

Development of a Remote Sensing-Based System for Monitoring Crop Water Use in Agricultural Water Management in Thailand

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Abstract

Efficient water management is crucial for enhancing crop productivity and ensuring food security, especially with growing global water scarcity. To support data-driven agricultural decision-making, this research develops a spatial decision support system using satellite-based Big Earth Observation Data. The system leverages MODIS time-series products to automatically retrieve and analyze Evapotranspiration (ET) and Gross Primary Production (GPP), which are used to calculate Water Use Efficiency (WUE)—a key metric for assessing crop water productivity.

The core innovation is a scalable architecture that integrates multi-temporal satellite data with a Web GIS platform. The system uses PostgreSQL with PostGIS for efficient spatial database management and optimized SQL queries. Its backend, powered by Node.js, delivers RESTful APIs, while GeoServer publishes spatial layers as Web Map Services (WMS). These layers are visualized on an interactive, React-based interface using Leaflet.js, allowing users to dynamically analyze historical water use patterns by region and time via a standard browser.

This system's ability to process and visualize large-scale spatiotemporal data empowers agricultural stakeholders to identify inefficiencies, adapt irrigation practices, and optimize resource allocation. The platform demonstrates how advanced geospatial information and Big Data processing contribute to sustainable agriculture and climate resilience, ultimately helping to improve crop yields and secure long-term food stability. Future enhancements may integrate ground-based or farmer-contributed data to further strengthen its decision-making capacity.

1. Introduction

Water resource management in the agricultural sector is a critical factor affecting crop yields and national food security. Water resources serve as a primary determinant of plant growth efficiency and productivity. However, climate change has resulted in precipitation uncertainty, including drought problems and water shortages in numerous regions (AghaKouchaket et al., 2015, Zhao et al., 2020). In Thailand, an agricultural country heavily dependent on water resources, these issues significantly impact crop yields, particularly rice and durian, which are key economic crops. Therefore, it is essential to implement advanced technologies to effectively monitor and manage water resources in the agricultural sector

Geoinformatics technology and satellite data have been continuously developed and can assist farmers and stakeholders in comprehensively monitoring plant water consumption trends across large areas (Bwambale et al., 2022). MODIS (Moderate Resolution Imaging Spectroradiometer) is a satellite system capable of providing continuous data on plant evapotranspiration (ET) and gross primary production (GPP) on a weekly temporal scale (Restrepo-Coupe, et al., 2017, Silva et al., 2021). These data can be analyzed to calculate plant Water Use Efficiency (WUE), a key indicator for evaluating water utilization in agricultural systems (Wang et al., 2016).

Studies have shown that the application of MODIS data and GIS enables efficient monitoring of drought conditions in agricultural areas and facilitates appropriate water management (Hossein-zadeh et al., 2023, Sun et al., 2019). This is particularly relevant in Thailand, where Web GIS has been developed to support agricultural decision-making and drought management at the farm level (Auntanon et al., 2024). The

implementation of Web GIS for monitoring and managing water in the agricultural sector enhances the precision and efficiency of analyzing plant water consumption trends across different regions (Patel et al., 2023).

Therefore, the primary objective of this research is to develop a remote sensing-based system for monitoring and evaluating crop water use efficiency (WUE) within Thailand's agricultural sector. To achieve this overarching goal, this study aims to accomplish three specific objectives: first, to integrate MODIS satellite data (Evapotranspiration and Gross Primary Production) with a Web GIS platform for automated, large-scale data processing; second, to design and implement a scalable Web GIS platform that enables agricultural stakeholders to visualize, analyze, and retrieve historical spatiotemporal data on water use efficiency; and third, to validate the system's performance and data accuracy to ensure it serves as a reliable decision-support tool for optimizing irrigation practices and enhancing water resource management.

2. Literature Review

This literature review focuses on two main aspects related to water management in the agricultural sector: Water Use Efficiency (WUE) and Web GIS platforms for monitoring and decision support.

2.1 Agricultural Water Use in Crops

WUE is a crucial metric for assessing the relationship between plant growth and water consumption, often derived from satellite-based measurements like MODIS (Wang et al., 2016, Restrepo-Coupe et al., 2017).

Studies have shown that drought conditions significantly impact WUE, affecting crop productivity and water resource availability (Zhao et al., 2020, Hosseinzadeh et al., 2023).

Remote sensing and eddy covariance methods have been effective in evaluating WUE at both regional and global scales, helping optimize water resource management in agriculture (Silva et al., 2021).

2.2 Plant Water Use Monitoring and Alert Systems

The integration of GIS and Remote Sensing has enhanced precision irrigation and drought monitoring (Bwambale et al., 2022).

