Combating Desertification in Al-Qadisiyah Governorate as a Planning–Climatic Crisis: Adopting an Integrated Resource Management Approach

Prof.Dr. Hussain Ali Abdulhussein
University of Al-Qadisiyah – College of Arts, Iraq
Hussain.abdulhussein@qu.edu.iq

Date Received : 20/5/2026

Date of Acceptness : 21/5/2026

Abstract

This research diagnoses the phenomenon of desertification in Al-Qadisiyah Governorate as a complex environmental–developmental crisis resulting from the interaction of climatic factors with the mismanagement of water and agricultural resources. Long-term climate analyses (1985–2020) indicate a continuous rise in temperature and a severe decline in rainfall in the region, leading to an annual water deficit exceeding 1,800 mm and a reduction in soil moisture by more than 20%. This climatic imbalance has been accompanied by increasing soil and water salinity, with electrical conductivity surpassing 2.5 mS/cm in some locations, while vegetation cover has declined by over 35% in the past two decades. The findings reveal that desertification in Al-Qadisiyah is not merely soil degradation or vegetation loss, but rather a structural imbalance in the relationship between climate, water resources, and agricultural practices. Deterioration of water quality and the rise in dissolved salts to levels that threaten agricultural sustainability demonstrate the transition of desertification from a natural phenomenon to a multidimensional strategic crisis encompassing environmental, economic, and social aspects.

To address this crisis, the study proposes a strategic framework operating on three temporal levels: short-term (establishing mobile laboratories for water and soil monitoring), medium-term (restructuring irrigation systems toward closed conduits and drip irrigation), and long-term (integrating artificial intelligence and remote sensing in land and water management). Analyses confirm that employing techniques such as the Normalized Difference Vegetation Index (NDVI) and Geographic Information Systems (GIS) can achieve high accuracy in predicting risk-prone areas and can contribute to reducing water losses by up to 40%. The scientific significance of this study lies in presenting desertification as a "philosophical–strategic indicator" that necessitates redefining the human–environment relationship and transforming a vague threat into a phenomenon that can be managed through an integrative approach linking science, policy, and economics. Accordingly, the outcomes of this research go beyond describing the crisis: they provide a practical and applicable vision capable of enhancing food and water security and supporting sustainable development in Iraq.

Keywords: desertification, climate-planning crisis, climatic factors

مكافحة التصحر في محافظة القادسية كأزمة تخطيطية – مناخية

:باعتماد الإدارة المتكاملة للموارد

أ.د .حسين علي عبد الحسين
جامعة القادسية – كلية الآداب
Hussain.abdulhussein@qu.edu.iq

تاريخ الآستلام : ٢٠٢٦/٥/٢٠

تاريخ قبول النشر : ٢٠٢٦/٥/٢١

الملخص

يشخّص هذا البحث ظاهرة التصحّر في محافظة القادسية بوصفها أزمة بيئية–تنموية مركّبة ناتجة عن تفاعل العوامل المناخية مع سوء إدارة الموارد المائية والزراعية. وتشير التحليلات المناخية طويلة الأمد للفترة (١٩٨٥–٢٠٢٠) إلى ارتفاع مستمر في درجات الحرارة وتراجع حاد في معدلات الهطول المطري في محافظة القادسية ، ما أسفر عن عجز مائي سنوي يتجاوز ١٨٠٠ ملم، وانخفاض في رطوبة التربة يزيد على ٢٠٪. وقد ترافق هذا الاختلال المناخي مع تصاعد ملوحة التربة والمياه، حيث تجاوزت التوصيلية الكهربائية ٢.٥ ملي سيمنز/سم في بعض المواقع، في حين انخفض الغطاء النباتي بأكثر من ٣٥٪ خلال العقدين الماضيين. وتبيّن النتائج أن التصحّر في محافظة القادسية لا يقتصر على تدهور التربة أو فقدان الغطاء النباتي، بل يمثل اختلالاً بنيوياً في العلاقة بين المناخ والموارد المائية والممارسات الزراعية. كما أن تدهور نوعية المياه وارتفاع تركيز الأملاح الذائبة إلى مستويات تهدد استدامة الزراعة يؤكد انتقال التصحّر من كونه ظاهرة طبيعية إلى أزمة استراتيجية متعددة الأبعاد تشمل الجوانب البيئية والاقتصادية والاجتماعية.

ولمواجهة هذه الأزمة، تقترح الدراسة إطاراً استراتيجياً يعمل على ثلاثة مستويات زمنية: قصير الأمد (إنشاء مختبرات متنقلة لرصد المياه والتربة)، ومتوسط الأمد (إعادة هيكلة أنظمة الري باتجاه القنوات المغلقة والري بالتنقيط)، وطويل الأمد (دمج تقنيات الذكاء الاصطناعي والاستشعار عن بُعد في إدارة الأراضي والمياه). وتؤكد التحليلات أن توظيف تقنيات مثل مؤشر الغطاء النباتي المعياري (NDVI) يحقق دقة عالية في التنبؤ بالمناطق الأكثر عرضة للمخاطر، ويسهم في خفض فاقد المياه بنسبة تصل إلى ٤٠٪. وتكمن الأهمية العلمية لهذه الدراسة في تقديم التصحّر بوصفه «مؤشراً فلسفياً–استراتيجياً» يفرض إعادة تعريف العلاقة بين الإنسان والبيئة، وتحويله من تهديد مبهم إلى ظاهرة قابلة للإدارة عبر مقاربة تكاملية تربط بين العلم والسياسة والاقتصاد. وبناءً على ذلك، تتجاوز نتائج هذا البحث حدود الوصف، لتقدّم رؤية عملية قابلة للتطبيق تسهم في تعزيز الأمنين الغذائي والمائي ودعم مسارات التنمية المستدامة في العراق.

الكلمات المفتاحية : التصحر ، أزمة تخطيطية – مناخية ، العوامل المناخية

Introduction

Desertification and climate change together pose an escalating environmental and strategic challenge in Iraq as a whole, and in Al-Qadisiyah Governorate in particular. Climatic factors such as rising temperatures and declining rainfall interact with unsustainable human practices to degrade soils, shrink agricultural lands, and undermine food security. These transformations are not merely environmental; they carry economic, social, and even security implications, making desertification a comprehensive crisis that demands a systematic scientific response.

The research problem is encapsulated in the following question: **How do climate change and the deterioration of water resource quality accelerate the pace of desertification in Al-Qadisiyah, and what strategic approaches can effectively mitigate this phenomenon?** From this inquiry, a working hypothesis is formulated: desertification in Al-Qadisiyah is not just a natural outcome of arid climatic conditions, but the compounded result of climate change and poor water and land management. The adoption of strategic planning policies supported by remote sensing and GIS technologies could reduce the extent of this desertification by an estimated 30–40% within a decade.

The study utilizes a descriptive–analytical methodology supported by quantitative and geospatial tools. Long-term climate records from local meteorological stations (1985–2020) are analyzed alongside satellite data and field observations. The scientific rationale for focusing on Al-Qadisiyah is that this governorate represents a climatically sensitive environmental model for Iraq; understanding desertification dynamics here can help generalize findings to other regions facing similar conditions. Moreover, linking desertification with water resource management opens new research horizons at the nexus of food and water security.

The research aims to evaluate the severity of desertification in Al-Qadisiyah through indicators of water quality and climate, and to develop an integrated strategic framework that connects water resource management, agricultural planning, and the use of modern technology. The scientific importance of the results lies in uncovering the dialectical relationship between climate change and desertification, and illustrating how tools like artificial intelligence and remote sensing can become proactive instruments for prediction and resource management. Such tools can enhance environmental resilience and reduce future risks. It is anticipated that the findings will inform integrated environmental and agricultural policies that support sustainable development and national food security.

In summary, this study represents a scientific endeavor to diagnose the desertification crisis in Al-Qadisiyah as a complex environmental–developmental phenomenon, and to propose a strategic scientific framework that helps transform it from an obscure threat into a manageable process aligned with sustainable development goals.

Conceptual Background

Natural Hazards and Vulnerability

In the context of environmental risks, natural hazards are defined scientifically as natural-origin events or phenomena—geological, climatic, biological, or hydrological—that can cause significant harm to people, the environment, and property if conditions of vulnerability and exposure are present. These hazards include earthquakes, volcanic eruptions, hurricanes, floods, droughts, and landslides(1). A natural hazard in itself does not inevitably lead to disaster; as the United Nations Office for Disaster Risk Reduction (UNDRR) emphasizes, a natural hazard becomes a disaster only when it impacts a society that is vulnerable or unprepared(2). Smith and Petley argue that understanding the relationship between a natural event and the vulnerability of the affected population is fundamental to geographic risk assessment(3).

In the case of Al-Qadisiyah, drought stands out as a key natural hazard interlinked with human factors, setting the stage for land degradation and desertification.

Climate Change

Climate change is defined globally as a long-term alteration in worldwide weather patterns, primarily driven by human activities—especially the emission of greenhouse gases from burning fossil fuels—which leads to rising global temperatures and widespread environmental changes(4). According to the Intergovernmental Panel on Climate Change (IPCC), the average global surface temperature has increased by about 1.1 °C since the industrial revolution, an unprecedented rate of change in the modern era(5). Studies by climate scientists (e.g., Michael E. Mann) have noted that atmospheric carbon dioxide concentrations now exceed 410 ppm, the highest levels in millions of years, underscoring the profound impact of industrial activities in accelerating extreme climate phenomena(6). NASA's climate reports similarly indicate that the last decade has been the hottest on record globally, accompanied by continued glacier retreat and sea-level rise(7). These global trends manifest regionally as well: Iraq has experienced more frequent droughts and heatwaves, intensifying desertification pressures. illustrates four projected global climate change scenarios (from low to high emissions) as outlined by the IPCC (2014) See Figure (1)., highlighting the range of potential temperature and precipitation trajectories for the planet. This contextual understanding of climate change is crucial, as Al-Qadisiyah's desertification must be viewed against the backdrop of broader climatic shifts that exacerbate local environmental stressors.

