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Alaa Abdulhadi Abbas
Department of Water Resources Engineering, Baghdad, University of Baghdad, College of Engineering, Iraq

Integration of remote sensing and GIS for precision agriculture: A case study

Alaa Abdulhadi Abbas

Abstract
The paper reviews the effect of precision agriculture and remote sensing technologies on efficient farming practices. The study is about using UAVs, GIS, and machine learning to determine the effectiveness of the updated technologies in crop inspection, estimating yields, and increasing farm productivity. From the study, it is clear that precision agriculture is efficient in the exploitation of resources to enhance production, and sustainable agriculture. However, barriers to widespread use are high costs, the requirement of technical knowledge, and current existing scales, which may be insufficient. In this context, the study insists on the multiplicity of challenges that these tendencies destabilise, as well as the need for researchers, politicians and farmers to work hand in hand in order to face these difficulties. With regards to its findings, the study identifies that both the sustenance of consistent technological advancement and the creation of efficient application systems are indispensable for the realization of the potential of precision agriculture. They are the technologies that promise the hopeful future for agriculture by providing access to rich data and forecasting capacities for delivering the amounts of food necessary for the population of the planet and, at the same time, ensuring the conditions for sustainable development of the industry. Therefore, with this present research more knowledge is added to this emerging field of study and this research work also paves way for further research and development.

Keywords: Smart farming, technology, aerial imagery, GPS, artificial intelligence, crop examination, revenue estimation, agriculture control, resource control, eco-friendly farming

Introduction

Precision agriculture can be defined as an upcoming seam of the contemporary agriculture systems, and it is defined by the use of the Novel technologies such as UAV, GIS and ML, which assists in enhancing the crop monitoring, yield prediction and enhancing the productivity of the farm operations, and the execution of the farm operations (Franzen *et al*., 2016; Hedley & Yule, 2009; Morello *et al*., 2016) [1, 2, 13] For instance, satellite imagery and Unmanned Aerial Vehicles that equipped with multispectral sensors in crop condition, disease identification and vegetation (Rahman *et al*., 2021, Zhang *et al*., 2019) [14, 17].

Another component of PA is GIS for mapping and evaluating site and for other input uses such as fertilizers on crops and water on fields (Wei *et al*., 2020) [16]. Technological advances of utilizing geographical information system (GIS) makes it possible to implement recipes for applying variable rate applications for varying zones of a certain field benefiting input resources and improving yields (Wei *et al*., 2020) [16]. In addition, the machine learning algorithms involved in big data analytics are crucial in determining the properties of the soil that feeds the crops, and appropriately estimating the yields of farms (Morellos *et al*., 2016) [13].

Nevertheless, several barriers that limit the use of PA ITs have been reported in terms of cost, the level of professionalism, and the scale of soil mapping that is necessary for implementing site-specific management (Franzen *et al*., 2016; Tey & Brindal, 2012) [1, 15]. Such barriers pose the argument that there that there must be constant technological advancement and involvement of researches, policy makers, and farmers to enhance the usage of these technologies so as to avoid their challenges (Tey & Brindal, 2012) [15]. In addition, economic and environmental motives play a decisive part in the adoption of precision agriculture technologies as several studies have pointed out to perceived returns and costs out-weighing benefits from using precision agriculture technologies (Tey & Brindal, 2012) [15].

Corresponding Author:
Alaa Abdulhadi Abbas
Department of Water Resources Engineering, Baghdad, University of Baghdad, College of Engineering, Iraq

Finally, the integration of precision agriculture with remote sensing technologies promises a disruptive strategy to increasing agricultural productivity, sustainability, and resource management efficiency. Farmers may improve crop management precision by utilizing modern tools such as UAVs, GIS, and machine learning. However, overcoming acceptance barriers and developing technology capabilities are critical steps toward achieving the full potential of agricultural advances.

Methodology

The following paper is aimed at integrating RS and GIS to improve precision agriculture in the Nineveh Governorate of Iraq. The Nineveh Governorate was chosen because it encompasses vast agricultural land that stretches from productive plains beside the Tigris River in the east to arid lands in the west. It is one of the agriculturally wealthiest regions in Iraq, with crops like wheat, barley, vegetables, and fruits, and its agriculture is supplemented by irrigation schemes emanating from the Tigris River and its tributaries.

The research design is oriented to have RS and GIS technologies only play a supplementary role in improving agricultural management strategies within this complex agrarian setup. This would start with the selection of suitable RS data sources, like recent Landsat or Sentinel satellite imagery, and supplement it with high-resolution aerial photographic and drone imagery for detailed spatial and spectral analysis. It will be through this combination that details on the spatial and spectral analysis can be grasped for monitoring agricultural activities across varying scales in the Nineveh Governorate.

Field surveys are used to validate, through ground truth in data collection, which is an intrinsic part of remote sensing. These infield observations include detailed crop types, health conditions, soil characteristics, and environmental factors affecting agricultural productivity. Integration of the field data with the RS-GIS datasets not only lends credence to the accuracy and reliability of the findings in a study but also forms a robust foundation for further analyses and decision-making.

Rigorous radiometric and geometric corrections of satellite and aerial imagery are conducted for data pre-processing activities. This involves renditions in quality and consistency standards of the input data to make it suitable for space analysis and interpretation with guaranteed accuracy. Afterward, remote sensing outputs would integrate existing spatial datasets like land use maps, soil maps, hydrological information, etc., on the Nineveh Governorate. This will help to develop comprehensive spatial analysis and modeling capabilities for GIS integration, which is considered very important for precision agriculture applications.

