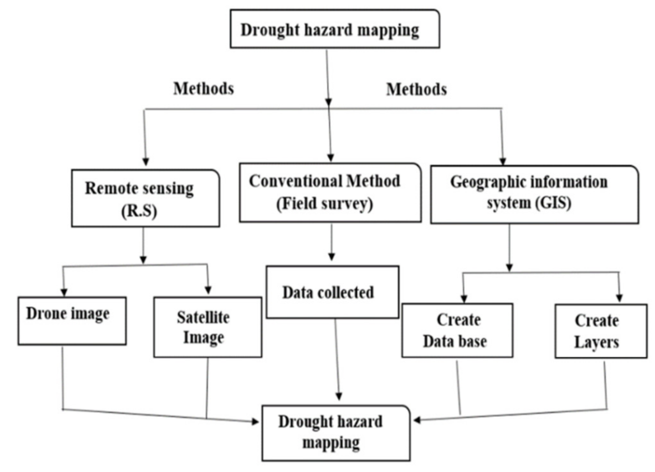

Fig. 1. Workflow summary of reviewed techniques.

III. STUDY AREA

The study area covers the Southern Iraq marshlands, within Universal Transverse Mercator (UTM) coordinates approximately spanning from (603,249, 3,467,534) to (742,417, 3,410,208) in Zone 38R, situated in the lower Mesopotamian Basin between the Tigris and Euphrates Rivers. These wetlands extend across portions of the Basra, Maysan, and Dhi Qar governorates in southern Iraq. Traditionally, the marshlands are divided into three primary regions: the Al-Hammar marshes, the Central marshes, and the Al-Hawizeh marshes, as illustrated in Figure 2.

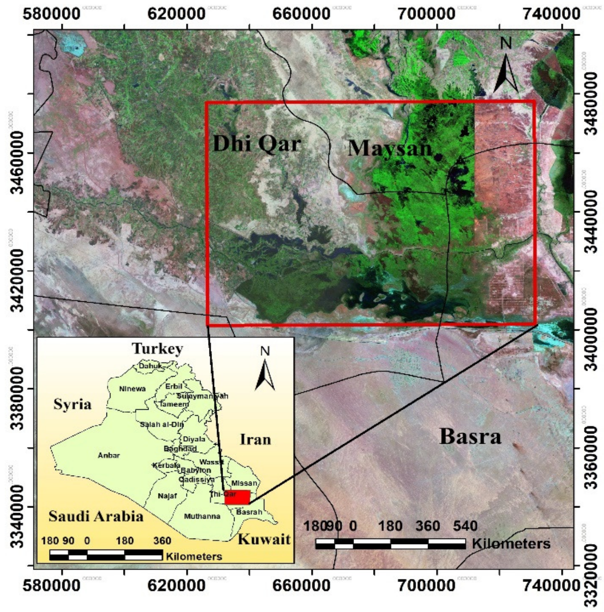

Fig. 2. Location of the study area.

IV. RELATED STUDIES

A. *Geographic Information Systems (GIS)*

The GIS study examines the impact of climate change on drought risk in semi-arid regions, which are particularly vulnerable due to shifting precipitation patterns and increasing global temperatures [12]. In similar contexts, such as tropical regions of Zimbabwe and Southern Africa, GIS combined with the Analytic Hierarchy Process (AHP) has been employed to support collaborative planning among development stakeholders and classify drought severity into moderate, severe, and very severe categories [13]. In the context of Iraq, GIS analyses and field surveys reveal that drainage infrastructure in the southern regions is hindered by multiple factors, including the absence of natural outlets, rising salinity levels, increasing water scarcity, unsustainable land use practices, and limited governmental intervention. The Environmental Sensitivity Areas Index (ESAI) has been used to evaluate desertification trends in the Southern marshes, indicating a critical decline in WQ during 2015 due to acute water shortages [11]. Notably, 2019 marked a recovery point, as efforts to enhance inflow contributed to improved WQ conditions [14], consistent with the observed positive correlation between flow rates and WQ, where increased flow typically leads to better WQ conditions. Additionally, water temperatures in the Central marshes fluctuate significantly throughout the year, ranging from 10 ºC to 35 ºC [15]. Table I presents a summary of GIS-based methodologies applied in drought research from 1970 to 2024, offering a structured overview that is particularly useful in data-scarce environments and provides organized spatial insights for assessing environmental change in the study area.