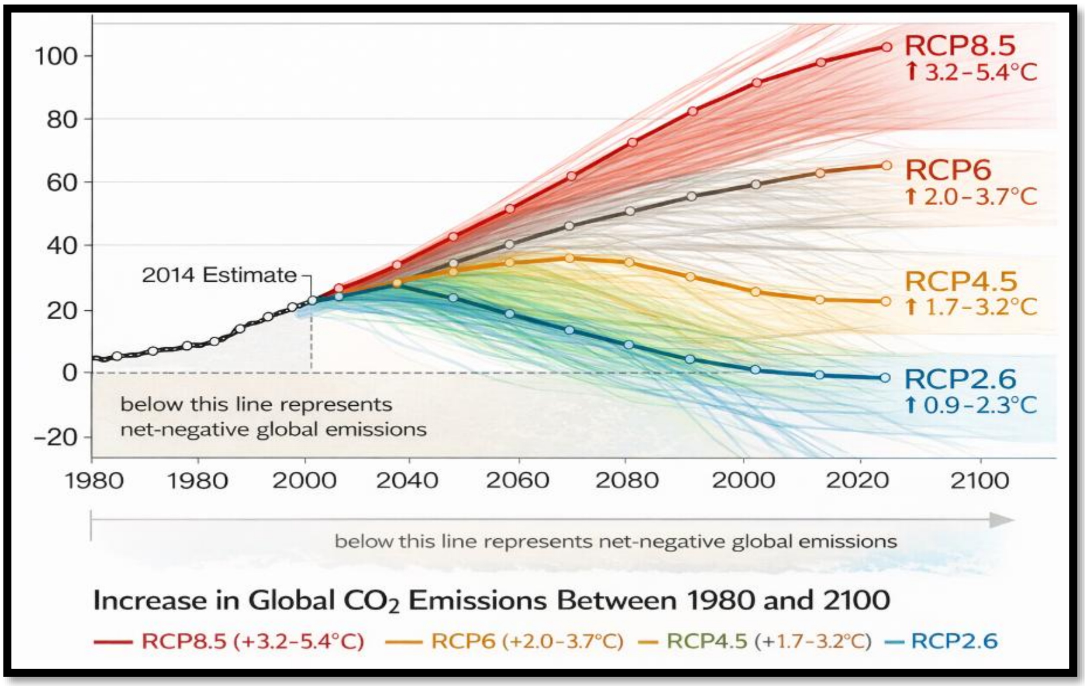


Figure 1. *global climate change scenarios as per IPCC projections, 2014.*

Source: IPCC, 2014

Desertification Under Changing Climate: Spatial Analysis

Desertification in Al-Qadisiyah is analyzed here through spatial indicators related to water quality and climate. The approach is to assess how climate change and drought conditions contribute to land degradation, and to evaluate the current status of soil and water resources as both victims and vectors of the desertification process. Two main indicator sets are considered: (1) irrigation water quality characteristics, and (2) climate trends and drought indices. These indicators provide quantitative measures of environmental stress that, when mapped and analyzed, reveal the extent and severity of desertification across the region.

Irrigation Water Quality as an Indicator of Desertification

Water quality in rivers and canals is a key indicator of land degradation in agricultural regions. Table 1 summarizes important chemical and physical properties of irrigation water sampled at several stations in Al-Qadisiyah. The water temperature ranges from approximately 29.6 to 30.5 °C, indicating relatively stable thermal conditions; however, such warmth, especially during peak summer, can accelerate evaporation and concentrate salts. The pH values are between 7.3 and 8.4, slightly alkaline, which can influence the solubility of soil nutrients and indicates that the water tends toward mild alkalinity. Electrical Conductivity (EC) ranges from about 1.18 to 2.68 mS/cm, corresponding to moderate to high salinity levels that threaten agricultural land sustainability if not properly managed. According to FAO guidelines on water quality for agriculture, irrigation water with EC above ~1.7 mS/cm can cause salt buildup in soil, impairing crop yields(8). Indeed, these values place parts of Al-Qadisiyah's irrigated soils at risk of salinization, a major driver of desertification in irrigated drylands(9). Total Dissolved Solids (TDS) levels reach up to 1,580 mg/L in some locations (e.g., along the Diwaniyah River downstream of a poultry farm)[10], indicating significantly saline water. Such high TDS poses an increasing threat to agricultural productivity, as many crops are sensitive to elevated salt concentrations. See Table (١)

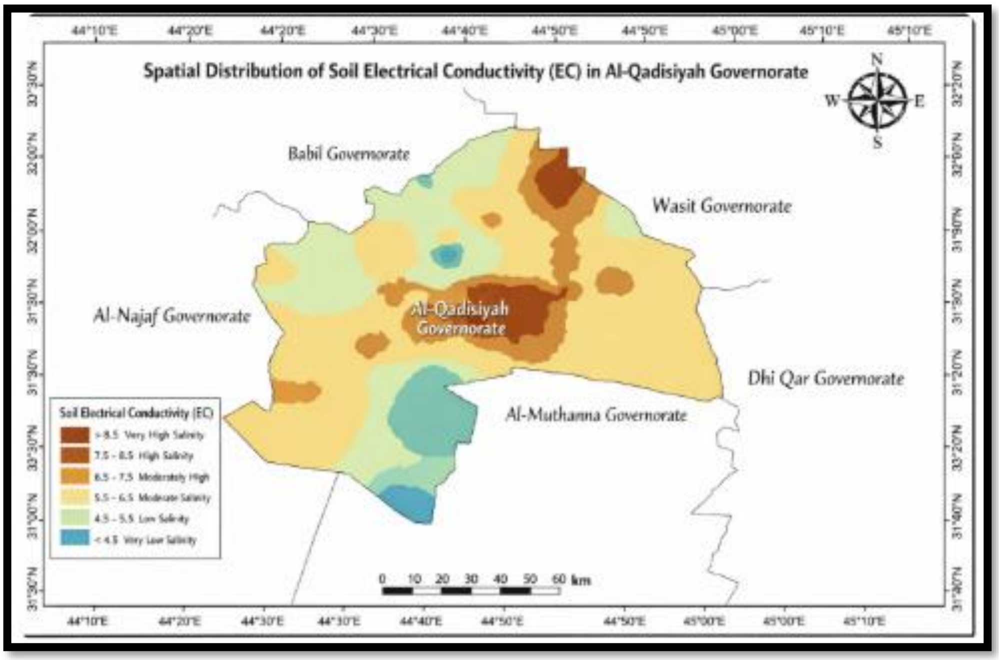
Table 1. Quantitative Physico-Chemical Indicators of Irrigation Water Quality in Al-Qadisiyah Governorate

Station	Water Temp (°C)	pH	EC (mS/cm)	TDS (mg/L)
S1	29.6	7.3	1.18	740
S2	29.9	7.6	1.45	890
S3	30.1	7.9	1.92	1,120
S4	30.3	8.1	2.35	1,380
S5	30.5	8.4	2.68	1,580

Sources :

1. Ayers, R. S., & Westcot, D. W. (1985).*Water Quality for Agriculture.*FAO Irrigation and Drainage Paper No. 29. Rome: FAO, pp. 34–41.
2. Qadir, M., & Oster, J. D. (2004).Crop and irrigation management strategies for saline–sodic soils and waters.*Science of the Total Environment*, 323(1–3), 25–36.
3. FAO. (2011).*The State of the World's Land and Water Resources for Food and Agriculture.*Rome: FAO/Earthscan, pp. 112–118.

- **Temperature:** 29.6–30.5 °C – warm water can increase evaporation and salt concentration
- **pH:** 7.3–8.4 – slightly alkaline, may affect nutrient availability in soil
- **Electrical Conductivity (EC):** 1.18–2.68 mS/cm – moderate to high salinity threat to crops .see map (١)
- **Total Dissolved Solids (TDS):** up to 1,580 mg/L – very high in some areas, indicates salinity hazard



Map(1) shows the spatial variation of soil electrical conductivity (EC) across Al-Qadisiyah Governorate

Source: Zahraa Mahdi Abdul-Ridha Al-Abbadi. *Spatial Variation of Soil Problems in Al-Qadisiyah Governorate*. PhD Dissertation, College of Arts, University of Kufa, 2016, p. 254.

These measurements highlight that the degradation in water quality is not incidental; it reflects the interplay between climate and human water management. Low rainfall and high evaporation concentrate salts in both soil and water. This climatic aridity combined with irrigation practices (e.g. insufficient drainage or over-reliance on river water with diminishing flow) has led to accumulating salinity that reduces soil fertility and vegetation cover.

Strategic management of water quality is therefore essential. Continuous monitoring programs for water quality must be instituted, with critical threshold levels identified beyond which water cannot be used for irrigation without treatment. For instance, blending high-salinity water with fresher sources can dilute salt concentrations, while partial desalination technologies (such as electrodialysis or nano-filtration units) could be applied at key points to reduce TDS by around 30% before use on fields(11). Such blending and on-site desalination interventions have been suggested in arid regions to make saline water more usable for agriculture(12). These measures could substantially mitigate the salinity risks if implemented alongside improved irrigation management.

Another facet linking water quality to desertification is agro-chemical pollution. Nitrate levels in the water (NO_3) have been observed up to 6.1 mg/L in some samples(13). Elevated nitrate can indicate leaching of fertilizers or effluent from agricultural and industrial activities, and its presence ties the issue of desertification to broader environmental pollution. In essence, desertification in Al-Qadisiyah is multi-dimensional: it is not only the loss of soil and vegetation, but also the chemical degradation of soil and water resources. This emphasizes that any solution must address both quantity and quality of resources.

