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# Time Series Analysis For Evaluating The Irrigation Adequacy and Soil Variation Impacts On The Crop Dynamic Response Using Remote Sensing

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## ABSTRACT

This study investigates water scarcity and soil heterogeneity challenges in Egyptian agriculture, focusing on potato cultivation under a center pivot irrigation system. The research underscores the critical need for optimal water management to address the country's agricultural water scarcity, with a particular emphasis on implementing best practices. Initial steps involve evaluating irrigation system performance, emphasizing the importance of meeting crop water requirements and assessing adequacy. Utilizing satellite data and unsupervised classification, the study identifies five main soil classes 1, 2, 3, 4 and 5 with areas about 31, 37, 28, 37 and 22 acres respectively, revealing high variability in soil properties. Time series analysis demonstrates significant impacts of soil variability on crop dynamics, indicating variations in germination time, density, maturity, and productivity across soil classes. Potato in class3 and class 4 germinated earlier than class 1 and class 2 by nearly 10 days and by 20 days from class 5 and the same thing occurred in maturity. Class 1 and class 2 showed more capability to save water and hadn't been stressed along the season, class 3 and class 4 showed weakness in saving water and always being stressed. While class 5 catches more water but the water is unavailable image so it always seemed stressed and too late in germination and maturity. The findings recommend precision farming techniques to optimize agricultural inputs and address soil variability challenges. Furthermore, a variable rate irrigation system is proposed to effectively manage variations in soil characteristics and deliver water requirements accurately.

**KEYWORDS:** Remote sensing, Irrigation performance indicators, Uniformity, Adequacy.

# 1. INTRODUCTION

Fresh water resources are becoming increasingly limited in many parts of the world, and decision makers are demanding new tools for monitoring water availability and rates of consumption. In general, water availability is a major limitation for crop production and agriculture development specially, in arid and semi-arid regions (Baioumy et al 2016). Egypt's water situation is intricately tied to its heavy reliance on the Nile River, which supplies approximately 95% of its freshwater resources. The country faces a multitude of challenges, notably water scarcity driven by population growth and escalating demand. Ongoing disputes with upstream Nile nations, particularly Ethiopia, concerning the Grand Ethiopian Renaissance Dam's potential downstream impact further exacerbate Egypt's water concerns. Concurrently, water pollution issues persist in urban areas and the Nile Delta, posing risks to water quality and public health. In light of these challenges, Egypt has initiated measures to enhance water conservation and improve infrastructure, alongside investments in desalination projects. However, it's imperative to acknowledge the climate's role, which has contributed to changing rainfall patterns and temperature increases, compounding the country's water stress (EcoMENA). Global estimates of water consumption by sector indicate that irrigated agriculture is responsible for 85% of the water-use and that consumption in this sector will increase by 20% by 2025 (Droogers et al 2010). Irrigated agriculture is, on average, at least twice as productive per unit of land as rainfed agriculture, thereby allowing for more production intensification and crop diversification. The FAO forecasts a growth in irrigation withdrawals from 1995 to 2025 of 14%, while the IWMI sees a 17% growth in withdrawals for irrigation. But food production from irrigated lands during the same period must grow by at least 40% to meet the needs of a 33% increase in population, and to satisfy trends for improved nutrition (Karatas et al 2009). Irrigation process is an interactive process between four elements soil, plant, weather and the irrigation system which is responsible for providing the crops with its water requirements based on the crop stage, soil properties and weather information. Each element must take a priority to understand its influence in the irrigation process and implement better water management through providing water by equivalent manner in right place and right time which called “precision irrigation” (Baioumy et al, 2016). Time series analysis is a powerful and versatile technique used in various fields to extract meaningful insights from sequential data points collected over time (Gómez et al, 2016). In agriculture, it has proven to be invaluable for monitoring crop growth, assessing the impact of environmental variables, and optimizing farming practices. The integration of remote sensing technologies has further enriched the capabilities of time series analysis by providing a wealth of data on land surface conditions, vegetation health, and other critical parameters (Atzberger, 2013). One of the critical applications of time series analysis and remote sensing in agriculture is the assessment of irrigation adequacy. This involves monitoring and evaluating the effectiveness of irrigation practices in supplying the required amount of water to crops. It is a measure of how well irrigation systems, methods, and schedules align with the water requirements of the cultivated crops (Elnmer, et al, 2018). Time series data from remote sensing can provide valuable insights into crop water stress, which is a key indicator of irrigation adequacy. In addition to evaluating irrigation adequacy, time series analysis with remote sensing data allows for a deeper understanding of how soil variations influence crop dynamics (Sheffield et al, 2018). Soil properties such as texture, moisture content and nutrient levels can have a significant impact on crop growth and yield. Also, soil characteristics such as soil water holding capacity and depth of soil have significant effects on water requirements and the crop yield, hence irrigation strategies should be adjusted in regard to the soil type (Duncan, 2012 and Haghverdi et al, 2016). This paper explores the application of time series analysis in agriculture, focusing on its role in assessing irrigation adequacy and understanding the impact of soil variations on crop dynamics, all with the aid of remote sensing data.

