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# Irrigation Performance, Drainage Conditions and Soil Fertility in the Susoh Irrigation Area, Indonesia

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**ABSTRACT**

Sustainable management of irrigated rice systems requires an integrated understanding of irrigation performance, drainage conditions, and soil fertility status. This study evaluated these components in the Susoh Irrigation Area (Susoh IA), Southwest Aceh, Indonesia. Field observations, interviews with P3A representatives, and soil sampling and analyses were conducted in 2024. Water availability, planting area, and rice productivity data referred to 2023, while irrigation performance and soil fertility were assessed using the Indonesian irrigation performance assessment standard and soil fertility criteria from the Bogor Soil Research Center, respectively. The irrigation system obtained an overall performance score of 75.72%, indicating good performance. Planting productivity was a major strength, whereas drainage channels, documentation, and operation and maintenance support facilities were the principal weaknesses. The aggregate water-supply-to-demand ratio calculated from the 2023 records was approximately 1.44, indicating that recorded water availability exceeded demand at the aggregate assessment level. Rice productivity in 2023 was 7.32 t $ha^{-1}$, slightly higher than the regency average. In contrast, the five soil samples collected in 2024 were classified as having low chemical fertility status based on the combined assessment of the five soil chemical indicators. These findings support considering drainage and soil fertility alongside irrigation performance when identifying management priorities.

## 1. INTRODUCTION

Irrigated agricultural systems play an important role in maintaining food security, particularly in regions where productivity depends on reliable water distribution and efficient water resource management. Under increasing pressure from climate variability, irregular rainfall, and the need to use limited water resources more efficiently, sustainable irrigation management has become essential for maintaining agricultural production and conserving natural resources [1]. Irrigation infrastructure supports crop water supply, planting intensity, and yield stability; however, its performance may decline due to inefficient water distribution, suboptimal operation and maintenance, infrastructure deterioration, and weak institutional management [2]. In Aceh, agricultural water-footprint assessment has also identified irrigated paddy rice as a major component of agricultural water use, highlighting the importance of irrigation efficiency and integrated water-resource management [3].

Nevertheless, irrigation adequacy alone does not ensure sustained productivity when drainage conditions, soil fertility, and land suitability remain limiting. Soil properties such as texture, drainage condition, organic carbon, cation exchange capacity (CEC), base saturation (BS), pH, and nutrient availability influence nutrient retention, root-zone conditions, and land suitability for irrigated rice cultivation [4, 5]. In irrigated areas, soil and water-related constraints, including drainage conditions, groundwater dynamics, and nutrient limitations, can influence land management decisions and long-term agricultural productivity [6, 7]. Evidence from Indonesian rice systems further indicates that agricultural sustainability needs to be considered beyond production performance alone by incorporating environmental and management dimensions [8]. Therefore, evaluating irrigation performance together with drainage conditions and soil fertility provides a more comprehensive basis for identifying constraints in irrigated agricultural systems.

Aceh Province is one of Indonesia's important rice-producing regions [9]. The Susoh Irrigation Area (Susoh IA), located in Blangpidie District, Southwest Aceh Regency, is one of the important irrigation systems in the province. It is an important rice-producing area in Southwest Aceh Regency and supports regional food production. Irrigation water is diverted from the river through Susoh Weir and distributed through the irrigation network serving five sub-districts: Blangpidie, Susoh, Jeumpa, Setia, and Tangan-Tangan [10].

In Indonesia, irrigation system performance is commonly evaluated based on the Regulation of the Minister of Public Works and Public Housing No. 12/PRT/M/2015, which includes six indicators: physical infrastructure, planting

productivity, operation and maintenance support facilities, personnel organisation, documentation, and Water User Farmers Association (P3A) institutions [11]. Irrigation performance evaluation is also important for improving water-use efficiency, optimising limited water resources, supporting agricultural productivity, and informing evidence-based irrigation management strategies [12, 13].

Although irrigation performance and soil fertility are closely related to agricultural productivity, their combined evaluation remains limited in Susoh IA. An overall irrigation performance score may indicate satisfactory system operation while still concealing specific field-level constraints related to drainage and soil nutrient status. The contribution of this study is therefore the integrated interpretation of an established irrigation performance framework together with drainage observations and laboratory-based soil fertility information.

This study examined whether satisfactory irrigation performance and sufficient water availability could coexist with drainage and soil fertility limitations, highlighting the importance of considering these components together rather than relying solely on the overall irrigation performance score. Accordingly, this study aimed to jointly assess irrigation performance, drainage conditions, and soil fertility status to identify physical, institutional, water-related, and soil-related management constraints relevant to irrigated rice production in Susoh IA.

## 2. METHODOLOGY

### 2.1 Study area and research design

This study was conducted in the Susoh IA, Southwest Aceh Regency, Aceh Province, Indonesia, from June to December 2024. The area is centrally managed through the Southwest Aceh Regency Public Works and Spatial Planning Agency. The study area, field observation points, and soil sampling locations are presented in Figures 1, 2, and 3, respectively.