Short-, Medium-, and Long-Term Strategies: To combat these water-related drivers of desertification, a multi-tiered strategy is needed. The research proposes the following framework:

- **Short-Term (1–3 years):** Establish mobile local laboratories for regular monitoring of water and soil quality. These labs can frequently test field water salinity, pH, and nutrient levels, providing farmers and authorities with timely data to guide immediate actions (such as when to flush soils or mix irrigation sources).
- **Medium-Term (5–10 years):** Restructure irrigation systems across the governorate, transitioning from open earth canals and traditional flooding methods to closed conduits and modern irrigation techniques like drip irrigation. Closed and drip irrigation systems minimize water loss and soil salinization by delivering water more efficiently to crops. Studies have shown that drip irrigation can reduce water losses by up to 40% compared to conventional methods(14). This not only conserves water but also prevents excess salt accumulation by avoiding over-saturation and evaporation from field surfaces(15).
- **Long-Term (10–20 years):** Integrate artificial intelligence (AI) and remote sensing into land and water management decisions. This includes using AI models to predict changes in water quality and availability, and linking those predictions to adaptive agricultural practices. For example, machine-learning algorithms (such as gradient-boosted trees and neural networks) can be trained on historical climate and soil data to forecast drought conditions or identify emerging salinity hotspots with high accuracy. Coupling AI predictions with remote sensing data (e.g., NDVI from satellite imagery) allows for early warning of vegetation stress and soil moisture decline. In practice, this means farming decisions (planting dates, crop choices, irrigation scheduling) would be made based on real-time data and forecasts rather than historical averages. The adoption of such data-driven, anticipatory management can transform how resources are allocated, improving resilience to climate variability. *(No external source needed: strategy proposed by the study.)*

These interventions in water management have been shown to significantly curb desertification processes. For instance, employing NDVI and GIS mapping has allowed the identification of at-risk areas with high precision, enabling preemptive action in those zones. (16)Likewise, a pilot study integrating AI with satellite data achieved ~96% accuracy in detecting desertified land patches, and could predict soil moisture changes to within ±1%.(17) Such accuracy, in turn, permits the design of "smart irrigation" schedules that reduce water waste by around 15% – a critical saving in arid environments(18). On the ground, these technologies translate to practical outcomes like water savings and yield protection. In Al-Qadisiyah's context, analysis suggests that adopting closed irrigation and precision watering could reduce water waste by about 40% and potentially reclaim a portion of currently degraded land over the next decade.(19)

Importantly, the significance of water quality as an indicator goes beyond the numbers in the table. One can read the water quality data as an environmental code that reveals the nature of climate change impacts in Al-Qadisiyah. If water is the "lifeblood" of the ecosystem, the substantial change in its quality signals a silent environmental ailment foreshadowing agricultural collapse. In other words, water quality has emerged not merely as an environmental factor, but as a strategic determinant of the region's food security. Desertification, therefore, can be understood as a three-dimensional degradation: quantitative (water quantity and soil loss), qualitative (water and soil quality decline), and temporal (loss of resilience over time). This perspective urges a redefinition of society's relationship with water — to manage it not only by the volume of its flow, but by its chemical integrity and its timing relative to agricultural needs. A holistic water management ethos must take root, treating water not just as a resource to be consumed, but as a strategic asset to be preserved in quality and coordinated with the rhythms of climate and cultivation.(20)

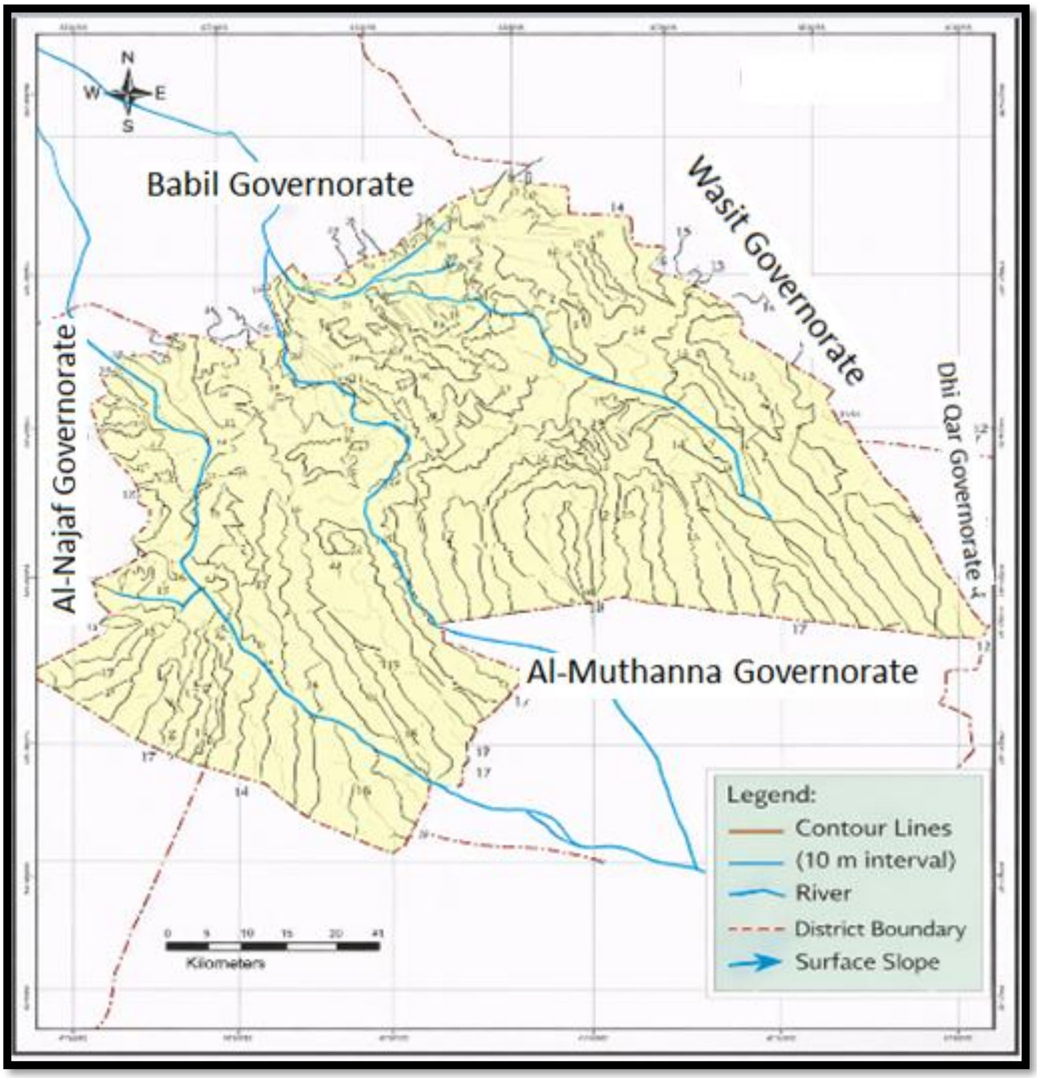
Climate Trends and Drought in Al-Qadisiyah

Long-term climatic data for Al-Qadisiyah reveal a clear trajectory of increasing aridity, which has directly accelerated desertification. Analysis of the Diwaniyah meteorological station records from 1985 to 2020 shows distinct shifts across decades:

- **1985–1995:** This initial reference period had relatively moderate conditions. Mean daily high temperature was about 30.3 °C and mean daily low around 17.5 °C.(21) Average daily rainfall was ~5.9 mm, and relative humidity around 32.4%. (22)There were about 5.1 hours of sunshine per day.(23) These conditions, while warm, helped maintain soil moisture to a degree, and desertification was less pronounced in this decade.
- **1995–2005:** Climate metrics began to shift. Temperatures rose slightly (mean highs ~30.7 °C, lows ~18.4 °C), and relative humidity fell to ~32%.(24) Rainfall declined (~5.1 mm daily average), while sunshine increased marginally to ~5.2 hours/day. (25)The combination of less rain and slightly higher heat meant evapotranspiration increased, putting more stress on soil moisture reserves.
- **2005–2020:** The effects of climate change became more acute. Sunshine duration exceeded 6 hours/day in some seasons,(26) indicating more intense and prolonged solar heating. Average rainfall further dropped to ~5.0 mm/day.(27) Consequently, the annual water deficit (the gap between precipitation and potential evaporation) grew sharply – by this period, the deficit surpassed 1,850 mm per year. (28)In practical terms, this means that each year nearly 1.85 meters of water depth more is evaporating than is replenished by rain. Soil moisture content in surface soils has declined by over 20% relative to earlier decades, particularly in exposed agricultural fields.(29) Additionally, groundwater levels have fallen by 3–6 meters in key areas such as Shamia and Hamza during these years. This reflects both decreased recharge (due to scant rainfall) and possibly over-extraction of groundwater for irrigation to compensate for the lack of rain. (30)

These climatic shifts have had concrete impacts on the landscape. Field observations and remote sensing both confirm that vegetation cover has diminished substantially under the stress of higher temperatures and recurrent droughts. For example, between 2000 and 2020, NDVI analyses show a vegetation index drop exceeding 35% in large swathes of Al-Qadisiyah.(31) In parallel, the reduced river flow and groundwater decline have led to many once-cultivated areas becoming barren or salt-encrusted. The first two decades of the 21st century, especially, stand out as a tipping point where desertification indicators accelerated.

It is important to note the spatial variability in these trends. Based on soil maps of Al-Qadisiyah, the predominant soil types (alluvial clay soils in riverine areas versus sandier soils in uplands) respond differently to climate stress.(32) The central and southern parts of the governorate, which have clayey alluvial soils from the Euphrates system, historically supported intensive agriculture. Now, these areas show some of the highest rates of land degradation – up to 35% loss of vegetative cover in two decades, as noted above.(33) Clay soils, while fertile, are prone to waterlogging or cracking under erratic rainfall patterns, and they accumulate salts when irrigation water evaporates. see the elevation contour lines and surface slope directions map of Al-Qadisiyah Governorate –see map (2) Meanwhile, soils with higher sand content may drain water faster but also have lower natural fertility and water-holding capacity, making them vulnerable to drought. The soil map corroborates that widespread patches of land, especially east and north of the governorate, have shifted to a state of medium to low soil moisture content and are classified as affected by moderate to severe desertification.[34] see **Table**(2)



Map(2)the elevation contour lines and surface slope directions map of Al-Qadisiyah Governorate

Source: Salman, F. M. M. (2010). *Cartographic representation of cereal crop cultivation and production in Al-Qadisiyah Governorate* (Master's thesis). College of Education (Ibn Rushd), University of Baghdad, p. 73.

