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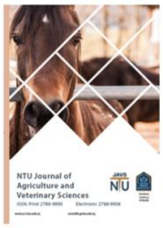

The Role of GIS in Enhancing Agricultural Planning and Mechanization in Climatically Diverse Areas: An Analytical Study in Nineveh

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A B S T R A C T

This study showed the role of geographic information systems (GIS) in enhancing future agricultural planning and decision-making related to the use of agricultural mechanization in the areas of Al-Qosh and Hammam al-Alil/Ninawa Governorate/Iraq. The study showed the possibility of conducting descriptive analysis using satellite images and maps of exploited agricultural areas to assess the suitability of agricultural land based on the nature of the land, climatic changes and soil. The results showed significant differences between the two regions in the amount of rainfall, the size and area of agricultural holdings and the slope of the land, which requires a mechanism adapted to local conditions. The study highlighted the importance of integrating GIS with precision farming systems to optimize the use of machines and increase productivity. The proposed strategies included improving the use of water resources through irrigation projects, improving rural roads and infrastructure to facilitate the movement of agricultural machinery. This research contributes to the policies of using sustainable agricultural mechanization based on the accuracy of spatial analysis, support food security and the advancement of the agricultural sector in various climatic conditions.

Introduction

Climate change, the depletion of natural resources, and the increasing strain on food security brought on by rapid population increase are just a few of the many issues facing agricultural systems in developing nations, especially Iraq. In this regard, Geographic Information Systems (GIS) have become sophisticated analytical tools that allow decision-makers to combine agricultural and environmental factors, enabling more efficient and sustainable spatial planning in the agricultural industry [1]. Several studies have shown that GIS technologies are essential to the shift to precision agriculture, especially in arid and semi-arid regions, especially when combined with remote sensing (RS). For example, a study conducted in Egypt by [2] shown that the definition of management zones based on soil properties was made possible by merging GIS with Gps data and soil sensors. As a result, productivity increased and operating expenses decreased. In addition, [3] showed the importance of GIS in analyzing long-term changes in some soil elements when using different tillage systems over a period of 26 years. In addition, a significant correlation (R^2 = 0.73–0.85) was observed between soil organic carbon levels and agricultural management practices, and this was verified by [4]. In studies conducted across Iraq, [5] GIS with Analytical Hierarchy (AHP) was used to integrate topographic, climatic, and soil data using spatial analysis in ArcGIS to identify the best locations for rainwater harvesting in Karbala Governorate. In this context, a recent study conducted by [6] demonstrated the effectiveness of GIS and RS in classifying agro-ecological areas in Nineveh Governorate. In this context, a recent study conducted by [6] demonstrated the effectiveness of GIS and RS in classifying agro-ecological areas in Nineveh Governorate. By integrating multiple spatial layers - such as terrain, soil type, soil and climate - this study produced a detailed map that identifies nine agro-ecological regions. This classification enhances the possibility of identifying crops based on the environmental characteristics of the region and supports agricultural planning in Iraq. Here, the increasing importance of using geographic information systems as one of the main tools to support and guide decision-making and agricultural planning in light of climate change and resource shortages becomes clear, in addition to the lack of field studies in Nineveh Governorate that combine geographic information systems with the needs of agricultural mechanization. Accordingly, this study aims to achieve:

- To evaluate the role of Geographic Information Systems (GIS) in improving agricultural planning and supporting decision-making related to agricultural mechanization operations.
- To identify agricultural areas where productivity can be improved through the application of mechanization practices supported by spatial data.
- To analyze the relationship between the application of agricultural mechanization and smart farm management systems using GIS techniques to increase production and reduce costs.
- To propose an integrated GIS-based model to improve the scheduling of mechanized agricultural operations and optimize the allocation of material and human resources across different agricultural areas.

Materials and Methods:

1. Research Methodology:

A approach based on analytical spatial description employing geographic information systems and re mote sensing was used to evaluate the research area s' agricultural and spatial features:
Rainfall is almost certain in the district of Hamma m Al Alil and is assured in the district of Al Qosh. This methodology aimed to develop an integrated s patial database that integrates environmental, agric ultural, and human elements in order to identify the optimal locations for future agricultural operations, including the growing of strategic commodities lik e wheat and barley.

