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Environmental and Ecosystem Roles in Sustainable Pollution Mitigation for Grapevine Cultivation in Thi-Qar Province: A GIS-Based Analysis

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I. Abstract*:*

The combined environmental pollutants such as soil salinity and industrial contamination are great threats to viticulture in arid regions. This is a threat to vineyard sustainability and the livelihoods of the local people in the Thi-Qar Province, Iraq. Such challenges have been traditionally examined separately in previous studies without a comprehensive and spatially explicit framework that uses native ecosystems as a way of mitigation. This study answers this gap since it creates a GIS-based Multi-Criteria Decision Analysis (MCDA) framework to figure out and harness environmental and ecosystem features to carry out sustainable mitigation of pollution. The main environmental parameters and sources of pollution are catalogued and mapped up to derive a composite Pollution Risk Index (PRI). At the same time, the Ecosystem Mitigation Capacity (EMC) of natural features is measured. These layers are added together in order to create a Sustainable Pollution Mitigation Zonation Map. Findings show a PRI of mean 0.334 and an EMC of mean 0.301 in vineyards and the relationship between risk and natural mitigation is weakly negative (r = -0.193). There are four different management zones which are: Priority Protection (0.1% of area), Ecosystem Restoration (12.4%), Sustainable Management (16.8%), and Low Intervention (8.0%). The framework presents an operationally practical spatial resource in the conversion of ecosystem-based, accuracy management of vineyard landscapes.

Keyword: Ecosystem Services, GIS, Pollution Mitigation, Sustainable Viticulture, Thi-Qar.

II. INTRODUCTION

The cultivation of grapevine (*Vitis vinifera*) in Thi-Qar Province and Iraq in general is a major economic and cultural aspect in the region, which constitutes a traditional agricultural sector that supports the livelihood of the local community and food security as well as heritage of the region Howell (2001). Nevertheless, a combination of environmental stressors is becoming a menace to the productivity and sustainability of viticulture. The vulnerabilities are intensified by climate change due to the increase in temperatures and changing precipitation patterns, and the problem of chronic water shortage and soil degradation introduces the challenges to the resilience of agriculture on a fundamental level Giffard et al. (2022). These global problems are enhanced in Thi-Qar by certain, localized threats of pollution. These are secondary salinization through irrigation using salty water, pollution through agricultural run-off (salts and pesticides) as well as possible leaching of industrial pollutants, air particulate matter through frequent dust storms and progressive salinization of soils De Micco et al. (2024), Lavoie-Lamoureux et al. (2017). These contaminants have a direct negative impact on grapevine physiology, lower the yield quantity and quality, and threaten the sustainability of the soil.

Addressing these issues requires paradigm shift in the traditional remediation approach to the proactive approach of ecosystem-based approach. This approach is critically framed by the concept of ecosystem services- especially regulating and supporting services Bonfante et al. (2017). Natural or semi-natural landscape components like riparian buffers, wetlands and native vegetation patches have the ability of undertaking critical roles such as phytoremediation, run-off filtration, windbreak establishment and regulation of the microclimate. The power of such inherent capabilities is a sustainable channel of reducing pollution, not depending on energy-consuming engineering measures and making agrarian landscapes more functional Bonfante et al. (2017).

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Thi-Qar has been identified to be under pressure because of pollution on agriculture, but there exists a gap in knowledge that is critical. It has not been integrated with a spatially explicit assessment that critically determines the ability of the province to utilize the native environmental features and current ecosystems to reduce pollution to produce sustainable grapes. The existing management is usually based on generalized practices which fail to consider the high degree of spatial variation of the sources of pollution and the natural abilities of mitigating the effects of pollution. Such a gap results in the ineffective allocation of the resources and the opportunities to utilize natural capital. The resulting threats are complex: the further reduction of the productivity of the vineyards and the quality of grapes, the loss of money to the farming communities, and the gradual destruction of the ecosystems around which the farming communities are eventually dependent.

This research will give a priority to creating a Geographic Information Systems (GIS) based spatial model to determine and utilize environmental and ecosystem features to reduce pollution risks to the grapevine production process in Thi-Qar Province, Iraq in a sustainable way.

In order to reach this goal, the specific objectives are set as following:

1. To list, map, and assess the main environmental parameters (soil, water, air, climate), and presence features of the ecosystem (natural vegetation, wetlands, buffer zones) in the grape growing regions of Thi-Qar.
2. To be able to define, categorize, and map the main causes and types of pollution of the grapevine health and productivity.
3. To evaluate and map the potential of existing ecosystems to deliver regulating services (e.g. phytoremediation, filtration, windbreaks, micro climatic control) to mitigate pollution.
4. To combine these analyses and develop a Sustainable Pollution Mitigation Zonation Map and recommend specific and site-specific management strategies to the grape farmers, as well as regional policymakers.

This study has unique contributions in the practical, scientific and policy spheres. In practice, it offers a spatially explicit planning instrument of the agricultural extension services and farmers, whereby they can be subjected to interventions which optimize the use of natural mitigation features. Scientifically, it develops the use of integrated GIS and ecosystem service ideas within the framework of arid-land agriculture and is a replication of a methodology on a spatially-informed approach to environmental management. Politically, the policy implications of the findings include informing the agricultural and environmental protection policies in the region to know regions to be conserved, restored, and invested in sustainably to help in achieving a more resilient agro-ecological system.

This study is geographically restricted to the Thi-Qar Province, Iraq, and the list of the key recorded types of pollution (soil salinity, water contamination, airborne particulates) and the most important regulating ecosystem services that are considered in their mitigation. Various shortcomings are recognized, such as reliance on the accessibility and quality of secondary data, time representativeness of the analysis of a particular period, and future ground-truting to confirm some model outputs.

The rest of this paper will be organized in the following way: Section 2 will provide a review of literature on the topic of viticulture stresses, ecosystem services and geospatial applications. Section 3 provides the description of the study area and sources of data that will be used. Section 4 gives the GIS-based integrated approach. Section 5 gives the findings of the spatial analysis and zonation. The implications of the findings are described in Section 6, and the conclusions of the research are made in Section 7.

III. LITERATURE REVIEW

A. Sustainable Viticulture and Pollution Challenges

Sustainable viticulture in the modern world is an activity that incorporates measures that are to be taken to reduce the environmental impact with the intended goal of sustaining a stable economy. Such activities are accuracy irrigation to fight water shortage, integrated pest control to minimize the use of chemicals, soil health control through organic

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additions and cover crops. The key point in this method is the knowledge of specific grapevines weaknesses to anthropogenic pollutants Rogiers et al. (2022).