B. *Remote Sensing (RS)*

An overview of studies employing the RS techniques in drought and wetland research from 1978 to 2022 is presented in Table II. According to [20], the marsh regions experienced significant reflooding in 2020, recovering between 50% and 90% following a substantial decline of 79% and a subsequent increase of 90% between 1972 and 2000. A 2019 study reported severe ecological degradation based on Landsat satellite spectral reflectance and wavelength analysis for land cover classification [21]. Furthermore, degradation trends in the Mesopotamian marshlands observed via Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2000 to 2012 underscore the long-term detrimental impact of human activities [22]. One useful technique for characterizing the changes in each land use category is the change detection analysis. According to the categorization of maximum likelihood method's results, the region's land use and land cover have changed noticeably between 1990 and 2016. The study reveals that Iraqi lakes lose over 2.5 meters of water annually due to high evaporation rates in an arid region, with only 10% returning to aquifers [23]. Long-term observations using Advanced Very High Resolution Radiometer (AVHRR)/Normalized Difference Vegetation Index (NDVI) data from 1982 to 2017 across three major marshes revealed that ecosystem conditions, water levels, and vegetation coverage have been profoundly influenced by both environmental variability and anthropogenic activities and were categorized using Landsat images [24]. Evaporation in Iraq's arid southern regions continues to exacerbate marsh degradation, particularly in ecosystems sustained by the Tigris, Euphrates, Karkheh, and Karun Rivers. Managing water inflow and outflow through the Shatt Al-Arab is therefore essential in understanding and stabilizing marsh water levels [25].

C. Statistics and Field Survey

Table III provides a comparative overview of methodologies employed in studies involving statistical analysis and field surveys between 1979 and 2022. This study emphasizes the critical importance of monitoring WQ parameters in southern Iraq's marshlands. WQ degradation has been largely attributed to prolonged droughts, upstream damming, and the discharge of untreated wastewater from industrial, residential, and agricultural sources. The marsh serves as a natural filter and bioremediation system, with studies reporting a decline in concentrations of major ions and heavy metals over time [39, 40].

TABLE I. OVERVIEW OF GIS APPROACHES IN DROUGHT STUDIES (1970-2024)

Subject Area	Area of Focus	Publication Period	Reference
Medalus event models	Classification and mapping of land degradation in southern Iraqi marshlands using GIS models.	2020-2021	[11]
Evaluate drought risk	Assessment of climate change impacts on drought risk in Sabarmati River Basin, India.	2023-2024	[12]
Impact of climate change on drought	GIS and AHP application to evaluate drought risk in southwestern Zimbabwe.	1971-2022	[13]
WQ assessment	Analysis of hydraulic behavior and WQ in southern Iraq marshlands using GIS.	2020-2010	[14]
Drought risk	MODS satellite data analysis of marshland changes over a 13-year period.	2000-2012	[15]
Drought risk assessment	Integrating conservation principles for World Heritage-listed marshes with water balance data.	1970-2010	[16]
Building a spatial geodatabase	GIS/RS-based change detection and geodatabase development in southern Iraq.	1973-2016	[17]
Drought and groundwater	Evaluation of water and drought interaction in Barind Tract, Bangladesh using GIS.	2017-2018	[18]
Drought risk	Satellite and statistical evaluation of drought in southern Iraqi marshes.	1970-2022	[20]

TABLE II. OVERVIEW OF THE DIFFERENT RS TECHNIQUES USED FOR DROUGHT STUDIES (1978-2022)