2. Study Area:

The environment, biography, and agricultural clima te were all taken into consideration when choosing the two study areas:

- **Al-Qosh:** positioned north of the city, this location offers unique characteristics. It is believed to be perfect for growing a range of crops because it receives 400% of the totoal annual rainfall.
- **Hammam Al-Alil:** Due to its dependency on irrigation and groundwater, this area, which is south of Mosul, is considered semi-important for rainfall.

Figure 1, shows the circular air map of the study's areas. Situated south of Mosul, this region is regarded as semi-important for rainfall due to its reliance on irrigation and groundwater. The circular air map of the study areas is displayed in figure 1.

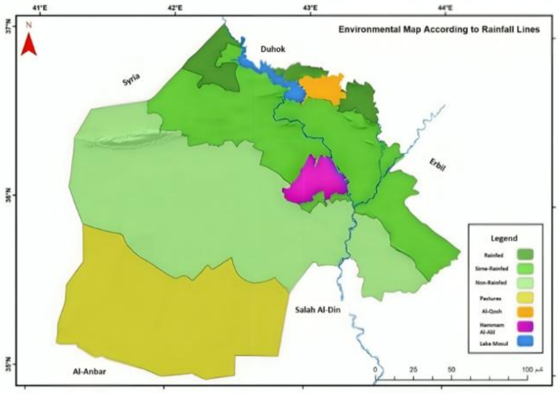


Figure1. A map showing the rainfall rates for the two study areas.

3. **Data Sources Data were collected from multiple sources, including:**

Official maps were obtained from the Nineveh Agriculture Directorate.

4. Statistical Analysis

4.1 Analytical Framework

The study used an integrated statistical approach using ArcGIS 9.3 and SPSS v26 with the workflow as follows as shown in Table 1.

Table 1. Integrated Analytical Workflow for Agricultural Data Processing

Analysis Type	Method/Tool	Parameters	Output Metrics	Validation
Descriptive Stats	Mean ± SD	Rainfall, temperature, soil properties	CV = 12-18%	N/A
Land Classification	Weighted Overlay (GIS)	FAO soil/terrain criteria	5 suitability classes	Field verification
ANOVA	One-way (α=0.05)	Arable land areas by region	F=6.21, p<0.01	Tukey post-hoc
Regression	Linear model	Rainfall vs. productivity	R^2=0.82, p<0.001	Shapiro-Wilk test
AHP	Multicriteria analysis	Slope (0.4), water (0.3), soil (0.3)	CR=0.08	Expert survey
Spatial Analysis	Kernel Density, Kriging	Labor clusters, SOC distribution	RMSE=0.12	50 ground-truth points
Accuracy Assessment	Kappa coefficient	Land classification	κ=0.82, OA=85.3%	Confusion matrix

Key:

CV = Coefficient of Variation, SOC = Soil Organic Carbon, OA = Overall Accuracy

4.2 Data Collection

A) Spatial Data:

Table 2. Spatial and Field Data Sources

Data Type	Source	Resolution/Scale	Year
Satellite Imagery	Landsat 8 (Path/Row: 165/38)	30m	2023
Soil Maps	Nineveh Agriculture Directorate	1:50,000	2021-2023
Climate Data	Iraqi Meteorological Org.	Daily records	2000-2023

B) Field Surveys:

- 50 random verification points (GPS: Garmin 64s)
- Soil samples (0-30cm depth) analyzed at NTU Labs

4.3 Study Area Characteristics

Table 3. Comparative Analysis of Study Subdistricts

Parameter	Al-Qosh Subdistrict	Hammam Al-Alil Subdistrict
Coordinates	36°11'N, 43°21'E	36°02'N, 43°30'E
Rainfall (mm/yr)	400 ± 35	250 ± 28
Dominant Soil	Clay Loam	Sandy Clay Loam

4.4 GIS Processing Workflow

Table 4. Step-by-Step Geospatial Analysis Protocol

Step	Tool/Module (ArcGIS 9.3)	Input Data	Output
1. Preprocessing	Georeferencing	Scanned maps	Digitized layers
2. Classification	Spatial Analyst	Landsat 8 + Soil maps	Land suitability map
3. Validation	Accuracy Assessment	Field points	κ = 0.82

5. A series of procedures and steps were followed to achieve the research objectives, as shown below:

Paper maps were formatted and converted to digital format using a scanner. Performing georeferencing on maps and determining control points with accurate coordinates. The study areas were redrawn and their characteristics analyzed using ArcMap tools. Representing spatial data for the two study areas in the form of analytical maps such as maps of arable and non-arable lands, maps of sewage networks, and population distribution maps. Lands were classified using environmental and agricultural criteria including soil, climate, slope and water sources. A spatial variation analysis of agricultural production was conducted for the two study areas based on climate and soil data.