Studies have shown that grapevines are very sensitive to soil salinity that distorts the osmotic balance and ion toxicity, and this has a direct effect of suppressing photosynthesis and yield. The accumulation of the heavy metals as cadmium and lead is also found in the plant tissues, which may find its way to the food chain and lead to oxidative stress. In addition, it is recorded that troposphere ozone and airborne PM damage foliage, affect the amount of gas exchanged, and decrease fruit quality. These biological strains point to the need of specially designed mitigation measures in the vineyard ecosystem Horel et al. (2025).

B. Ecosystem Services in Agricultural Landscapes

In agroecosystems, the systematic perspective of understanding the value of natural capital involves the ecosystem services framework that especially focuses on the categories of regulating and supporting services. Landscape elements carry out the regulation of services like water purification, erosion and climate regulation without any direct human intervention. The effectiveness of certain characteristics in the reduction of pollution is proven by the empirical research done in different agricultural settings Kumar et al. (2023). Riparian buffer strips are always depicted to be able to effectively filter the nitrate, phosphate and sediment runoff on the adjacent fields before it flows to the watercourses. Hedges and windbreaks slow down the velocity of the wind, thus managing land erosion and airborne contamination and harm. Phytoremediation through the use of particular cover crops is encouraged and among them are nutrient uptake and the uptake of heavy metals in the soil. Bio-remediation of agricultural wastewater is done using constructed and natural wetlands whereby microbe and plant activities are used to degrade contaminated water Dayer et al. (2022).

C. Geospatial Technologies in Precision Agriculture and Environmental Management

The foundation of the modern spatial analysis of environmental management is the geospatial technologies that are Remote Sensing (RS) and Geographic Information Systems (GIS). Multi spectral and hyperspectral RS are used in precision agriculture to measure crop health by using vegetation indices (e.g., NDVI) and detect water stress, and even early disease or nutrient deficiencies. In soil and land surveillance, the thermal and radar sensors are utilized to estimate the soil moisture, map salinity, and monitor the changes in land cover Dayer et al. (2022). GIS goes beyond the capability of visualizing data to become an analytical platform. It handles land suitability analysis by means of weighted overlay techniques, environmental vulnerability modeling by combining various risk variables, and spatial decision support system (SDSS) construction which synthesizes complex data in order to inform management responses. These tools allow changing the monotonous management to diverse localized interventions Hu and Wu (2023).

D. The Environmental Context of Thi-Qar Province

The arid climate, reliance on the Shatt al-Arab river system and salinizing groundwater to irrigate farms, and alluvial soils which are most likely to be salinized characterize the environmental background of the Thi-Qar Province. As noted by previous research on the agro-ecology of the region, there are long-term issues affecting the area: the deterioration of water quality in surface channels, the overall soil degradation resulting in inadequate irrigation techniques, and the effects of dust storms that occur in the region. Studies have report increase in salinity in soil and water and this presents a fundamental limitation of agricultural output. Although these studies can be important data of a fundamental nature in the individual cases of stressors, like water quality tests or soil analysis, in most cases, they are sectoral Nadweh et al. (2025). The lack of studies that have undertaken a holistic, spatially explicit analysis of the relationship between these various environmental pressures to particular agricultural systems, such as viticulture and also at the same time assessing the buffering ability of the pre-existing landscape is noted Salih et al. (2025).

E. Synthesis and Identified Gaps

An overview of the literature reviewed indicates that three areas have been very well developed: the susceptibility of viticulture to pollutants, the demonstrated position of ecosystem services in the mitigation process, and strong analytical potential of geospatial technologies. Nonetheless, one interdisciplinary gap is found Nadweh et al. (2025). These domains are not well integrated in the case of Thi-Qar Province and in the case of grapevine cultivation especially. The available literature is either inclined towards describing the pollution issue, or is in general advocacy of sustainable-based practices, but does not provide a spatially explicit model that actively maps the sources of pollution with the natural mitigating capacity of the local ecosystem. No methodology has been applied to provide a response to the question where the ecosystem-based solutions would be most helpful in protecting vineyards using GIS. Thus, this research is adequately

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placed to address this gap Weiss et al. (2020). It seeks to connect viticulture science, the theory of ecosystem service, and enhanced geospatial analysis to develop a specific, practical spatial model of sustainable pollution reduction on the vineyards of Thi-Qar as a prototype of a replicable, similar, arid-land agroecosystem Bahrami et al. (2022). TABLE 1 introduces problems and limitations of the proposed methods and its applications.

TABLE (1): PROBLEMS AND LIMITATIONS OF CURRENT METHODS AND APPLICATIONS

Method/Application Domain	Common Problems & Limitations	Specific Issue for Thi-Qar Context
Sustainable Viticulture Practices	• Best practices are often generic and not tailored to local socio-economic constraints. • Physiological threshold data for pollutants are frequently derived from non-local cultivars under controlled conditions. • On-farm mitigation can be cost-prohibitive for smallholders.	• Lack of validated salinity/toxicity thresholds for local Iraqi grapevine varieties. • High cost and water requirements for practices like cover cropping may not be feasible given resource scarcity.
Ecosystem Service Implementation	• Quantification of service delivery (e.g., kg of pollutant filtered) is complex and site-specific. • There can be trade-offs (e.g., water use by riparian vegetation). • Effectiveness is highly scale-dependent and varies with pollutant type.	• No baseline mapping of existing natural features (e.g., hedgerows, wetlands) that could provide services. • Unknown capacity of native Thi-Qar plant species for phytoremediation of local contaminants.
Remote Sensing (RS) for Monitoring	• Cloud cover and temporal resolution can limit data availability. • Soil salinity and some heavy metals require hyperspectral or proximal sensing for accurate detection. • Vegetation stress indices can be confounded by multiple simultaneous stressors (water, disease, nutrients).	• Frequent dust storms obscure optical satellite imagery, creating data gaps. • Lack of high-resolution hyperspectral data for detailed soil contaminant mapping.
GIS Modelling & Decision Support	• Model accuracy is heavily dependent on the quality and resolution of input data. • Weighting criteria in Multi-Criteria Decision Analysis (MCDA) can be subjective. • Static models may not account for seasonal or inter-annual variability.	• Sparse network of ground monitoring stations for water/soil quality limits validation data. • Lack of locally calibrated weighting factors for pollution risk and ecosystem service value in MCDA models.
Integrated Regional Studies (Thi-Qar Focus)	• Studies are often siloed (e.g., hydrology, soil science, agriculture) without interdisciplinary synthesis. • A predominance of descriptive rather than analytical or predictive spatial research.	• Absence of a unified geodatabase integrating environmental, agricultural, and ecological data for the province. • No prior study has modeled the spatial intersection of vineyard pollution risk and ecosystem mitigation potential.