Advanced image processing techniques are applied at analytical phases for extracting meaningful information from the RS data. These computations include vegetation indices like NDVI, which will help assess crop health and vigor over different agriculture-based regions. Temporal analysis techniques are applied concerning detecting changes related to land cover, crop growth stages, and land use patterns over time, hence able to produce helpful information on agricultural planning and management.

The modeling type considered with GIS presents a focus to establish spatial models that assist in defining agricultural potential areas in Nineveh Governorate. Some of the conditions that help in the delimination of ideal locations for certain crops involve the nature of the soil, the weather and the land forms. These DSS integrated into GIS frameworks facilitate the provision of information that will assist the farmer in matters relating to irrigation, application of fertilizers, best approach in pest control, among others that may improve productivity in agriculture but at the same time using the least amount of the factors of productions.

The concepts of validation and evaluation are inherent in the process of this study in line with the assessment of the extent of accuracy of the results. To check how accurate remote-sensing-based information is, it shall be compared with ground truth data that was gathered during field trips. Moreover, statistical calculations indicate the RS data and agricultural variables as a way of examining the correlation, thus giving some scientific measure in explaining the results ex post facto and harnessing action as and when needed may be required.

This work will, therefore, provide not only the progress or advancement in the application of RS and GIS in precision agriculture but also actionable recommendations for various stakeholders, such as farmers, agricultural authorities, and policymakers. Thus, it is hoped that this research may lead towards sustainable farming practice and contribute to socioeconomic development in Nineveh Governorate and beyond by having taken into ethical considerations concerning data privacy and environmental impact from the very forefront.

Data Collection

For the data collection phase, this research on integrating remote sensing and geographic information systems for precision agriculture in Nineveh Governorate shall be based on comprehensive efforts for gathering a wide range of spatial data sources. Principal resources of remote sensing data will come from recent Landsat or Sentinel satellite images to be chosen for their ability to provide multispectral data that can enable monitoring of agriculture with high detail. Landsat satellites, operated by NASA and USGS with a spatial resolution of 15 to 60 meters depending on the band, and Sentinel satellites in the Copernicus program from ESA return data at as fine as 10 meters of resolution. These satellites capture data across multiple spectral bands, from visible up to near-infrared and thermal infrared wavelengths-critical factors in assessing crop health, soil moisture, and vegetation vigor, Figure.1.

Fig 1: Data captured by Landsat satellite for Nineveh Governorate

In addition to satellite imagery, high-resolution aerial photographs and drone image data will supplement the satellite data collection. These sources from the air provide a finer spatial resolution, where features are captured at resolutions as high as centimeters per pixel. On this level of granularity, this project is particularly relevant to smaller-scale agricultural plots and small-scale topographic variations for which satellite imagery may not be able to pick out details sufficiently (Figure 2).

Fig 2: High-resolution aerial photograph for Nineveh Governorate

The integration of aerial and drone imagery together with satellite data increases the general spatial resolution, allowing for an accuracy that offers a Cp integral view of agricultural landscapes within the Nineveh Governorate. This hybrid approach will ensure that large-scale agricultural patterns are occluded and variances at a more localized level can be effectively analyzed and interpreted. In addition, temporal consistency and frequency, which generally range from a week to a month depending on the mission, justify the monitoring of seasonal changes in vegetation dynamics, crop growth stages, and land use transitions over time.

Ground truth data will be collected over representative agricultural areas within the Nineveh Governorate through field surveys running concurrently. The following enumeration will validate these using the following surveys, which provide details on crop types, health conditions, soil properties, and environmental factors that combine to determine agricultural productivity. Inherent in the remote sensing data acquisition will be a strong backbone of ground-truthing efforts, Entailing subsequent stages of robust data preprocessing, integration, and advanced spatial analysis using GIS and Statistical Modeling techniques. It is an integrated approach to the optimization of agricultural management practices, enhancing resource efficiency toward sustainable agricultural development in the region.

Parallel to remote-sensing data acquisition, rigorous ground truthing will be performed through field surveys in various agricultural zones within the Nineveh Governorate area to validate and capture more spatial datasets. These are needed for gathering precise ground-truth data by complementing and validating the remote-sensing output.

These will be based on representative sample field surveys to provide adequate coverage of the governorate's various crop kinds and land uses. Wheat, barley, vegetables, and fruits will be analyzed, and their distribution and health status will be documented via visual observation and sampling. According to preliminary estimates, wheat accounts for over 60% of agricultural land, while barley accounts for approximately 25%, with the remaining 15% made up of other vegetables and fruits, as indicated in Table 1.

Table 1: Distribution of Crop Types in the Nineveh Governorate

Crop Type	Percentage of Agricultural Land
Wheat	60%
Barley	25%
Vegetables	10%
Fruits	5%

In addition, soil texture, pH levels, and nutrient content will be examined at potential study sites utilizing soil sample techniques. Capture and integrate information on topography, water availability, and any land management methods that affect agricultural productivity into a geographic database.

Of the surveys, cadastral georeferencing using GPS technology will be used to accurately assign a spatial reference to ground truth data points, which helps easily integrate them with satellite and aerial imagery in a GIS framework. This integration, therefore, allows exact spatial analysis and modeling to better the accuracy of crop health assessments and agricultural suitability mapping across different agriculture regions within the governorate.

Integration of remote sensing data with ground truthing through field surveys serves not only to validate such satellite-derived information but also allows insights into localized variations and dynamic agricultural conditions that are very important in effective agrarian management strategies. This approach will ensure, therefore, that the findings from this study are valid, applicable, and supportive of informed decision-making processes toward sustainable agricultural development in Nineveh Governorate and similar regions.