6. Criteria Used in the Analysis

- Based on official sources and scientific investigations, a set of agricultural and geographical standards were adopted, such as: • Average annual rainfall > 400 mm in areas with guaranteed rainfall, as this value is deemed suitable for sustained crop growth [7].
- Use a slope of less than 8% as a criterion to identify areas that are acceptable for agricultural mechanization, since steeper terrain increases the danger of erosion and decreases machine efficiency [8].
- Among the fundamental elements influencing crop productivity are soil fertility and organic matter content [9].
- proximity to surface or groundwater sources, which is essential for figuring out how much water is needed for irrigation. [10].
- The efficiency of agricultural activities depends on the availability of agricultural mechanization and infrastructure, such as roads, equipment, and warehouses [11].

Results and Discussion

1. **Spatial Map Analysis and Study Findings**

The study relied on a series of digital spatial maps resulting from analyzing data for the study areas using geographic information systems (ArcGIS 9.3). This made it possible to obtain accurate results regarding the suitability of lands for agriculture in the Al Qosh and Hammam Al-Alil.

The findings based on the analytical maps that are attached are listed below:

1. The computerized map of AlQosh district's agricultural areas (Figure 2) shows how the cultivated fields are split geographically throughout 69 districts totaling 181,066 dunums.The region is designated as a guaranteed rainfall area since the average annual rainfall exceeds 400 mm.Satellite image analysis and maps from the Agricultural Area Index served as the foundation for these findings.

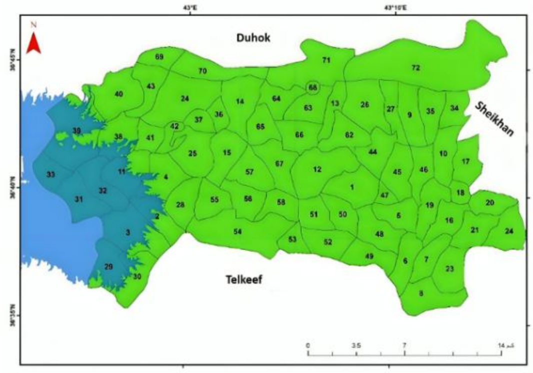


Figure2. Shows the distribution of arable areas in Alqosh district.

2. The geographical distribution of the farmed areas in the Hammam Al Alil district, which spans 44 districts and 272,348 dunums, is depicted on the map in Figure 3. The average annual rainfall is less than 400 mm, making it within the region almost guaranteed rain. The map also showed the great variation in the sizes of regions, emphasizing the importance of allocating mechanization according to the size of each region. These results were based on maps of agricultural areas and analysis of Landsat 8 satellite images.

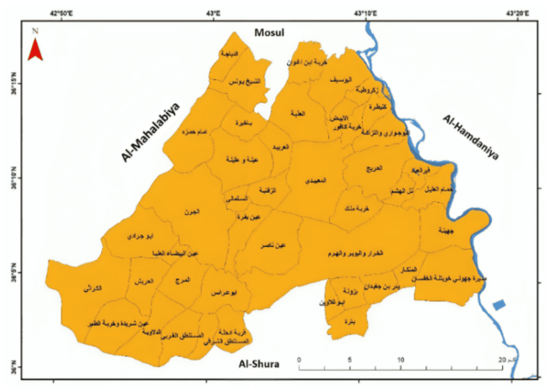


Figure3. Shows the distribution of agricultural areas in the Hammam Al Alil district.

2. **Division of lands according to their agricultural suitability:**

The land in the two study areas was classified as arable land, characterized by low slope, soil fertility, and abundant water availability. Lands that are not suitable for agriculture, have steep slopes or poorly drained soil. This classification is illustrated (Figures 4 and 5) respectively.

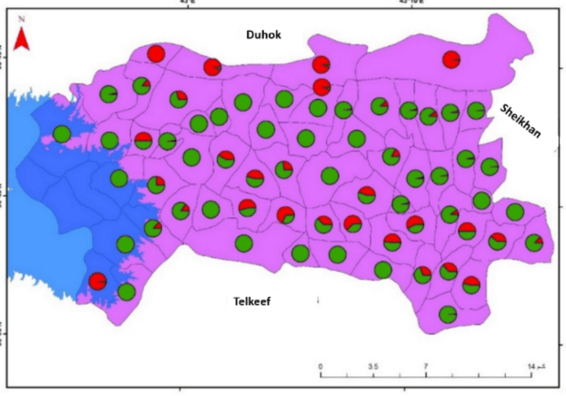


Figure4. Shows the distribution of arable land in Alqosh district.