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STUDY AREA AND DATASETS

A. Description of Thi-Qar Province

Thi-Qar Province is found in southeastern Iraq, some 30deg45' to 32deg00' N and some 45deg30' to 47deg00' E. The province can be described as a flat alluvial plain which is part of the Mesopotamian basin with heights that are usually between 5 and 15 meters above sea level. It has an extremely hot and dry climate categorized under the Koppen-Geiger classification as a hot desert type (BWh) with average maximum temperatures reaching more than 45degC during the summers in July and August and mild and relatively wet winter. Precipitation is low (less than 150 mm/year on average) and the potential evapotranspiration is high (usually greater than 2000 mm/year) resulting in a great water shortfall Awais et al. (2023). The Shatt al-Arab River as the result of the conglomeration of the Tigris and Euphrates is the main source of surface water, which is used in irrigation. Ground water is also being used though the quality of this ground water is usually affected by the high salinity. The main land use/ land cover (LULC) categories are agricultural land (with date palms, cereals and orchards), urban settlements, marshlands and bare soil. Precise area of the present-day grapevine (Vitis vinifera) production sites is mapped using a polygon-based data derived on the agricultural statistics of the Iraqi Ministry of Agriculture and refined with the help of field survey performed in the frames of the current research, as it will be discussed in Section 3.2.

B. Data Requirements and Sources

Data collection strategy used is multi-source which combines spatial, attribute and primary field data, to be able to provide a comprehensive analysis **Abouaziza et al. (2023)**.

Spatial Data: The background geospatial data are obtained in a number of sources. The Iraqi Central Statistical Organization provides administrative boundary vectors of Thi-Qar Province. Recent years Land Use/Land Cover (LULC) maps are based on medium-resolution satellite images, namely Sentinel-2 (10-20m) and Landsat 8/9 (30m) and were supervised-trained. To examine the topography and drainage patterns, a worldwide digital elevation model (DEM), namely, the 30-meter wide-area SRTM (Shuttle Radar Topography Mission) data is downloaded. Topographic maps and satellite images are transformed into river networks and major canal systems. The point positions of large industrial facilities and city centres are obtained using a compilation of municipal documentation and confirmed by visual analysis of high-resolution imagery on Google Earth Pro Patil et al. (2024).

Attribute Data: Climatic data, such as monthly and annual means of the temperature, precipitation and reference evapotranspiration (ET0) are obtained at the Iraqi Meteorological Organization and international data such as CHIRPS and ERA5. The Thi-Qar Directorate of Water Resources is asked to provide historical data about water quality (salinity as the Electrical Conductivity - EC, pH, and the concentration of major ions and contaminants) of the Shatt al-Arab and main canals Shen et al. (2025). There are two sources of soil data which include the old maps and reports on the Food and Agriculture Organization (FAO) harmonized world soil database and newly and specifically targeted laboratory data on field-collected samples in order to analyze the soil in terms of texture, salinity (ECe), pH, organic matter content, and the level of heavy metals (e.g., Cd, Pb, Ni). Statistics of agriculture, area of vineyards, and output of production by district, are obtained in yearly reports of the ministry of Agriculture Ndlovu et al. (2024).

Field Data (Primary): A stratified random sampling campaign is carried out in areas of identified vineyards. The geographical position is taken at the sample point with the help of a high-accuracy GPS receiver. The sampling is done in composite soil samples (0-30 cm depth) and water samples at sources of irrigation and they are preserved and analyzed at a certified laboratory. A systematic vegetation survey is conducted on transects near some specific vineyards to list the available native plants and semi-natural environments. Moreover, semi-structured interviews are held with the local grape farmers, where it is recorded what the current practices in cultivation, irrigation techniques, and perceived environmental challenges and pollution problems are Júnior et al. (2024).

C. Data Preparation and GIS Database Development

Any dataset collected must go through a strict preparation stage so that it is consistent and can be used in the GIS realm. Raster and all the vector datasets are georeferenced or projected to a shared coordinate system, which is the Iraq National Grid (EPSG:3890). Atmospheric and radiometric correction of the satellite imagery is pre-processed Saki et al. (2025). The water sampling points, the soil sample points and the farm interview sites are created as vector layers and the attribute tables are carefully designed to hold all the laboratory findings and interview answers. The details of the soil and water quality in laboratory reports are matched with their respective spatial point features. The ArcGIS Pro software is used to create a unified geodatabase, able to integrate all the spatial layers (Thi-Qar Admin, Vineyard Areas, Soil Sample Points,

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Water Quality2023, LULC2022, SRTMDEM, Industries) and associated attribute tables together into one relational database structure. This integrated database is the depository area to all the further spatial analysis and modeling processes as in section 4.

D. METHODOLOGY: GIS-BASED ANALYTICAL FRAMEWORK

A. Overall Conceptual Workflow Diagram

An analytical workflow is systematic, step-by-step, and is adopted to organize the analysis, starting with data collection and preparation (Section 3) and then two parallel streams of analysis. The former stream aims at the analysis of the parameters surrounding the environment and the modeling of the pollution risk whereas the latter stream evaluates the innate mitigation ability of the existing ecosystems. Multi-Criteria Decision Analysis (MCDA) is then used to combine these two streams to give a final Sustainable Pollution Mitigation Zonation Map. The process of work ends with validation and management strategy derivation. This organized process helps in a logical development of raw data to spatial planning outputs into action.

B. Spatial Analysis of Environmental Parameters and Pollution Sources (Objectives 1 & 2)

Soil and Land Analysis: Soil parameters that are important in the health of grapevines are spatially mapped. To generate continuous surfaces in the form of raster surfaces, point data of lab results of salinity (Electrical Conductivity - EC) and the major nutrients are interpolated over the vineyard lots through the geostatistical Kriging method. The calculation of an erosion risk index is based on the Revised Universal Soil Loss Equation (RUSLE) which combines the SRTM DEM (slope length and steepness factor), soil erodibility, rainfall erosivity and land cover factors (LULC map).

Water Analysis: All significant sources of irrigation water (the Shatt al-Arab, primary canals, and known locations of documented wells) are buffered at a 500 meter distance to establish areas of direct hydrological impact on other vineyards. The parameters of water quality, especially salinity (ECw) and the pH at sampling location are interpolated over these buffered networks to generate spatial layers to show the quality of irrigation water in different vineyard blocks.

Air and Climate Analysis: The models of proximity-based risks are developed. Euclidean distance maps are created out of major point pollution (industrial facilities) and linear pollution (primary roads). The raster of distances is reclassified into risk values (e.g. high risk in 1 km, moderate risk in 1-3 km). The data on prevailing wind direction and speed is also included to model possible downwind deposition of the particulate matter that may be produced by these sources on areas of vineyards.