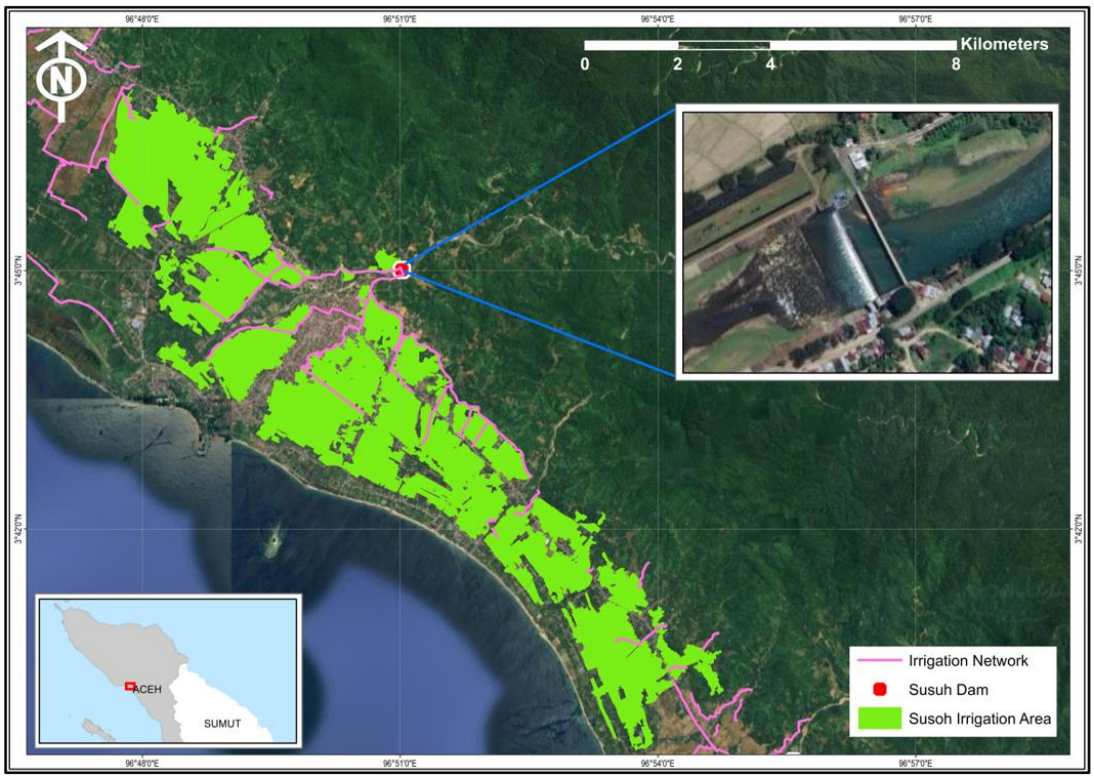


**Figure 1.** Study area of the Susoh Irrigation Area (Susoh IA) in Southwest Aceh Regency, Indonesia

The study used a survey approach with descriptive qualitative and quantitative analyses. Primary data were collected from June to December 2024 through field observations of irrigation network conditions, interviews with P3A representatives, and soil sampling and analysis. Secondary data included irrigation network diagrams, irrigation area maps, cropping information, and the organisational structure of operation and maintenance personnel. Water availability and cumulative planting-area data for 2023 were obtained from records of Balai Wilayah Sungai Sumatera-1, while rice productivity data for the same year were obtained from the Department of Agriculture and Food of Southwest Aceh Regency. These historical records were combined with field observations, interviews, and soil assessments conducted in 2024 to provide a descriptive assessment of complementary irrigation performance, water availability, planting productivity, and soil conditions rather than to establish direct temporal comparisons or causal relationships. Differences in the reference periods were therefore considered when interpreting the findings.

Field observations were conducted at 14 observation points covering different aspects of the irrigation system, including intake structures, irrigation channels, division gates, and soil-related observations. These observation points are shown in Figure 2. The five soil sampling locations (ST1–ST5) are presented separately in Figure 3 to distinguish them from the broader field observation network.

Institutional information was collected through in-depth interviews with members of five Water User Farmers Associations (P3A). Eight respondents were selected from each P3A, representing approximately 10% of the average membership of 80 members per organisation, resulting in 40

respondents. Respondents were selected from active P3A members who had at least one year of membership and experience participating in organisational or irrigation management activities. Interviews focused on participation in irrigation meetings, maintenance activities, and financial contributions. Additional institutional information was obtained from the P3A chairperson and the Susoh IA observer.

Interview responses were analysed descriptively according to the P3A institutional assessment indicators, including participation in irrigation meetings, maintenance activities, and financial contributions. The responses were summarised under these indicators without formal thematic coding. The findings were considered alongside institutional assessment records and field observations to support the interpretation of P3A performance.

