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Spatiotemporal Platform for Assessing the Quality of Irrigated Paddy Soils in Cidadap Village, Subang Regency

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Abstract: Indonesia is one of the world's largest rice producers, with national rice production reaching 34.1 million tons. In order to maintain food security and support the national economy, soil quality plays a crucial role in sustaining agricultural productivity. Soil salinity is an important indicator affecting nutrient availability and plant growth. Increased salt content in paddy soils can inhibit water and nutrient uptake, leading to reduced rice yields, particularly in intensively managed irrigated paddy fields. Cidadap Village, Subang Regency, as an intensively cultivated agricultural area, experiences interannual fluctuations in soil salinity levels. The methods used in this study include irrigated paddy field detection through supervised classification using Landsat 8 OLI/TIRS imagery and estimation of electrical conductivity (EC) as a salinity indicator based on regression analysis with the Vegetation Soil Salinity Index (VSSI). All analyses were conducted on the Google Earth Engine (GEE) platform to support efficient and large-scale spatial data processing. Monitoring results indicate that salinity levels in irrigated paddy fields in Cidadap Village fluctuated during the 2020–2024 period, with EC values predominantly falling within the non-saline to low-salinity categories (1.8–3.6 dS/m), although several areas exhibited moderate salinity increases (>4 dS/m). These variations are influenced by hydrological conditions, rainfall, and irrigation water distribution. All spatial visualizations are presented through the Data Indo InaPad platform based on Earth Engine Apps as a practical and easily accessible tool for monitoring soil salinity conditions.

Keyword: Salinity, Soil quality, Paddy, Remote sensing

INTRODUCTION

Indonesia is an agrarian country and also one of the world's largest rice producers. According to data from USDA (2024), Indonesia ranked fourth in global rice production, with a total output of 34.1 million tons. Based on data BPS (2024) from the Central Bureau of Statistics, the national harvested area of rice reached approximately 10.05 million hectares, with an average productivity of 5.2 tons per hectare. Despite relatively high rice production, Indonesia continues to import rice in certain amounts each year, indicating that the achievement of rice self-sufficiency has not yet been fully stable (Ramadhan *et al.*, 2025). This condition highlights that rice production holds a strategic position in maintaining national food security as well as supporting the livelihoods and economy of the population.

Soil quality is a key factor in sustainable agricultural management, including rice cultivation (Wihardjaka, 2021). Healthy soils are able to supply water, retain nutrients, and provide an optimal growing medium for plants (Zebua *et al.*, 2025). A decline in the soil's ability to perform these functions indicates a degradation of soil quality, which leads to an expansion of degraded land, reduced soil productivity, and environmental pollution (Juarti, 2024). When soil quality declines, the capacity of land to produce rice also decreases (Robbo & Galib, 2023). Salinity is a major cause of soil degradation in agricultural lands worldwide, particularly affecting arid and semi-arid climate zones (Tomaz *et al.*, 2020). Land with high salinity levels or elevated salt content is referred to as saline land (Nusantara & Sulakhudin, 2021). Increased soil salinity is caused by an imbalance between transpiration rates and water inputs from rainfall or irrigation (Narayana *et al.*, 2023). Specifically, salinity can affect soil biodiversity, microbial activity, biogeochemical cycles, soil respiration, organic residue decomposition, nitrification, and denitrification processes (Singh, 2016). Rising salinity levels in rice fields often lead to yield reductions, particularly during the dry season or when irrigation management is suboptimal (Karolinoerita & Annisa, 2020). Therefore, soil salinity represents a major challenge in irrigated agriculture, with significant implications for crop sustainability and food security (Sanga *et al.*, 2024). Given the importance of accurate soil condition monitoring, numerous global studies have employed remote sensing approaches to efficiently and extensively map salinity levels, as implemented in China, Kazakhstan, Iran, Iraq, the United States, the Netherlands, and Australia (Shi *et al.*, 2021).

To date, studies focusing on the monitoring of salinity levels in irrigated paddy fields in Cidadap Village remain unavailable, resulting in limited information regarding the spatial and temporal patterns of soil changes in the area. Remote sensing–based monitoring enables the assessment of soil conditions across space and time without the need for intensive field measurements (Wang *et al.*, 2024). Therefore, the development of the spatiotemporal Data Indo InaPad platform using Earth Engine Apps aims to identify, prevent, and mitigate changes in soil salinity in irrigated paddy fields. The findings of this study are expected to provide a scientific basis for formulating more adaptive and sustainable irrigated paddy field management strategies, as well as to strengthen the role of Subang as one of Indonesia's national rice production centers.