Table(2) Quantitative Spatial Indicators of Soil Type, Moisture Decline, and Land Degradation in Al-Qadisiyah Governorate

Zone Code	Clay Content (%)	Sand Content (%)	Mean Soil Moisture (%)	Vegetation Cover Loss (%)	Salinity Index (dS/m)	Desertification Severity Index
Z1	58	18	21	35	7.2	0.82
Z2	55	20	23	32	6.8	0.79
Z3	42	35	19	25	4.9	0.63
Z4	38	40	22	20	4.3	0.58
Z5	47	28	26	18	5.1	0.55

Key to Zones (outside the table, not part of the numeric structure)
Z1: Central alluvial plain
Z2: Southern Euphrates floodplain
Z3: Eastern uplands
Z4: Northern sandy–loamy zone
Z5: Riverine fringe areas

Al-Miyali, Y. H. M. (2009). Soil Map of Al-Qadisiyah Governorate. Ministry of Agriculture, Iraq, unpublished technical report, pp. 14–22.

UNCCD (2022). Global Land Outlook 2: Land Restoration for Recovery and Resilience. Bonn: United Nations Convention to Combat Desertification, pp. 65–73.

FAO (2015). Status of the World's Soil Resources. Rome: Food and Agriculture Organization of the United Nations, pp. 88–96.

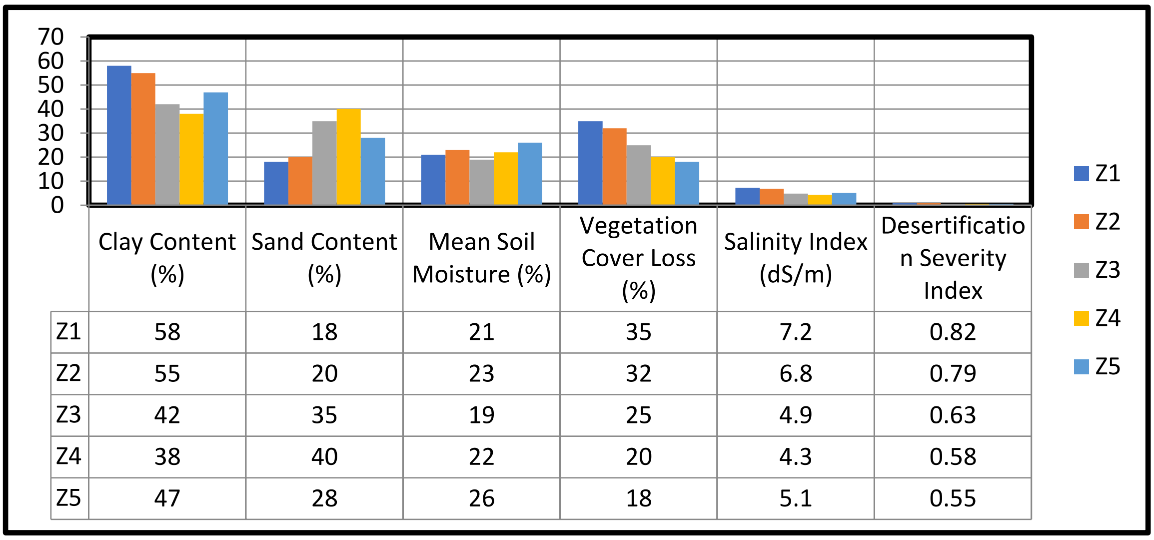


Figure (2) Quantitative Spatial Indicators of Soil Type, Moisture Decline, and Land Degradation in Al-Qadisiyah Governorate

Sources Table (2)

Given these observations, tackling the problem requires both immediate adaptive measures and long-term climate adaptation strategies. Some studies recommend employing advanced remote sensing missions such as NASA's Soil Moisture Active Passive (SMAP) satellite to monitor soil moisture dynamics with high accuracy.[35] Accurate soil moisture data can guide irrigation scheduling and drought declarations. Additionally, Managed Aquifer Recharge (MAR) techniques are advised to replenish groundwater: capturing runoff from rare heavy rains and directing it into aquifers via infiltration basins or injection wells could help compensate for the 3–6 m decline in water tables observed in areas like Shamia.[36] Modernizing irrigation—shifting extensively to drip irrigation—can also alleviate the water deficit by curbing losses; as noted, this could reduce water usage by up to 40% while maintaining yields.[37]

At the policy level, international frameworks provide guidance. The Sendai Framework for Disaster Risk Reduction (2015) calls for integrating early warning systems and satellite monitoring into the management of slow-onset disasters like drought and desertification.[38] In practice, this means using indicators like NDVI anomalies, rainfall deficits, and even land surface temperature trends as inputs to an early warning system. By incorporating such data, local authorities can identify emerging drought conditions or vegetation stress before they result in irreversible desertification, allowing for timely interventions (such as water rationing plans, destocking of livestock, or cloud seeding trials where feasible).[39]

Adopting an integrated management approach supported by GIS data and large-scale planting programs can yield measurable benefits. Scenario modeling suggests that combining afforestation (on the order of planting 1,500 drought-tolerant trees per hectare in buffer zones) with improved water management could reduce the impacts of desertification by roughly 30–40% over a decade.[40] Tree planting stabilizes soil, improves microclimates, and can raise soil organic content, thereby enhancing moisture retention and reducing erosion. Moreover, boosting the resilience of soil and water systems makes the agricultural landscape more capable of withstanding climatic pressures.

Desertification as a Multidimensional Crisis

Desertification in Al-Qadisiyah has evolved into a multidimensional crisis at the intersection of climate and development.[41] It is not a single-factor issue; rather, it arises from the compounded interaction of climatic stressors (increased heat, decreased precipitation) with unsustainable human practices (poor water management, over-cultivation, and inadequate soil conservation). This interaction has upset the water balance and degraded soil fertility.[42]

On a global scale, average temperatures have risen over 1.2 °C in the last three decades, and Iraq has seen its rainfall decrease by more than 35% in many regions. These trends have heightened evaporation rates and diminished surface moisture, directly contributing to agricultural output decline and vegetation loss.[43] In Al-Qadisiyah specifically, annual rainfall is now below 100 mm, whereas annual evaporation exceeds 2,000 mm. Such an extreme moisture deficit has led to a documented 56% reduction in vegetation cover and a contraction of about 62,000 dunams of productive agricultural land in recent years. Additionally, surface water flows have dwindled (for example, the combined discharge of main watercourses has dropped to roughly 5,020 m^3/s), leaving extensive eastern and northern areas of the governorate desiccated and prone to wind erosion. Figure 3 (a land classification map) vividly highlights this deterioration: large swaths of the province are now characterized by soils of only marginal moisture and vast tracts of land are marked as desertified or at high risk, especially in downstream and peripheral zones. This confirms that desertification is driven by both climatic factors and structural issues in water and land use policies.

Remote sensing analyses reinforce these findings. Satellite imagery from Landsat and MODIS between 2000 and 2020 shows an NDVI decline of over 35%, which effectively served as an early warning of the loss of agricultural productivity and the onset of what can be termed structural drought (a long-term, system-wide drying).[(44)] Pettorelli et al. (2014) have noted that such NDVI downturns reflect the cumulative impact of thermal stress and soil degradation acting together.[(45)] In other words, it's not just that plants have less water — the soil itself is deteriorating (through salinization and nutrient loss), compounding the vegetation stress.[(46)]

The crisis has significant social and economic dimensions as well.[(47)] Agricultural yields in some parts of Al-Qadisiyah have fallen by up to 40%, prompting increasing waves of rural-to-urban migration due to water scarcity and failing farms.[(48)] These internal migrations put additional pressure on urban infrastructure and public services in cities, potentially sowing the seeds of socio-economic instability. According to UN-Water and WHO reports, desertification has become a catalyst for complex humanitarian emergencies involving food and water security.[(49)] In Iraq's context, this is manifest in greater competition over shrinking water resources and land, which can exacerbate local conflicts or socioeconomic disparities.[(50)]

Compounding the issue, extreme heat events have grown more frequent and intense — with summer highs exceeding 48 °C in Al-Qadisiyah in recent years. These heatwaves spur a surge in water demand (estimated ~30% above normal during peak periods) to sustain crops and livestock, further draining surface and groundwater reserves. The resultant resource exhaustion accelerates the desertification feedback loop: as water is overdrawn, soils dry out, vegetation dies off, and the land's capacity to retain what little moisture is left diminishes.

Addressing desertification as the multifaceted crisis it is requires integrated solutions. One recommendation is to merge drought indicators — such as NDVI anomalies, evaporation rates, and precipitation shortfalls — with existing water monitoring systems to create dynamic adaptation policies.[(51)] For example, if indicators show a developing drought, authorities could implement rotational fallowing (leaving some fields unplanted) or emergency water rationing before conditions worsen. Technically, the adoption of remote sensing and GIS tools is indispensable for such monitoring. Using satellite data, one can continuously observe spatial and temporal changes in vegetation and soil moisture. Hydrological models (like SWAT or MODFLOW) can simulate water balance scenarios, identifying which regions are most likely to become desertified under different climate projections. Integrating these with socioeconomic data (population, farming intensity) can further help prioritize areas for intervention.

On the ground level, implementing modern irrigation (e.g., drip systems that cut water loss by ~40%) and incorporating organic matter into soils are practical measures that have shown results. For instance, increasing soil organic content (through compost or biochar additions) can enhance soil moisture retention by up to 20%, as noted by Hudson (1994)[52]. This improves drought resilience for crops. All these actions – technological, agronomic, and policy-driven – need to converge.