## 2. MATERIALS AND METHODS

### 2.1. Study area

Fig. 1 depicts the location of The 6th of October Company in the eastern Nile Delta. 13,800 hectares is roughly how much land is involved in the project.

Drip irrigation and center pivot irrigation are the two irrigation systems used in the project. A hundred pivot irrigation units or so are included in the project. Each pivot unit, with a typical pivot length of roughly 450 meters, irrigates a total of 63.6 hectares. The Köppen Climate Classification System classifies the climate in the study area as dry and arid, with precipitation accounting for less than 50% of potential evapotranspiration. Over 18°C is the average annual temperature. About 20 millimeters of rain fall on average each year. With an average of 6.9 (mm), January sees the most rain overall. The coldest month is January, with an average high temperature of 19.0°C. June has a median maximum temperature of 34.6°C. The minimum temperature varies from 8.0 °C in January to 21.5 °C in August.

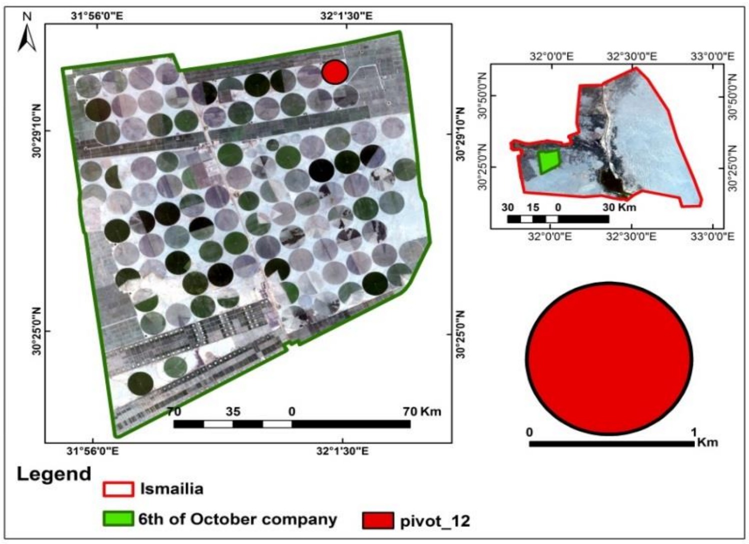


**Figure 1. Study area**

### 2.2.Data

Time series analysis as a technique needs for continuous and frequently data for verifying occurred changes and determining directions of trends. Satellites provide vital and variety of space images which have a different spatial and temporal resolutions that serve this analysis. Hybrid of Landsat 7 and Landsat 8 sensors data were chosen (Row = 39 and Path = 176) to be used in this study to cover the winter season crops of 2020. These time series data were used to investigate irrigation adequacy by estimating of the crop water stress index with its spatial maps. A time series data of sentinel 2 satellites images also used to produce the soil classification map to check the soil variability and monitoring the crop patterns and trends in a period scale during e growing season.