METHODOLOGY

Study Area

Cidadap Village is geographically located between 6°27'40.35" S and 107°46'00.14" E. Administratively, the study area is situated in Subang Regency, West Java Province. Cidadap Village is bordered by Bendungan Village to the north, Cidahu Village to the south, Sumbergintung Village to the east, and Batusari Village (Dawuan District) and Kawunganten Village (Cikaum District) to the west, encompassing adjacent villages within the Pagaden Barat, Dawuan, and Cikaum districts (Fig. 1).

Data Source and Data Processing

Data for assessing the quality of irrigated paddy soils were obtained using Landsat 8 OLI/TIRS imagery (Fig. 2). Landsat 8 is equipped with two onboard sensors, namely the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) (Primadipta *et al.*, 2025). This satellite carries eleven spectral bands, consisting of nine OLI bands (Bands 1–9) and two TIRS bands (Bands 10 and 11). The specifications of each band of the Landsat 8 OLI/TIRS imagery are presented in Table 1.

The OLI sensor acquires data in eight multispectral bands with a spatial resolution of 30 meters, as well as a high-resolution panchromatic band at 15 meters, while the TIRS records data in two thermal infrared bands with a spatial resolution of 100 meters (Zhao *et al.*, 2023). The imagery was obtained from the cloud-computing data catalog of Google Earth Engine (GEE).

Data Analysis

Rice Distribution Mapping

Processing of rice distribution data was conducted to generate spatial datasets of rice distribution, which were used as the Area of Interest (AoI) in this study, as well as to produce spatial mapping outputs and specific graphical models. Spatial mapping of the AoI was performed using Geographic Information System (GIS) analysis. Detection of paddy and non-paddy areas was carried out through supervised classification using the Random Forest algorithm. Random Forest (RF) is a machine learning method that consists of an ensemble of decision trees, in which the final classification decision is determined based on majority voting (Marlina, 2022). Machine learning–based classification results are generally influenced by bias that may reduce the quality of the resulting information; therefore, retraining (training) and data validation processes are required. Classification accuracy was evaluated using Overall Accuracy (OA) and the Kappa coefficient, calculated through the Google Earth Engine (GEE) platform. The evaluation process involved 33 training points distributed across each land cover class and classification time series, with the number of points in each class adjusted according to the proportional area of land cover within the AoI (Table 2). Validation data were grouped into two main classes, namely rice and non-rice areas. The number of validation points for each classification result and observation period was varied, resulting in different annual accumulations of validation points, while considering clearly distinguishable urban boundaries observed in the RGB composite imagery for each classification year. All validation data collection and processing were conducted on the GEE platform to enhance analytical efficiency and consistency, whereas the calculation of Overall Accuracy and the Kappa coefficient was performed using Equations (E1) and (E2). Graphical modeling, meanwhile, was carried out using RStudio software.

$$\text{OA} = \frac{\sum_{i=1}^{r} X_{ii}}{N} \times 100\% \qquad \text{……(E1)}$$

$$\text{K} = \frac{\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+} \cdot X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} \cdot X_{+i})} \qquad \text{……(E2)}$$

Salinity Data Analysis

The results of the classification of paddy field areas in Cidadap from 2020 to 2024 were used to assess soil quality based on salinity indicators using the Vegetation Soil Salinity Index (VSSI). This index integrates spectral information from vegetation and bare soil to provide a more representative salinity