Subject Area	Area of Focus	Publication Period	Reference
Environmental influences	The study focused on the environmental impacts on the settlement patterns of communities in the Iraqi marshes by conducting a descriptive study of traditional housing patterns.	2020-2021	[19]
Impact of the drought	Assessment of marshland degradation due to limited water release and low rainfall in the southern regions of Iraq.	2003–2013	[22]
Flood risk	Use of equations and statistical data to measure flood risk in Al-Hammar marsh.	1985-2022	[23]
Monitoring system	Monitoring Mesopotamian climate change and its impact on marshlands using RS.	1980-2017	[24]
Monitoring system	Evaluation of irrigation, hydrology, and agricultural feasibility in the marshland region of southern Iraq.	1978-2010	[25]
Change detection	Analysis and classification of land cover of satellite images of Al-Dalmaj marsh between Wasit and Diwaniyah Governorates in the Republic of Iraq.	2000-2016	[26]
Meteorological drought	The study presented an exploration of the temporal and spatial patterns of hydrological drought based on total water storage in the Horn of Africa region of Africa.	1979-2014	[27]
Change detection	This dataset has recently been used at specific spatial and temporal resolutions and on a daily-to-daily basis to monitor the spatial and temporal variability of vegetation along with other hydrological variables such as land surface temperature, precipitation, and evapotranspiration.	1981-2018	[28]
Integration of sustainable	Using satellite images to rehabilitate marshland villages in southern Iraq.	1991-2003	[29]
Impact of the drought	The study topic dealt with drought, water cover, and vegetation cover in specific areas in the marshlands of Basra Governorate in Iraq.	1992-1994	[30]
WQ	Mathematical models and RS applied to WQ in southern marshlands.	1994-2014	[31]
Drought stress	Application of RS (Normalized Humidity and Precipitation Index) calculated by data analysis in assessing plant drought and climate in China.	2000-2017	[32]
Monitoring system	Satellite-based monitoring of lake area variability in Iraq.	2001-2012	[33]
WQ	The study focused on analyzing the WQ of the central marshes in southern Iraq	2013-2014	[34]
Impact of the drought	RS-based assessment of land cover and drought impact in southern Iraq.	2017-2019	[35]

TABLE III. OVERVIEW OF METHODOLOGIES USED IN STUDIES OF STATISTICS AND FIELD SURVEY (1979-2022)

Subject Area	Area of Focus	Publication Period	Reference
WQ	Fixed-station method for physical and chemical WQ analyses in southern Iraq marshes.	2007-2008	[21]
WQ	Using satellite images and mathematical models to analyze the waters of Al-Hawizeh marsh to obtain salinity maps and spatial analysis in Maysan Governorate, southeast of Iraq	2019-2020	[36]
Investigation area	Using a combination of drone photography and magnetic gradient data to infer the locations of indigenous marshland inhabitants in upland areas only.	2020-2021	[37]
Water management	Analysis of water salinity sources in Shatt al-Arab and marshlands.	2021-2022	[38]
Environment assessment	The study focused on using multivariate statistics and collecting water and sediment samples to determine the physical and chemical properties of the Hammar marsh in southern Iraq.	2016-2017	[39]
Ecological assessment	Use of environmental indicators to assess annual variation in Al-Hammar marsh.	2012-2013	[41]
WQ	Statistical modeling to evaluate spatial/temporal WQ changes in marshlands.	1980-2000	[42]
Drought risk	The study focused on the previous policies and regimes in destroying the Iraqi marshes using international statistics and documents.	1991-1992	[43]
Drought analysis	Using Standardized Precipitation Evapotranspiration Index (SPEI) to determine the level of drought in Rajasthan during the period (1979-2013). The spatial distribution showed a high level of drought during different time periods.	1979-2013	[44]
Sustainable management	The study focused on plans to re-transform the Iraqi marshes after following up on twelve years of data and statistical information on the rates of submergence.	2009–2020	[45]

Field observations revealed seasonal variations in physicochemical properties. The pH ranged from 7.9 in July to 8.5 in February, while water temperatures fluctuated between 14.6 ℃ in January to 31.7 ℃ in August. Dissolved oxygen concentrations varied from 6.2 mg/L in March and April to 10.2 mg/L in December. Salinity levels ranged between 2.0‰ in October–November and peaked at 9.7‰ in February. Water transparency was lowest in March (50.0 cm) and highest in December (78.7 cm). Reactive nitrate levels measured 6.8 µg-N/L in October and increased to 19.6 µg-N/L in February. Beyond environmental parameters, field surveys also documented the distinctive lifestyle of marsh Arabs (Marshmen), who maintain traditional practices adapted to the harsh wetland environment. These include the use of reeds in housing construction, fishing, hunting, livestock herding (notably buffalo), and milk production from cows and goats, all of which support sustainable living within the ecosystem [41]. Statistical analyses identified Electrical Conductivity (EC) and Total Dissolved Solids (TDS) as the most significant WQ variables contributing to regional disparities. High salinity levels were particularly prevalent in the Central and Al-Hammar marshes [42].