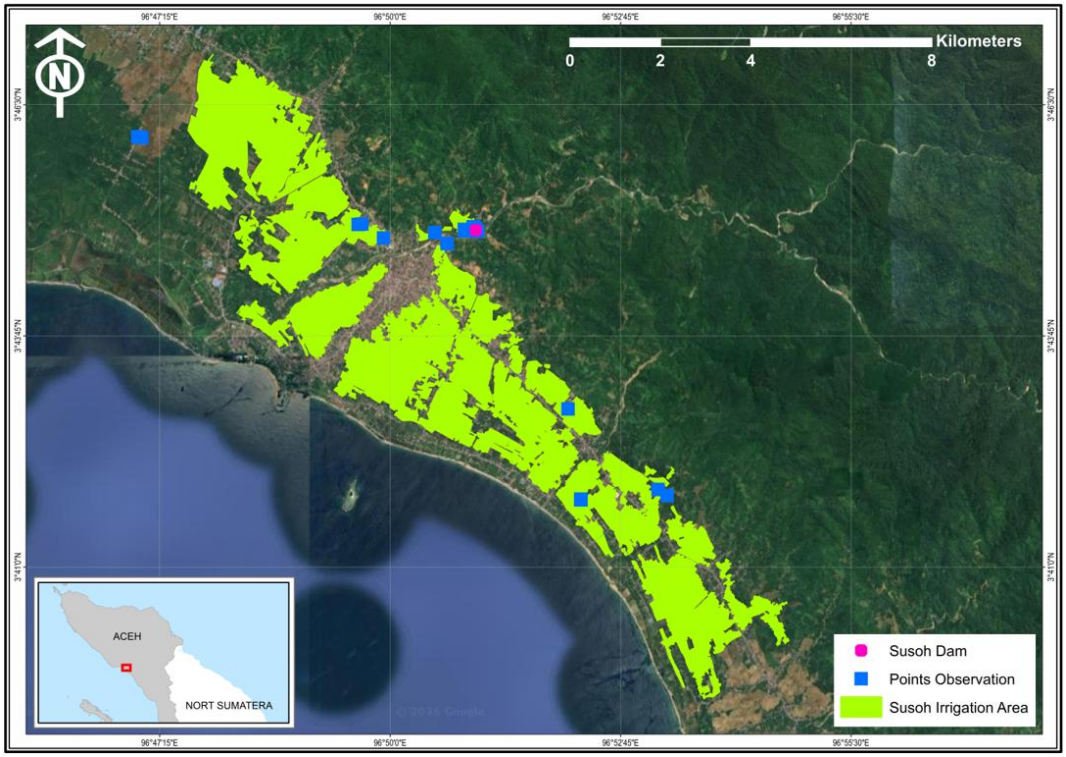


**Figure 2.** Locations of 14 field observation points used in the irrigation system and soil-related field assessments in the Susoh Irrigation Area (Susoh IA), Southwest Aceh Regency, Indonesia

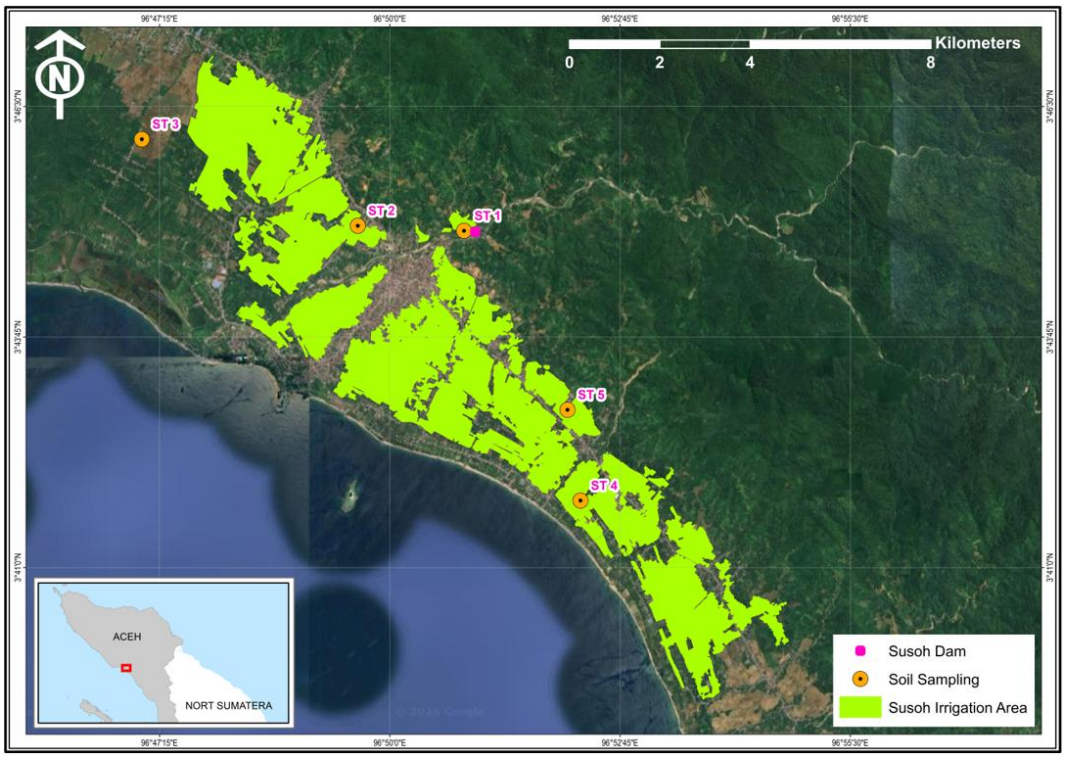


**Figure 3.** Locations of five soil sampling sites (ST1–ST5) within the Susoh Irrigation Area (Susoh IA), Southwest Aceh Regency, Indonesia

## 2.2 Irrigation system performance assessment

Irrigation system performance was assessed according to the Regulation of the Minister of Public Works and Public Housing No. 12/PRT/M/2015 [11]. The overall performance categories were classified as very good (80–100%), good (70–<80%), poor and requiring attention (55–<70%), and very poor and requiring attention (<55%).

Six components were evaluated: physical infrastructure (45%), planting productivity (15%), operation and maintenance support facilities (10%), personnel organisation (15%), documentation (5%), and P3A institutional conditions (10%), following Regulation No. 12/PRT/M/2015 [11]. Each subcomponent was assigned a performance condition score (PCS) ranging from 0 to 100% based on the applicable assessment indicators and supporting field observations or administrative records. Performance ratings were assigned through joint assessments involving the research team and relevant irrigation personnel or P3A representatives, depending on the component evaluated. The final score for each subcomponent was calculated by multiplying its performance rating by the corresponding standard weight and dividing by 100. These scores were aggregated to obtain the final score for each of the six components, and the overall irrigation performance score was calculated by summing the six component scores. The same weighted scoring formula was applied consistently across all components, although the indicators and supporting evidence used to assign performance ratings differed according to the component being evaluated. Normalised scores were calculated as (final score / standard weight) × 100 to facilitate comparisons among components with different standard weights.

For physical infrastructure, condition assessments were guided by the damage classifications specified in Regulation No. 12/PRT/M/2015: good condition (0–10% damage), minor damage (10–20%), moderate damage (21–40%), and severe damage (>40%). These categories served as reference points for assessing infrastructure conditions, whereas the numerical PCS values reflected the recorded assessment of individual subcomponents. The damage categories did not, by themselves, define a unique numerical PCS within each category. Non-physical components were assessed using their respective performance indicators and supporting administrative or institutional records.