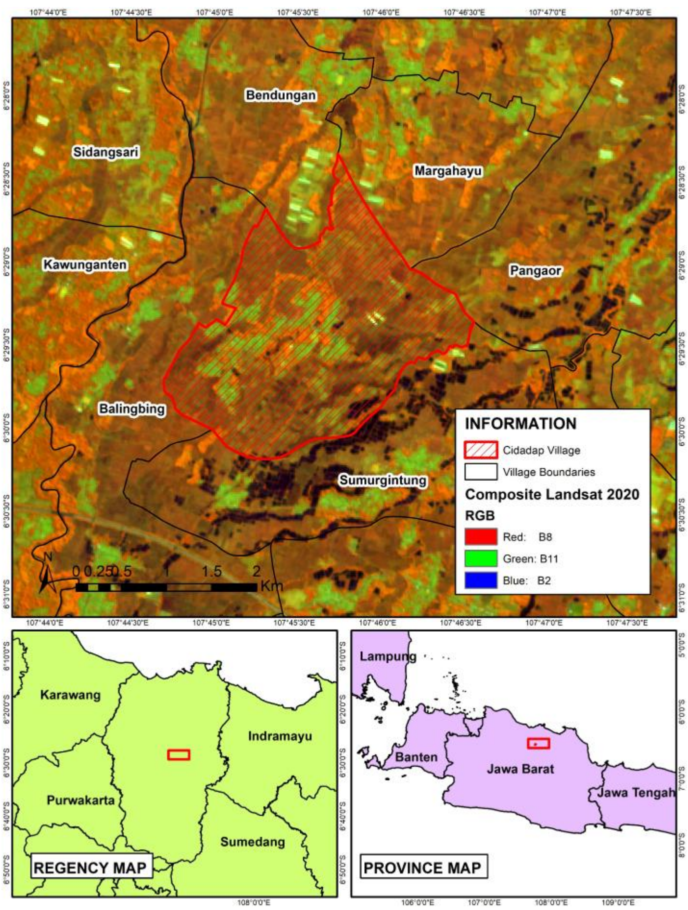

Figure 1. Research area map

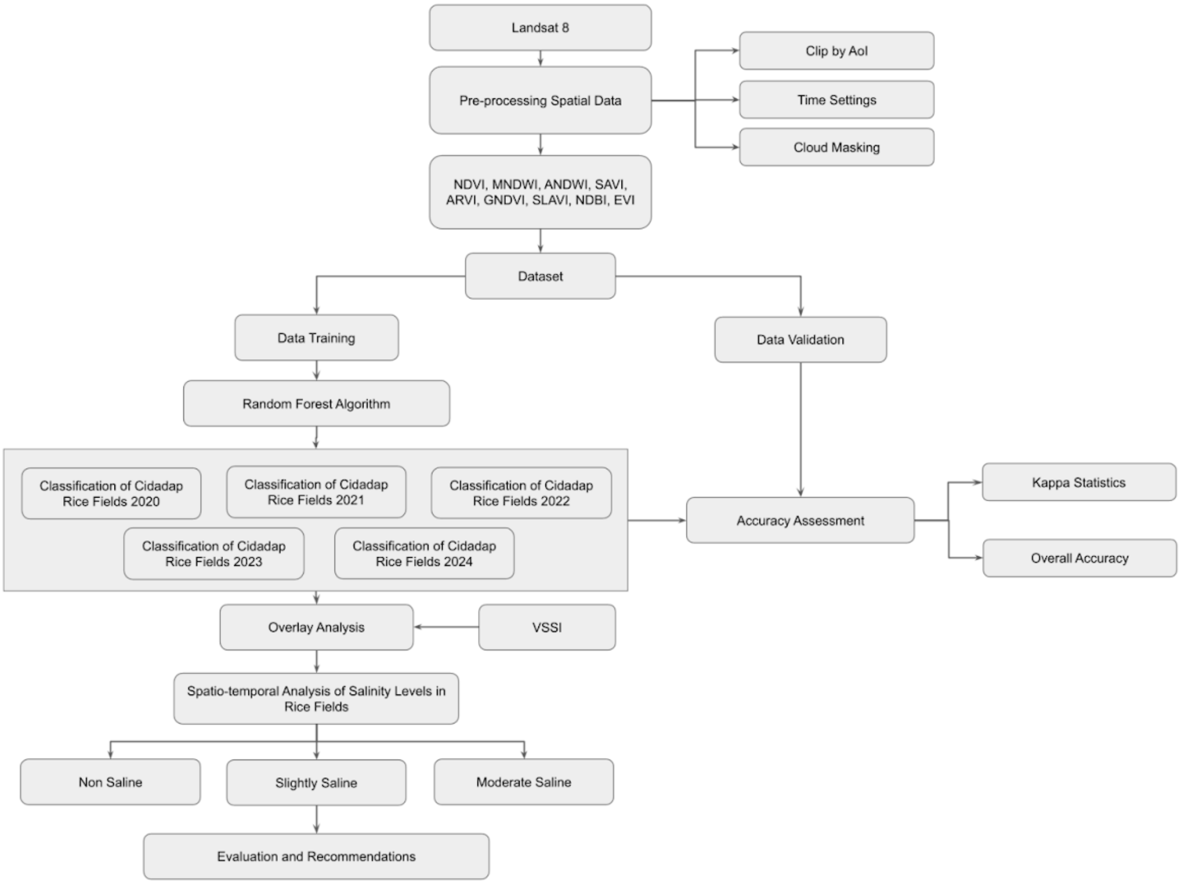

Figure 2. Research workflow

indicator, particularly in areas with mixed land cover (Asfaw et al., 2018). The equation used is as follows:

VSSI = 2 x Green Band - 5 x (NIR Band + RED Band) …(E3)

The VSSI index was subsequently used to predict electrical conductivity (EC) using the equation proposed by Nguyen *et al.* (2020), as follows:

EC = 72.859e2.8802

EC values were used to determine land salinity classification using three salinity classes, as presented in Table 3.

RESULTS AND DISCUSSION

Condition of Irrigated Paddy Fields in Cidadap Village

Cidadap Village is one of the villages located in Pagaden Barat District, Subang Regency, West Java Province, covering an area of 5.76 km² and classified as part of the North Coast (Pantura) lowland region. Based on data from Statistics Indonesia (BPS), rice productivity in Subang Regency declined in 2022 and then increased markedly in 2023–2024, reaching 65.10–67.95 quintals per hectare, as illustrated in Fig. 3.

Geomorphological assessments conducted by Fariza (2016) from BBSDLP, based on a 1:50,000 soil map in 2016, along with data from Statistics Indonesia (BPS 2024) Subang Regency, indicate that the Pagaden Barat area is characterized by undulating terrain with slopes ranging from 3–8% and an average elevation of approximately 0–50 m above sea level. The relatively flat topography, combined with the dominance of Aquic Eutrudepts (Inceptisols) characterized by fine texture, high organic matter content, moderate to high cation exchange capacity, and good drainage, makes this area well suited for irrigated paddy field agriculture (Waas *et al.*, 2016). However, these soil characteristics may also contribute to fluctuations in salinity levels,