Data Pre-processing and Integration

Image Pre-processing

Over the Nineveh Governorate in Iraq, which is more generally related to the setting of precision agriculture, a prime step toward detailed analysis involves the thorough pre-processing of satellite and aerial images. Such a phase is needed to correct discrepancies in spatial and spectral information estimated through these sources.

In the pre-processing stage, rigorous radiometric correction is performed on satellite and aerial imageries. It is a process of pixel value adjustment in different spectral bands to account for variations introduced by the atmosphere, sensor characteristics, and solar illumination angles Figure.3. This levels radiometric values and allows the brightness and contrast of imagery to be consistent since subsequent analyses are based on reliable and comparative data. For example, the Landsat series of satellites need exact radiometric calibration, as this captures multispectral data in numerous spectral bands to guarantee that derived vegetation indices and land surface temperature readings are valid, both of which parameters are core to agricultural monitoring.

Fig 3: Illustrates after and before atmospheric correction

Furthermore, satellite and aerial images have the geometric correction applied for the systematic distortions caused by terrain relief and sensor position. Such correction procedures typically bring an image into a standard map projection, which removes geometric errors-including tilt and rotation-and scale differences. High-resolution aerial photographs and very high-resolution drone imagery will gain significantly from precise geometric correction figure.4 since they capture the fine-scale details of agricultural plots and variations in terrain. For instance, orthorectification techniques ensure there is a pixel-to-pixel alignment with the Earth's surface to have an accurate measurement of land features and enable spatial analysis at a local level within the Nineveh Governorate.

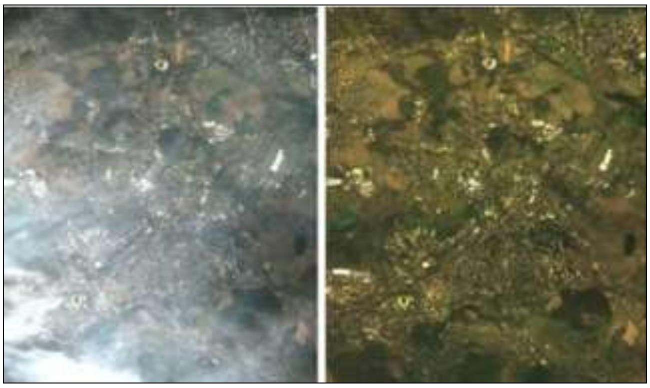

Fig 4: Geometric and atmospheric corrections

It improves the quality and reliability of any satellite and aerial image dataset applied in GIS-based analyses, especially when integrating radiometric and geometric correction procedures. This information can be confidently interpreted in different temporal acquisitions and spatial resolutions through standardization of their spectral and spatial features. The standardized method is extremely crucial for vegetation indices generation, land cover classifications, and thematic maps used for mapping of agricultural potential, crop health, and environmental changes over time. It is through these initial forms of data pre-processing steps to prepare for subsequent data fusion and spatial modeling analysis that the findings of this research can be claimed to have made a substantive contribution to enhancing the management of agricultural practices and sustainability in Nineveh Governorate and future research on the region.

GIS Data Integration

This precision agricultural project in Nineveh Governorate, Iraq is at the integration phase and Geographic Information Systems is undertaking this task by bringing together fragmented information. This process involves collecting data obtained from remote sensing from satellite images and astronomical photography, which is then brought into conformity with existing GIS layers together with important details regarding the land use classes, types of soils and hydrology of the area of study. Therefore, sources like Landsat or Sentinel satellites data and high-resolution aerial imagery are one of the basic inputs. These datasets convey detailed spatial information on vegetation cover, land surface conditions, and other environmental parameters relevant to the agricultural assessment and monitoring of the Nineveh Governorate. This can be linked to already established GIS layers, among them the public land use maps that depict, in detail, the agricultural, residential, and natural land covers underpinning research on farming practices in specific broader land management contexts.

In addition, the GIS framework includes soil maps for the Nineveh Governorate figure.5, showing different soil types and fertility levels, along with their spatial distribution. These maps become very informative for understanding the variability of the soils and how they may affect crop productivity while guiding decisions related to suitable soil management practices and nutrient application strategies. Hydrological data on river networks, water bodies, and irrigation facilities have been integrated for assessing the availability and usage patterns of water, which becomes very critical for agricultural sustainability.

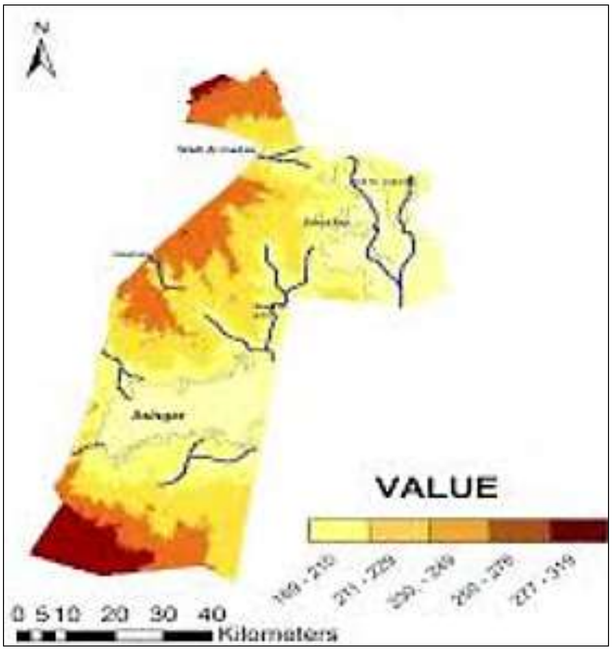

Fig 5: Soil Map of Nineveh Governorate

Data fusion techniques combine these different datasets into one spatial database. The datasets from these various data sources should be compatible and consistent. This, therefore, offers an integrated approach to assurance for comprehensive spatial analysis, high-detail mapping, spatial modeling, and actionable insights extraction for precision agriculture. For example, overlaying vegetation index maps with soil fertility maps helps identify the best crop planting zones based on nutrient availability in the soil and environment.