V. RESULTS AND DISCUSSION

This study provides a comprehensive analysis of the environmental and ecological state of the southern Iraqi marshlands using advanced geospatial tools and methodologies. Through the integration of GIS and various environmental models, this research highlights the critical issues the marshes are facing, including WQ degradation, loss of biodiversity, and the increasing threat of desertification due to both natural and anthropogenic factors.

GIS has proven essential in managing and analyzing spatial datasets, supporting land degradation mapping, resource management, and vulnerability assessments. Coupled with RS data from satellites, these tools have enabled precise monitoring of land use, vegetation dynamics, water body fluctuation, and drought risks. The use of statistical models and environmental indices further enhances the robustness of ecological assessments.

Despite restoration initiatives, uncertainties persist regarding the long-term effects of climate change on the hydrological and ecological stability of the marshes. The study emphasizes the need for integrated approaches that combine geospatial tools, statistical methods, and field surveys to inform sustainable management strategies. Notably, regional cooperation is essential to ensure the sustained inflow of water from the Tigris and Euphrates rivers, critical for the ecological resilience of the marshes.

Ultimately, the integration of GIS, RS, statistical modeling, and socioeconomic analysis can support more informed, adaptive, and sustainable decision-making. This interdisciplinary framework is vital for safeguarding the biological, cultural, and economic significance of Iraq's southern marshlands.

VI. CONCLUSION

This study has demonstrated the critical value of integrating Remote Sensing (RS), Geographic Information Systems (GIS), and advanced environmental modeling in evaluating the complex dynamics of Iraq's southern wetlands. The use of geospatial tools enabled a comprehensive assessment of land degradation, declining Water Quality (WQ), biodiversity loss, and shifting land use patterns.

Key findings indicate that, without sustained intervention and improved regional water governance, these marshlands will continue to degrade, threatening ecological functions and the livelihoods of dependent communities. Given the compounded effects of climate change and upstream water management pressures, this review strongly advocates for a multidisciplinary, data-driven approach to marshland conservation. Such an approach should prioritize transboundary water cooperation, investment in ecologically sustainable rehabilitation, and the integration of socioeconomic dimensions into environmental decision-making. Continued application of geospatial technologies, complemented by field validation and active community participation, is essential to secure the long-term resilience and ecological integrity of this vital ecosystem.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Laith A. Naji for his valuable contributions and insights. The support and resources provided by the School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, are also gratefully acknowledged.

REFERENCES

[1] H. Merza and Z. A. Muneam, "The Iraqi Marshland and the Quest of Tourism and Development," in *Reconciliation, Heritage and Social Inclusion in the Middle East and North Africa*, I. M. AlDajani and M. Leiner, Eds. Cham: Springer International Publishing, 2022, pp. 273–295.

[2] N. A. Fawzi, K. P. Goodwin, B. A. Mahdi, and M. L. Stevens, "Effects of mesopotamian marsh (iraq) desiccation on the cultural knowledge and livelihood of marsh arab women," *Ecosystem Health and Sustainability*, vol. 2, no. 3, Mar. 2016, Art. no. e01207, https://doi.org/10.1002/ehs2.1207.

[3] R. Giblett, "Marsh Arabs in Iraq," in *Wetland Cultures*, Cham: Springer Nature Switzerland, 2024, pp. 65–92.

[4] M. A. Alani, J. Shen, and A. F. Koko, "A comprehensive study of Iraqi marshlands, with the emphasis on the development possibilities." Research Square, Apr. 28, 2022, https://doi.org/10.21203/rs.3.rs-1487276/v2.

[5] A. A. K. Hussein and A. A. Asal, "Drying water and its impact on the vital system in the marshes of southern Iraq," *IOP Conference Series: Earth and Environmental Science*, vol. 1129, no. 1, Jan. 2023, Art. no. 012032, https://doi.org/10.1088/1755-1315/1129/1/012032.

[6] W. H. Hassan, S. T. Khazaal, and M. H. Al-Shammari, "Effect of Climate Change on Wetland Areas in West Iraq Using Satellite Data and GIS Techniques," *Civil Engineering Journal*, vol. 10, no. 9, pp. 2966–2978, Sep. 2024, https://doi.org/10.28991/CEJ-2024-010-09-013.