As an example of the weighted scoring procedure, the spillway PCS was calculated from two recorded condition ratings: 90% for the spillway crest and 80% for the sluice-gate pier, resulting in PCS = (90 + 80)/2 = 85%. With a standard weight score (SWS) of 0.80%, the final weighted score (FWS) was (85 × 0.80)/100 = 0.68%. Similarly, the documentation component comprised four assessed subcomponents with PCS values of 60%, 70%, 0%, and 60%, and corresponding SWS values of 2%, 1%, 1%, and 1%. The resulting FWS was 2.50%, equivalent to 50.00% of the component's maximum standard weight. A summary of the irrigation performance results is provided in Appendix Table A1, while detailed subcomponent ratings, rating criteria, standard weights, FWS, supporting evidence, and assessor roles are provided in Supplementary Table S1. Worked examples of performance scoring are presented in Appendix Note A1.

Physical infrastructure was assessed through field observations along the irrigation network from upstream to downstream. The assessment covered main structures, conveyance channels, structures in conveyance channels, drainage channels and their structures, access and inspection roads, and offices, housing, and storage facilities. Planting productivity was assessed using Factor K, realised planting area, and rice productivity. Factor K was defined as the ratio of available irrigation discharge to required irrigation discharge at the diversion weir, following the irrigation operation framework in Regulation No. 12/PRT/M/2015 [11]. For the water-adequacy performance assessment, the aggregate Factor K was calculated as the ratio of the summed reported water availability values to the corresponding water requirement values for the two planting seasons. The Factor K performance rating was calculated as K × 100% for K values below 1.0, with the maximum rating capped at 100% for K ≥ 1.0. The seasonal Factor K values were also reported separately to describe differences in water availability between planting seasons.

For example, the recorded water availability and requirements were 57.54 and 33.62 $m^3/s$ for MT I, giving K = 57.54/33.62 = 1.71, and 44.34 and 37.04 $m^3/s$ for MT II, giving K = 44.34/37.04 = 1.20. The aggregate Factor K was (57.54 + 44.34)/(33.62 + 37.04) = 1.44. As the aggregate K exceeded 1.0, the maximum PCS of 100% was assigned according to the applied scoring rule. With an SWS of 9.00%, the corresponding FWS was (100 × 9.00)/100 = 9.00%.

The P3A institutional assessment covered legal and organisational status, participation in irrigation meetings, involvement in planning and maintenance activities, financial contributions to tertiary channel improvements, and participation in monitoring and evaluation. Performance ratings were assigned to these indicators according to the irrigation performance assessment framework, and the corresponding weighted scores were aggregated to determine overall P3A institutional performance. Interview findings were considered alongside institutional assessment records to support the interpretation of P3A performance.

## 2.3 Soil fertility status assessment

Soil fertility status was assessed using five chemical parameters: CEC, BS, $P_2O_5$, $K_2O$, and organic carbon. Five non-composite soil samples (ST1–ST5) were collected from rice fields within quaternary irrigation plots in the Susoh IA during the field survey conducted on 12–14 July 2024. Sampling locations were selected purposively within quaternary irrigation plots, taking into consideration the relative homogeneity of the soil conditions at the selected rice-field locations. Soil samples were collected at a depth of 0–30 cm and submitted to the Soil and Plant Research Laboratory, Faculty of Agriculture, Universitas Syiah Kuala, on 16 July 2024. The laboratory report was issued on 1 August 2024. The sampling locations are presented in Figure 3. The soil fertility assessment was limited to these five sampling locations and was not assumed to represent the entire Susoh IA.

Soil samples were air-dried, crushed, and passed through a 2-mm sieve before chemical analysis. Soil chemical analyses were conducted in duplicate. Soil structure was assessed through field observations, while soil texture was determined using the sieving and pipette methods. Soil permeability was measured using the constant-head method based on Darcy's law, with moderate permeability corresponding to 2.00–6.25 $cm\ h^{-1}$.

Soil chemical analyses were performed using established methods consistent with those described in the study [14]. Organic carbon was determined using the Walkley–Black

method. Phosphorus and potassium were analysed as HCl (25%)-extractable $P_2O_5$ and $K_2O$, respectively, and expressed in mg/100 g of soil. CEC and exchangeable Ca, Mg, K, and Na were determined using 1 N ammonium acetate ($NH_4OAc$) extraction at pH 7. For CEC determination, the soil exchange complex was saturated with $NH_4^+$, excess extraction solution was removed by alcohol washing, and the retained ammonium was subsequently determined to calculate CEC, expressed in cmol(+)/kg. Exchangeable $K^+$ and HCl-extractable $K_2O$ represent different soil potassium fractions determined using different extraction methods and are not directly interchangeable. HCl-extractable $K_2O$ was used for soil fertility classification, whereas exchangeable $K^+$ was included in the assessment of exchangeable base cations. Soil pH was assessed in the field using a portable soil pH meter but was not included in the chemical fertility classification.

Soil fertility was classified according to the criteria established by the Bogor Soil Research Center (Table 1) [14].

**Table 1.** Classification criteria for soil chemical properties

| Soil Properties | Very Low (VL) | Low (L) | Moderate (M) | High (H) | Very High (VH) |
|---|---|---|---|---|---|
| Organic carbon (%) | <1 | 1–2 | 2.01–3.00 | 3.01–5.00 | >5 |
| $P_2O_5$ HCl 25% (mg/100 g) | <10 | 10–20 | 21–40 | 41–60 | >60 |
| $K_2O$ HCl 25% (mg/100g) | <10 | 10–20 | 21–40 | 41–60 | >60 |
| Base saturation (%) | <20 | 20–35 | 36–50 | 51–70 | >70 |
| Cation exchange capacity (CEC) (cmol(+)/kg) | <5 | 5–16 | 17–24 | 25–40 | >40 |

Notes: Classification criteria are based on the Bogor Soil Research Center, as cited in the study [14].