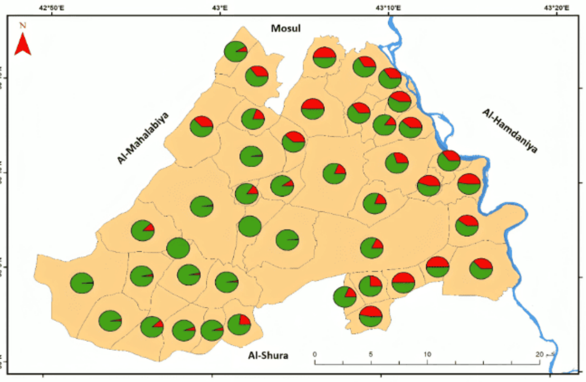


Figure5. Shows the distribution of arable land in Alqosh district.

3. **Classification of lands based on the distribution of valleys and waterways.**

The map illustrates the potential location of groundwater, wells, and sewage networks in the two research fields, which opens the way for the execution of water harvesting projects, particularly in light of rainfall unpredictability and climate change. The findings suggest that this method could improve the usage of supplemental irrigation in regions where rain is almost certain.

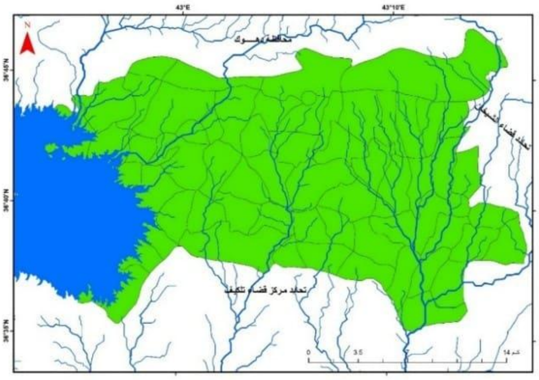


Figure6. Shows the distribution of valleys in the Alqosh district.

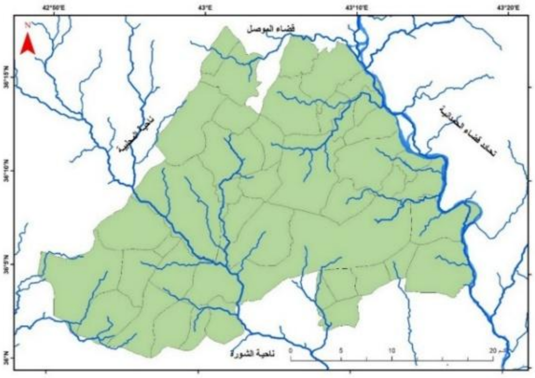


Figure7. Shows the distribution of valleys in the Al-Alil district.

4. **Classification of the Study Areas Based on Population Clusters**

The spatial distribution of population clusters involved in agriculture was also mapped by the research, with a focus on their direct ties to the agricultural areas. 32 of these agricultural population clusters were detected on the map for the Al-Qosh subdistrict. This geographical connection between farms and settlements emphasizesnhow important it is to have smart logistical planning when distributing agricultural equipment and services.

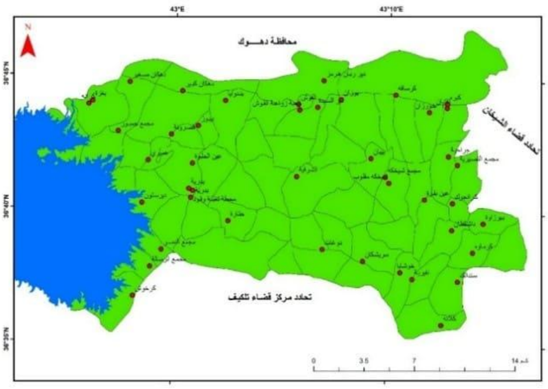


Figure8. Shows the population distribution of agricultural workers in Alqosh district.