### 2.3. Methods

#### 2.3.1. Soil spatial variability

Using of remote sensing data is effectively to map the spatial variability of soil properties across the study area (Fathololoumi et al, 2020). This can help identify regions with varying soil characteristics. Different soil types can have distinct spectral signatures, which are detectable through remote sensing. Remote sensing can help assess soil texture (sand, silt, clay content) and composition (organic matter content) by

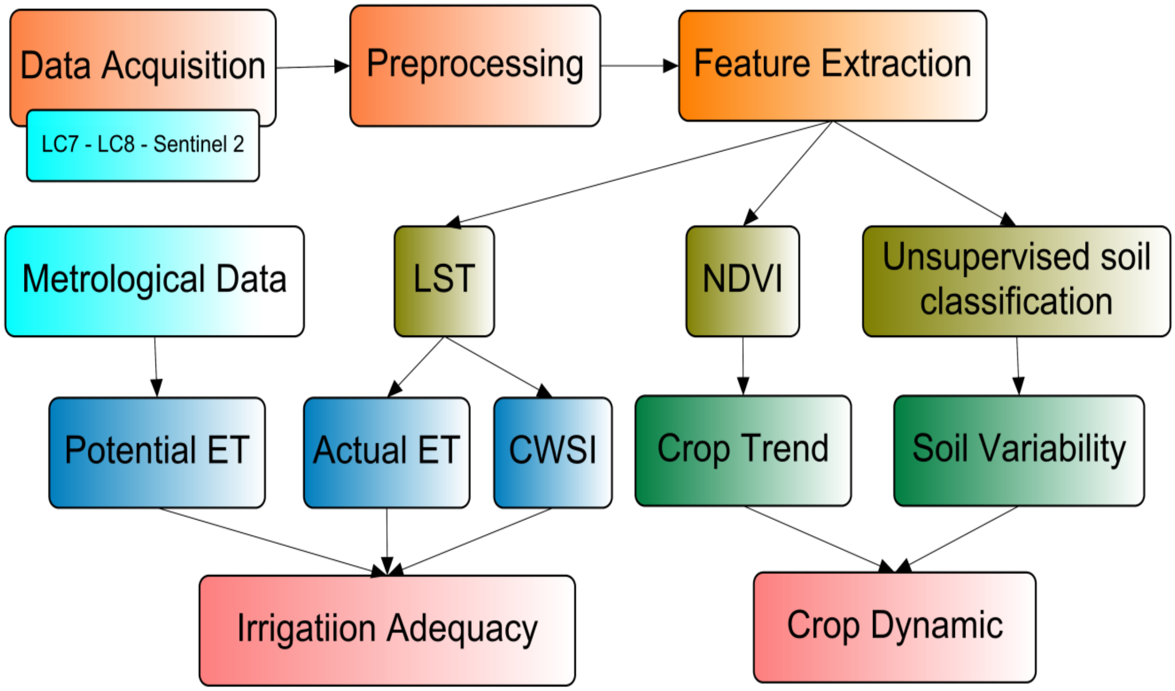


**Figure 2. Time series analysis strategy**

measuring reflectance patterns and spectral responses in the imagery and provide information on soil moisture content by detecting temperature variations in the soil surface (Maynard et al, 2017). Wetter soils tend to have different thermal properties than drier soils. Integrate remote sensing data with Geographic Information Systems (GIS) to make spatial interpolation to create soil property maps based on remote sensing data can visualize soil variability more effectively.

Using landsat8 satellite imagery, unsupervised classification conducted to investigate of exist soil variability or not in order to detect and monitoring the influence and the changes in vegetation cover, soil moisture, and other parameters over time.

### 2.3.2. Time Series Analysis in Agriculture

Time series analysis is a method that involves the examination of data points collected, recorded, or observed over successive intervals of time (Glass et al., 2008). Within the domain of agriculture, this approach is instrumental in studying trends, patterns, and variations in various parameters that are pertinent to crop growth, yield, and environmental conditions (Wohlfart et al., 2017). The advent of remote sensing technologies, such as satellite imagery and drones, has revolutionized data collection, offering high-resolution, multi-spectral, and regularly updated images of agricultural landscapes, thereby enabling a more in-depth analysis of crop dynamics.