Web GIS applications, such as those developed for drought risk management, provide real-time spatial visualization and analysis for farm-level decision-making (Auntanon et al., 2024).

Open-source technologies like PostgreSQL/PostGIS, GeoServer, and Leaflet enable scalable and interactive Web GIS systems for monitoring agricultural water use (Running et al., 2017, Mu et al., 2011, Wan et al., 2017).

Decision Support Systems (DSS) based on Web GIS help optimize irrigation planning and resource allocation by integrating real-time satellite and meteorological data (Patel et al., 2023).

The literature review indicates that integrating satellite data for WUE calculation with Web GIS can effectively enhance agricultural water management efficiency. Satellite-based monitoring of plant water use enables more accurate analysis of water consumption trends and drought impacts, while Web GIS facilitates efficient decision-making and water resource management.

3. Methodology

This research focuses on developing a plant water use monitoring and alert system through Web GIS, utilizing MODIS satellite data to calculate Water Use Efficiency (WUE) and presenting it via a GIS system. This approach enables farmers and policymakers to efficiently monitor plant water consumption. The methodology can be divided into four main stages

3.1 Data Collection and Preparation

This study utilizes MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data, which is a key component of the NASA Earth Observing System. The MODIS sensor, operating on both the Terra and Aqua satellites, provides frequent, large-area coverage. Specifically, the data products used in this research have a moderate spatial resolution of 500 meters and a high temporal resolution, providing data every 8 to 16 days. These characteristics make MODIS suitable for monitoring large-scale agricultural landscapes and long-term trends in plant physiological parameters. The primary data parameters related to plant water use include:

- Gross Primary Production (GPP): Represents the net photosynthetic production of plants in grams of carbon per square meter per day ($\text{gC/m}^2/\text{day}$), reflecting plants ability to convert solar energy into biomass. It serves as an indicator of plant growth

efficiency and can effectively assess plant responses to water availability and climate conditions (Silva et al., 2021).

- Evapotranspiration (ET): Measures water loss from soil surfaces and plants through evaporation and plant transpiration, with units in millimeters per day (mm/day). This is a primary indicator for evaluating plant water consumption (Mu et al., 2011).

Data	Data Type	Source
Evapotranspiration	Raster (GeoTIFF)	MODIS Data Collection (GEE)
GrossPrimary Production	Raster (GeoTIFF)	MODIS Data Collection (GEE)
Water Use Efficiency	Raster (GeoTIFF)	MODIS Data Collection (GEE)

Table 1. Detail of data

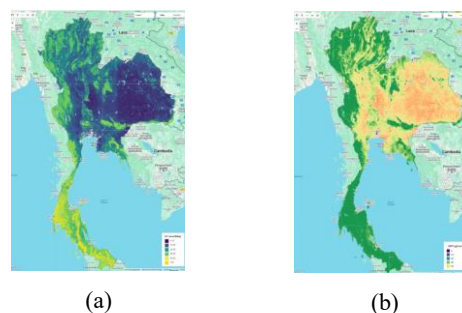


Figure 1. Preparation of Data and Databases for Research (a) Evapotranspiration: ET (b) Gross Primary Production: GPP

3.2 Water Use Efficiency (WUE) Calculation

WUE is calculated as the ratio between Gross Primary Production (GPP) and plant Evapotranspiration (ET) (Wang et al., 2020). As shown in the following equation:

$$WUE = \frac{GPP}{ET}$$

Where:

- WUE is the Water Use Efficiency ($\text{gC/kg H}_2\text{O}$)
- GPP is the Gross Primary Production ($\text{gC/m}^2/\text{day}$)
- ET is the Evapotranspiration (mm/day or $\text{kg H}_2\text{O/m}^2/\text{day}$)