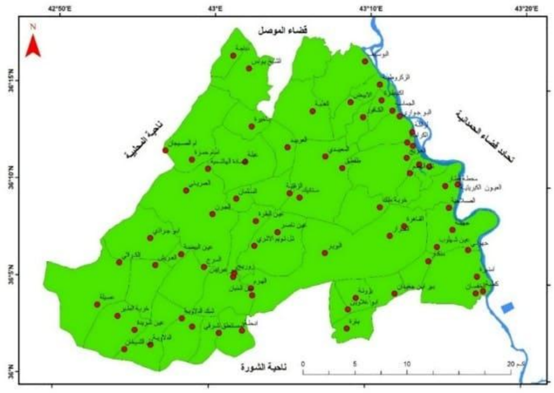


Figure9. Shows the population distribution of agricultural workers in Hammam Al-Alil district.

The maps clearly demonstrated the following distinctions between the two research areas:

1. Low annual rainfall: In order to enhance water use efficiency, regions with low rainfall, like Hammam al-Alil, frequently rely on more irrigation systems such sprinklers and drip irrigation [12]. This tumultuous climate change necessitates new mechanization strategies.
2. Relative reliance on supplemental irrigation: Water management requires the use of specialized mechanical equipment, such as pumps, sensors, and GIS to monitor soil moisture and control irrigation, in areas that rely significantly on irrigation [13]
3. The two research areas' agricultural areas were significantly, ranging from 2,171 to more than 33,000 dunams:
   This variation highlights the pressing necessity of developing mechanical solutions tailored to local conditions.Larger regions employ larger machine tools to increase operational efficiency and save labor costs, while smaller farms might use tractors and other small machinery [14].
4. The rural road network has to be enhanced:Good infrastructure for the movement of machinery between agricultural areas is essential to effective mechanization.Inadequate rural roads make it difficult for big machinery to move, which slows down agricultural activities and raises expenses.
   Thus, the performance of agricultural operations depends heavily on road infrastructure [15].

Discussion

The study's findings demonstrated the critical function that geographic information systems (GIS) play in offering a precise and thorough understanding of how agricultural land is classified in various climatic conditions and surroundings.
The maps' analysis reveals the following:

- Combining local maps and satellite images shows high accuracy in spatial analysis [16].
- The possibility of identifying arable and non-arable lands provides an accurate tool to direct agricultural plans towards areas with guaranteed agricultural production. The relationship between spatial analysis results and agricultural mechanization requirements can be determined under land classification with respect to slope, soil type and water availability. This allows practical indicators related to the selection of agricultural machinery and the appropriate farming system to be obtained. Low-slope lands (<8%) and deep clay soils are suitable for plate or disc plows, while lands with steep slopes (8-15%) may require the adoption of reduced tillage systems or even zero-tillage cultivation to reduce soil erosion and reduce land preparation operations [15].
- Large agricultural areas in some areas, especially in Hammam Al-Alil, indicate the possibility of adopting agricultural machines with a large working width (such as seeding machines with a working width greater than 4 m), which reduces operating time and increases the efficiency of resource use. While small and medium agricultural holdings, especially in Alqosh, may require smaller agricultural machines such as precision seeding machines and multi-purpose harvesters [17].
- These results support the transformation of adopting precision agriculture systems supported by GIS to customize agricultural machinery and processes according to the conditions of each agricultural area, thus improving productivity and reducing waste of resources and energy.
- Mapping drainage networks increases opportunities to use water harvesting, especially in areas almost guaranteed rain, such as Hammam Al-Alil.
- Dividing agricultural holdings by size helps in the fair and efficient distribution of resources, especially mechanization and irrigation [18].
- The spatial representation of agricultural population centers is an essential element for guiding logistics services, achieving development, and integrating human and natural resources [19].

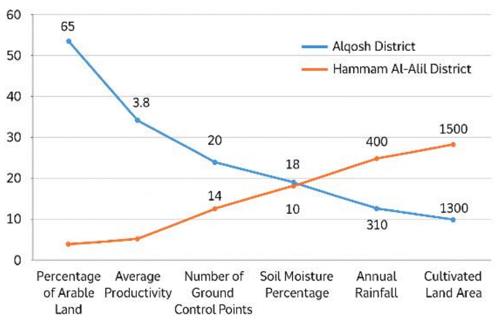
Comparison Between the Two Study Areas

Figure 10 shows a chart comparing Al Qosh and Hammam Al Alil districts based on the main agricultural and environmental indicators:

1. Number of agricultural areas and population centers: Figure 10 indicates an increase in the number of areas occupied by settlements in Alqosh to smaller agricultural divisions and a higher

population density, which necessitates the use of lightweight, adaptable equipment suitable for small fields, such as compact tractors or multi-use machines.