Table 1 Band specifications on Landsat 8 OLI/TIRS

Band	Wavelength (µm)		Resolution	Application
1	0.433–0.453	Ultra blue/violet	30 m	Coastal, Aerosol
2	0.450–0.515	Blue	30 m	
3	0.525–0.600	Green	30 m	Visible spectrum
4	0.630–0.680	Red	30 m	
5	0.845–0.885	Near-infrared	30 m	
6	1.560–1.660	SWIR 1	30 m	Vegetation analysis
7	2.100–2.300	SWIR 2	30 m	
8	0.500–0.680	Panchromatic	15 m	Higher spatial resolution
9	1.360–1.390	Cirrus	30 m	Cloud analysis
10	10.6–11.2	Thermal	100 m	Land surface temperature
11	11.5–12.5	Thermal	100 m	

Table 3 Variation in salinity levels

Electric Conductivity	Salinity Level
<2	Non-saline
2–4	Low salinity
4–8	Intermediate salinity

(Nguyen *et al.,* 2024)

Table 2 Dataset sample

No	LULC Class	Training Data	Validation
1	Paddy field area	20	7
2	Non-Paddy field area	13	8
	Total	**33**	**15**

which can be influenced by variations in rainfall or uneven irrigation water distribution.

Pagaden Barat District, as one of the rice production centers in Subang Regency, is located within the Cipunagara Watershed and utilizes a technical irrigation system. Technically irrigated paddy fields are defined as rice fields that receive water supply from permanent irrigation channels equipped with water-level control and measurement structures, and that have designated inlet and outlet channels to ensure efficient flow regulation (Minsyah *et al.*, 2014). The primary source of irrigation water is the Jatiluhur Reservoir, which ensures a reliable and continuous water supply throughout the year. According to data from the Central Statistics Bureau (BPS 2024) Subang Regency, the area of irrigated paddy fields in Pagaden Barat