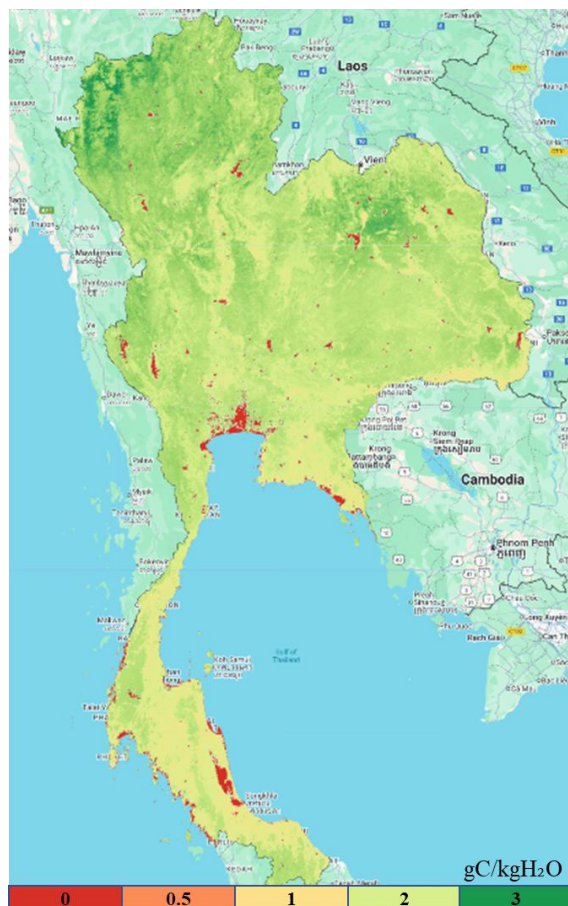


Figure 2. Example of Data WUE

3.3 Web GIS Platform Development

The Web GIS Platform developed in this research aims to serve as a monitoring and alert system for plant water use utilizing MODIS satellite data. The system is designed to display plant water consumption data through an interactive online map, employing the following technologies:

- **Spatial Database:** PostGIS on PostgreSQL is used for storing spatial data, such as agricultural plot information, plant evapotranspiration (ET) data, and water use efficiency (WUE). Data from MODIS and other sources are imported and processed through this database management system.
- **Geospatial Data Server:** GeoServer is employed to provide WMS (Web Map Service) and WFS (Web Feature Service) map services, supporting the viewing and display of various data layers on the Web GIS.
- **Frontend Development:** Leaflet.js or OpenLayers is used for creating interactive maps, while React.js is utilized for developing an efficient and user-friendly UI. The system supports area selection, toggling data layers, and historical data visualization.
- **API and Server-Client Communication:** Node.js and Express.js are used to create APIs for retrieving data from

the database and transmitting it to the display interface. The system supports RESTful API to ensure efficient data retrieval.

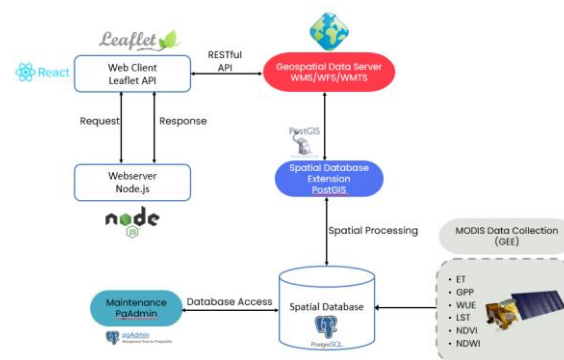


Figure 3. Web GIS Platform

3.4 System Testing and Evaluation

System testing and evaluation will be conducted in two main parts: (1) testing the efficiency of the Web GIS system and (2) verifying data accuracy.

- **Spatial Database:** PostGIS on PostgreSQL is used for storing spatial data, such as agricultural plot information, plant evapotranspiration (ET) data, and water use efficiency (WUE). Data from MODIS and other sources are imported and processed through this database management system.
- **Data Accuracy Verification:** This involves comparing the Water Use Efficiency (WUE) values obtained from the system with values from actual data sources, and verifying water usage through interviews with farmers in the area.

The developed Web GIS system will enable efficient monitoring and alerting of plant water use by utilizing MODIS satellite data and other data sources. The system is designed to support rapid operation and can assess plant water situations in each area. Testing and evaluation will ensure that the system can provide accurate information and is practical for real-world agricultural applications.

4. Results and Discussion

4.1 Results of Water Use Efficiency (WUE) Calculation

Analysis of MODIS satellite data throughout the 12-month period in 2024 revealed that both plant types, durian and rice, exhibited distinctly different trends in Evapotranspiration (ET), Gross Primary Production (GPP), and Water Use Efficiency (WUE) as follows:

1) Evapotranspiration (ET) Trends

- **Durian** maintained relatively constant ET values throughout the year, averaging between 28-38 mm/month, indicating consistent and continuous water use throughout the seasons.
- **Rice** showed clear seasonal variations in ET values, with peaks during mid-year (May-June) and significant decreases during March-April and

September-December, reflecting periods without cultivation, harvesting, or during soil preparation.

2) Gross Primary Production (GPP) Trends

- **Durian** exhibited continuous and relatively consistent GPP values, with higher values during early and late year (January-March and October-December), which corresponds to the characteristics of fruit trees that photosynthesize throughout the year.
- **Rice** showed highly fluctuating GPP values, reflecting seasonal cultivation cycles, with peaks during growing seasons (May-August) and lows during harvesting periods (September-November).