[7] H. M. Bedair, H. T. Al Saad, and N. A. Salman, "Iraq's Southern Marshes Something Special To Be Conserved; A Case Study," *Marsh Bulletin*, vol. 2, no. 1, pp. 99–126, 2006.

[8] B. M. Hashim, M. A. Sultan, M. N. Attyia, A. A. Al Maliki, and N. Al-Ansari, "Change Detection and Impact of Climate Changes to Iraqi Southern Marshes Using Landsat 2 MSS, Landsat 8 OLI and Sentinel 2 MSI Data and GIS Applications," *Applied Sciences*, vol. 9, no. 10, May 2019, Art. no. 2016, https://doi.org/10.3390/app9102016.

[9] R. H. Abood, A. H. Mahdi, A. G. Khalaf, and A. A. Kadhim, "Evaluation of Land Cover Changes in Karbala Governorate Using Remote Sensing and GIS Techniques," *Iraqi National Journal of Earth Science*, vol. 24, no. 2, pp. 177–185, July 2024, https://doi.org/10.33899/earth.2023.143323.1144.

[10] A. G. Khalaf and R. H. Abood," Evaluation of Groundwater Quality in Najaf and Hilla Area of Iraq based on Weighted Arithmetic Method and GIS," *in The 4th International Conference on Sustainable Engineering Techniques (ICSET), Oct. 2022, Baghdad, Iraq*, https://doi.org/10.1063/5.0212629.

[11] W. J. Al-rikabi and B. S. Abed, "Improvement of the Hydrodynamic Behavior and Water Quality Assessment of Al-Chibayish Marshes, Iraq," *Journal of Engineering*, vol. 27, no. 12, pp. 50–68, Dec. 2021, https://doi.org/10.31026/j.eng.2021.12.05.

[12] O. Jasim, N. Hamed, and T. Abdulgabar, "Change detection and building spatial geodatabase for Iraqi marshes," *MATEC Web of Conferences*, vol. 162, 2018, Art. no. 03021, https://doi.org/10.1051/matecconf/201816203021.

[13] S. Shahid and M. K. Hazarika, "Groundwater Drought in the Northwestern Districts of Bangladesh," *Water Resources Management*, vol. 24, no. 10, pp. 1989–2006, Aug. 2010, https://doi.org/10.1007/s11269-009-9534-y.

[14] K. J.L. Al-Zaidy and G. Parisi, "Re Extrapolation For The Iraq Marshes Which Falling Within The World Heritage List (A Literature Review)," *Al-Qadisiyah Journal For Agriculture Sciences*, vol. 8, no. 2, pp. 65–81, Dec. 2018, https://doi.org/10.33794/qjas.Vol8.Iss2.60.

[15] Y. Al-Mamalachy and Z. J. Al-Saedi, "Analysis and Detection of Inundation in Al-Hammar and Central Marshes/ Southern Iraq Using Google Earth Engine," *Iraqi Bulletin of Geology and Mining*, vol. 18, no. 1, Aug. 2022, https://doi.org/10.5281/ZENODO.7018225.

[16] M. F. A. Jabbar, A. F. Al-Ma'amar, and A. T. Shehab, "Change Detections in Marsh Areas , South Iraq , Using Remote Sensing and GIS Applications," *Iraqi Bulletin of Geology and Mining*, vol. 6, no. 2, pp. 17–39, 2010.

[17] M. M. Hason, I. S. Abbood, and S. A. Odaa, "Land cover reflectance of Iraqi marshlands based on visible spectral multiband of satellite imagery," *Results in Engineering*, vol. 8, Dec. 2020, Art. no. 100167, https://doi.org/10.1016/j.rineng.2020.100167.

[18] A. A. Z. Douabul, H. T. Al-Saad, D. S. Abdullah, and N. A. Salman, "Designated Protected Marsh within Mesopotamia : Water Quality," *American Journal of Water Resources*, vol. 1, no. 3, pp. 39–44, Nov. 2013, https://doi.org/10.12691/ajwr-1-3-4.

[19] S. R. Yousif and W. F. Shneen, "Assessment of the Marshes in Southern Iraq Using Remote Sensing Techniques: A Review," *International Journal of Geography, Earth and Environment Science*, vol. 1, no. 1, pp. 23–33, 2022.