### 2.3.3. Assessing Irrigation Adequacy

One of the primary applications of time series analysis in agriculture is the assessment of irrigation adequacy (i.e., sufficiency of water use to meet the crop water requirement) (Blatchford et al., 2020). This entails the monitoring and evaluation of irrigation practices to ensure they provide the necessary amount of water to crops as the efficient irrigation system should meet crop demands for water (Pan et al., 2013). Time series data derived from remote sensing plays a crucial role in this evaluation, primarily through illuminate temporal patterns of crop water stress, helping to identify critical stages where consistent water stress can result in yield losses and comparing actual water application to reference evapotranspiration (ET0) or potential ET, representing the water that crops require based on environmental conditions. Such comparisons can highlight under- or over-irrigation. The adequacy indicator can be assessed as the ratio of the delivered water (QD) to the required irrigation water (QR) for an area (R) over a period (T) (Enemr et al., 2018). It also can be assessed by using the relative evapotranspiration (relative ET) indicator, which is estimated as the ratio of actual ET to the potential ET (Blatchford et al., 2020). This work proposed a procedure to assess the irrigation adequacy at daily scale and intervals times through the growing season using the crop water stress index (CWSI) which can be employed to quantify crop water stress levels and guide irrigation decisions eq.2.

Adequacy= Relative evapotranspiration= ETa/ETP eq.1

Where ETa: actual ET, ETp: potential ET based on the environmental conditions soil type and the crop stage.

CWSI= (Ti-Ta)/(Tmax-Tmin) = 1-(ETa/ETp) eq.2

Where CWSI: Crop water stress index, Ti: actual crop surface temperature, Ta: surrounding air temperature, (Tmax, Tmin): temperature of the dry edge and the wet edge respectively, ETa: actual evapotranspiration and ETp: potential evapotranspiration.

### 2.3.4. Crop dynamic response:

Heterogeneity in soil properties and variation in water distribution uniformity must influence the crop response and its bio characteristics (Maynard et al, 2017). A time series satellite images of sentinel_2 had been used to monitor the study area from the point of the crop dynamic response and interaction both with soil variability and water requirements. Germination time, germination density and maturity are monitoring parameters over the cropping season. NDVI extracted from sentinel_2 images provided an overview deserves explanation about this interaction. The Normalized Difference Vegetation Index (NDVI) eq.3 proposed vital information about the crop behavior against soil properties variation and absence of enough water distribution uniformity.

NDVI = (NIR-Red)/(NIR+Red) eq.3

Where

NDVI: The Normalized Difference Vegetation Index, NIR: near infrared spectrum and Red: red spectrum.

## 3. RESULTS

### 3.1. Soil spatial variability

Remote sensing data is employed to map soil properties across a field and crop performance can be subjected to correlation analysis to identify relationships between specific soil characteristics and crop responses. By doing classification for the center pivot soil, the results detected existence of the soil variability and showed the classes distribution inside the pivot Figure 2. Regarding to results, soil variability determined by five main different classes, based on the soil color and properties, distributed randomly. Each class has more than two replicates with varied areas.

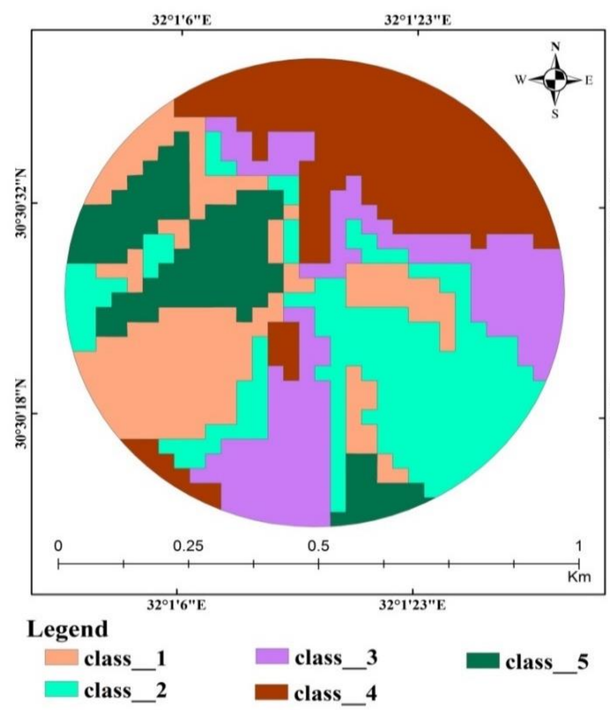


**Figure 3. Soil variability of pivot 12**

The following table elaborates the detailed area of each class and its percentage referring to the total cultivated land.