**Table 2.** Combination of soil chemical properties and soil fertility status

| No. | CEC | BS | $P_2O_5$, $K_2O$, Organic C | Fertility Status |
|---|---|---|---|---|
| 1 | H | H | ≥2 H without L | High |
| 2 | H | H | ≥2 H with L | Moderate |
| 3 | H | H | ≥2 M without L | High |
| 4 | H | H | ≥2 M with L | Moderate |
| 5 | H | H | H > M > L | Moderate |
| 6 | H | H | ≥2 L with H | Moderate |
| 7 | H | H | ≥2 L with M | Low |
| 8 | H | M | ≥2 H without L | High |
| 9 | H | M | ≥2 H with L | Moderate |
| 10 | H | M | ≥2 M | Moderate |
| 11 | H | M | Other combinations | Low |
| 12 | H | L | ≥2 H without L | Moderate |
| 13 | H | L | ≥2 H with L | Low |
| 14 | H | L | Other combinations | Low |
| 15 | M | H | ≥2 H without L | Moderate |
| 16 | M | H | ≥2 M without L | Moderate |
| 17 | M | H | Other combinations | Low |
| 18 | M | M | ≥2 H without L | Moderate |
| 19 | M | M | ≥2 M without L | Moderate |
| 20 | M | M | Other combinations | Low |
| 21 | M | L | 3 H | Moderate |
| 22 | M | L | Other combinations | Low |
| 23 | L | H | ≥2 H without L | Moderate |
| 24 | L | H | ≥2 H with L | Low |
| 25 | L | H | ≥2 M without L | Moderate |
| 26 | L | H | Other combinations | Low |
| 27 | L | M | ≥2 H without L | Moderate |
| 28 | L | M | Other combinations | Low |
| 29 | L | L | All combinations | Low |
| 30 | VL | H, M, L | All combinations | Very Low |

Notes: CEC = Cation Exchange Capacity, BS = Base Saturation, H = High, M = Moderate, L = Low, VL = Very Low. Combinations of Soil Chemical Properties and Soil Fertility Status are based on the Bogor Soil Research Center, as cited in the study [14].

The overall soil fertility status was determined by combining the individual classifications of CEC, BS, $P_2O_5$, $K_2O$, and organic carbon using the classification matrix presented in Table 2. This matrix defines the overall fertility class based on the combination of CEC, BS, and the classifications of the remaining three chemical indicators. For application of the classification matrix, very high (VH) categories were grouped with the high (H) category.

### 2.4 Integrated interpretation

Irrigation performance, drainage conditions, planting productivity, and soil fertility were considered together to identify differences between overall system performance and conditions observed at the sampled locations. The assessment was descriptive and did not test statistical or causal relationships among these indicators.

## 3. RESULTS AND DISCUSSION

### 3.1 Overall irrigation system performance

The irrigation system performance assessment of the Susoh

IA was conducted using six indicators: physical infrastructure, planting productivity, operation and maintenance support facilities, personnel organisation, documentation, and P3A institutional conditions. Based on the detailed weighted component scores, Susoh IA obtained an overall performance score of 75.72%, indicating good performance. Table 3 summarises the weighted performance scores of the six assessment components.

As shown in Tables 3 and 4, planting productivity was the strongest overall component, whereas drainage channels and structures were the weakest physical infrastructure component. Operation and maintenance support facilities and documentation also showed relatively low performance. These findings indicate that Susoh IA can still support rice production, but improvements in drainage, maintenance capacity, technical documentation, and farmer institutional involvement are needed [15]. The contrast between the overall good classification and the weaker performance of specific components also shows that the aggregate performance score should be interpreted together with its individual components.

### 3.2 Physical infrastructure performance and drainage conditions

The physical infrastructure assessment covered main structures, conveyance channels, structures in conveyance channels, drainage channels and their structures, access and inspection roads, and offices, housing, and storage facilities. The summary of physical infrastructure performance is presented in Table 4. Most physical components obtained relatively high final scores, whereas drainage channels and their structures had the lowest score.

**Table 3.** Overall irrigation system performance in Susoh Irrigation Area (Susoh IA)

| Component | Standard Weight (%) | Final Weighted Score (%) | Normalised Performance (%) |
|---|---|---|---|
| Physical Infrastructure | 45.00 | 34.60 | 76.89 |
| Planting Productivity | 15.00 | 14.01 | 93.40 |
| O&M Support Facilities | 10.00 | 5.70 | 57.00 |
| Personnel Organisation | 15.00 | 11.55 | 77.00 |
| Documentation | 5.00 | 2.50 | 50.00 |
| P3A Institutional Conditions | 10.00 | 7.36 | 73.60 |
| Total Irrigation Performance | 100.00 | 75.72 | 75.72 |

Note: Normalised performance (%) = (final weighted score (FWS) / Standard Weight) × 100. Physical infrastructure subcomponent scores are included in the physical infrastructure total and are not added separately to the overall performance index. O&M: Operation and maintenance.