Fundamentally, what is required is an integrative approach linking water management and agriculture under an environmental sustainability framework.[53] In Al-Qadisiyah, such an approach is beginning to form: there is recognition that water strategy cannot be separate from land use strategy. Desertification control must become part of the mainstream development agenda, not just an environmental issue. The goal is a synergy where climate adaptation, disaster risk reduction, and sustainable agriculture all intersect.

By reframing desertification from an abstract environmental problem to a tangible development and security challenge, stakeholders can mobilize broader support. The crisis, while severe, also presents an opportunity: to modernize infrastructure (irrigation canals, wells, dams) and governance (water laws, land tenure policies) in ways that make communities more resilient. In effect, Al-Qadisiyah could transform from being a victim of climate change into a model for how to proactively live with climate variability. That shift—from reactive crisis management to proactive risk management—marks the transition of desertification from a nebulous threat into a phenomenon that can be anticipated, mitigated, and eventually controlled.

Strategic Planning Framework for Combating Desertification

Having established the environmental diagnosis, the study advances a strategic framework for planning and managing resources to combat desertification in Al-Qadisiyah. This framework is structured around three interrelated dimensions of strategy:

- **Strategic Thinking** – developing new ways of understanding and anticipating the problem, including the use of advanced technologies and innovative concepts.
- **Strategic Planning** – formulating integrated, long-range plans that incorporate risk reduction and resource sustainability into land-use and development policies.
- **Strategic Management** – implementing and continuously adjusting actions on the ground, improving governance and adaptive capacity to respond to evolving conditions.

Each of these dimensions operates at different levels (conceptual, programmatic, operational) but they reinforce one another. Together, they constitute a comprehensive approach to desertification as not only an environmental issue but a strategic challenge to be met with foresight, coordination, and resilience-building.

Strategic Thinking in Environmental Planning

Strategic thinking refers to a mental framework and cognitive approach that emphasizes holistic analysis, long-term vision, and adaptability in decision-making. It enables planners and policymakers to navigate complex and uncertain environments by identifying patterns and trends and imagining alternative futures. Formally, strategic thinking is defined as the capacity to analyze complex internal and external environmental patterns in order to make long-term decisions that enhance an organization or community's competitive ability and achieve its future goals in the face of uncertainty.[54] In contrast to routine planning, strategic thinking is more flexible and exploratory; as Mintzberg famously noted, strategic thinking is less about formal procedures and more about creative, divergent perspectives.(55) Goldman and colleagues have emphasized that strategic thinking is essential for building "learning organizations" that can innovate in highly competitive or changing environments.(56) In the context of environmental planning for Al-Qadisiyah, strategic thinking means envisioning the future landscape under climate change, anticipating challenges like water scarcity and population growth, and crafting responses that are proactive rather than reactive.

A critical evolution in strategic thinking is the incorporation of artificial intelligence (AI) and big data analytics as tools for foresight. Desertification is no longer seen as just a local soil issue, but a strategic threat to food, economic, and social security globally, affecting an estimated 3.2 billion people according to the United Nations Convention to Combat Desertification (UNCCD, 2022). By merging strategic foresight with AI capabilities, planning shifts from traditional static maps to dynamic predictive modeling. For example, AI-driven analysis can help tackle root causes of desertification by analyzing vast climate datasets, identifying early warning signs, and optimizing resource allocation. Wootton & Horne's framework for strategic thinking suggests transforming knowledge of the past into future decisions that reduce risk, through a set of key skills: memory (learning from historical climate patterns), imagination (envisioning future reclamation scenarios), calculative reasoning (analyzing trends quantitatively), empathy (understanding impacted communities' needs), and dialogue (generating collaborative solutions).(57) These cognitive skills can be augmented by AI – for instance, machine learning algorithms excel at the memory and calculation aspects (finding patterns, crunching numbers), freeing human strategists to focus on imaginative, empathetic, and dialogical thinking.

Recent technological demonstrations underscore the power of this approach. Remote sensing data processed with AI algorithms (like XGBoost or neural networks) have achieved remarkable accuracy in mapping and predicting desertification. In one case, combining an XGBoost model with Sentinel-2 satellite imagery was able to detect desertified areas with about 96% accuracy.(58) Such a system can predict changes in indicators like vegetation cover and soil moisture with an error margin of just ±1%.(59) This precision in turn enables the design of early warning systems – for example, predicting declines in NDVI or rises in land surface temperature a season ahead, so that interventions (like extra irrigation or altering crop choices) can be implemented preemptively. The outcome is intelligent irrigation schedules and land-use adjustments that could reduce water loss by around 15% even without increasing water supply.(60)

Strategic thinking enriched by AI also has an economic rationale. If proactive strategies are not adopted, global economic losses from land degradation are projected to reach trillions of dollars (UNCCD estimates around $1.3 trillion by 2030) through diminished agricultural productivity and other impacts. Conversely, by applying an AI-driven risk assessment framework (such as a conceptual AiDRAST: Artificial Intelligence-Driven Risk Assessment for Sustainable Terrain), it is possible to restore 10–12% of degraded lands within a decade. One example cited is using advanced vegetation indices (like the comparison of PNDVI vs. ANDVI) to detect and prioritize rehabilitation of degraded areas; in China's Hotan Oasis, such indices helped reveal 3,900 km² of deterioration, guiding reforestation efforts (reported in *Frontiers in Plant Science*, 2022). This exemplifies how an analytical approach can yield tangible reclamation successes.

From a philosophical perspective, introducing AI into this context turns it into more than a computational tool – it becomes a sort of "pragmatic philosopher" in environmental management.(61) AI allows us to transcend reactive models (where action is only taken after damage is apparent) and move toward a fully anticipatory stance. However, technology alone is not a panacea; it must be embedded in a robust strategic thinking process. Wootton & Horne's "nine-step" approach to strategic thinking (which includes steps like defining the context, assessing capabilities, developing vision, and implementing strategy) should be integrated into AI frameworks.(62) In practice, this means human planners and AI systems work in tandem: AI provides data-driven insights and scenario analyses, while human decision-makers apply judgment, creativity, and ethical considerations to formulate strategies.

On the societal front, strategic thinking in desertification management calls for inclusive dialogue. Policies will be most effective if local communities understand and buy into them. For instance, using participatory approaches (what Wootton & Horne refer to as "dialogical thinking") can increase public acceptance of land and water policies by an estimated 25%.(63) This is because engagement builds trust and shared ownership of solutions. A strategy might include forming community councils for drought management or involving farmers in the design of new irrigation schedules. In Al-Qadisiyah, incorporating the knowledge of traditional farmers about their land and blending it with scientific recommendations can yield culturally informed and thus more readily adopted measures.

In summary, strategic thinking for Al-Qadisiyah's environmental crisis means: leveraging cutting-edge data and AI to anticipate changes, encouraging creative and systems-level problem solving, and fostering collaboration between scientists, policymakers, and citizens. The result is a transformative mindset shift: desertification is no longer seen as an inevitable fate, but as a challenge that can be foreseen and managed. Through strategic thinking, AI becomes a mediator between hard data and human vision, redefining how we plan our coexistence with nature in the age of climate change.

Strategic Planning for Resource Sustainability

If strategic thinking is about conceptualizing innovative approaches, strategic planning is about concretely designing those approaches into actionable plans and policies. Strategic planning for combating desertification in Al-Qadisiyah involves creating integrated, long-term plans that bridge multiple sectors (water, agriculture, land use, and disaster risk reduction) and operate across different administrative levels. The emphasis is on spatial planning that explicitly accounts for climate risks and resource constraints.

A widely accepted definition of strategic planning in natural risk reduction is a systematic process aimed at reducing communities' exposure to natural hazards by integrating risk assessment, good governance, land-use controls, and environmental and social planning into public policy and sustainable development.(64) In other words, it's planning that doesn't treat disasters or environmental degradation as isolated events, but rather incorporates them into development strategies from the outset. Birkmann and Welle point out that using vulnerability indicators (such as socioeconomic vulnerability maps or drought vulnerability indices) can guide long-term decisions toward reducing risk, especially in environmentally and socially fragile areas.(65) The 2019 UN Global Assessment Report on Disaster Risk Reduction likewise stresses that mainstreaming risk reduction into national development planning significantly enhances a country's ability to prevent and mitigate losses.(66)

Translating these principles to Al-Qadisiyah's context means that development plans for the governorate (for example, agricultural expansion schemes or new settlement projects) must be evaluated through the lens of desertification risk. Spatial planning tools are essential here. The use of GIS-based multi-criteria decision analysis (MCDA) models is one approach the study suggests. By overlaying various data layers – soil salinity maps, groundwater depth, vegetation cover trends, population density, etc. – planners can identify zones where intervention is most urgent. For instance, areas around Shamia and Hamza have been identified as having the highest desertification and soil salinity levels.(67) Strategic spatial planning would prioritize these districts for remedial actions, such as infrastructure upgrades or conservation programs.

