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Optimization Strategies for Tidal Swamp Irrigation Operation Based on Hydroinformatics: Research Trends and Future Gaps

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ABSTRACT

Tidal swamp irrigation management faces complex challenges due to hydrological dynamics, fluctuations in water quality (pH and salinity), and limitations of manual operating systems. This article presents a systematic literature review (SLR) on the development of the Operation and Maintenance (O&M) optimization model of swamp irrigation networks with the integration of hydroinformatics technology. Using the PRISMA protocol, this study reviewed the literature from reputable databases (Scopus, ScienceDirect, and Google Scholar) in the 2015-2025 time frame. The results of the review show a methodological shift from conventional rule-based approaches towards IoT-based decision-making systems, real-time sensors, and advanced optimization algorithms such as MILP and NMPC. Key findings identify research gaps in the integration of multi-criteria optimization models that bring together aspects of agricultural production, energy efficiency, and wetland environmental protection in near real-time. This article provides a roadmap for the development of future decision support systems (DSS) for swamp irrigation, especially in the context of tidal lands in Indonesia.

Keywords: swamp irrigation, hydroinformatics, O&M Optimization, Decision Support Systems, PRISMA.

INTRODUCTION

Swamp/tidal irrigation systems have typical hydrological dynamics influenced by sea tides, shallow groundwater level interactions, and water quality (pH/EC/salinity) so that their operation and maintenance patterns cannot be equated with ordinary land irrigation [1, 2, 3]. The groundwater level response and salinity to the shear signal show different time-lags and attenuation according to topographic conditions and soil structure (capillaries-macropores), which demands a door/pump operation policy that is adaptive to daily and seasonal dynamics [18]. In acidic peatlands/sulfates, the entry of brackish water during certain phases of sludge can neutralize acidity but at the same time increase EC, so a one-way operation strategy with flap gates is often needed to maintain water quality and soil health [4].

Research on swamp systems in South Sumatra shows that proper water level regulation in tertiary plots is able to suppress pyrite oxidation and maintain nutrient availability, so that rice productivity increases significantly [5]. Sluice gate operation with a closure of 40–50 cm during the vegetative phase has been shown to maintain the water level and improve the quality of sour sulfate soils, while in the generative phase the direction of the door is changed inwards to hold the recede water [5, 6]. This principle underlies the controlled drainage strategy that is now widely adopted in the design of swamp irrigation operations.

In coastal areas that rely on groundwater pumping, excess pressure triggers salt intrusion and soil subsidence, so that safe yield calculations based on hydrogeological simulations are a prerequisite for the sustainability of irrigation services [7]. Institutionally, the improvement of service performance is determined not only by the physical improvement of the network, but also by the reliability of the water supply, service indicators, as well as non-physical factors such as the attack of plant pest organisms and the climate [8]. Water reliability has been proven to be positively correlated with the productivity of farming, so it is worthy of being used as an indicator of goals in managing network operations [9]. Farmer participation in collective maintenance also determines the sustainability of O&P, with significant influences from social, institutional, and water cost incentives [10].

In addition to the technical aspect, [11] emphasized that the key to the success of agricultural cultivation in swampland is the extent to which farmers are able to carry out water system network operations according to the needs of plants, time, and place. Water management in tidal areas not only removes excess water, but also maintains the depth of the groundwater table, prevents saline intrusion, and washes acidic substances in the root zone. An integrated approach from macro (primary-secondary) to micro (tertiary) networks must be carried out simultaneously so that water supply is stable and soil quality is maintained [12].

Advances in hydroinformatics—including IoT/WSN, GIS/RS integration, and data-driven/AI-driven analytics—have led to the birth of a "smart" irrigation framework from the manual level to the supervisory/farmerless level, but its adoption in the field is still constrained by cost, interoperability, and communication infrastructure [13, 14]. IoT-AI pipelines for water demand prediction (e.g. metaheuristically optimized LSSVMs) have shown increased accuracy and reliability as a data feed for operational decision modules [38]. In the context of Indonesian swamps, data digitization initiatives and performance indicators through platforms such as SIRAISA show the need and opportunity to incorporate asset-performance data into a Decision Support System for O&M.