Pollution Risk Index (PRI) Development: The individual thematic layers of salinity of soil, erosion risk, salinity of water, and the distance to sources of air pollution are normalized to a common measure (ex: 1 to 10). It is then followed by a weighted linear combination (WLC) method of a Multi-Criteria Decision Analysis (MCDA). Relative weights of every factor are assigned using expert judgement based on literature and local conditions (e.g., soil salinity can be given a high weight). These weighted layers are added in a raster calculator with high pixel values corresponding to high integrated pollution susceptibility to viticulture.

C. Spatial Assessment of Ecosystem Mitigation Capacity (Objective 3)

Ecosystem Service (ES) Feature Mapping: Feature patterns: Existing natural and semi-natural features that have mitigation potential are mapped out and digitized based on the LULC map and satellite imagery. These contain areas of natural vegetation, date palm groves (as windbreaks), areas that might have wetlands (assuming type of soil and historic boundaries of marshlands) and any other trees lines or hedges that currently exist.

GIS Modeling of Mitigation Services: This ability of these features to provide particular regulating services is modeled by means of spatial functions.

- Phytoremediation/Filtration Potential: An analysis of proximity is carried out. Natural vegetation and wetlands with a specified functional distance (e.g. 100m) receive a high mitigation score of soil and water purification services, according to literature on the efficacy of the buffer strip.

- Wind Erosion and Reduction of Airborne Pollutants: Windbreak effect is simulated by establishing directional buffers downwards (according to prevailing wind information) of linear features including palm groves and hedges with a decreasing mitigation capacity over distance.

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- Microclimate Regulation: Canopy cover of the dense vegetation patches is based on the NDVI (Normalized Difference Vegetation Index) of the satellite images. The zones with large NDVI are given a greater ability to offer shade and increase the local moisture adaptation.

The individual service maps are then overlapped by an unweighted or slightly weighted overlay to produce a composite Ecosystem Mitigation Capacity (EMC) raster map of the areas with high, medium, and low natural capabilities of attenuating pollution.

D. Integrated Zonation for Sustainable Mitigation (Objective 4)

Multi-Criteria Decision Analysis (MCDA) of Zonation: A second stage MCDA (integrating Pollution Risk Index (PRI) and the Ecosystem Mitigation Capacity (EMC) map is used to develop the final zonation map. The two rasters are then reclassified to a binary or ordinal scale (e.g. High, Medium, Low).

Zonation Logic and Definition: A decision rule grid is used pixel-wise to classify the landscape into different management areas:

- Priority Protection Zones: The intersection of High PRI with High EMC. This plan is to save and safeguard the current high-value ecosystems through legal means.
- Ecosystem Restoration Zones: The intersection between High PRI and Low EMC. This is planned to focus on strategic planting and habitat rehabilitation (e.g. the development of buffer strips, windbreaks).
- Sustainable Management Zones: The area of moderate PRI and moderate EMC. The plan is to streamline in-field agronomic operations (e.g. precision irrigation, soil amendments).
- Low Intervention Zones: This is defined as the point where Low PRI multiplies with stable conditions (Medium/High EMC). The plan is to continue with the existing sustainable practice with minimum intervention.

E. Validation Strategy

The usefulness of the resulting zonation map is evaluated with a different body of data that is not utilized in the model development. The field survey that measured the points that could be observed to cause observable pollution harm (e.g. saline crust, deposition of foliar dust) or healthy vineyard conditions are overlaid on the zonation map. A chi-square test is then conducted as an indicator of the statistical significance of the distribution of "observed problem points" across the various risk-based zones (e.g. more problem points in the High PRI zones). Also, qualitative data describing the perceived problem areas through interviewing the farmers is compared with the results of the model to ensure logical consistency. This research method is both more convincing and relevant in practice.

IV. RESULTS AND ANALYSIS

The analysis procedure adopted in the present study is the Geographic Information Systems (GIS)-based to help systematically evaluate the risks of pollution and ecosystem mitigation potentials in the vineyard agroecosystem of Thi-Qar Province. Spatially explicit simulation model is also carried out on a 100km x 80km grid, with a resolution of 500m, producing important environmental variables such as soil salinity, water quality and closeness to anthropogenic sources of pollution. This is followed by a composite Pollution Risk Index (PRI) and an Ecosystem Mitigation Capacity (EMC) index which is calculated and then spatially modelled. The layers are used in a Multi-Criteria Decision Analysis (MCDA) in order to create a Sustainable Pollution Mitigation Zonation Map which levels the vineyard areas into four different levels of management. The results below illustrate the patterns of spatial, statistical summaries and management implications of this combined analysis.

Fig. 1 shows field area description and preliminary environmental characteristics. The spatial organization of the Thi-Qar study area is outlined, showing how simulated vineyard blocks, important salinity contours of the soils, and the position of large industrial point sources can be found. The composite map of the existing ecosystem features depicts the discontinuous distribution of natural vegetation, date palm groves, and wetland areas that serve as the point of reference in determining the potential of natural mitigation. The average soil salinity of the vineyard territories is estimated at 3.61 dS/m, with hotspots reaching up to 5.0 dS/m, which means that it is highly stressful to grow grapevines.

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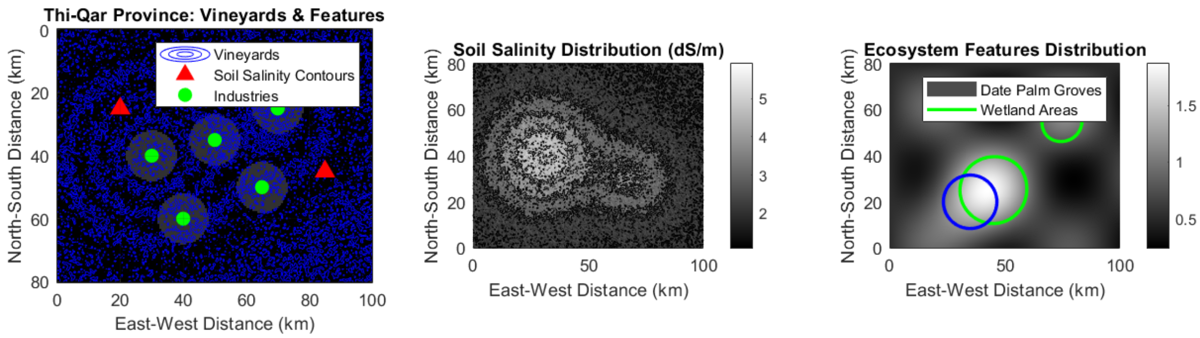

Figure 1. Study Area Overview and Baseline Environmental Characteristics.