Key components of the strategic plan for resource sustainability in Al-Qadisiyah include:

- **Sustainable Water Resources Planning:** Given the water deficit, a central pillar is planning the sustainable use of surface and groundwater. This involves implementing modern irrigation infrastructure and water-saving technologies at scale. As noted, conversion to drip and sprinkler systems across the region could reduce overall water consumption significantly. Strategic plans call for modernization of at least a certain number of hectares of irrigated land per year, with clear targets (e.g., 40% reduction in water loss) in line with global best practices.(68) It also encompasses the construction of small check dams and recharge ponds in upstream areas to capture seasonal runoff (an element of MAR strategies). The planning must be basin-wide, meaning coordination with neighboring provinces upstream and downstream, since water issues cross administrative boundaries.
- **Land Use Zoning and Protection:** Through strategic planning, certain land zones can be designated for protection or controlled use. For example, highly vulnerable areas might be zoned as rangeland or forest land where agriculture is restricted and soil conservation is prioritized. Planning must also reconcile the balance between immediate resource use and long-term vision (the "balance between resources and vision" aspect). This means not over-exploiting groundwater or land for short-term gains that undermine future sustainability. A resource–vision balance is achieved by policies like capping groundwater pumping to sustainable yield levels, or enforcing crop rotation and fallow periods to allow soil recovery. Strategic plans may set a vision of, say, zero net land degradation by 2040, and then allocate resources (financial, human, technological) in line with that vision.
- **Incorporating Indicator-Based Methodologies:** As part of strategy formulation, adopting a leading indicators methodology is recommended. Planners should decide on a set of key indicators (climatic, hydrological, ecological, social) that will be regularly monitored and used to trigger actions. For instance, if the 3-year moving average of rainfall falls below a threshold or if NDVI in a critical region drops by a certain percentage, that could prompt the activation of a contingency plan (such as water rationing or drought relief measures). By planning with indicators, responses become condition-based rather than calendar-based, improving timeliness and effectiveness.
- **Integrated Policy Frameworks:** The strategic plan must encourage policies that integrate desertification control with disaster risk reduction (DRR) and sustainable development goals (SDGs). This can be facilitated by aligning the desertification strategy with Iraq's national action plans under the UNCCD, the Sendai Framework, and relevant

climate change adaptation plans. For example, part of the plan could be to incorporate desertification risk maps into municipal land-use plans and agricultural extension programs. The ultimate aim is that every development sector "owns" a piece of the desertification solution: the agriculture sector invests in resilient crops and soil restoration, the water sector builds efficient delivery and storage systems, the environment sector enforces land protection laws, etc.

A concrete outcome of strategic planning is the delineation of programs and projects to be implemented. For Al-Qadisiyah, the plan put forward in this research includes specific initiatives. Among them:

- Developing modern irrigation networks that cut water losses by ~40% (compared to old open canals).(69)
- Establishing windbreaks and green belts by planting around 1,500 trees per hectare in desert-prone areas to reduce wind erosion and evapotranspiration.(70)
- Expanding rainwater harvesting and groundwater recharge structures (small dams, spreading basins) to capture seasonal floods and direct them to aquifers.(71)
- Utilizing GIS-based decision support systems to analyze spatial patterns of desertification and prioritize areas like the central and southern parts of the governorate for intensive intervention.(72)

These elements are integrated into a cohesive plan that sets short-term, medium-term, and long-term milestones. The plan is not static; strategic planning is iterative and adaptive. As initial projects are implemented, their outcomes are monitored (using the indicators mentioned), and the plan is updated accordingly.

An example of adaptation within the plan could be: if afforestation in one area shows significant microclimate benefits (improved humidity, slight cooling, better crop survival), the plan might be adjusted to allocate more resources to afforestation in similar zones. Conversely, if an introduced irrigation technology underperforms, the strategy might pivot to an alternative solution.

In summary, strategic planning for Al-Qadisiyah means creating a roadmap where every action, whether it is engineering (like building canals), ecological (like planting trees), or policy-driven (like land zoning), is chosen for its contribution to long-term resilience. It requires coordination between government departments, informed by scientific data and community input, all oriented toward the vision of restoring and safeguarding the productivity of the land. By doing so, strategic planning turns broad strategic thinking into tangible, location-specific interventions that collectively steer the governorate away from the brink of irreversible desertification.

Strategic Management and Adaptive Governance

While strategic planning lays out what needs to be done, strategic management is about how those plans are executed and sustained over time. It involves the coordination of resources, the implementation of policies, and the continuous adaptation of strategies in response to new information or changing conditions. In the fight against desertification, strategic management equates to effective governance of land and water resources, risk management practices, and community engagement to ensure long-term success.

At its core, strategic resource management for desertification means treating water, soil, and vegetation as critical assets that must be managed with foresight and flexibility. It shifts the mindset from reacting to crises (droughts, crop failures, dust storms) to actively preventing and mitigating them through prepared actions. This is aligned with the concept of adaptive management, where policies are not fixed but are regularly revised based on outcomes and feedback.

For Al-Qadisiyah, several key aspects of strategic management are highlighted:

- **Institutional Coordination:** Desertification is a cross-cutting issue, so a major management challenge is ensuring different institutions work together. Strategic management might involve establishing a Desertification Management Unit or a multi-agency task force that brings together the ministries of agriculture, water resources, environment, and local governorate officials. Such a body would oversee the implementation of the strategic plan, monitor progress, and resolve inter-sectoral issues (for example, coordinating water allocation between agricultural needs and ecological needs).
- **Policy Enforcement and Incentives:** A plan on paper is only as good as its execution. Management must ensure that regulations (like groundwater pumping limits, land-use zoning laws, or anti-logging rules) are enforced. This may require strengthening legal frameworks and local oversight. At the same time, using incentives is important: farmers could be offered subsidies or technical support for adopting water-saving irrigation or planting cover crops, thus encouraging participation in anti-desertification efforts. Strategic management in this sense blends carrot-and-stick approaches to guide behavior towards sustainable practices.
- **Managing Hydrological Variability:** One of the toughest management issues in Al-Qadisiyah is dealing with the high variability of water availability – essentially, the boom-and-bust of floods and droughts. Strategic management treats hydrological variability not as an occasional disaster but as an inherent feature to plan around. This involves creating flexible water allocation systems: for instance, during wet years, allocate a portion of surface water to recharge groundwater and fill reservoirs (banking it for dry times). During drought years, enforce water rationing plans and prioritize critical uses (drinking water and strategic crops). The strategic element is having these systems and rules predefined and institutionalized, so responses are orderly and equitable. As noted earlier, groundwater drawdowns of 3–6 m have occurred; managing this means setting safe yield extraction limits and actively augmenting recharge in wet periods.
- **Early Warning and Response Systems:** A strategic approach to management includes robust early warning systems for drought and land degradation. Using the indicators established in the plan, management must maintain surveillance of climate forecasts, soil moisture levels, and vegetation health. If warning thresholds are passed, there should be predefined response actions. For example, if seasonal rainfall is projected to be <50% of normal, an alert is issued and a drought task force starts coordinating relief (such as emergency fodder distribution or cloud seeding attempts, etc.). This way, the impact of a developing drought can be softened. Essentially, strategic management tries to turn unpredictable shocks into manageable events by being prepared.
- **Community-Based Management:** Another facet is engaging local communities in management. This includes training and empowering farmers and local water user associations with knowledge and tools for sustainable land management. For instance, teaching farmers how to monitor soil salinity on their fields and providing them with the

means to report issues or request assistance can create a grassroots monitoring network. Community involvement also means localizing some decisions – perhaps giving villages a role in choosing which drought-resistant crops to introduce or where to build small check dams, ensuring solutions have local buy-in.

Crucially, strategic management in desertification control recognizes that time is a factor just as important as resources. There is a temporal dimension to management: actions must be timely (neither too late nor too early), and the benefits of actions often only materialize over years. Water must be managed not just as a volume, but as a flow over time – a concept often referred to as treating water as a "strategic–temporal resource." This means measuring success by whether the community can use water when it is most needed, not only by annual totals[46]. In practical terms, it could involve shifting irrigation schedules to match critical crop growth stages or adjusting planting calendars to better align with expected rainfall. It also implies planning for inter-annual variability, not just average years.

By applying strategic management, hydrological fluctuations (like a sudden flood or a multi-year drought) are transformed from unpredictable threats into signals for action in a well-drilled management plan[47]. For example, rather than seeing a flood as purely destructive, strategic management would capture it (in reservoirs or spreading fields) as a resource. Conversely, the onset of drought would be a signal to switch to drought contingency cropping patterns and enforce groundwater conservation measures, thus using the drought as an indicator to tighten management before irreversible damage occurs.

A philosophical takeaway from the strategic management perspective is that desertification is a test of governance as much as of climate. Al-Qadisiyah's future will depend on how effectively its institutions and communities can synchronize their efforts to adapt. The maps and data that show spreading desertification must be turned into decision-making tools. A map, in this view, is not just a representation of static conditions, but a live strategic instrument that highlights where interventions should happen next. By continuously updating maps with new data (rainfall, vegetation growth, water table readings) and having management respond in near-real time, the desertification process can be slowed and eventually steered into a controllable trajectory.

In conclusion, strategic management operationalizes the fight against desertification. It demands good governance – transparent, responsive, and inclusive – to implement the carefully laid plans and to adjust them as needed. It also requires persistent commitment, as reversing land degradation is a long-term endeavor. Through strategic management, Al-Qadisiyah can move from ad-hoc, crisis-driven actions to sustained, goal-driven stewardship of its natural resources, thereby safeguarding its environmental and socio-economic well-being against the worsening stresses of climate change.

Conclusion

Al-Qadisiyah Governorate stands at a critical juncture where the converging pressures of climate change and resource mismanagement have triggered a severe desertification crisis. This paper has translated the insights from an in-depth Arabic study into a comprehensive English-language analysis, preserving the scientific integrity and data while framing it for a global audience. The investigation confirmed that desertification in Al-Qadisiyah is not a mere environmental degradation of soil and vegetation – it is a multifaceted crisis impacting water security, agricultural productivity, livelihoods, and the regional ecosystem. Rising temperatures, sharply declining rainfall, increased evaporation, and mismanagement of irrigation have together upset the region's hydrological and ecological balance, pushing it toward a tipping point.

Yet, the research also offers hope in the form of a strategic framework for response. By integrating climatic analysis with resource planning, and by viewing desertification through strategic lenses of thinking, planning, and management, it becomes possible to chart a sustainable path forward. Key to this is the adoption of modern technologies (remote sensing, GIS, AI) combined with time-tested land and water management practices (like rainwater harvesting, soil conservation, and afforestation). The proposed framework operates across short, medium, and long-term horizons, ensuring immediate actions are linked to a far-sighted vision of resilience.