At the decision-making level, the optimization/control approach offers a systematic way to schedule doors and pump operations with a variety of objectives and constraints: MILP for realistic door scheduling, NMPC to minimize leaks/seepage through low-level strategies, and surrogate-based MIQP to accelerate computing towards near-real-time operations [14]. On the supply side, surface water utilization (SWI) can reduce dependence on groundwater and is geospatially feasible for location targeting, while an "ecological compensation allocation" policy is needed so that on-farm efficiency does not trigger a rebound in consumption at the watershed scale and harm wetlands [16].

Thus, a hydroinformatics-based swamp irrigation network operation and maintenance optimization model is needed that brings together real-time/near-real-time field data, hydrometeorological and water quality predictions, as well as multi-criteria decision formulation (production, service reliability, O&M/energy costs, and environmental protection) that is compatible with local practices of door/pump operation [17]; Valley, 2018; Permana, 2024; Putra et al., 2022; Hadi et al., 2024; Pakpahan et al., 2014; Dantas et al., 2025; S u et al., 2022; Conde et al., 2025; Don et al., 2006; Imanudin et al., 2011; Imanudin, 2022). Especially in the Indonesian context—especially the tidal swamps in Kalimantan—these needs are urgent and the focus of this research.

Although research on individual components such as groundwater sensors or door scheduling optimization algorithms has developed, a comprehensive review integrating these aspects in the framework of swamp irrigation O&M is still limited. This article aims to conduct a systematic synthesis of the current literature in order to answer questions about the most effective optimization techniques, the role of hydroinformatics in decision-making, as well as the identification of research gaps for future model development.

Swamp Land

Swamp land is soil that forms in areas with permanent and seasonal waterlogged conditions. Based on Government Regulation No. 73 of 2013, swamps are defined as water containers and the water power contained in them, are continuously or periodically flooded, are formed naturally on flat or concave land with mineral or organic deposits (peat), and are overgrown with certain vegetation.

Acidic sulfate soils on the coast are formed from marine deposits rich in sulfate and iron; when exposed to oxygen, pyrite (FeS_2) oxidizes to sulfuric acid (H_2SO_4) which lowers pH, increases Al/Fe solubility, and interferes with nutrient uptake [18]. Therefore, the water table must be maintained above the sulfide layer as a basic condition for network operation [19].

In flooded conditions, the diffusion of O_2 decreases sharply so that the activity of pyrite-oxidizing microbes is depressed and some sulfates can be reduced again; this practice lowers Fe/Al toxicity

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and raises soil pH [16]. Water level management that maintains a reductive atmosphere is therefore a key element of the operation design [20].

Swamp land has a strategic role in supporting sustainable development, but it also requires careful management so as not to cause environmental problems, such as ecosystem degradation, soil subsidence, and the release of greenhouse gas emissions

Basic Concepts and Definitions of Tidal Swamp Irrigation

Tidal swamp irrigation is the management of water systems on flat land that are influenced by tides so that the groundwater level (MAT), salinity, and water quality of canals fluctuate according to the cycle of tides and rainfalls; In the hydrotographic typology A–D, type A is most often flooded while type C–D is not flooded but MAT still responds to subsurface sediment [21].