### 3.2.Crop dynamic response

Time series data on soil properties and crop performance can be subjected to correlation analysis to identify relationships between specific soil characteristics and crop responses. Remote sensing data is employed to map soil properties across a field. Time series analyses then reveal how variations in soil properties affect crop growth and yield at different locations. Time series data is created by collecting multiple observations of the selected features over time. Data points are typically collected at regular intervals (e.g., weekly or monthly) to capture seasonal variations and crop growth dynamics.
The results showed that there is a high correlation between the soil variability classes and all of measurements parameters. The crop germination trend and also germination density (Fig. 4) influenced by soil properties and took a pattern simulated the varied soil classes. At the begging of germination (date: 23-2-2019), some areas had germinated like class 3 and class 4 but others still too late and had non vegetation yet like class1, class2 and class5 which is the most obvious. The vegetation density still influenced by the soil variation and has same pattern till the 15$^{th}$ of Mar but in 24$^{th}$ of Apr, which represents the peak of growth, the total area has high and very high vegetation despite the area of the soil class5 which still has modest vegetation. In the 4$^{th}$ of May, which represents the period before the harvest, the vegetation pattern simulated the soil map again as the first to germinate is the first to mature and has low vegetation on the other hand, the last to germinate is he last o mature and has a high vegetation at the end of season.

**Table 1. Number of classes in the pivot and the area of each one in acres**

| Item | Class_1 | Class_2 | Class_3 | Class_4 | Class_5 | Total |
|---|---|---|---|---|---|---|
| Area (acre) | 31 | 37 | 28 | 37 | 22 | 155 |
| % | 20 | 23.8 | 18 | 23.8 | 14.2 | |