**Table 4.** Summary of physical infrastructure performance in Susoh Irrigation Area (Susoh IA)

| Physical Infrastructure Component | Standard Weight (%) | Final Score (%) | Normalised Score (%) | Main Observed Condition |
|---|---|---|---|---|
| Main structures | 13 | 11.20 | 86.15 | Most weir components were in good to very good condition; weaknesses were found in the staff gauge and the sluice gate and gear mechanism of the sediment basin. |
| Conveyance channels | 10 | 7.60 | 76.00 | Channel capacity was generally adequate, but illegal taps, leakage, sedimentation, and deposits reduced distribution efficiency. |
| Structures in conveyance channels | 9 | 6.73 | 74.78 | Regulation and auxiliary structures were functional, but several gates and water measurement facilities were damaged or incomplete. |
| Drainage channels and structures | 4 | 2.12 | 53.00 | Earthen drainage channels were vulnerable to sedimentation, erosion, seepage, embankment damage, and flooding. |
| Access and inspection roads | 4 | 3.71 | 92.75 | Access to the main structures and inspection routes was generally good, although some secondary channel access was limited. |
| Offices, housing, and storage facilities | 5 | 3.24 | 64.80 | Administrative offices were relatively adequate, but staff housing and storage facilities remained weak. |
| Total physical infrastructure | 45 | 34.60 | 76.89 | Overall physical infrastructure performance was relatively good, with drainage as the weakest component. |

Note: Normalised score (%) = (Final weighted score / Standard weight) × 100.

As shown in Table 4, the main structures obtained an FWS of 11.20% out of a maximum weight of 13%. Susoh Weir has an Ogee-shaped crest and is equipped with a sediment basin. The sediment basin reduces flow velocity and allows sediment deposition before irrigation water enters the conveyance system. Excessive sediment accumulation may reduce storage capacity and disrupt water conveyance, while sediment basin performance is influenced by sediment particle size, discharge, settling velocity, and basin dimensions [16, 17]. Although the main structure was generally functional, the staff gauge and the sluice gate and gear mechanism of the sediment basin require attention.

Conveyance channels and structures in conveyance channels obtained final scores of 7.60% out of 10% and 6.73% out of 9%, respectively. Field observations showed that illegal taps, leakage, sediment deposits, damaged gates, and incomplete water measurement facilities reduced distribution reliability.

Drainage channels and their structures were the weakest physical component, with a final score of 2.12% out of 4%. The drainage channels were predominantly earthen and showed weaknesses in maintenance and embankment condition. Similar drainage and groundwater-related constraints have been reported to influence land management decisions in irrigation schemes [7]. Access and inspection roads obtained 3.71% out of 4%, supporting routine field inspection, while offices, housing, and storage facilities obtained 3.24% out of 5%, indicating that logistical support for operation and maintenance still needs improvement.

These results emphasise that irrigation sustainability

depends not only on delivering water to agricultural land but also on the ability of the system to remove excess water. Consequently, relatively good irrigation infrastructure performance may coexist with drainage limitations that affect field-level soil-water conditions.

### 3.3 Water availability and planting productivity

Planting productivity was assessed using Factor K, realised planting area, and rice productivity. In 2023, the first planting season (MT I) was associated with the rainy season and scheduled to begin in October, while the second planting season (MT II) was associated with the drier season and scheduled to begin in April. The irrigation-water assessment used dependable discharge data derived from river or weir measurements and historical hydrological records. Water availability and irrigation-water requirements were evaluated at 15-day intervals over approximately 120 days per planting season.

According to Balai Wilayah Sungai Sumatera-1 records, irrigation-water availability and requirements were 57.54 and 33.62 $m^3 s^{-1}$ for MT I, and 44.34 and 37.04 $m^3 s^{-1}$ for MT II, respectively. The corresponding Factor K values were 1.71 and 1.20. The aggregate ratio, calculated from the total reported water availability (101.88 $m^3 s^{-1}$) and requirements (70.66 $m^3 s^{-1}$), was approximately 1.44. This ratio represents a descriptive summary rather than a time-weighted assessment and does not exclude temporary water shortages or uneven distribution within the irrigation network. Planting productivity performance is summarised in Table 5.

**Table 5.** Summary of planting productivity assessment in Susoh Irrigation Area (Susoh IA)

| Planting Productivity Component | Standard Weight (%) | Final Score (%) | Normalised Score (%) | Main Observed Condition |
|---|---|---|---|---|
| Factor K | 9 | 9.00 | 100.00 | Seasonal K values were 1.71 and 1.20, with an aggregate ratio of approximately 1.44. As the aggregate ratio exceeded 1.0, the maximum performance rating of 100% was assigned, resulting in a weighted score of 9.00%. |
| Realised planting area | 4 | 3.01 | 75.25 | The cumulative planted area across two planting seasons in 2023 was 4,510 ha, compared with a functional irrigated area of 3,000 ha. The cropping index was 150.33%, while planting-target achievement was 75.17%, based on a target cropping index of 200% (6,000 ha over two seasons). |
| Rice productivity | 2 | 2.00 | 100.00 | Rice productivity reached 7.32 t $ha^{-1}$, slightly higher than the regency average of 7.22 t $ha^{-1}$; therefore, the productivity percentage was recorded as 100% according to the scoring criteria. |
| Total planting productivity | 15 | 14.01 | 93.40 | Planting productivity was the highest-performing major component. |

Note: Normalised score (%) = (Final weighted score / Standard weight) × 100.

As shown in Table 5, the aggregate Factor K was approximately 1.44, exceeding the threshold of 1.0 for the maximum performance rating. Accordingly, Factor K received a performance rating of 100%, resulting in a weighted score of 9.00% out of 9%. The corresponding seasonal K values were 1.71 for MT I and 1.20 for MT II. Although both values indicated sufficient water availability at the seasonal assessment level, the smaller supply margin in MT II highlights the importance of appropriate irrigation scheduling under seasonal variability [1].

In 2023, the cumulative planted area across two planting seasons was 4,510 ha, while the functional irrigated area was 3,000 ha. This corresponded to a cropping index of 150.33% (4,510/3,000 × 100) and a planting-target achievement of 75.17% (4,510/6,000 × 100), based on a target cropping index of 200%. Rice productivity reached 7.32 t $ha^{-1}$, slightly exceeding the Southwest Aceh Regency average of 7.22 t $ha^{-1}$, and received a performance rating of 100% according to the scoring criteria. These findings indicate favourable planting productivity performance, although water availability and rice productivity should be considered alongside the drainage and soil constraints identified in this study.