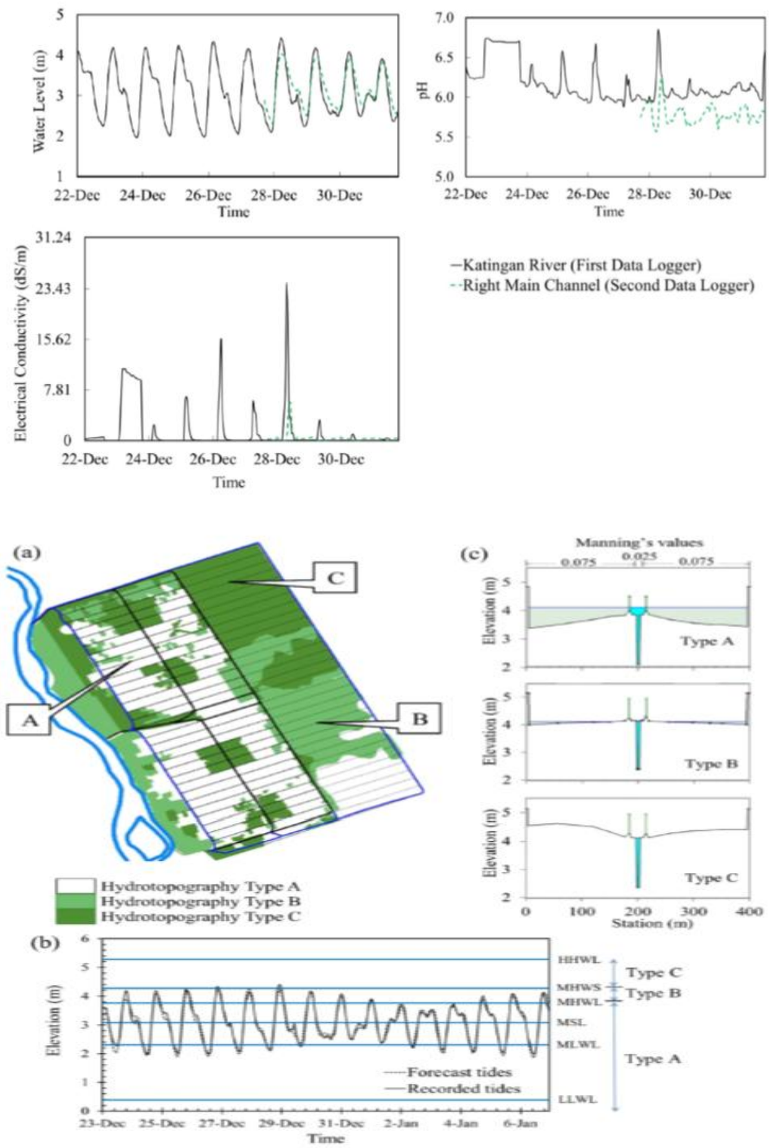

Figure 1. Water level, pH, and EC data recorded by data loggers installed in Sungai Katingan (thick black line) and main channel (dotted line) Source: Hadi, 2024

In muddy mangrove environments, MAT and salinity responses show different time-lag and attenuation between the shallow zone (dominant macropore) and the middle zone; the amplitude of the mudflat response tends to be greater in fringe/mudflat topography than in riverine [22].