2. The size of huge agricultural holding in Hammam Al-Alil: The figure shows the potential for the use of large, productive machniery, which lowers operating expenses per unit area and improves labor efficiency.
3. Rainfall rate per year: The first research region Al-Qosh has a high rainfall rate, which makes it possible to rely on organic farming which calls for machinery that can handle wet soil conditions (such as light plows or direct seeds. On the other hand, contemporary irrigation systems (sprinklers and drips) may be necessary due to the low rainfall rate in the second study region (Hmmam Al-Alil), which calls for specialized mechanization for the installation and upkeep of the irrigation equipment.
4. Arable land: Compared to Hammam Al-Alil, Which requires careful planning of the deployment of machinery based on the agricultural sustainability of the land, Al-Qosh's high percentage of arable land supports the viability of investing in comprehensive mechanization.



5.

Fig. 10. Shows an analysis of agricultural and environmental indicators in Alqosh and Hammam Al Alil

Practical Significance of the Results

This research's consequences go much beyond merely charting our field of study. We have created a useful framework that can direct agricultural policy in the direction of a more sustainable and productive future. In order to promote longterm agricultural sustainability, this entails strategically focusing on highproductivity zones for ideal land use and utilizing satellite images and spatial analysis. The end, this method gives farmers accurate, useful information about their own fields, such as soil composition and water availability, empowering them to make better, more effective decidions.

Conclusions

1. Geographic information system helps in decision-making and improve agricultural planned: The study's findings demonstrated the usefulness of geographic information systems in assessing the use of agricultural land and its sustainability for cultivating strategic crops, particularly in light of climate change. This enhances the decision-making process concerning the application of agricultural mechanization.
2. The ability to identify agricultural areas where output can be increased: The Al-Qosh area, where rain is guaranteed, and Hammam Al-Alil, where rain is almost guaranteed, had significantly different land sustainability, according to analytical maps. This highlights the significance of spatial data in identifying areas where mechanization practices can significantly and effectively increase productivity.
3. Examining the relationship between smart agricultural systems and agricultural mechanization using geographic information systems: The study highlighted the need for smart farm management systems that use geographic information systems to maximize resource exploitation, tower costs, and increase production. It also demonstrated how sewage networks could be used to implement water harvesting projects and encourage the expansion of arable land in rain-dependent areas.
4. Developing an integrated model to improve resource and machinery investment and agricultural operations management through the use of geographic information systems:
Spatial analysis revealed a severe lack of rural road networks, particularly in the second research region Hammam Al-Alil, which had a detrimental impact on farmers ability to transfer mechanization. This confirms the necessity of finding an integrated model based on geographic information systems to improve future planning, management of agricultural operations, and investment of machinery and resources.
5. The necessity of adopting detailed graphical models for the use of mechanization based on various geographical and agricultural characteristics: The study showed that there are large differences in the areas of agricultural holdings among farmers, which calls for the development of fair policies for water distribution and mechanization. It also highlighted the importance of using GIS to design differential mechanization distribution models based on precise

spatial criteria for more effective and efficient management.

Recommendations

1. Ministry of Agriculture and its Provincial Directorates: It is recommended to update agricultural databases using recent satellite imagery (e.g., Landsat, Sentinel-2) in coordination with the Geographic Information Systems (GIS) Center to ensure planning is based on accurate and up-to-date data.

2. Irrigation and Land Reclamation Authorities: Utilize the results of drainage network maps to prioritize the implementation of water harvesting projects, especially in semi-rainfed areas such as Hammam Al-Alil subdistrict.

3. Agricultural Mechanization Companies and Services: Direct investments towards providing machinery appropriate for the size and slope of agricultural districts, such as conservation seeders in medium-slope areas and shallow plows in flat lands.

4. Universities and Agricultural Research Centers: Develop digital applications integrating GIS, soil, and climatic data to assist farmers in selecting suitable crops and agricultural machinery for each location.

5. Local Governments: Improve rural road infrastructure connecting population clusters with agricultural districts to reduce the costs of transporting machinery and products.

6. International Organizations such as FAO and ICARDA: Support projects aimed at building spatial databases in dry and semi-arid regions as part of strategies to achieve sustainable food security.

Conflict of Interest:

The author declare that there are no conflicts of interest regarding the publication of this manuscript

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