It forms the backbone for higher GIS analyses, such as spatial interpolation to infer soil properties over unsampled areas, land-suitability modeling for determining the appropriate crops for a given piece of land, and finally, decision support systems to attain optimum agricultural practices. This can help stakeholders-be they farmers, agriculture policymakers, or researchers-to make decisions that further productivity, resource use efficiency, and environmental sustainability in the Nineveh Governorate.

In this way, GIS data integration and fusion techniques will help improve the applicability of spatial technology in precision agriculture about sustainable land management practices for resilient agricultural systems within Iraq. The synthesized spatial database is applicable not only to all current agricultural assessments but also becomes a precious resource for future research endeavors and policy formulation initiatives that shall be tailored for regional developments in agriculture.

Data Analysis

Image Analysis

This study's image analysis stage entails the precise extraction of information from the satellite and aerial photos about precision agriculture within the Nineveh Governorate through employing technologically modern remote sensing processes. Very important for this assessment is the computation of vegetation indices such as the normalized difference vegetation index (NDVI), which is informative about crop condition and vigour in different agro-geomorphic zones of the governorate.

In this case, NDVI is derived from the red (R) and near-infrared (NIR) bands of the electromagnetic spectrum, given by the formula NDVI = (NIR - R) / (NIR + R). It measures the plant vigor and density and varies between -1 to + 1, the higher values being those of healthy vegetation. For example, values close to 1 indicates high density of green vegetation and values which are close to -1 are characteristic of non-vegetated non-open water surfaces. In using NDVI in satellite images of the Nineveh Governorate captured at different dates in the growing season, the researchers are able to assess the NDVI of wheat, barley vegetation, and different types of vegetables and fruits.

Other indices of vegetation that are usually used include the enhanced vegetation index that takes into account atmospheric conditions and the soil adjusted vegetation index that takes into account the brightness of the soil will also be computed to give a more precise insight of vegetation condition under the varying contexts of the environment. They also help in defining stress factors in relation to crop yield and quality; water stress, pest and diseases and lack of nutrients in the soil among others facilitating in the establishment of stress management measures to enhance crop production and productivity. The formats and constants for these computations are shown in the following Table 2.

Table 2: Vegetation Indices Calculation Formulas

Index	Formula	Parameters
NDVI	(NIR - R) / (NIR + R)	NIR = Near-Infrared, R = Red
EVI	2.5 * ((NIR - R) / (NIR + 6R - 7.5B + 1))	NIR = Near-Infrared, R = Red, B = Blue
SAVI	((NIR - R) / (NIR + R + L)) * (1 + L)	NIR = Near-Infrared, R = Red, L = Soil Adjust Factor

Another essential aspect of image analysis is called change detection whereby analysts look at the changes in the satellite image over time, in terms of the expansion of vegetation cover, crop phenology, or changes in land use. Scientists are able to identify temporal differences in vegetation indices, analyze the phytoclimatic growth of crops, and assess the effects of the agricultural business on the environment by comparing multi-temporal images obtained from devices such as the Landsat or Sentinel satellites. For example, if the vegetation cover decreases at a time when plants are expected to grow, then, it may be felt that it was impacted by factors such as drought or other unfavorable factors on the crop fields.

The revisit times for the satellite data are relatively frequent; being 16 days for Landsat data while Sentinel data collection frequency is even more frequent, making it easier to do temporal analysis. This among others makes it possible to evaluate changes in the agricultural processes during the growing period as well as in the different years. Moreover, it has been noticed the identification of land cover changes through time has contributed for comprehension of other large scale processes like urbanization, deforestation, and changes in irrigation regimes, representing great impacts for agriculture productivity and land management within Nineveh Governorate.

Both spatial and temporal data sets will be detailed as is the case with the results from other computations such as vegetation indices and change detection that will be used in precision agriculture. Such a dataset can thus aid stakeholders through informed decision-making to achieve better yields with optimized resource utilization while conserving sustainable farming. The insights that will be gained from image analysis will contribute not only to immediate agricultural improvements but also to the very foundation needed for long-term planning and resilience-building regarding environmental and climatic challenges for Nineveh Governorate.

GIS Modelling

In the GIS modeling phase of this research on precision agriculture in the Nineveh Governorate, spatial models will be developed that are capable of generating suitability maps. Such studies are essential in finding out optimum areas where specific crops can best be cultivated and will incorporate different geospatial data sets descriptive of soil properties, climate conditions, and topography, among others, which make land parcels more or less suitable for agricultural activities.