3) Water Use Efficiency (WUE) Trends

- **Durian** demonstrated high and consistent WUE trends throughout the year, averaging more than 1.20-1.80 gC/kg H₂O, indicating good efficiency in water use for growth.
- **Rice** exhibited highly variable WUE values, with peaks only during growing seasons (March and December) but dropping significantly during harvesting periods (September-November), sometimes below 0.6 gC/kg H₂O, indicating water use with no return in terms of photosynthesis.

These results indicate that durian utilizes water efficiently and consistently throughout the year, while rice demonstrates high water use efficiency only during growing seasons. This analysis can serve as baseline data for water management planning in agricultural areas where both crops are cultivated together, enabling appropriate water usage according to temporal requirements.

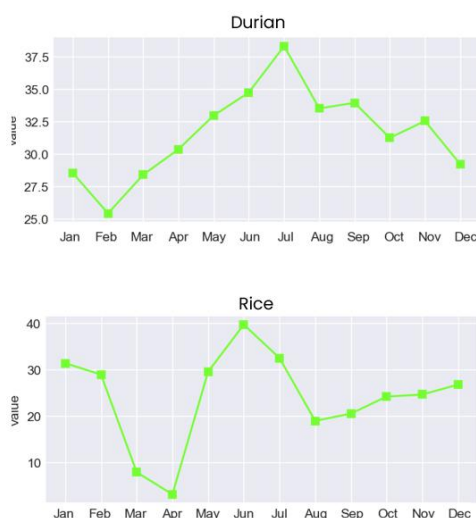


Figure 4. Monthly ET trends in rice and durian plots during 2024

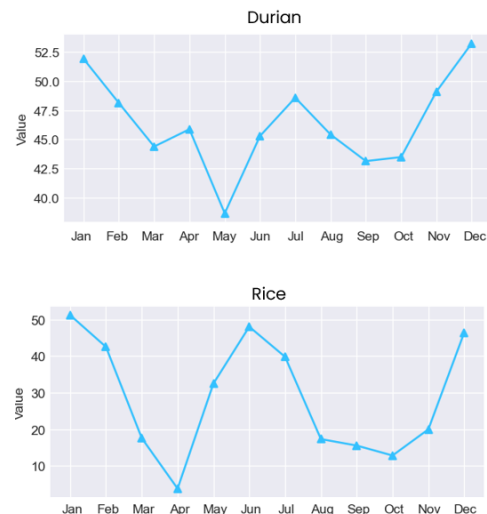


Figure 5. Monthly GPP trends in rice and durian plots during 2024

4.2 Discussion Part

In addition to the MODIS-derived trends, field observations provided further insight into the underlying causes of temporal variability in physiological parameters, particularly for durian. Farmers reported performing pruning and canopy management practices during April and May, which resulted in a temporary decline in the canopy's photosynthetic area. This agronomic activity directly corresponds with the drop in GPP observed in the satellite data during the same period. By June, nutrient supplementation and increased irrigation were applied, facilitating canopy recovery and an upward trend in GPP values. Interestingly, while GPP dipped during pruning, ET remained relatively stable or slightly increased, reflecting a decoupling between water loss and photosynthetic gain during that transitional stage.

In contrast, rice showed tightly coupled patterns between GPP and ET due to its seasonal cropping nature. The drop in both parameters during non-cultivation months (especially March–April and post-harvest in September–November) confirms the absence of active biomass production. However, a sharp increase during the growing season reflects the coordinated rise in photosynthetic activity and water consumption. The inconsistency in WUE for rice, particularly its decline during harvesting, may be attributed to residual soil evaporation and irrigation events occurring after peak biomass accumulation but before complete canopy senescence.

These spatiotemporal patterns emphasize the importance of crop-specific management strategies. Perennial systems like durian benefit from continuous monitoring to capture physiological shifts due to management interventions, while seasonal crops such as rice require precise identification of phenological phases to interpret biophysical trends effectively. The integration of remote sensing with agronomic calendars enhances the reliability of crop water productivity assessments and supports evidence-based decisions in regional irrigation planning, especially in multi-cropping environments where water demand is highly dynamic and resource allocation must be optimized.