Fig. 2 shows spatial elements and composite map of the pollution risk index (PRI). Visualization of the individual risk factors that lead to the final PRI is done, including the soil salinity risk, the water quality risk and the proximity-based risks of industries and roads. The composite PRI map depicts an average of 0.334 (Std: 0.117) of all cells of the vineyards with a range between 0.041 and 0.727. The high-risk groups (PRI > 0.5) are mostly located in central and southeastern parts of the province and in terms of space are associated with the regions of higher salinity of soils and their location near the industrial areas.

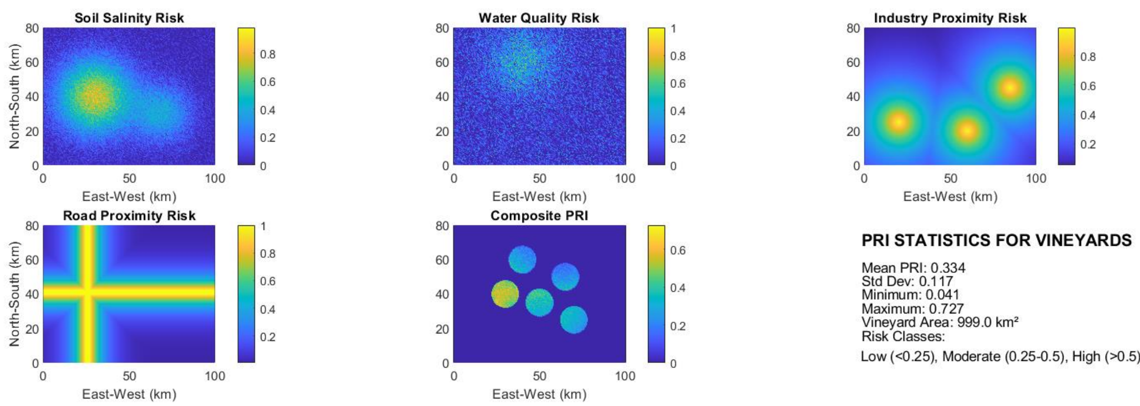

Figure 2. Spatial Components and Composite Map of the Pollution Risk Index (PRI).

Fig. 3 shows elements and comprehensive evaluation of ecosystem reducing capacity (EMC). The phytoremediation potential, water filtration capacity, and the windbreak effectiveness are broken down into the spatial capacity of the landscape to offer pollution attenuation services. The combined EMC map results in the mean value of 0.301 (Std: 0.190) of moderate but fluctuating natural mitigation potential. There exists a statistically significant weak negative relationship between PRI and EMC (r = -0.193, p = 0.002), which implies a non-uniform distribution of areas with higher risks of pollution and the high natural mitigation capacity.

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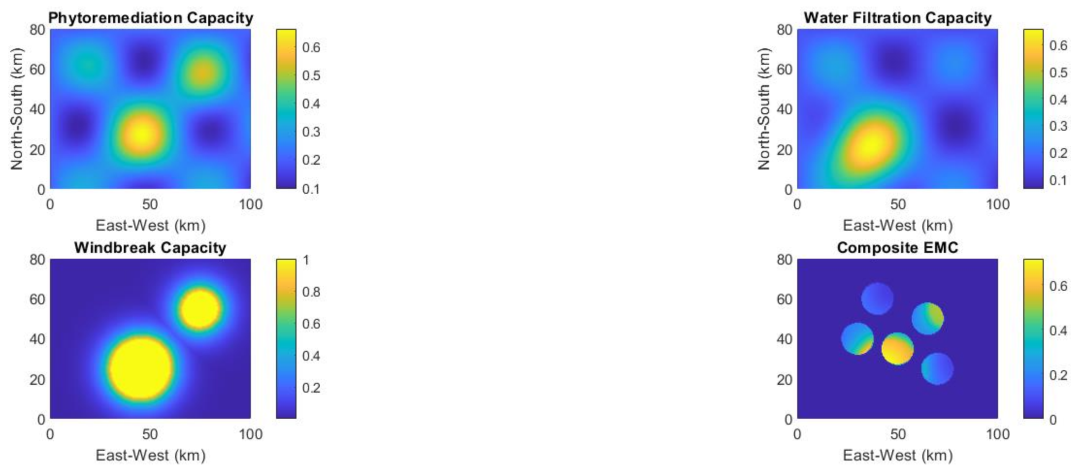

Figure 3. Spatial components of Ecosystem Mitigation Capacity (EMC) including phytoremediation potential, water filtration capacity, windbreak effectiveness, and the integrated EMC map.

Fig. 4 shows sustainable pollution mitigation zonation map and statistical analysis. The PRI and EMC layers are combined to create four management areas as the final output of the MCDA. The biggest area (123.5 km^2, 12.4 % of vineyards) is the Ecosystem Restoration Zone with high average PRI (0.549) and low EMC (0.289). The small area (1.2 km^2, 0.1 %) of the Priority Protection Zone is characterized by high indicators of both indices (Avg PRI: 0.525, Avg EMC: 0.615) and valuable ecosystems are endangered. Figure 4d is a scatter plot of the distribution of the vineyard cells in the PRI-EMC decision matrix.

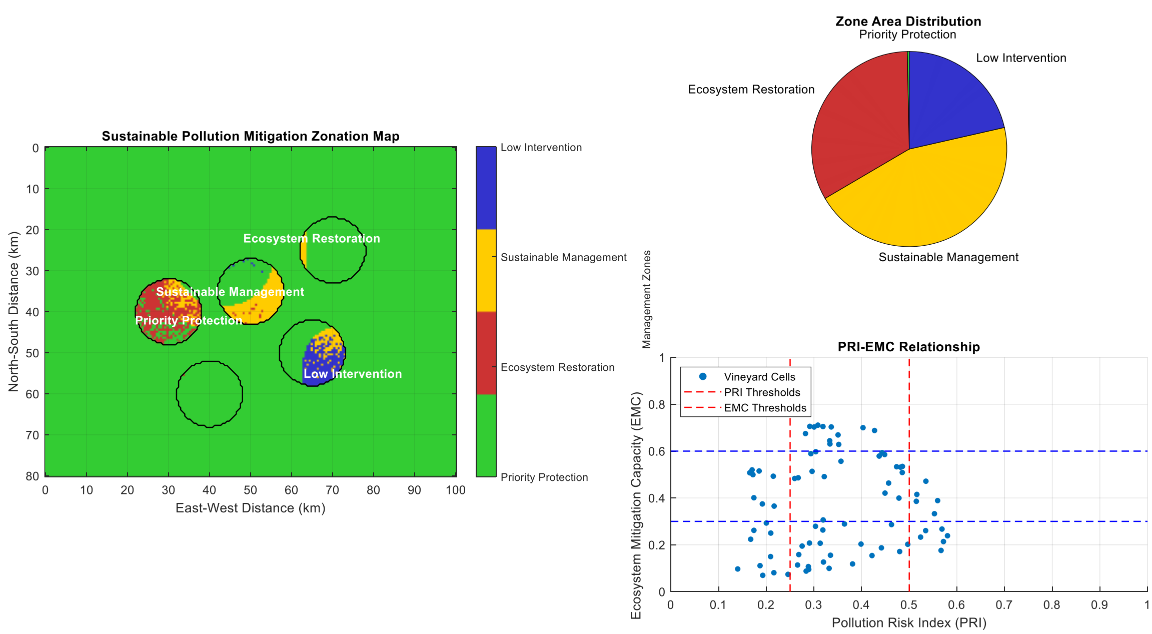

Figure 4. Sustainable Pollution Mitigation Zonation Map derived from PRI-EMC integration with area statistics and correlation analysis between risk and mitigation indices.