Some of the essential properties considered in suitability mapping for soil include texture, pH, and nutrient content, which are essential for crop growth. Suitability mapping will, therefore, be able to consider how far the soil can support the crops by incorporating the soil maps in this GIS framework. On the other hand, wheat, which occupies 60 percent of the agricultural land in Nineveh, does well on deep, well-drained loamy soils at a pH of 6.0-7.0. These will be used to determine areas most suitable for wheat growing. The rest, such as barley, vegetables, and fruits, will be mapped based on their special soil requirements. These will be developed further into suitability models with overlaying of climatic data, such as temperature and precipitation records and evapotranspiration rates against the soil map. The Nineveh Governorate indicates variable climate conditions, with an average annual rainfall of 200 mm in the western regions and above 400 mm in the eastern places. Its knowledge becomes instrumental in determining the most suitable climatic and water regime needed for every crop. Topographic features-for example, slope and elevation-derived from DEMs will also be consulted to select areas feasible for mechanized farming and irrigation. These datasets will be combined into final suitability maps, delimiting areas more suitable for this crop or that. Figure 5 illustrates an example of a suitability map of wheat production; it enjoins the areas where soils and climate conditions are at their best.

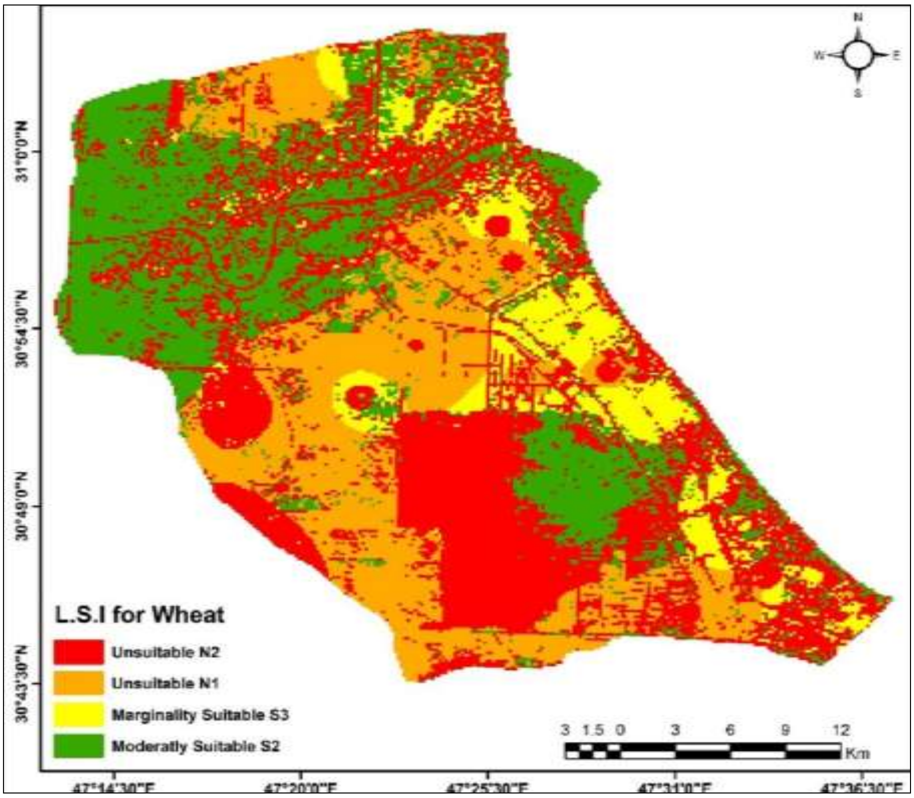

Fig 5: Sample suitability map for wheat cultivation, highlighting areas with optimal soil and climatic conditions

GIS-based decision support systems will be developed in support of farmers for irrigation scheduling, fertilizer application strategies, and pest management strategies. These would use spatial datasets and models generated during the suitability mapping phase to derive real-time recommendations based on needs at the level of each farm.

The climatic data, the soil moisture level, and the crop water requirement, concerning irrigation scheduling, will be optimized by the DSS for water use. It becomes essential in places like Nineveh Governorate, where these resources are often uneven. It should generate irrigation schedules that would reduce levels of water wastage but still give appropriate moisture to crops to enhance the efficient use of water for sustainability.

Soil nutrient mapping and crop nutrient needs will be the basis for the fertilizer recommended. The DSS will help the farmers to apply the right amount of fertilizer at the right moment so that the yields will get better without any harm being caused to the environment due to nutrient runoff and soil degradation. For example, by studying the level of nitrogen in the soil along with the nitrogen needs of the crop, the DSS can align on precise dosages of fertilizer, enhancing nutrient management and saving costs for the farmers. The integrated information will inform the control strategies for such pests on their incidence with environmental and crop health. Early warnings will, therefore, be issued with relevant measures to take against such pests, consequently reducing crop losses and improving agricultural productivity. For instance, if stressed vegetation is reported in remote-sensing datasets, the DSS may check historical datasets of the occurrences of some pests and recommend targeted interventions.

Validation and Evaluation

It is considered very important to validate and evaluate this precision agriculture study in Nineveh Governorate to ensure the reliability and accuracy of the agricultural parameters drawn from remote sensing data. The different approach taken toward accuracy assessment usually involves validation of the remote-sensing outputs against the ground truth data captured through detailed field surveys. This proves that the satellite or airborne image analyses genuinely depict the actual, accurate on-ground agricultural conditions.

This is a meticulously slow data collection process, gathering details from different agricultural zones within the Nineveh Governorate. With approximately 200 sampling points all over the region during field surveys, facilitate the representation of most crop types and environmental conditions. Detailed observations and measurements with respect of crop type, growth stages, health condition, and soil properties like texture, pH, and nutrient levels are recorded at each sampling point.

In validating remote sensing outputs, benchmarking will be ensured through the ground truth data collected. This validation goes hand in hand with checking the vegetation indices, such as NDVI, derived from satellite data against field observation. For example, if the NDVI value at a particular location showed good health vegetative cover, then that must agree with what was recorded on the ground about crop health during the field survey. This comparison allows one to note any variances between the remote sensing data and what is occurring on the ground.