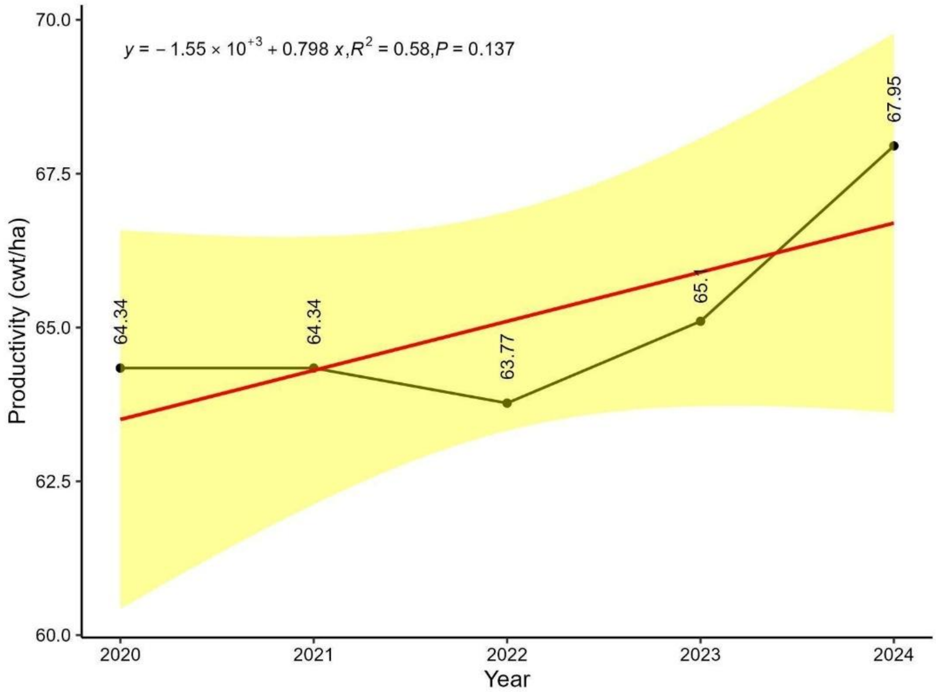

Figure 3. Rice productivity trends in Cidadap Village from 2020 to 2024

District reaches 3,318 hectares out of a total of 3,424 hectares of paddy land.

Spatial Classification Analysis of Rice Field Distribution

The classification results of Land Use/Land Cover (LULC) for rice field distribution in Cidadap Village were generated through visual interpretation of Landsat 8 imagery using the Google Earth Engine (GEE) platform. The classification distinguished two main classes, namely paddy fields and non-paddy areas, achieving an overall accuracy of 93% (Fig. 4). According to Sivanpillai *et al.* (2021), this accuracy level is categorized as very good, exceeding the 80% accuracy threshold. The classification process was based on the intrinsic reflectance characteristics of surface objects, where each land cover component exhibits distinct spectral reflectance patterns across different wavelengths (Hamad, 2020). LULC information plays a critical role in analyzing land-use patterns and serves as a fundamental basis for formulating sustainable land management strategies in the future (Seyam *et al.*, 2023). In addition, the classification results of this study have methodological significance, as they provide data that are more aligned with the analytical requirements compared to datasets from the Geospatial Information Agency (BIG), for which the reference year of the data is not specified.

Salinity Levels of Irrigated Paddy Fields in Cidadap Village

The relationship between EC and VSSI follows a positive exponential pattern, as formulated by Nguyen *et al.* (2020), whereby an increase in VSSI corresponds to an increase in EC values. EC is influenced by the accumulation of mineral ions contained in groundwater (Swardana *et al.*, 2022). This indicates that areas exhibiting high reflectance in the blue band and low reflectance in the green and red bands tend to have greater salt accumulation on the soil surface. Based on the classification proposed by Asfaw *et al.* (2018), EC values <2 dS/m are categorized as non-saline, 2–4 dS/m as low salinity, and 4–8 dS/m as moderate salinity. Interpretation results show that EC values in Cidadap Village are predominantly within the range of 1.8–3.6 dS/m, indicating that soil quality remains generally suitable for irrigated rice cultivation. This finding is consistent with the study by Swardana *et al.* (2022), which reported that rice plants have an EC tolerance of approximately 2 dS/m. However, areas exhibiting moderate to high salinity levels require particular attention, as such conditions may reduce rice productivity through stomatal closure, decreased photosynthetic rates, reduced chlorophyll content, and diminished potassium and calcium availability (Nasrudin & Fahmi, 2022).