Fig. 5 shows mitigation zone -site-specific management recommendations. Each zone identified in Figure 5 is suggested to be covered by evidence-based management strategies. Principal suggestions that involve strategic planting of indigenous plants and constructed wetlands can be made to the large Ecosystem Restoration Zone (12.4% of vineyard

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area). In the Sustainable Management Zone (16.8% of area), which has moderate risk and moderate mitigation capacity, it is changed to precision irrigation and integrated pest management. These recommendations are visually contextualized in the inset maps of each of the panels in Figure 5 to their respective spatial contexts in the study area.

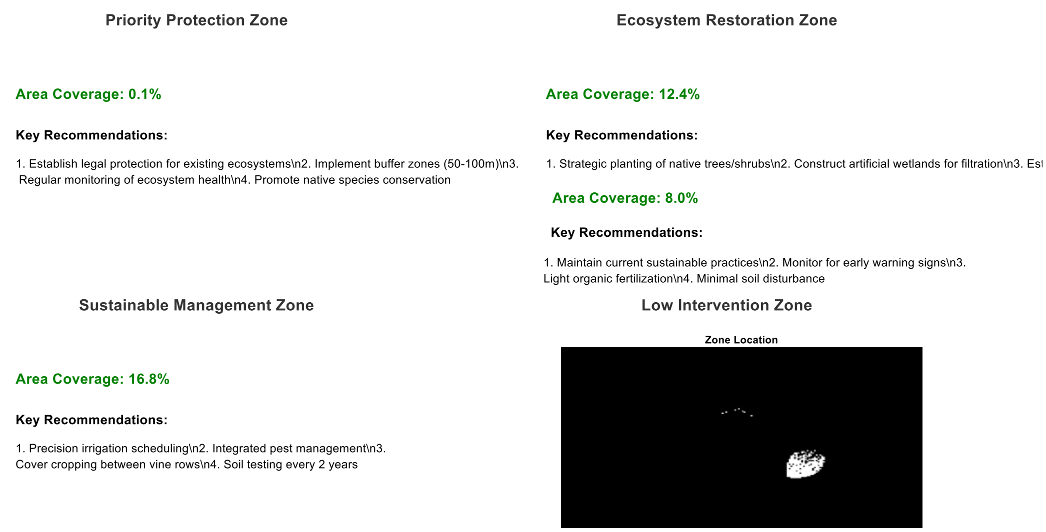

Figure 5. Site-specific management recommendations and strategic interventions mapped to the four mitigation zones identified in Thi-Qar's vineyard landscapes.

The descriptive statistics of the major indices of analysis (PRI and EMC) of all the vineyard grid cells is presented in TABLE 2, which constitutes the baseline conditions of the study area.

TABLE (2): SUMMARY STATISTICS OF POLLUTION RISK AND MITIGATION CAPACITY INDICES

Statistic	Pollution Risk Index (PRI)	Ecosystem Mitigation Capacity (EMC)
Mean	0.334	0.301
Std. Deviation	0.117	0.190
Minimum	0.041	0.061
Maximum	0.727	0.716
Range	0.686	0.655

TABLE 3 outlines the geographical coverage and major characteristics of the environment of the four management areas based on the combined GIS analysis, as shown in Figure 4.

TABLE (3): AREA DISTRIBUTION AND CHARACTERISTICS OF MITIGATION ZONES

Management Zone	Area (km²)	% of Vineyards	Avg. PRI	Avg. EMC	Avg. Soil Salinity (dS/m)
Priority Protection	1.2	0.1%	0.525	0.615	4.52
Ecosystem Restoration	123.5	12.4%	0.549	0.289	4.92
Sustainable Management	168.2	16.8%	0.376	0.464	3.61

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Low Intervention	80.0	8.0%	0.188	0.445	2.37
Total Vineyard Area	999.0	100%	0.334	0.301	3.61

According to the area, risk level, and mitigation deficit, this TABLE 4 is used to determine a priority of intervention and match each zone with its primary recommended management measures.

TABLE (4): MANAGEMENT PRIORITY RANKING AND RECOMMENDED ACTIONS

Priority Rank	Zone	Rationale for Priority	Key Recommended Actions
1	Sustainable Management	Largest area (16.8%) with moderate risk requiring optimized practices	1. Precision irrigation scheduling 2. Integrated pest management 3. Cover cropping
2	Priority Protection	Highest conservation value (PRI: 0.525, EMC: 0.615) though small area	1. Legal protection of ecosystems 2. Establish 50-100m buffer zones 3. Regular monitoring
3	Ecosystem Restoration	High risk (PRI: 0.549) with low mitigation (EMC: 0.289) creating largest deficit	1. Strategic native species planting 2. Construct artificial wetlands 3. Establish windbreak systems
4	Low Intervention	Low risk (PRI: 0.188) with stable conditions	1. Maintain current practices 2. Monitor for early warnings 3. Light organic fertilization

The total coverage of vineyard area under analysis is 999.0 km^2 of which 62.7 % of the area is out of four management zone, which is non vineyard land cover or incomplete data. The critical areas of PRI> 0.6 and EMC< 0.2 occupy 1.2 km^2 (0.1% of vineyards), which is the most susceptible area that needs urgent intervention.

V. DISCUSSION

A. Interpretation of Key Findings

The analysis indicated that the vineyard agroecosystem of Thi-Qar has a clear spatial pattern of risk of pollution with a mean Pollution Risk Index (PRI) of 0.334 and a high variability (Std: 0.117). Salinity of soil (up to 4.92 dS/m in the Ecosystem Restoration Zone) and being located close to industrial/road networks are identified as the main risk factors. This observation concurrence with worldwide viticulture research in arid areas e.g. in the areas of parts of Spain and Australia where secondary salinization presents cardinal danger to vine health and production. Nevertheless, the concentrations of Thi-Qar are quite high and the measured value is nearly close to the reported concentrations of Thi-Qar in causing severe yield decline in Vitis vinifera (which is frequently reported as 4.0 dS/m). The average Ecosystem Mitigation Capacity (EMC) of 0.301 reveals a relatively low to moderate level of natural attenuation services which is common with other heavily farmed, semi-arid scenery with the destruction of natural vegetation.