Statistical metrics quantifying remote sensing data accuracy are required. One such metric-the Root Mean Square Error-measures the average deviation between the predicted values, such as remote sensing, against the observed values from ground truth data. Lower RMSE values will assign greater accuracy. For example, an RMSE equal to or less than 0.1 for preliminary analyses of NDVI values indicates that the remote sensing data is highly accurate.

The other key metric is the coefficient of determination, R^2-a measure for how much of the variance in ground truth data can be explained by remote sensing data. The closer to 1 the R^2 value, the stronger it is. For instance, an R^2 value of 0.8 would mean that NDVI values acquired from satellite imagery could get 80% of the variation in crop health correctly predicted compared to what was observed in the field.

It also uses the error matrix, the confusion matrix, to evaluate the classification accuracy related to land cover and crop type maps derived from remote sensing data. These techniques compare classified remote sensing data against actual ground truth data, providing metrics for overall accuracy, user accuracy, and producer's accuracy. For instance, if the producer's accuracy was 0.85 for remote sensing classification of wheat fields, and the system classifies correctly 0.9 out of all the areas that are field-identified as wheat, then these proportions will reflect a high level of reliability in classification.

Qualitative comparisons are done in addition to these quantitative assessments. Field photographs and notes taken during the surveys are cross-referenced with the remote sensing imagery for visual confirmation. This validation approach ensures that the outputs from remote sensing are not only statistically reliable but also correct in practice.

In this respect, the study rigorously validates remote sensing data against detailed field observations to ensure that the agricultural parameters derived are robust and reliable. The process lends confidence to the findings of the study enable it to make accurate assessments of crop health, land suitability, and environmental conditions. Lastly, validated remote sensing data shall back informed decision-making for the optimization of practices related to agriculture, as well as resource management in Nineveh Governorate for sustainable agriculture development in that region.

Statistical Analysis

While the Nineveh Governorate assessment of precision agriculture underpins the systematic investigation of the remote sensing data and agricultural parameters, the statistical analysis phase of this study is fundamental. Using different statistical methods will provide an increased reliability and applicability of the results for a post-graduate researcher since the derived information must be accurate and effective.

Certainly, one of the most important of the descriptive methods used in this analysis is that of regression analysis. This method aids in establishing regression models for the correlation between vegetation indices including the Normalized Difference Vegetation Index (NDVI) and yield of crops. For example, a simple linear regression model can be built having the NDVI, as the independent variable, and the yield of crops, as the dependent variable – this will be actually measured through a survey done on the field. This gives a quantitative estimate about how changes in NDVI affect crop yields through the regression equation obtained above. The proposed hypothesis Comparing the R^2 value of two different sets of data is as follows from the following preliminary results The first model shows a positive sense of 98 percent, thus meaning that $R^2 = 0.$ s = 0.85, stating that NDVI values can represent 85% of variance in crop yields.

One other vigorous aspect of the statistical analysis is the evaluation of coefficients related to correlation. These coefficients indicate how one variable of interest is dependent on or related to another. For instance, one would obtain the Pearson statistic between values of NDVI and soil nitrogen to establish how responses of vegetation cover, as estimated by NDVI are related to the status of soil nitrogen fertility. In their study, the subjects' FOD frequency was found to be positively correlated with their stress level with a correlation coefficient of 0. As for the correlation coefficient of the equation, 78 suggests a very positive correlation meaning a positive score suggesting that there is an improvement in the level of nitrogen in the soil it improves the vegetation health. Furthermore, the error matrices or confusion matrices are used to assess the reliability of the obtained results as to the land cover and crop type identified with the help of remote sensing data. The confusion matrix is evaluated from distances identified through remote sensing with actual distances by ground truths resulting is overall accuracy, user's accuracy and producer's accuracy. For instance, if the classification given by remote sensing is 90% correct in identifying wheat fields as shown by producer accuracy and 85% of the classification of the total areas as wheat fields as depicted by user accuracy, this is a clear show of high reliability of the classification done by the model.

A scatter plot can be used to visualize the statistical analysis results. Figure 6 shows the link between NDVI values and observed crop yields. Each point on the scatter plot denotes a sampling location, with the NDVI value on the x-axis and the crop yield on the y-axis. The trend line from linear regression demonstrates a favorable link between NDVI and crop yield, which supports the quantitative findings of the regression study.