### 3.4 Operation, maintenance, documentation, and farmer institutions

Operation, maintenance, documentation, and farmer institutional performance were assessed through four components: operation and maintenance support facilities, personnel organisation, documentation, and P3A institutional conditions (Table 6).

Operation and maintenance support facilities obtained a final score of 5.70% out of 10% (Table 6), indicating limitations in routine maintenance tools, personnel equipment, heavy equipment, transportation facilities, and some office equipment. Personnel organisation obtained 11.55% out of 15%, reflecting an established operation and maintenance (O&M) organisational structure but variations in civil servant representation and technical competence among personnel. These findings indicate that field-level support and personnel capacity still require strengthening. Effective irrigation management requires continuous institutional capacity development and trained personnel [18].

Documentation was one of the weakest components, with a final score of 2.50% out of 5%. The irrigation area data book received a performance rating of 60%, while maintenance maps and structure drawings received 0%, indicating important gaps in the available technical documentation. Incomplete documentation may weaken planning and monitoring, while digital or GIS-based records can support irrigation performance assessment and management [19]. The P3A institutional component obtained a weighted score of 7.36% out of 10%. Interview findings further indicated that financial contributions for irrigation maintenance were not collected consistently and that participation in irrigation network inspections was uneven among P3A members. These findings provide additional context for the institutional assessment, particularly the lower ratings for financial contributions and monitoring and evaluation.

The assessment recorded relatively high ratings for participation in irrigation meetings (80%) and maintenance activities (85%), while financial contributions to tertiary

channel improvements (50%) and participation in monitoring and evaluation (55%) received lower ratings. Strengthening farmer participation is therefore important to support irrigation operation and maintenance [20].

These findings indicate that irrigation performance cannot be interpreted solely as an engineering issue. Maintenance resources, personnel capacity, documentation, and farmer participation influence whether infrastructure performance can be maintained over time. This broader interpretation is consistent with sustainability assessments of Indonesian rice farming that recognise environmental and farmer-management dimensions alongside agricultural production [8].

**Table 6.** Operation, maintenance, documentation, and farmer institutional performance in Susoh Irrigation Area (Susoh IA)

| Component | Standard Weight (%) | Final Score (%) | Normalised Score (%) | Main Observed Condition |
|---|---|---|---|---|
| Operation and maintenance support facilities | 10 | 5.70 | 57.00 | Routine maintenance tools, personnel equipment, heavy equipment, transportation facilities, and some office equipment were inadequate or damaged; communication equipment obtained the highest subcomponent score. |
| Personnel organisation | 15 | 11.55 | 77.00 | The O&M organisational structure had been established, but civil servant representation was limited and technical competence varied among personnel. |
| Documentation | 5 | 2.50 | 50.00 | The irrigation area data book was incomplete; maintenance maps and structure drawings were unavailable, while other maps and irrigation network schemes were incomplete. |
| Water User Farmers Association (P3A) | 10 | 7.36 | 73.60 | P3A participation in irrigation meetings and maintenance activities received relatively high ratings, while monitoring and evaluation and financial contributions received lower ratings. |
| Total operation, maintenance, documentation, and institutional components | 40 | 27.11 | 67.78 | Documentation and O&M support facilities were the weakest non-physical components. |

Note: Normalised score (%) = (Final weighted score / Standard weight) × 100. O&M: Operation and maintenance.

**Table 7.** Soil sampling coordinates, chemical properties and fertility status in Susoh Irrigation Area (Susoh IA)

| Sample | Longitude | Latitude | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ | $Na^{+}$ | CEC | BS | $P_2O_5$ | $K_2O$ | OC | Fertility Status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ST1 | 96°50′53.264″ | 3°45′0.965″ | 4.68 | 0.95 | 0.08 | 0.09 | 10.40 (L) | 55.77 (H) | 70 (VH) | 60 (H) | 1.53 (L) | Low |
| ST2 | 96°49′37.099″ | 3°45′4.540″ | 6.14 | 1.36 | 0.08 | 0.09 | 14.80 (L) | 51.82 (H) | 100 (VH) | 20 (L) | 1.85 (L) | Low |
| ST3 | 96°47′2.371″ | 3°46′6.467″ | 7.95 | 1.48 | 0.08 | 0.08 | 20.00 (M) | 47.95 (M) | 210 (VH) | 20 (L) | 1.86 (L) | Low |
| ST4 | 96°52′16.719″ | 3°41′47.915″ | 3.77 | 1.17 | 0.13 | 0.11 | 14.00 (L) | 37.00 (M) | 130 (VH) | 30 (M) | 1.98 (L) | Low |
| ST5 | 96°52′7.428″ | 3°42′52.866″ | 4.09 | 1.22 | 0.10 | 0.07 | 10.40 (L) | 52.69 (H) | 50 (H) | 20 (L) | 1.44 (L) | Low |

Notes: $Ca^{2+}$, $Mg^{2+}$, $K^{+}$, and $Na^{+}$ refer to exchangeable cations. Exchangeable cations and cation exchange capacity (CEC) are expressed in cmol(+)/kg; base saturation (BS) and organic carbon (OC) in %; and $P_2O_5$ and $K_2O$ in mg/100 g. L = low; M = moderate; H = high; VH = very high. Soil chemical properties and overall fertility status were classified according to Tables 1 and 2, respectively.

### 3.5 Soil physical and chemical fertility status

Field observations indicated blocky soil structure in ST1, ST2, and ST5 and angular blocky structure in ST3 and ST4. Soil textures were classified as loam (ST1), silt loam (ST2 and ST5), and clay (ST3 and ST4), with moderate permeability at all five locations. These characteristics may influence soil-water movement and retention, highlighting the importance of appropriate drainage management.