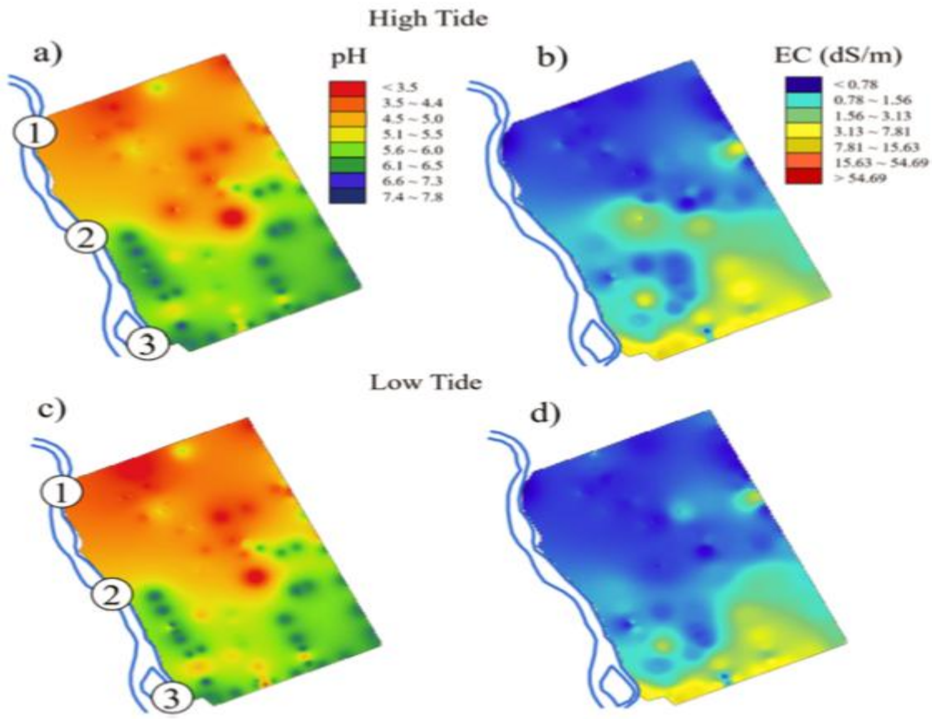

Figure 2. pH and EC maps as representations of acidity and salinity after interpolation, respectively at high tide (a and b) and tidal (c and d) conditions. Source : , 2024

Hydroinformatics integrates data-logger sensors (level, pH/EC), telemetry, GIS/RS, and modeling to support operation decisions; In the Katingan swamp study, the pH-EC level logger data was used as a boundary/initial condition and for calibration of unstable 1D HEC-RAS (advection-dispersion of pH/EC as a conservative constituent), while the water quality map was constructed with QGIS-IDW [17]. On the climate side, FAO-PM/pan-Kp-based ETo estimation and GIS spatial mapping are the backbone of hydrometeorological inputs when data are limited [23].

Network operation & maintenance (O&M) arrangements for opening/closing doors and pump operation to achieve target levels and maintain water quality; in swamps affected by brackish water and acidic peat/sour sulfur, a one-way flow (flap gate) is often chosen to take advantage of pH neutralization by brackish water while suppressing EC spikes and avoiding dead zones [17]. At the tertiary scale, the fuzzy ON/OFF automatic control of the pump/valve has been tested and is able to keep the MAT close to the set-point despite the interference and electrical limitations [24].

The water quality in swamp irrigation shows a distinctive character: peat water tends to be low pH and EC low, while brackish water tends to be near neutral pH but high EC; in Katingan, brackish water influx raises pH (≈5-7) but also raises EC, with different responses according to hydrotopography type and pasut phase, so flushing strategies and door scheduling need to be adjusted [25].

In tidal swamp irrigation, the concept of MAT/salinity swamp response [26], quality monitoring-modeling [27], automatic control at the map scale [28], and network scale optimization/control formulation [29]-is the foundation of the hydroinformatics-based O&M optimization model that will be developed in this dissertation.

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Four forms of networks that are widely adopted—handil/people's trenches, anjir/canalization, forks (GAMA), and combs—answer the hydrotographic variations A–D, from regularly flooded land to those that are not overflowing [30]. The separation of the giving and discharge channels and the installation of automatic doors in the tertiary estuary make one-way flow and flushing effective [31].

The concept of one-way flow is effective when the bottom elevation of the channel is uniform and equipped with doors; in the field, farmers often add connections to make water circulation and acid leaching more intensive, as long as there is control in the tertiary estuary [32].

Tidal Swamp Hydrology

Tidal signals and water level response. In flat swamplands connected to rivers/estuaries, tidal fluctuations control the height of the canal water level and groundwater level (MAT) with different time-lag and damping characteristics according to the nature of the soil and topographic position. Simultaneous monitoring in the shallow root zone and the silt layer (intermediate zone) showed that the amplitude and phase of the piezometric response/salinity followed the dominant pasut constituent (especially M2), but the amplitude in the intermediate zone was much smaller or even zero for salinity; The strongest response appears in fringe/mudflats, weaker in riparian forests further inland. These findings confirm the combined role of macropores (biota/root holes) and capillary effects in modulating the propagation of shale signals to shallow aquifers.