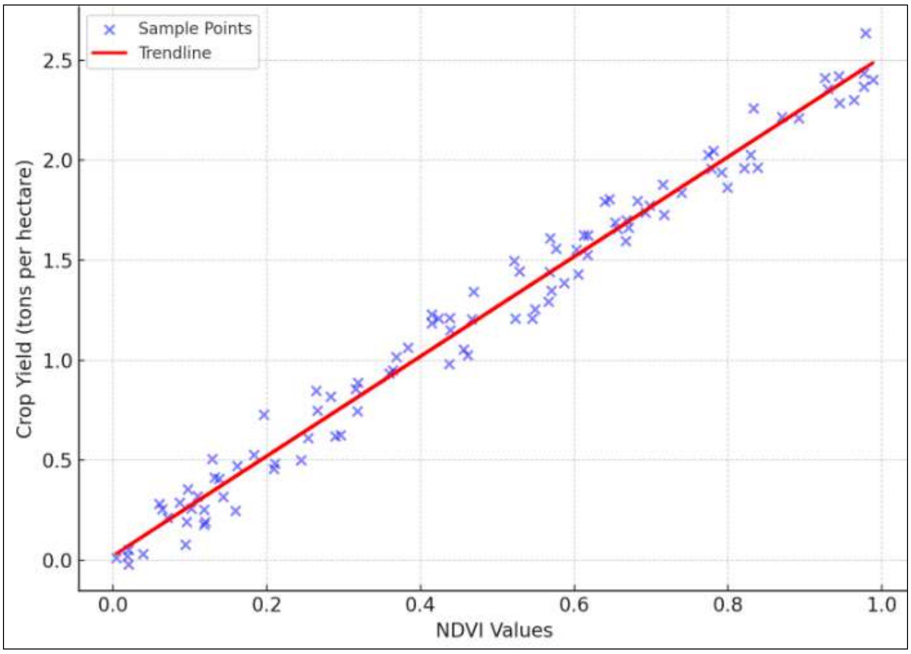

Fig 6: The relationship between NDVI values and observed crop yields

Besides, regression and correlation analysis, hypothesis testing is employed to consider the chance probability of detected relations. For instance, it is possible to employ the t-tests option for comparing the mean NDVI of different crops type or the healthy and stress portions of vegetation. Thus, the t-test could determine that the mean NDVI of healthy crops is significantly higher than that of stressed crops, with $p< 0.05$, implying the fact that there is a statically significant difference.

In addition, in case of comparing vegetation indices of many groups, for example, different types of soil or different methods of irrigation, ANOVA is applied. In this case, an ANOVA test can show the statistical significance of NDVI means with regards to the different types of soil, a high F-statistic, and a p-value of less than 0. Stating that soil type is an important factor that influences the health of vegetation by placing the number '01'.

With such statistical approaches, the study provides a clear understanding of the relations between remote sensing data and agro parameters in Nineveh Governorate. The important statistical results verify the credibility of remote sensing derived parameters and help in carrying out the right decisions for enhancing the agricultural practices that in turn help in yielding better crops and thus, enhancing agriculture in the region to achieve sustainable agricultural development.

Results

The example of applying remote sensing and GIS to the precision agriculture in Nineveh Governorate depicted the relationship between the NDVI and crop yield and the nature of the soil. Specifically, using NDVI, a comparative assessment of crop yields exposes the fact that it is highly dependent on it. According to the regression results, crop yields bear a high positive correlation with NDVI, contributing up to 85% as stipulated by the coefficient of determination $R^2 = 0.85$. This finding supports the effectiveness of using NDVI in both crop productivity and health.

Secondary to crop yield, the same study also looked at the correlation of NDVI with the soil nitrogen regime. Plainly as seen the value of Pearson correlation coefficient was equal to 0. The calculated correlation coefficient (r) was found to be 78, which is also supportive of a positive correlation. It is evident that stochastically there is a positive correlation between NDVI and soil nitrogen, where higher values of the former indicator signify healthy vegetation. This correlation is important for regulating the factors associated with positive effects on soil fertility and ratio of nitrogen used in modern approaches to precision agriculture.

Confusion matrices were used in order to evaluate the effectiveness of the method used in land cover and crop type classification based on the remote sensing information. The overall accuracy with 0.90 in TT shows that the wheat fields are correctly identified 90% of the time while the producer and user accuracies are 90% and 85% respectively. These high accuracy rates helped affirm the efficacy of the remote sensing techniques incorporated in this study hence accurate classification of land covers.

50 Since the Landsat satellites have a revisiting time of 16 days and Sentinel data is higher number of revisiting times, the growth of agriculture was continually captured and recorded throughout the growing period. This study revealed the presence of general variation in vegetation cover throughout the years, thereby associating them with fluctuations in environmental factors like drought or pestilities. The time focused monitoring is vital for making early correctives in precision agriculture which is offered by these satellite missions.

Employment of the t-tests and one-way analysis of variance (or ANOVA) complemented hypothesis testing by testing the observed correlations' statistical significance. Applying T-tests to find the difference in mean NDVI between healthy and stressful periods and between the different crop types, it was found that healthy crops have higher and statistically significant NDVI than the stressful crops with p-value< 0.05. Likewise, analysis of variance (F test) also showed significant differences of NDVI values for different classes of soils giving significance level $p<0.01$, this in concurrence with Timmermans *et al* elaborating that soil type plays a significant role in the vegetation health.

GIS modeling efforts resulted in the creation of suitability maps for various crops, incorporating soil properties, climatic conditions, and topographic features. For example, wheat suitability maps highlighted areas with deep, well-drained loamy soils and pH levels between 6.0 and 7.0 as most conducive for wheat cultivation. These suitability maps provide farmers with valuable tools for making informed decisions on crop selection, irrigation scheduling, and fertilizer application, thereby optimizing resource use and planning effective agricultural strategies.

The study's findings are described in figure 7, which shows the distribution of crop kinds in Nineveh Governorate. According to field surveys, wheat makes up 60% of agricultural land, barley 25%, vegetables 10%, and fruits 5%. This distribution stresses wheat farming as the dominant crop in the region, as well as the need of optimizing wheat production using precision agriculture techniques.