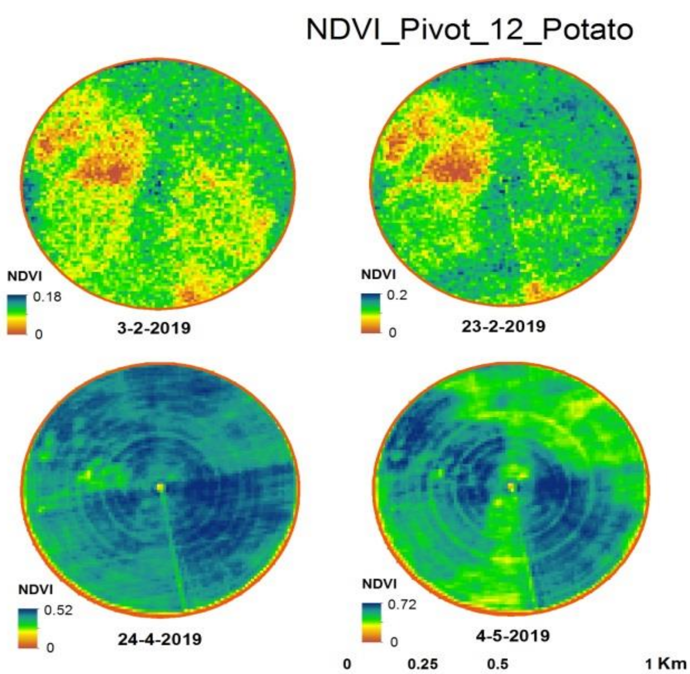


**Figure 4. Crop pattern during the entire season**

### 3.3. Irrigation Adequacy

Assessing irrigation adequacy is a critical component of effective water management in agriculture. It involves determining whether the irrigation practices are supplying the right amount of water to meet the specific needs of the crops based on the crop type, growth stage, and local climate data (evapotranspiration, rainfall, temperature). Comparing the actual amount of water applied by the irrigation system to the calculated water requirements for the crop leads to calculate the deficit or surplus, which indicates under-irrigation or over-irrigation, respectively. Time series data can illuminate temporal patterns of crop water stress, helping to identify critical stages where consistent water stress can result in yield losses. Here, the irrigation deficit determined by estimating the Crop water stress index (CWSI) using eq.1 for different dates during the growing season. The following figure (figure 3) shows layouts for entire the pivot which illustrates absence of the adequacy in the first three dates, especially the circular edge, as the vegetation is a little. By going with time, the vegetation density increased in style influenced by the soil properties and also the water shortage is exist and the adequacy is absent in some regions of the pivot and achieved in another, see (figure 3) dates, the 13$^{th}$ of Mar and the 16$^{th}$ of May. The thing which worth to recognize, although the user applying more than the crop water requirements to overcome the soil properties heterogeneity the irrigation adequacy had not existed during the season. In general, class 1 and class 2 showed more capability to save available water and hadn't been stressed along the season, class 3 and class 4 showed weakness in saving water and always being stressed. While class 5 in special class as, although it catches more water but the water is in unavailable image so it always seemed stressed and too late in germination and maturity.