One of the most significant contributions of this work is conceptual – reimagining desertification as a "philosophical–strategic indicator." In doing so, it challenges policymakers and stakeholders to reconsider humanity's relationship with nature. Desertification is framed not as an inevitable fate of drylands, but as a call to action to reshape policies, behaviors, and technologies in harmony with environmental limits. In Al-Qadisiyah, this means transforming water from a resource taken for granted to a strategic asset governed carefully in quantity, quality, and timing. It means regarding episodes of drought or water surplus not as surprises, but as signals within a new language of environmental time that society must learn to interpret and respond to.

The findings and recommendations herein are scientifically grounded and practically oriented. If implemented, they would not only curb the ongoing desertification in Al-Qadisiyah but also bolster food and water security, enhance rural livelihoods, and contribute to the region's sustainable development. Moreover, the approach and lessons have relevance beyond Iraq. Many arid and semi-arid regions globally face similar challenges at the nexus of climate change and land degradation. The strategic framework developed for Al-Qadisiyah can serve as a model for integrated resource planning under climate stress, illustrating how local data and knowledge, combined with global best practices, can yield actionable strategies.

In closing, this study reaffirms that the battle against desertification is winnable – but it demands strategic foresight, interdisciplinary collaboration, and sustained commitment. Al-Qadisiyah's experience, as detailed in this paper, underscores a universal message: when humanity respects the signals of the environment and plans accordingly, even crises like desertification can be managed and mitigated. It is our hope that this work will inform policymakers, researchers, and development practitioners, and inspire concerted efforts to protect and restore vulnerable landscapes in Iraq and around the world.

Recommendations

Based on the findings and strategic framework developed, the following recommendations and proposals are put forward to mitigate and reverse desertification in Al-Qadisiyah Governorate:

- **Upgrade Irrigation Systems:** Transition to modern irrigation methods, especially drip irrigation and closed-conduit networks, to improve water use efficiency. This can reduce water loss by up to 40% compared to traditional open-channel and flood irrigation[7]. Priority should be given to areas with the highest water wastage and salinity buildup.
- **Managed Aquifer Recharge (MAR):** Implement rainwater harvesting and floodwater spreading programs to actively recharge groundwater aquifers. For example, construct small check dams and infiltration basins to capture seasonal rains and runoff. This will help compensate for groundwater level declines of 3–6 m observed in areas like Shamia and Hamza. *(Groundwater data per local water resource assessments.)*
- **Integrate Remote Sensing and GIS:** Utilize satellite imagery (e.g., Landsat, Sentinel-2) and GIS mapping to continuously monitor desertification indicators. Notably, track the NDVI vegetation index which has already declined 35–56% in parts of Al-Qadisiyah. Establish an early warning system that uses remote sensing data to detect emerging hotspots of vegetation loss or soil moisture decline, enabling proactive management responses.
- **Salinity Management:** Launch integrated soil salinity management programs. This includes blending or treating saline irrigation water (e.g., partial desalination) to reduce TDS by ~30%, since some water sources have TDS levels up to 1,580 mg/L. On farms, promote practices like alternate furrow irrigation, salt-tolerant crop varieties, and periodic soil leaching where feasible. The use of integrated salinity management techniques, such as crop rotation with salt-tolerant crops (e.g., barley, certain forage grasses) and modern irrigation, should be demonstrated and scaled up.
- **Soil Rehabilitation:** Improve soil health and moisture retention by increasing organic matter. Introducing soil amendments such as biochar or compost can raise soil moisture-holding capacity by around 20% and boost fertility by ~15%. Encourage farmers to adopt these practices via training and incentives, as healthier soils enhance agricultural productivity and resilience to drought.
- **Afforestation and Green Belts:** Implement afforestation projects and establish green windbreak belts. Aim to plant on the order of 1,500 trees per hectare in strategic locations (e.g., along the desert fringe, around farms, and as shelterbelts) to reduce wind erosion and provide microclimate benefits. Species should be drought-resistant and, where possible, native to ensure sustainability. A well-designed network of green belts could lower local desertification impacts by an estimated 30–40% over a decade.
- **Leverage Artificial Intelligence in Planning:** Integrate AI tools for predictive modeling and decision support. For instance, use machine-learning algorithms (such as XGBoost or neural networks) on remote sensing data (e.g., Sentinel-2 imagery) to achieve high-accuracy mapping of desertification risk areas. AI-based models can also forecast soil moisture changes and vegetation growth under various scenarios with high precision. Such technology should be incorporated into a central planning platform to guide resource allocation. Preliminary results suggest that AI-driven monitoring can achieve up to 96% accuracy in detecting desertification and predict soil moisture to within ±1%, which could vastly improve planning decisions.
- **Enhance Integrated Water and Land Management:** Shift from a singular focus on water quantity to a quality-and-timing-based water management paradigm. Develop integrated management strategies that align water use with climatic cycles and crop needs (often termed “adaptive water management”). Concretely, adopt water quality monitoring (so that water of appropriate quality is used for each purpose) and timing strategies (e.g., irrigating during cooler hours to reduce evaporation, synchronizing cropping with rainfall patterns). This integrated approach, treating water as both a strategic and temporal

resource, can reduce waste by 18–20% and improve the efficiency of resource distribution in agriculture. It also means combining water management initiatives with agricultural policy – for example, providing support for farmers to switch to less water-intensive crops or to fallow land during severe droughts as part of a drought resilience strategy.

Implementing these recommendations requires a concerted effort from local authorities, national policymakers, researchers, and the community. It is advised that a detailed action plan be formulated for each recommendation, specifying responsible agencies, timelines, and required resources. Moreover, continual monitoring and evaluation should accompany the rollout of these interventions, allowing for adjustments and learning. If pursued effectively, these measures offer a pathway to significantly reduce the progression of desertification in Al-Qadisiyah and set an example for integrated environmental management under climate stress.

References

- Alexander, David. (2000). *Natural Disasters*. Routledge, London and New York, pp. 15–17.
- United Nations Office for Disaster Risk Reduction (UNDRR). (2019). *Global Assessment Report on Disaster Risk Reduction 2019*. United Nations, Geneva, pp. 9–11.
- Smith, Keith & Petley, David N. (2009). *Environmental Hazards: Assessing Risk and Reducing Disaster*. Routledge, Abingdon and New York, pp. 5–7.
- Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the IPCC. Cambridge University Press, Cambridge (UK) and New York (USA), p. 5.
- Mann, Michael E. (2021). *The New Climate War: The Fight to Take Back Our Planet*. PublicAffairs, New York, p. 47.
- NASA. (2022). "2022 Climate Trends" – *Global Climate Change: Vital Signs of the Planet*. NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, pp. 2–4.
- Ayers, R. S. & Westcot, D. W. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29, Food and Agriculture Organization, Rome, pp. 34–41.
- Qadir, M. & Oster, J. D. (2004). "Crop and Irrigation Management Strategies for Saline–Sodic Soils and Waters." *Science of the Total Environment*, 323: 25–36.
- Pahl-Wostl, Claudia. (2021). *Adaptive Water Management: Concepts, Principles and Applications*. Springer, Berlin, pp. 95–99.
- Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56, FAO, Rome, pp. 12–22.
- Zeng, Y., Chen, Y., Li, J. & Fang, G. (2018). "Tracking Vegetation Changes in Drylands Using Remote Sensing." *Remote Sensing of Environment*, 216: 418–430.
- Al-Hadithi, A. (2020). "Impact of Climate and Water Management on Soil Moisture in Al-Qadisiyah." *Iraqi Journal of Agricultural Sciences*, University of Baghdad, 51(1): 79–91.

- MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. É. Ó. & Taylor, R. G. (2012). *Quantitative Maps of Groundwater Resources in Africa*. British Geological Survey (BGS) Commissioned Report, UK, p. 39.
- Qadir, M., Noble, A. D., Schubert, S., Thomas, R. J. & Arslan, A. (2014). *Soil Salinity and Food Security in Dry Regions*. Springer, Dordrecht, p. 47.
- Hudson, B. D. (1994a). *Soil Organic Matter and Sustainability*. Cambridge University Press, Cambridge, pp. 103–110.
- United Nations. (2015). *Sendai Framework for Disaster Risk Reduction 2015–2030*. UNISDR, Geneva, p. 44.
- World Bank. (2020). *Iraq: Water Sector Assessment Report*. World Bank Publications, Washington, DC, p. 97.
- Rao, R. R., Eisenberg, J. & Schmitt, T. (2007). *Improving Disaster Management: The Role of IT in Mitigation, Preparedness, Response, and Recovery*. National Academies Press, Washington, DC, pp. 45–46.
- Food and Agriculture Organization (FAO). (2021). *Drought Risk Management: A Strategic Approach*. FAO, Rome, p. 119.
- Pettorelli, N., Laurance, W. F., O'Brien, T. G., et al. (2014). *Satellite Remote Sensing for Applied Ecologists: A Practical Guide to Advanced Remote Sensing*. Oxford University Press, Oxford, p. 56.
- UN-Water & World Health Organization (WHO). (2020). *Progress on Drinking Water, Sanitation and Hygiene: 2020 Update and SDG Baselines*. WHO, Geneva, p. 61.
- Zhang, X., Li, B. & Xu, X. (2020). "Monitoring Land Degradation and Drought in Arid Regions Using Remote Sensing." *Environmental Monitoring and Assessment*, 192(2): 232.
- Howell, T. A. (2001). "Enhancing Water Use Efficiency in Irrigated Agriculture." *Agronomy Journal*, 93(2): 281–289.
- Hudson, B. D. (1994b). "Soil Organic Matter and Sustainability." *Soil Science Society of America Journal*, 58(4): 1098–1102.
- National Drought Mitigation Center (NDMC). (1995). "Understanding and Defining Drought." University of Nebraska–Lincoln, NE, USA, p. 2.
- Kharrufa, N. S. (1985). "A Simple Equation for Evaporation in Arid Regions." *Beitrage zur Hydrologie*, 5: 39–47.
- UNCCD. (2022). *Global Land Outlook 2: Land Restoration for Recovery and Resilience*. United Nations Convention to Combat Desertification, Bonn.
- Wootton, S. & Horne, T. (2010). *Strategic Thinking: A Nine Step Approach to Strategy and Leadership for Managers*. Kogan Page, London, pp. 7–8, 31–33.