[20] R. Becker, "The Stalled Recovery of the Iraqi Marshes," *Remote Sensing*, vol. 6, no. 2, pp. 1260–1274, Jan. 2014, https://doi.org/10.3390/rs6021260.

[21] A. Al-Handal and C. Hu, "MODIS Observations of Human-Induced Changes in the Mesopotamian Marshes in Iraq," *Wetlands*, vol. 35, no. 1, pp. 31–40, Feb. 2015, https://doi.org/10.1007/s13157-014-0590-6.

[22] M. M. Kadhim, "Monitoring Land Cover Change Using Remote Sensing and GIS Techniques: a Case Study of Al-Dalmaj Marsh, Iraq," *Journal of Engineering*, vol. 24, no. 9, pp. 96–108, Aug. 2018, https://doi.org/10.31026/j.eng.2018.09.07.

[23] N. J. Khalid and M. Farajzadeh, "The Role of Remote Sensing and Geographic Information System in Analyzing Climate Change in the Mesopotamian Marchlands, Iraq." Research Square, Nov. 07, 2022, https://doi.org/10.21203/rs.3.rs-2201943/v1.

[24] J. L. Awange, Khandu, M. Schumacher, E. Forootan, and B. Heck, "Exploring hydro-meteorological drought patterns over the Greater Horn of Africa (1979–2014) using remote sensing and reanalysis products," *Advances in Water Resources*, vol. 94, pp. 45–59, Aug. 2016, https://doi.org/10.1016/j.advwatres.2016.04.005.

[25] R. Albarakat, V. Lakshmi, and C. J. Tucker, "Using Satellite Remote Sensing to Study the Impact of Climate and Anthropogenic Changes in the Mesopotamian Marshlands, Iraq," *Remote Sensing*, vol. 10, no. 10, Sep. 2018, Art. no. 1524, https://doi.org/10.3390/rs10101524.

[26] S. Najim, N. A. Alslam, and I. A. Albazzaz, "Environmental Influences on the Settlements Patterns of Communities in the Marshes of Iraq," *International Journal of Design & Nature and Ecodynamics*, vol. 16, no. 6, pp. 657–663, Dec. 2021, https://doi.org/10.18280/ijdne.160606.

[27] A. A. Rashid Kbah, "The Integration of Sustainable Cities in the Marshes (Iraq)," *IOP Conference Series: Earth and Environmental Science*, vol. 290, no. 1, Jun. 2019, Art. no. 012125, https://doi.org/10.1088/1755-1315/290/1/012125.

[28] D. C. Munro and H. Touron, "The estimation of marshland degradation in southern Iraq using multitemporal Landsat TM images," *International Journal of Remote Sensing*, vol. 18, no. 7, pp. 1597–1606, May 1997, https://doi.org/10.1080/014311697218304.

[29] M. Marghany, H. A. Hasab, S. Mansor, and A. R. B. M. Shariff, "Developing hydrological model for water quality in Iraq marshes zone using Landsat-TM," *IOP Conference Series: Earth and Environmental Science*, vol. 37, Jun. 2016, Art. no. 012073, https://doi.org/10.1088/1755-1315/37/1/012073.

[30] H. Sun, Z. Xu, and H. Liu, "An evaluation of the response of vegetation greenness, moisture, fluorescence, and temperature-based remote sensing indicators to drought stress," *Journal of Hydrology*, vol. 625, Oct. 2023, 130125, https://doi.org/10.1016/j.jhydrol.2023.130125.

[31] A. Dawood, Y. Kalaf, N. Abdulateef, and M. Falih, "Investigation of surface area of lakes and marshes from satellite images by using remote sensing and geographic information system integration in Iraq," *MATEC*

Web of Conferences, vol. 162, 2018, Art. no. 03016, https://doi.org/10.1051/matecconf/201816203016.

[32] N. A. Fazaa, J. C. Dunn, and M. J. Whittingham, "Pollution threatens water quality in the Central Marshes of Southern Iraq," *Baghdad Science Journal*, vol. 18, no. 4, Dec. 2021, https://doi.org/10.21123/bsj.2021.18.4(Suppl.).1501.

[33] A. H. J. Abdullah, "Fish assemblage and impact of oscillation between drowning and drought on fish size-spectrum in the Al-Chibyaish Marsh, Southern Iraq," *IraqiJournal of Science*, vol. 60, no. 1, pp. 18–28, 2019.