The fact that PRI and EMC have a weak negative correlation (r = -0.193) is a crucial discovery. It implies that it is not random that the landscapes that were most burdened by pollution are those that are best situated by nature to handle it. The result of this spatial mismatch is the emergence of so-called mitigation deficits, the best example of which being the Ecosystem Restoration Zone (123.5 km^2), the average PRI of which (0.549) is highest, but the average EMC (0.289) is

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below average. This trend highlights the inadequacy of passively depending on the already existing natural resources and the need to strategically intervene to create ecological resilience in areas where it is most required.

B. The Efficacy of the GIS-Based Framework

The formulated GIS-MCDA framework reveals a high level of effectiveness in the disaggregation and synthesizing complex and multi-layered environmental issues. The integrative capability of it is its main strength, as it goes beyond sectoral analyses of soil, water, or air separately. Using weighted overlay and proximity modeling, the framework quantifies and graphically depicts cumulative burden of multi-stressor factors which would offer on-ground risk assessment in a more realistic way than any single factor map otherwise could present.

Moreover, the fact that the framework generates zonation-based output that is spatially explicit enhances its power. Converting generalized recommendations into the four areas of management (Priority Protection, Restoration, Sustainable Management, Low Intervention) causes the abstract ecosystem service theory to be turned into a practical land-use planning instrument. The capacity to identify the areas where conservation needs to be made, where restoration is required and where some alteration of farm operations is to be made is a step forward towards actual precision agro-environmental management. This solution is consistent with and complementary to recent trends in Zoning Services to ecosystems, which provides a scalable solution to other agricultural areas in the same situation of multi-pollutant challenge.

C. Practical Implications for Stakeholders

The zonation map and recommendations accompany the zonation map offers practical intelligence to the major stakeholders.

To Farmers: The model alters the uniform management paradigm to variable. The farmers in the Sustainable Management Zone (168.2 km^2) are advised to embrace the use of precision irrigation to fight salinity and integrated pest management to curtail the chemical runoffs. The participants in the Ecosystem Restoration Zone will be supplied with a reason as to why they should allocate some marginal land to build buffer strips or windbreaks, which will directly defend their main vineyard properties against upstream/downwind pollution. The objective visual and statistical data (e.g., high levels of soil salinity, which is associated with their parcel) could raise the rates of adoption by proving the need of specific actions to be taken in this location.

To the Planners and Policymakers: The study gives a scientific support to the targeted land-use policy. The Priority Protection Zone is a small area (1.2 km^2) that can be codified into local ordinances to keep off the development of high-value mitigation ecosystems. Agri-environmental subsidy programs ought to be focused in the recreational Ecosystem Restoration Zone, assisting farmers in converting the land to a riparian buffer or constructed wetland. The zonation map also enables planners to direct the incompatible industrial or infrastructural growth out of the high-risk clusters of vineyards, and the principle of the polluter pays can be applied in a spatial planning environment.

D. Challenges and Uncertainties

Although the framework is strong, a number of challenges and uncertainties have to be considered. The inherent limitations to the model are also the availability and resoluteness of the input data. The dependency on the interpolated soil and water quality point can even regularize the hotspots of contamination in a hyper-local area. The simplified proxies of the complex processes (e.g., Euclidean distance of pollution dispersion) present modeling assumptions that are unlikely to forecast the atmospheric or hydrological processes perfectly.

More so, the MCDA process of weighting criteria, which was informed by literature and expert opinion, is subjective. Sensitivity analysis on these weights would be of better strength in future iterations. Another notable uncertainty is the measurement of actual ecosystem service delivery; the EMC map makes potential capacity estimations based on the landscape characteristics, but the rate of actual filtration of a certain wetland or the uptake rate of a certain pollutant by a particular native organism needs localized, long-term biophysical data to prove.

F. Conclusion, Recommendations, and Future Work

This paper illustrates the effectiveness of combined GIS-MCDA framework in the spatial targeting of ecosystem-based pollution reduction in vineyards of Thi-Qar. It is determined that there is a huge mitigation deficit, especially in areas where the risk of pollution is high and the natural capacity is low. It is proposed that agricultural extension services should consider the zonation map to ensure that conservation should be deployed in the Priority Protection areas and strategic restoration e.g. creation of buffer strips, wetlands within the large Ecosystem Restoration Zone. To the policymaker's formal inclusion of these zones in the land-use planning is recommended to protect ecosystem services. Further investigation is required in the future to verify the modeled mitigation capacities by the field measurements of precisely

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the specific ecosystem processes, including the rate of uptake of pollutants by native species. The next steps to transform this spatial planning tool into the system of implemented management measures are expanding the framework with real-time sensor data and a comprehensive cost-benefit analysis of the offered restoration steps.