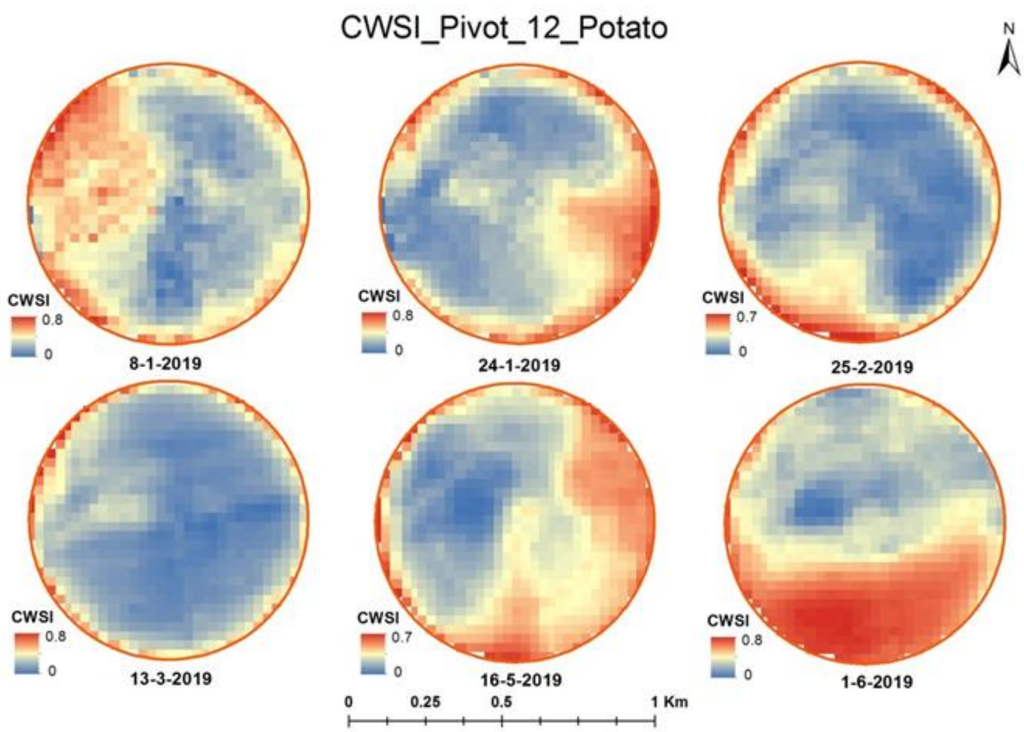


**Figure 5. CWSI during the entire season**

## 4. CONCLUSIONS

Time series analysis, when complemented by remote sensing data, serves as a potent approach for evaluating irrigation adequacy and comprehending the impact of soil variations on crop dynamics in agriculture. This interdisciplinary method provides invaluable insights into crop health, water stress, and soil conditions, empowering farmers and researchers to make informed decisions and optimize agricultural practices. As technology continues to advance, the integration of time series analysis and remote sensing will play an increasingly vital role in fostering sustainable and efficient agriculture. As time series data is created by collecting multiple observations of the selected features over time at regular intervals (e.g., weekly or monthly) to capture seasonal variations and crop growth dynamics, remote sensing is a vital method to feed the time series analysis with the required data compared with the traditional methods of field survey and collecting data. Conducting soil variability check previously as a base line for understanding and predicting the crop behavior showed exists of soil variation inside the study area and classified into five main classes. As the agricultural system s dynamic, the crop pattern influenced by the soil variability from the germination time, density and maturity insights. In addition to, the soil variability also has an essential effect on the irrigation adequacy during the season. Although, the water applied rate is more than theoretical water requirements, the irrigation adequacy hadn't achieved, in more than time and soil class (i.e. class_3 and class_4), due to the soil hasn't ability to catch and save the irrigation water for a long times or the soil catches more of water in un available form like in class_5. This study recommends using precision farming techniques to save the agricultural inputs and overcome the soil variability and also recommend to a variable rate irrigation system to can deal whit the soil characteristics variation and deliver the water requirements in right place and right time.

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## الملخص العربي

# تحليل السلاسل الزمنية لتقييم كفاية مياه الري وتأثيرات تباين التربة على الاستجابة الديناميكية للمحصول باستخدام الاستشعار عن بعد

**عصام محمد محمود بيومى[1]، محمد أحمد الشربينى[1]، محمد يوسف الانصارى[2] و منتصر عبد الله عواد[2]**

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تقوم هذه الدراسة بفحص تحديات ندرة المياه وتباين التربة في الزراعة المصرية مع التركيز على زراعة البطاطس تحت نظام الري المحورى. يؤكد البحث على الحاجة الحرجة لإدارة مثلى للمياه للتصدي لندرة المياه في الزراعة مع التركيز بشكل خاص على تنفيذ أفضل الممارسات. تتضمن الخطوات الأولية تقييم أداء نظام الري، مع التأكيد على أهمية ان يقوم نظام الرى بتلبية احتياجات المياه للمحاصيل وتقييم الكفاية المائية. باستخدام بيانات الأقمار الصناعية وعمل تصنيف للتربة، حددت الدراسة خمسة فئات رئيسية للتربة ١، ٢، ٣، ٤، و٥ بمساحات حوالي ٣١، ٣٧، ٢٨، ٣٧، و٢٢ فدانًا على التوالي، مكشفة عن تباين كبير في خصائص التربة. تظهر تحليل السلاسل الزمنية تأثيرات كبيرة لتباين التربة على ديناميكيات المحصول، مشيرًا إلى تغيرات في أوقات الانبات والكثافة والنضج والإنتاجية عبر فئات التربة المختلفة. البطاطس في الفئتين ٣ و ٤ أنبتت في وقتٍ مبك من الفئتين ١ و ٢ بحوالي ١٠ أيام وبـ ٢٠ يومًا من الفئة ٥، وحدثت نفس الظاهرة في مرحلة النضج. أظهرت الفئتان ١ و ٢ قدرة أكبر على الاحتفاظ بالمياه ولم تواجه الإجهاد طوال الموسم، بينما أظهرت الفئتان ٣ و ٤ ضعفًا في الاحتفاظ بالمياه وكانت دائمًا في حالة من الإجهاد. بينما تكتسب الفئة ٥ مياه أكثر، إلا أن المياه ممسوكة وفى صورة غير ميسرة لذلك يبدوالمحصول دائمًا مجهدا ومتأخرًا في الانبات والنضج. توصي النتائج باستخدام تقنيات الزراعة الدقيقة لتوفير المدخلات الزراعية ومعالجة تحديات تباين التربة. علاوة على ذلك، يُقترح نظام الري بمعدل متغير لإدارة التباينات في خصائص التربة بفعالية وتلبية متطلبات المياه بدقة.

**الكلمات المفتاحية:** السلاسل الزمنية–الإستشعار من البعد–الكفاية المائية– إختلافات التربة–مراقبة المحصول.