[34] H. A. Hasab, H. A. Jawad, H. Dibs, H. M. Hussain, and N. Al-Ansari, "Evaluation of Water Quality Parameters in Marshes Zone Southern of Iraq Based on Remote Sensing and GIS Techniques," *Water, Air, & Soil Pollution*, vol. 231, no. 4, Apr. 2020, Art. no. 183, https://doi.org/10.1007/s11270-020-04531-z.

[35] E. Hammer, "Multi-centric, Marsh-based Urbanism at the early Mesopotamian city of Lagash (Tell al-Hiba, Iraq)," *Journal of Anthropological Archaeology*, vol. 68, Dec. 2022, Art. no. 101458, https://doi.org/10.1016/j.jaa.2022.101458.

[36] K. Rahi and A. A. Ali, "Water management scheme to restore and sustain the Marshes and Shatt al-Arab, Southern Iraq," *IOP Conference Series: Earth and Environmental Science*, vol. 1002, no. 1, Mar. 2022, Art. no. 012009, https://doi.org/10.1088/1755-1315/1002/1/012009.

[37] H. F. A. Al-Gburi, B. S. Al-Tawash, and H. S. Al-Lafta, "Environmental assessment of Al-Hammar Marsh, Southern Iraq," *Heliyon*, vol. 3, no. 2, Feb. 2017, Art. no. e00256, https://doi.org/10.1016/j.heliyon.2017.e00256.

[38] A. A. H. Faisal, Z. A. Al-Ridah, L. A. Naji, Mu. Naushad, and H. A. El-Serehy, "Waste Foundry Sand as Permeable and Low Permeable Barrier for Restriction of the Propagation of Lead and Nickel Ions in Groundwater," *Journal of Chemistry*, vol. 2020, pp. 1–13, Jul. 2020, https://doi.org/10.1155/2020/4569176.

[39] D. N. Ahmed, A. A. H. Faisal, S. H. Jassam, L. A. Naji, and Mu. Naushad, "Kinetic Model for pH Variation Resulted from Interaction of Aqueous Solution Contaminated with Nickel Ions and Cement Kiln Dust," *Journal of Chemistry*, vol. 2020, pp. 1–11, Apr. 2020, https://doi.org/10.1155/2020/8732308.

[40] A. A. H. Faisal, L. A. Naji, A. A. Chaudhary, and B. Saleh, "Removal of ammoniacal nitrogen from contaminated groundwater using waste foundry sand in the permeable reactive barrier," *Desalination and Water Treatment*, vol. 230, pp. 227–239, Aug. 2021, https://doi.org/10.5004/dwt.2021.27436.

[41] S. S. Almaarofi, A. A. Zahra Douabul, H. Boyacioglu, and H. Boyacioglu, "Index and statistical methods in water management. A case study from the Mesopotamian marshes, Iraq," *Environment Protection Engineering*, vol. 43, no. 3, 2017, https://doi.org/10.37190/epe170302.

[42] A.-R. M. Mohamed, N. A. Hussain, S. S. Al-Noor, F. M. Mutlak, I. M. Al-Sudani, and A. M. Mojer, "Ecological and biological aspects of fish assemblage in the Chybayish marsh, Southern Iraq," *Ecohydrology & Hydrobiology*, vol. 12, no. 1, pp. 65–74, Jan. 2012, https://doi.org/10.2478/v10104-012-0006-2.

[43] A. H. Nama, I. A. Alwan, and Q. B. Pham, "Climate change and future challenges to the sustainable management of the Iraqi marshlands," *Environmental Monitoring and Assessment*, vol. 196, no. 1, Jan. 2024, Art. no. 35, https://doi.org/10.1007/s10661-023-12168-8.

[44] A. Raja and T. Gopikrishnan, "Drought Analysis Using the Standardized Precipitation Evapotranspiration Index (SPEI) at Different Time Scales in an Arid Region," *Engineering, Technology & Applied Science Research*, vol. 12, no. 4, pp. 9034–9037, Aug. 2022, https://doi.org/10.48084/etasr.5141.

[45] A. Raja and T. Gopikrishnan, "Drought Prediction and Validation for Desert Region using Machine Learning Methods," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 7, 2022, https://doi.org/10.14569/IJACSA.2022.0130707.