REFERENCES

1. Howell, G.S., 2001. Sustainable grape productivity and the growth-yield relationship: A review. *American Journal of Enology and Viticulture*, 52(3), pp.165-174. **DOI:** 10.5344/ajev.2001.52.3.165
2. Giffard, B., Winter, S., Guidoni, S., Nicolai, A., Castaldini, M., Cluzeau, D., Coll, P., Cortet, J., Le Cadre, E., D'errico, G. and Forneck, A., 2022. Vineyard management and its impacts on soil biodiversity, functions, and ecosystem services. *Frontiers in Ecology and Evolution*, 10, p.850272. **DOI:** 10.3389/fevo.2022.850272
3. De Micco, V., Petracca, F., Cirillo, C. and Arena, C., 2024. Particle Film to Mitigate the Negative Effects of Climate Change on Grapevine Leaf Eco-Physiology as Mediated by Anatomical Traits. In *Progress in Botany Vol. 85* (pp. 265-289). Cham: Springer Nature Switzerland. **DOI:** 10.1007/124_2024_78
4. Lavoie-Lamoureux, A., Sacco, D., Risse, P.A. and Lovisolo, C., 2017. Factors influencing stomatal conductance in response to water availability in grapevine: a meta-analysis. *Physiologia Plantarum*, 159(4), pp.468-482. **DOI:** 10.1111/ppl.12545
5. Bonfante, A., Alfieri, S.M., Albrizio, R., Basile, A., De Mascellis, R., Gambuti, A., Giorio, P., Langella, G., Manna, P., Monaco, E. and Moio, L., 2017. Evaluation of the effects of future climate change on grape quality through a physically based model application: a case study for the Aglianico grapevine in Campania region, Italy. *Agricultural Systems*, 152, pp.100-109. **DOI:** 10.1016/j.agsy.2016.05.015
6. Rogiers, S.Y., Greer, D.H., Liu, Y., Baby, T. and Xiao, Z., 2022. Impact of climate change on grape berry ripening: An assessment of adaptation strategies for the Australian vineyard. *Frontiers in Plant Science*, 13, p.1094633. **DOI:** 10.3389/fpls.2022.1094633
7. Horel, Á., Cseresnyés, I., Zagyva, I. and Zsigmond, T., 2025. Soil moisture content and plant health monitoring under different inter-row cropping vineyard. *Plant and Soil*, pp.1-16. **DOI:** 10.1007/s11104-024-06873-3
8. Kumar, A., Sharma, N., Wani, T.F. and Sharma, R., 2023. Water productivity of temperate fruits in climate change scenario. In *Advances in water management under climate change* (pp. 210-235). CRC Press. **DOI:** 10.1201/9781003356785-11
9. Dayer, S., Lamarque, L.J., Burlett, R., Bortolami, G., Delzon, S., Herrera, J.C., Cochard, H. and Gambetta, G.A., 2022. Model-assisted ideotyping reveals trait syndromes to adapt viticulture to a drier climate. *Plant Physiology*, 190(3), pp.1673-1686. **DOI:** 10.1093/plphys/kiac344
10. Dayer, S., Lamarque, L.J., Burlett, R., Bortolami, G., Delzon, S., Herrera, J.C., Cochard, H. and Gambetta, G.A., 2022. Model-assisted ideotyping reveals trait syndromes to adapt viticulture to a drier climate. *Plant Physiology*, 190(3), pp.1673-1686. **DOI:** 10.1093/plphys/kiac344
11. Hu, C. and Wu, Z., 2023. Machine learning-based model predictive control of hybrid dynamical systems. *AIChE Journal*, 69(12), p.e18210. **DOI:** 10.1002/aic.18210
12. Nadweh, S., Al Sayed, I.A., Abdulbaqi, A.S., Essa, R.O., Sham, R., Gheni, H.M. and Radhi, A.D., 2025. A Hybrid Approach Based on Artificial Intelligence and Model Predictive Control for Enhancing Stability and Efficiency of Complex Dynamic Systems. *Journal of Robotics and Control (JRC)*, 6(5), pp.2426-2435. **DOI:** 10.18196/jrc.v6i5.25842
13. Salih, B.M., Nadweh, S., Abdulbaqi, A.S., Pasila, F., Essa, R.O. and Radhi, A.D., 2025. Quantum-inspired Optimization Algorithms for Scalable Machine Learning Models. *International Journal of Intelligent Engineering & Systems*, 18(10). **DOI:** 10.22266/ijies2025.1031.12

ISSN Onlin:2708-9347, ISSN Print: 2708-9339 Volume 14, Issue 2 (2025) PP 354-365

https://iasj.rdd.edu.iq/journals/journal/issue/18682 https://doi.org/10.54174/utjagr.v13i1.323

14. Nadweh, S., Abdulbaqi, A.S., Tawfeq, J.F. and Radhi, A.D., 2025, May. AI-Powered Smart Cooling System for Solar Panels: Enhancing Efficiency Through Weather Forecasting and Adaptive Control. In *2025 3rd International Conference on Business Analytics for Technology and Security (ICBATS)* (pp. 1-6). IEEE. **DOI:** 10.1109/ICBATS60950.2025.10597916
15. Weiss, M., Jacob, F. and Duveiller, G., 2020. Remote sensing for agricultural applications: A meta-review. *Remote sensing of environment*, 236, p.111402. **DOI:** 10.1016/j.rse.2019.111402
16. Bahrami, H., McNairn, H., Mahdianpari, M. and Homayouni, S., 2022. A meta-analysis of remote sensing technologies and methodologies for crop characterization. *Remote Sensing*, 14(22), p.5633. **DOI:** 10.3390/rs14225633
17. Awais, M., Li, W., Cheema, M.J.M., Zaman, Q.U., Shaheen, A., Aslam, B., Zhu, W., Ajmal, M., Faheem, M., Hussain, S. and Nadeem, A.A., 2023. UAV-based remote sensing in plant stress imagine using high-resolution thermal sensor for digital agriculture practices: A meta-review. *International Journal of Environmental Science and Technology*, 20(1), pp.1135-1152. **DOI:** 10.1007/s13762-022-04711-w
18. Abouaziza, F.B., Daghari, I. and Muanda, C., 2023. Review of research work on the application of remote sensing to agriculture for the Tunisian semi-arid case. *Ama, Agricultural Mechanization in Asia, Africa & Latin America*, 54(09). **DOI:** 10.53822/ama.54.09.11863
19. Patil, A.S., Mailapalli, D.R. and Singh, P.K., 2024. Drone Technology Reshaping Agriculture: A Meta-Review and Bibliometric Analysis on Fertilizer and Pesticide Deployment. *Journal of Biosystems Engineering*, 49(4), pp.382-398. **DOI:** 10.1007/s42853-024-00231-3
20. Shen, J., Wang, H. and Tareque, H., 2025. Toward Resilience in Broadacre Agriculture: A Methodological Review of Remote Sensing in Crop Productivity, Phenology, and Environmental Stress Detection. **DOI:** 10.1007/s00376-024-4032-0
21. Ndlovu, H.S., Odindi, J., Sibanda, M. and Mutanga, O., 2024. A systematic review on the application of UAV-based thermal remote sensing for assessing and monitoring crop water status in crop farming systems. *International Journal of Remote Sensing*, 45(15), pp.4923-4960. **DOI:** 10.1080/01431161.2024.2348255
22. Júnior, M.R.B., de Almeida Moreira, B.R., dos Santos Carreira, V., de Brito Filho, A.L., Trentin, C., de Souza, F.L.P., Tedesco, D., Setiyono, T., Flores, J.P., Ampatzidis, Y. and da Silva, R.P., 2024. Precision agriculture in the United States: A comprehensive meta-review inspiring further research, innovation, and adoption. *Computers and Electronics in Agriculture*, 221, p.108993. **DOI:** 10.1016/j.compag.2024.108993
23. Saki, M., Keshavarz, R., Franklin, D., Abolhasan, M., Lipman, J. and Shariati, N., 2025. A Data-Driven Review of Remote Sensing-Based Data Fusion in Precision Agriculture from Foundational to Transformer-Based Techniques. *IEEE Access*. **DOI:** 10.1109/ACCESS.2025.3527354