Table 1. Amplitude of the extracted tidal signal and the results of the cross-correlation

Sampling site	Depth (m)	Parameter measured	Amplitude (M2 semidiurnal lunar)	Time lag (h)	Significance
GW1	0.2	Piezometric head	4.59 cm	0.75	0.76
	0.2	Salinity	0.11 psu	0.25	0.75
	1	Piezometric head	0.14 cm	3.5	0.46
	1	Salinity	0.00 psu	-	-
GW2	0.2	Piezometric head	3.33 cm	0.75	0.71
	0.2	Salinity	0.12 psu	0	0.63
	1	Piezometric head	0.09 cm	4.5	0.35
	1	Salinity	0.00 psu	-	-
GW3	0.2	Piezometric head	7.63 cm	0	0.84
	0.2	Salinity	0.10 psu	0	0.85
	1	Piezometric head	0.23 cm	4.25	0.48
	1	Salinity	0.00 psu	-	-
GW4	0.2	Piezometric head	13.87 cm	0	0.88
	0.2	Salinity	0.10 psu	0	0.84
	1	Piezometric head	0.43 cm	3.75	0.51
	1	Salinity	0.00 psu	-	-
GW5	0.2	Piezometric head	12.28 cm	0.75	0.93
	0.2	Salinity	0.17 psu	0.5	0.82
	1	Piezometric head	0.64 cm	3	0.61
	1	Salinity	0.00 psu	-	-

Source: Luo, 2020

Hydrotopography and channel–tile dynamics. In agricultural tidal systems, the A–D typology distinguishes the level of inundation exposure and how strongly the MAT responds to sting; Type A is flooded when the water level passes through the MSL, B when the MHWL >, C is not flooded but MAT is still affected, and D is relatively free from the influence of the sting. Monitoring of the logger–pH–EC level in Katingan and unsteady 1D HEC-RAS modeling showed that pasut drives the exchange of brackish water–peatwater/sour sulfate water masses in the network, with spatial patterns of pH/EC that can be mapped via QGIS-IDW