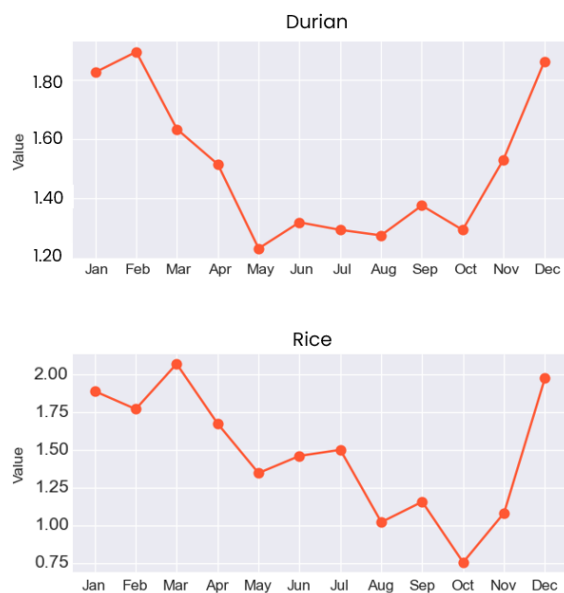


Figure 6. Monthly WUE trends in rice and durian plots during 2024

4.3 Web GIS Platform Visualization and Performance Evaluation

The developed Web GIS platform effectively visualizes crop water usage data, offering key functionalities as follows:

- **Study Area Selection** – Users can specify their area of interest and observe crop water usage data across different time periods.
- **Historical Data Comparison** – The system supports temporal analysis of Water Use Efficiency (WUE), allowing users to monitor changes over time.
- **System Performance** – Functionality tests demonstrate that the Web GIS platform loads spatial data efficiently, with an average map layer loading time of 1.2 seconds and API response time of approximately 1 second. Additionally, the system was evaluated by a sample group of users, including researchers and farmers. The user satisfaction score was rated at a “good” level on average, indicating both system usability and practical value in real-world agricultural monitoring

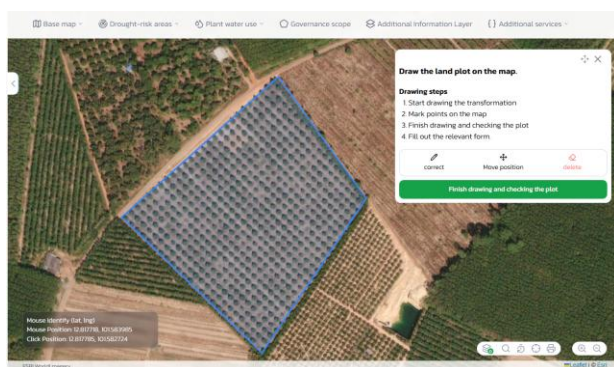


Figure 7. Results of Web GIS Platform

5. Conclusion

This study primarily aims to assess the Water Use Efficiency (WUE) of crops using MODIS satellite data and to develop a Web GIS platform for spatial monitoring and visualization. The findings demonstrate that Gross Primary Production (GPP) and Evapotranspiration (ET) data can be effectively utilized to compute WUE.

Monthly analysis of ET, GPP, and WUE for the year 2024 using MODIS data reveals that durian exhibits consistently efficient water usage throughout the year, whereas rice shows high WUE only during the cultivation season. Outside of this period, rice demonstrates a marked drop in WUE, indicating water use that does not contribute to biomass production.

These results underscore the importance of crop- and time-specific water management strategies, and can support agricultural water policy planning to enhance efficiency and minimize water loss during fallow periods.

The developed Web GIS platform effectively visualizes WUE as spatial maps. Users can explore monthly data, toggle data layers, and delineate specific farm plots to compare key factors affecting crop water use. The system is accessible via standard web browsers, supporting both desktop and mobile devices.

However, this study faced certain limitations, such as the moderate spatial resolution of MODIS data, which may not be ideal for small-plot analysis. Cloud cover also resulted in data gaps during some periods, necessitating pre-processing techniques like data filtering and gap-filling to ensure accuracy.

Future research should explore the integration of higher-resolution satellite data, such as Sentinel-2, Landsat, or UAV imagery, to address spatial limitations. Moreover, incorporating in-situ ground observations from Eddy covariance towers could

provide robust validation of remotely sensed estimates, thereby improving the reliability of WUE assessments. Combining these datasets with machine learning models may further enable more accurate forecasting of WUE dynamics. Enhancing the Web GIS platform with advanced analytics—such as WUE trend projections, multi-year comparisons, and cross-validation with ground-based flux measurements—is also recommended.

In summary, this research demonstrates that the integration of satellite remote sensing with Web GIS can significantly support agricultural water management. Such a platform offers valuable tools for monitoring and planning, and has strong potential for farm- or region-level applications. It enables farmers and policymakers to make more informed, data-driven decisions regarding irrigation and crop water use.

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