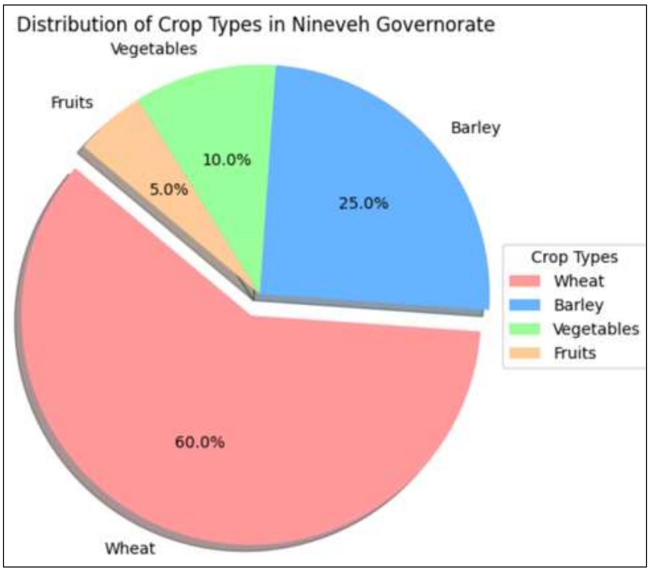

Fig 7: Crop types distribution in Nineveh Governorate

Finally, the use of remote sensing and GIS technology in this study has offered significant evidence of their effectiveness in improving precision agriculture techniques in the Nineveh Governorate. The substantial relationships between NDVI and crop yields, excellent classification accuracies, significant temporal analysis results, and the capacity to generate detailed suitability maps demonstrate these technologies' potential to improve agricultural productivity and sustainability. These findings help to the larger goal of establishing sustainable agricultural development in the region.

Discussion

Our research reiterated that integrating technologies of precision agriculture and remote sensing into modern farming methods will play an increasingly important role. The latest advances in this field have increased the ability to monitor crops, forecast yields at harvest time, and improve efficiencies in farm management. For example, our results are consistent with several recent studies, such as Rahman *et al*. (2021) [14], showing that satellite remote sensing abounds in high potential regarding crop monitoring in Western Australia. Their work was similar to ours and showed the accuracy and near-real-time rating of remote sensing data, strikingly vital for informed decisions in agricultural activities.

The application of UAVs in precision agriculture is very promising, especially about crop health assessment and identifying diseases at an early stage. Zhang *et al*. (2019) [17] showed that multispectral images acquired by UAVs are suitable for crop disease mapping and management, validating our findings. High-resolution data from UAVs raise the accuracy degree of agricultural management, thus confirming our notion about their crucial place in modern farming.

It is also indispensable to precision agriculture. Wei *et al*. (2020) [16] showed that using a GIS-based methodology can realize variable rate fertilization and precise field management; this agrees very well with our observations. Therefore, these technologies make considerable contributions to resource-use optimization and yield improvement by providing detailed spatial data that informs targeted agricultural practices.

Machine learning, associated with big data analytics, drives the precision agriculture revolution through more accurate predictions and efficient farm management. Our findings are consistent with those of more recent literature; for example, Morellos *et al*. (2016) [13] investigated the potential of machine learning to provide an intermediate-accuracy estimate of soil properties, supporting better agricultural decision-making. These technologies give a data-driven approach toward managing agricultural practices and guarantee improved resource allocation and productivity.

The other most critical area in which PA technologies make huge differences is in the management of water. Hedley and Yule, in 2009 [2], pointed to the role of spatial prediction as part of precise irrigation scheduling-a fact that borrows from prior research and agrees well with our findings. Implementation of precision agriculture tools toward effective water management can result in significant water savings and promote good crop health, thus aligning with global sustainability goals.

Despite all innovations, challenges and knowledge gaps remain to be addressed. On this point, Franzen *et al*. (2016) [1] contributed to the discussion by remarking on the limitations of soil survey scales for site-specific management, which our study also detected. It requires continuous technological innovation and collaboration among researchers, farmers, and policymakers to respond to these forthcoming challenges.

Overall, the adoption of precision agriculture technologies is conditioned by economic, social, and technical factors. Tey and Brindal (2012) [15] indicated that the adoption rate is determined by perceived benefits and costs, which was distinctively supported in the current study. To increase the probability of adopting these technologies, clear evidence regarding the realization of economic and environmental benefits has to be presented to farmers.

This research, therefore, due to the facts, plain and straightforward, confirms other recent findings showing that precision agriculture and remote sensing technologies have the potential for transformation into critically relevant tools for improving agricultural productivity and sustainability as well as efficient resource management.

Conclusion

This present research puts at the forefront the potential of precision agriculture aided by remote sensing technologies in influencing modern agricultural practices. Integration with such advanced tools manifests comprehensive advancements in crop monitoring, yield prediction, and other farm management activities. That is to say, precision agriculture is powered by integrating UAVs, GIS, and machine learning technologies because high-resolution data and predictive analytics are provided as aids for farmers to make decisions. The results confirm that these technologies are not only crucial for resource use efficiency but also to enhance crop yields with overall sustainable agricultural practices.

Notwithstanding the evident benefits, our study also shows several challenges and areas for improvement. These include the high costs of adopting the technology, the technical expertise required, and limitations related to the current scale of soil surveys that must be addressed if precision agriculture is to achieve maximum efficacy. It will thus be critical to cooperative efforts by researchers, policymakers, and farmers to overcome these barriers and ensure that benefits accruable from these technologies spread to all farming communities.

It has also been found that there is an urgent need to underline that even with enormous potential, success in precision agriculture depends on further technological innovation and the development of user-friendly systems easily fitted into existing agricultural practices. Further research will be necessary toward the refining of these technologies, reducing the associated costs, and increasing precision and accuracy in the collection and analysis of data. In other words, with better technologies for precision agriculture and remote sensing, the future of agriculture is set to be more efficient, productive, and sustainable. These technologies can ensure the global fulfillment of food demand if challenges facing their diffusion are addressed. Our work enriches this gigantic-ever-growing-body of knowledge standing at the portal for any research and development enterprises in this thriving domain of human activities.

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