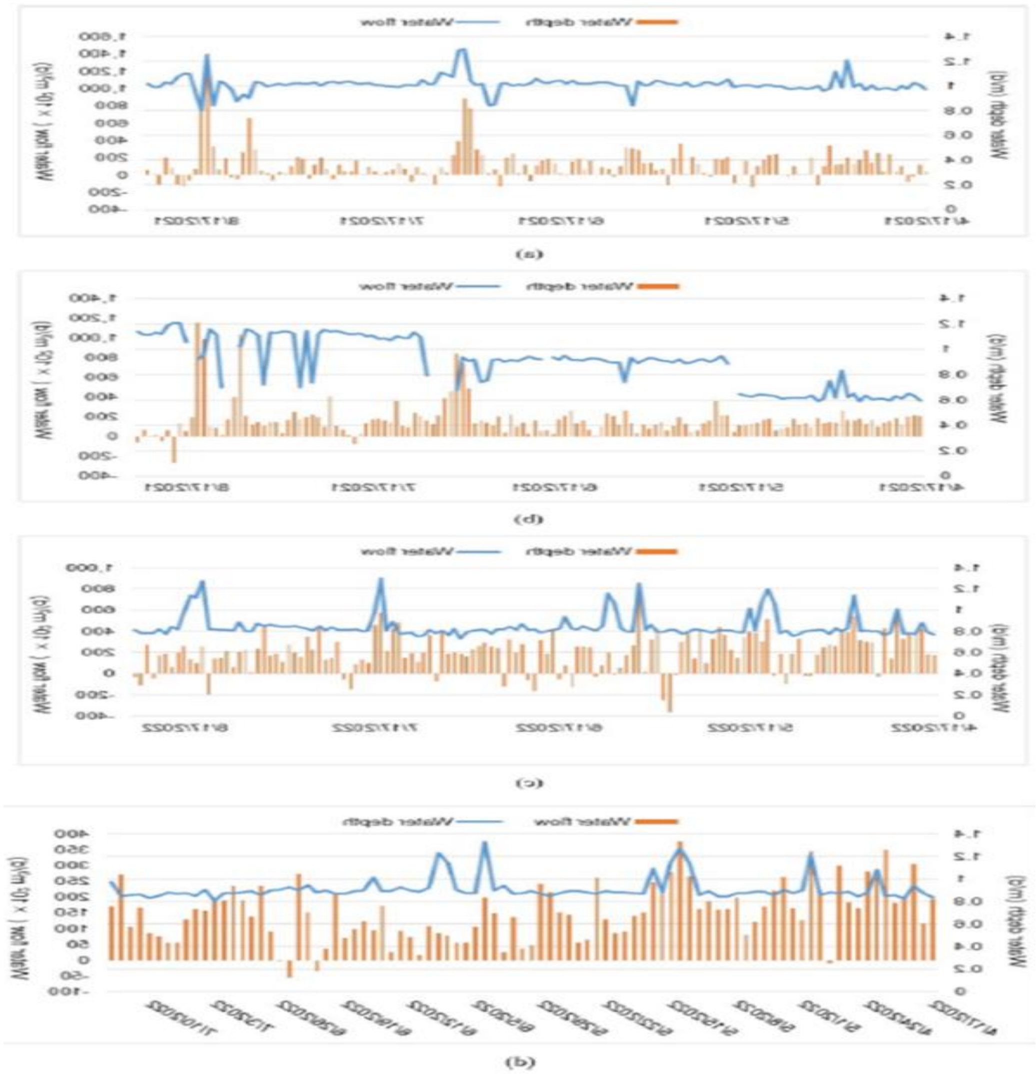

Figure 3. The results of ADCP monitoring at the North block locations in (a) 2021 and (c) 2022 and at the South block locations in (b) 2021 and (d) 2022. Source: Okura et al, 2025

Network Systems, Performance, and Institutions

Tidal swamp irrigation networks are generally multi-storey (primary–secondary–tertiary) with regulating buildings (doors/culverts or flap gates), pumps for supply/back-pumping, and small reservoirs/reservoirs to reduce fluctuations in salinity and water quality. In the B/C hydrotopography pump network design study, a configuration of 2×40 L/s with vertical heads of at least 35 m (right) and 30 m (left), a 6" PVC exhaust pipe from the plot to the tertiary channel, as well as the operation of the door at high tide to hold the volume show the relationship of hydraulic capacity with daily operations in tidal swamps [33].

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The success of O&P relies heavily on shared rules, division of tasks, and incentive mechanisms so that the opening and closing of doors are simultaneous along the channel (Suryadi & Schultz, 2001). Without synchronization, upstream-downstream losses increase so that the crop index is difficult to increase sustainably [34].