The soil chemical properties and fertility status are presented in Table 7. Calcium and magnesium were the predominant exchangeable base cations. CEC ranged from 10.40 to 20.00 cmol(+)/kg (low to moderate), while BS ranged from 37.00% to 55.77% (moderate to high). Organic carbon was low in all samples (1.44–1.98%). In contrast, HCl (25%)-extractable $P_2O_5$ ranged from 50 to 210 mg/100 g (high to very high), while $K_2O$ ranged from 20 to 60 mg/100 g (low to high).

Based on the classification matrix in Table 2, all five samples were classified as having low overall chemical fertility. For matrix application, the very high category was grouped with the high category. ST1 corresponded to Rule 24, ST2 and ST5 to Rule 26, ST3 to Rule 20, and ST4 to Rule 28. This classification reflects the combined soil chemical properties rather than demonstrated nutrient limitation or crop response. Previous research has also highlighted the importance of maintaining soil fertility under long-term agricultural use [21].

Drainage limitations may increase waterlogging risk and affect nutrient availability and root-zone conditions. However, this study does not establish a causal relationship between drainage conditions and soil fertility. Drainage maintenance, improved operation and maintenance support, and technical documentation should therefore be prioritised. Organic matter enrichment and site-specific nutrient management may also be considered, subject to further evaluation, as previous studies have reported potential benefits of organic amendments and

combined fertilisation [22, 23].

The findings demonstrate that good irrigation performance can coexist with drainage and soil fertility constraints at the evaluated locations. Integrating these assessments provides a broader basis for identifying sustainable irrigation management priorities.

## 4. CONCLUSIONS

The Susoh IA achieved an overall irrigation performance score of 75.72%, indicating good performance. Planting productivity was the strongest component, while drainage channels and structures, operation and maintenance support facilities, and documentation were the main weaknesses. The five soil samples (ST1–ST5) were classified as having low chemical fertility status based on the applied classification criteria.

These findings highlight the importance of supplementing conventional irrigation performance scores with field observations and soil information when identifying management priorities. Drainage maintenance, improved operation and maintenance support, and technical documentation should be considered immediate priorities, while potential soil-management measures, including organic matter enrichment and site-specific nutrient management, require further site-specific evaluation.

The study is limited by the use of datasets from different years (2023 and 2024), limited documentation of the original item-level irrigation performance assessments, restricted spatial coverage of soil sampling, and the absence of repeated seasonal drainage and soil observations. Therefore, the findings should be interpreted as a descriptive assessment rather than evidence of causal relationships, long-term sustainability, or the effectiveness of specific management interventions.

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## NOMENCLATURE

| | |
|---|---|
| BS | base saturation, % |
| CEC | cation exchange capacity |
| IA | irrigation area |
| K | ratio of available irrigation water to crop water requirement, dimensionless |
| O&M | operation and maintenance |
| P3A | Water User Farmers Association |

## APPENDIX

**Table A1.** Summary of irrigation system performance assessment

| Component | Standard Weight (%) | Final Weighted Score (%) | Normalised Performance (%) |
|---|---|---|---|
| **I. Physical Infrastructure** | **45.00** | **34.60** | **76.89** |
| Main Structures | 13.00 | 11.20 | 86.15 |
| Conveyance Channels | 10.00 | 7.60 | 76.00 |
| Structures in Conveyance Channels | 9.00 | 6.73 | 74.78 |
| Drainage Channels and Their Structures | 4.00 | 2.12 | 53.00 |
| Access and Inspection Roads | 4.00 | 3.71 | 92.75 |
| Offices, Housing, and Storage Facilities | 5.00 | 3.24 | 64.80 |
| **II. Planting Productivity** | **15.00** | **14.01** | **93.40** |
| **III. O&M Support Facilities** | **10.00** | **5.70** | **57.00** |
| **IV. Personnel Organisation** | **15.00** | **11.55** | **77.00** |
| **V. Documentation** | **5.00** | **2.50** | **50.00** |
| **VI. P3A Institutional Conditions** | **10.00** | **7.36** | **73.60** |
| **Total Irrigation Performance** | **100.00** | **75.72** | **75.72** |

Note: Normalised performance (%) = (FWS / Standard Weight) × 100. Physical infrastructure subcomponent scores are included in the physical infrastructure total and are not added separately to the overall performance index.

**Note A1. Worked Examples of Performance Scoring**

**Example 1. Spillway Assessment**

The spillway condition was evaluated based on two inspection criteria: the physical condition of the spillway crest (90%) and the condition of the sluice-gate pier (80%). The Performance Condition Score (PCS) was calculated as follows:

$$PCS = \frac{(90 + 80)}{2} = 85\%$$

With a Standard Weight Score (SWS) of 0.80%, the Final Weighted Score (FWS) was:

$$FWS = \frac{(85 \times 0.80)}{100} = 0.68\%$$

Thus, the spillway contributed 0.68 percentage points to the overall irrigation performance index.

**Example 2. Documentation Assessment**

The documentation component consisted of four assessed subcomponents with PCS values of 60%, 70%, 0%, and 60%, and corresponding SWS values of 2%, 1%, 1%, and 1%, respectively.

The FWS was calculated as:

$$FWS = \frac{(60 \times 2) + (70 \times 1) + (0 \times 1) + (60 \times 1)}{100} = 2.50\%$$

The normalised documentation performance was:

$$Normalised\ performance\ = \frac{2.5}{5.00} \times\ 100 = 50.00\%$$

Thus, the documentation component achieved 50% of its maximum standard weight and contributed 2.50 percentage points to the overall irrigation performance index.