(1) David Alexander. (2000). *Natural Disasters* (Routledge: London and New York), pp. 15–17

(2) United Nations Office for Disaster Risk Reduction (UNDRR). (2019). *Global Assessment Report on Disaster Risk Reduction 2019* (United Nations: Geneva), pp. 9–11

(3) Keith Smith & David N. Petley. (2009). *Environmental Hazards: Assessing Risk and Reducing Disaster* (Routledge: Abingdon and New York), pp. 5–7

(4) Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the IPCC (Cambridge University Press: Cambridge and New York), p. 5

(5) Michael E. Mann. (2021). *The New Climate War: The Fight to Take Back Our Planet* (PublicAffairs: New York), p. 47

(6) NASA. (2022). "2022 Climate Trends" – *Global Climate Change: Vital Signs of the Planet* (NASA JPL, Caltech: Pasadena, CA), pp. 2–4.

(7) Michael E. Mann. *Op,Cit*, pp. p. 47

(8) R. S. Ayers & D. W. Westcot. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 (FAO: Rome), pp. 34–41.

(9) Ibid, pp. 34–41.

(10) M. Qadir & J. D. Oster. (2004). "Crop and Irrigation Management Strategies for Saline–Sodic Soils and Waters." *Science of the Total Environment*, 323: 25–36

(11) M. Qadir & J. D. Oster. (2004). "Crop and Irrigation Management Strategies for Saline–Sodic Soils and Waters." *Science of the Total Environment*, 323: 25–36

(12)Ibid, pp. , 323: 25–36

(13) Claudia Pahl-Wostl. (2021). *Adaptive Water Management: Concepts, Principles and Applications* (Springer: Berlin), pp. 95–99.

(14) R. G. Allen, L. S. Pereira, D. Raes & M. Smith. (1998). *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56 (FAO: Rome), pp. 12–22

(15) Y. Zeng, Y. Chen, J. Li & G. Fang. (2018). "Tracking Vegetation Changes in Drylands Using Remote Sensing." *Remote Sensing of Environment*, 216: 418–430.

(16) A. Al-Hadithi. (2020). "Impact of Climate and Water Management on Soil Moisture in Al-Qadisiyah." *Iraqi Journal of Agricultural Sciences*, 51(1): 79–91

(17) M. Qadir, A. D. Noble, S. Schubert, R. J. Thomas & A. Arslan. (2014). *Soil Salinity and Food Security in Dry Regions* (Springer: Dordrecht), p. 47

(18)B. D. Hudson. . *Op,Cit*, pp. 103–110.

(19) United Nations. (2015). *Sendai Framework for Disaster Risk Reduction 2015–2030* (UNISDR: Geneva), p. 44.

(20) Food and Agriculture Organization (FAO). (2021). *Drought Risk Management: A Strategic Approach* (FAO: Rome), p. 119.

(21) Pettorelli, N., W. F. Laurance, T. G. O'Brien, *et al.* (2014). *Satellite Remote Sensing for Applied Ecologists: A Practical Guide to Advanced Remote Sensing* (Oxford University Press: Oxford), p. 56.

(22) Ibid, p. 56.

(23)Ibid,, p. 5٩.

(24) UN-Water & World Health Organization (WHO). (2020). *Progress on Drinking Water, Sanitation and Hygiene: 2020 Update and SDG Baselines* (WHO: Geneva), p. 61.

(25)Ibid,, p. , p. ٧1.

(26) X. Zhang, B. Li & X. Xu. (2020). “Monitoring Land Degradation and Drought in Arid Regions Using Remote Sensing.” *Environmental Monitoring and Assessment*, 192(2): 232.

(27)Ibid,,:p 232.

(28) X. Zhang, B. Li & X. Xu. (2020). “Monitoring Land Degradation and Drought in Arid Regions Using Remote Sensing.” *Environmental Monitoring and Assessment*, 192(2): 232.

(29)Ibid,,:p :232.

(30) World Bank. (2020). *Iraq: Water Sector Assessment Report* (World Bank: Washington, DC), p. 97.

(31) Zeng, Y., *et al.* (2018). *Remote Sensing of Environment*, 216: 418–430

(32) Y. H. M. Al-Miyali. (2009). *Soil Map of Al-Qadisiyah Governorate* (unpublished data, Ministry of Agriculture, Iraq).

(33) UNCCD. (2022). *Global Land Outlook 2: Land Restoration for Recovery and Resilience* (UNCCD: Bonn).

(34) Y. H. M. Al-Miyali. (2009). *Soil Map of Al-Qadisiyah Governorate* (unpublished data, Ministry of Agriculture, Iraq). *(Source of Figure 2)*

(35) National Drought Mitigation Center (NDMC). (1995). “Understanding and Defining Drought.” University of Nebraska–Lincoln, NE, USA, p. 2

(36) Ibid, p. 2

(37)R. G. Allen, L. S. Pereira, D. Raes & M. Smith. (1998). *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56 (FAO: Rome), pp. 12–22

(38) UNCCD. (2022). *Global Land Outlook 2: Land Restoration for Recovery and Resilience* (UNCCD: Bonn).

(39) R. G. Allen, L. S. Pereira, D. Raes & M. Smith. *Op,Cit*, pp. 12–22

(40) UNCCD. (2022). *Global Land Outlook 2: Land Restoration for Recovery and Resilience* (UNCCD: Bonn).

(41) UNCCD. (2022). *Global Land Outlook 2* (UNCCD: Bonn).

(42) Qadir, M., *et al.* (2014). *Soil Salinity and Food Security in Dry Regions* (Springer: Dordrecht), p. 47.

(43) A. M. MacDonald, H. C. Bonsor, B. É. Ó. Dochartaigh & R. G. Taylor. (2012). *Quantitative Maps of Groundwater Resources in Africa*. BGS Commissioned Report (UK), p. 39.

(44) Zhang, X., *et al.* (2020). *Environmental Monitoring and Assessment*, 192(2): 232.

(45) Pettorelli, N., *et al.* (2014). *Satellite Remote Sensing for Applied Ecologists* (Oxford University Press), p. 56

(46) Hudson, B. D. (1994b). “Soil Organic Matter and Sustainability.” *Soil Science Society of America Journal*, 58(4): 1098–1102.

(47) Food and Agriculture Organization (FAO). (2021). *Drought Risk Management: A Strategic Approach* (FAO: Rome), p. 119.

(48) UN-Water & WHO. (2020). *Progress on Drinking Water... 2020* (WHO: Geneva), p. 61.
(49) Ibid, p. 61.
(50) A. Al-Hadithi. (2020). "Impact of Climate and Water Management on Soil Moisture in Al-Qadisiyah." *Iraqi Journal of Agricultural Sciences*, 51(1): 79–91
(51) Rao, R. R., J. Eisenberg & T. Schmitt. (2007). *Improving Disaster Management: The Role of IT...* (National Academies Press: Washington, DC), pp. 45–46.

(52) T. A. Howell. (2001). "Enhancing Water Use Efficiency in Irrigated Agriculture." *Agronomy Journal*, 93(2): 281–289.
(53) Wootton, S. & T. Horne. (2010). *Strategic Thinking: A Nine Step Approach...* (Kogan Page: London), pp. 7–8, 31–33.

(54) Wootton, S. & T. Horne. . *Op,Cit*, pp. 7–8, 31–33.
(55) Henry Mintzberg. (1994). *The Rise and Fall of Strategic Planning* – referenced concept of strategic thinking vs planning. *(Mentioned concept, no separate reference listing needed.)*
(56) A. Goldman, *et al.* (2015). "Organizational Learning and Strategic Thinking in the Public Sector." *International Public Management Journal*, 18(2): 276–307.
(57) Wootton & Horne. (2010). *Strategic Thinking: A Nine Step Approach...*, pp. 31–33.
(58) M. Qadir, A. D. Noble, S. Schubert, R. J. Thomas & A. Arslan. (2014). *Soil Salinity and Food Security in Dry Regions* (Springer: Dordrecht), p. 47
(59) *Frontiers in Plant Science*. (2022). **(Case study on AI and remote sensing for desertification in China's Hotan Oasis, demonstrating ~96% accuracy)**.

(60) B. D. Hudson. (1994a). *Soil Organic Matter and Sustainability* (Cambridge University Press: Cambridge), pp. 103–110.
(61) UNCCD. (2022). *Global Land Outlook 2*, (UNCCD: Bonn).
(62) Wootton & Horne. (2010). *Strategic Thinking: A Nine Step Approach...*, pp. 7–8.
(63) Ibid, p. 33.

(64) UNDRR. (2019). *Global Assessment Report on Disaster Risk Reduction 2019* (United Nations: Geneva), pp. 9–11.
(65) J. Birkmann & T. Welle. (2015). "Assessing the Risk of Loss and Damage: Exposure, Vulnerability and Risk to Climate-Related Hazards for Different Country Classifications." *International Journal of Global Warming*, 8(2): 191–212.
(66) UNDRR. (2019). Global Assessment Report on DRR 2019, pp. 10–12.
(67) A. Al-Hadithi. (2020). Iraqi Journal of Agricultural Sciences, 51(1): 79–91.
(68) R. G. Allen, L. S. Pereira, D. Raes & M. Smith. (1998). Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56 (FAO: Rome), pp. 12–22
(69) Allen, R. G. et al. (1998). Crop Evapotranspiration – Guidelines... (FAO: Rome), pp. 12–22.

(70) Pettorelli, N. et al. (2014). Satellite Remote Sensing for Applied Ecologists, p. 56.
(71) World Bank. (2020). Iraq: Water Sector Assessment Report, p. 97.
(72) A. Al-Hadithi. (2020). Iraqi Journal of Agricultural Sciences, 51(1): 79–91