Soil salinity levels in a given area are influenced by multiple factors, including rainfall, rock weathering, wind-driven transport of materials from soil surfaces or lakes, irrigation water quality, seawater intrusion into inland areas, climatic conditions, and anthropogenic activities (Masganti *et al.*, 2023). Increases in soil salinity generally occur as a result of the upward movement of saline groundwater through capillary rise, particularly in areas with poor drainage and high evaporation rates (Nick *et al.*, 2024). Conversely, salinity decreases in areas with efficient water flow and optimal salt leaching due to high rainfall or well-managed irrigation water distribution (Tameno *et al.*, 2020). Based on spatiotemporal analysis, soil salinity levels in irrigated paddy fields in Cidadap Village exhibited significant fluctuations from 2020 to 2024 (Fig. 5). EC values, as the primary salinity indicator, show that most agricultural land falls within the non-saline to low-salinity categories; however, localized increases in EC were observed at several sites, particularly in the central and eastern parts of the paddy field area, indicating the accumulation of dissolved salts (Fig. 6). The accumulation of soluble salts in soil can impair plant water uptake, disrupt metabolic processes, and consequently reduce growth rates and productivity

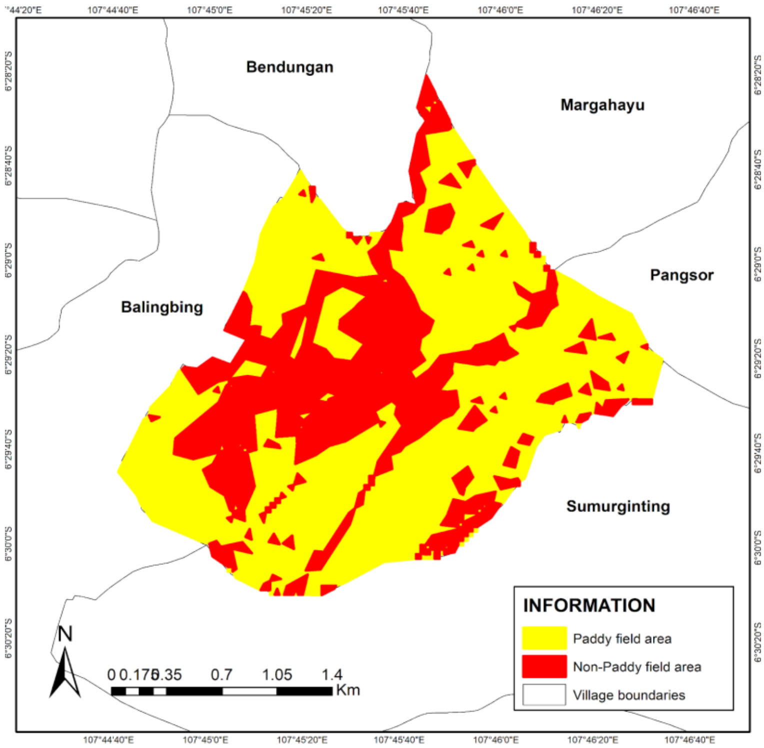

Figure 4 Classification of paddy field and non-paddy land cover

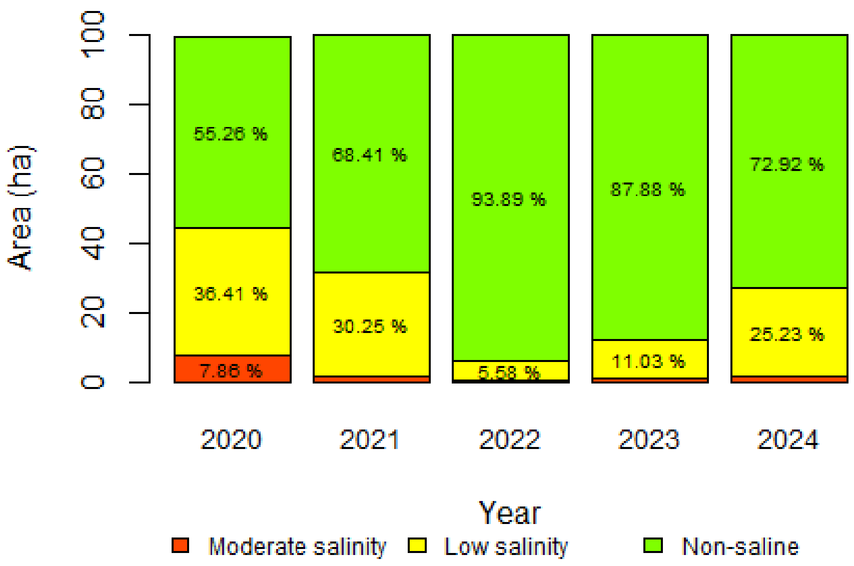

Figure 5 Salinity level trends in paddy field areas

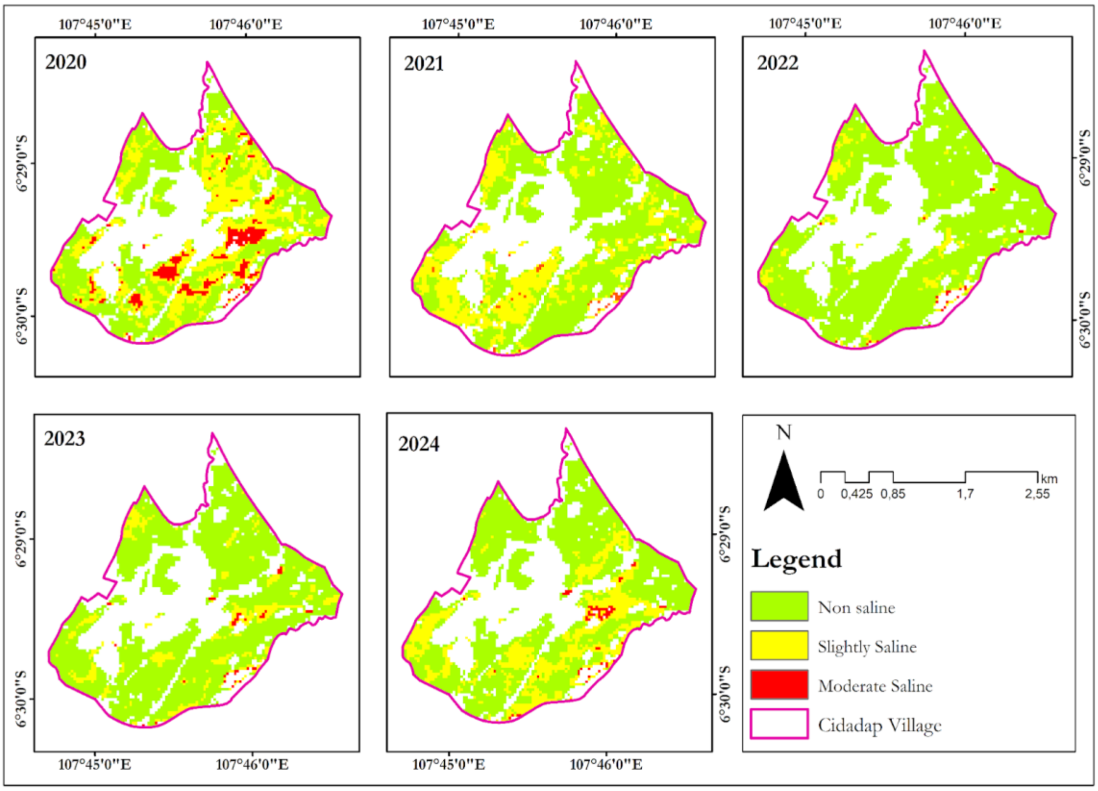

Figure 6 Spatiotemporal map of salinity levels in paddy field areas

(Karolinoerita & Yusuf, 2020). According to Lusiani *et al.* (2018), higher rainfall in a region leads to increased river discharge and lower salinity levels. Similarly, high rainfall in saline areas can reduce salt concentrations through enhanced leaching processes (Hamidah *et al.*, 2025).

Data Indo INAPAD Platform

The visualization of irrigated paddy field salinity levels is presented through the Data Indo InaPad platform (https://ee-dataindo ssrs.projects.earthengine.app/view/inapad), utilizing a cloud-computing framework based on Google Earth Engine Apps. This approach simplifies access to and interpretation of spatial salinity data for users without a GIS background. Salinity levels across the study area are differentiated using a color-coded map, where red indicates moderate salinity, yellow represents low salinity, and green denotes non-saline conditions. A similar approach was applied by Saputri *et al.* (2024) to monitor the physical conditions of peatland ecosystems and to support sustainable peatland management in Indonesia. Furthermore, Earth Engine Apps have also been employed to present spatial data within the AgriForScape landscape management framework to implement ecosystem design optimization strategies for effective pest control, thereby enhancing rice productivity and strengthening food security under climate change conditions (Tiyas *et al.*, 2024). Other studies have developed cloud-based platforms for rapid first-level disaster damage assessment to support effective mitigation and rehabilitation planning (Jauhary *et al.*, 2025). An additional advantage of Earth Engine Apps lies in their ability to provide direct access to GEE datasets without requiring data downloads, allowing information to be accessed anytime and anywhere, and serving as a comprehensive and user-friendly information source for diverse stakeholders (Amani *et al.*, 2020). The visualization results are displayed on the Data Indo InaPad platform (Fig. 7).

Conclusion

The assessment of irrigated paddy soil quality in Cidadap Village, Subang Regency, during the 2020–2024 period indicates that salinity conditions generally fall within the non-saline to low-salinity categories, with EC values predominantly ranging from 1.8 to 3.6 dS/m. Nevertheless, several localized areas exhibited increases toward moderate salinity levels (>4 dS/m), particularly in zones influenced by uneven irrigation water distribution, rainfall variability, and local hydrological conditions. The development of the Data Indo InaPad platform provides interactive and near–real-time visualization of salinity conditions, thereby supporting

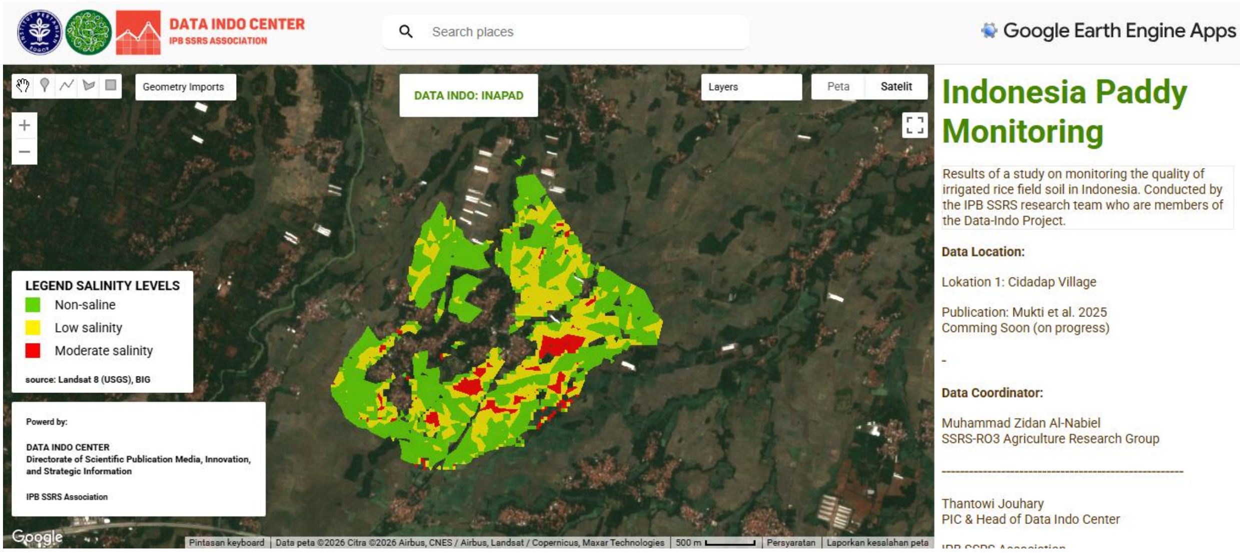

Figure 7 Spatiotemporal map of salinity levels in paddy field areas (https://ee-dataindo-ssrs.projects.earthengine.app/view/inapad)

informed decision-making processes for more adaptive and sustainable management of irrigated paddy fields. At the regional scale, the findings of this study can serve as a basis for irrigation management planning and salinity mitigation in major rice production areas, while at the national scale, the proposed approach and platform have the potential to be replicated as a paddy soil quality monitoring system to support food security and evidence-based agricultural policy formulation.

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