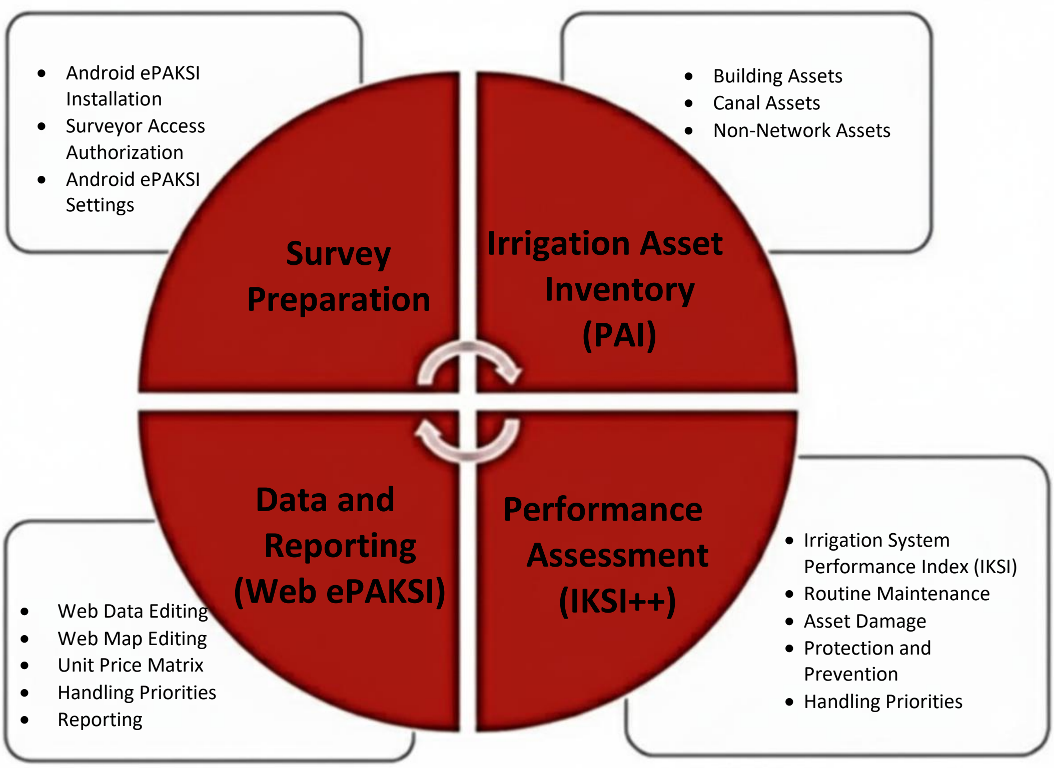

Figure 4. Figure 2.1 How PAI Works in ePAKSI Source: Ministry of Public Works and Housing, 2019

Performance measurement and assessment are not only technical (channel/building conditions), but also non-technical (productivity, institutional). The Irrigation System Performance Index (IKSI) framework combines the weights of the main vs. tertiary networks differently according to the scale of the Irrigation Area (DI) (e.g. DI > 1000 ha: 80% vs 20%), then recap the components of physical infrastructure, productivity, supporting facilities, organization, documentation, and P3A. The implementation of electronic Irrigation System Performance Assessment (ePAKSI) describes the flow of asset inventory (PAI) and Android–web-based IKSI assessment as support for annual monitoring/recap in the field [35]. An example of the 2023 DIR Terantang recap gives a total IKSI of 72.52 ("Good" category) along with details of the weights and scores per component [36].

Hydroinformatics for Network Operations

Hydroinformatics architecture for swamp irrigation generally includes four layers: (i) acquisition of field data via sensors/telemetry (water level, pH/EC, door/pump status), (ii) spatial integration of GIS/RS, (iii) operational databases, and (iv) Decision Support System (DSS) for operators. GIS–model integration has long been recommended because GIS excels in spatial management/visualization, while modeling captures process dynamics and their combination results in a more user-friendly and understandable analysis system for water resource planning/operation [37].

A national example is SIRAISA (web-based swamp information system) which documents swamp irrigation area profiles, planting data, harvesting, productivity, access to production facilities, and performance indicators and is developed through FGD stages, interface validation, to Norms, Standards, Procedures, and Criteria (NSPK) plans to be sustainable across stakeholders.

Loggers integrated into QGIS/HEC-RAS have been used to assess the impact of tide/brackish water and compile a water quality panel that can be connected to the network operational dashboard [38]. In terms of adoption, global trends show that the need for real-time monitoring and IoT-AI integration is still hampered by cost, interoperability, and governance but at the same time opens up opportunities to strengthen adaptive decisions through a good hydroinformatics architecture [39].

In addition to sensing and estimating, the prediction component can utilize ML/AI to speed up irrigation scheduling calculations; for example, the ReLU surrogate → MIQP is able to cut compute time by up to two orders of magnitude while maintaining MPC performance for irrigation scheduling so that the prediction output is ready to be used as a decision input in DSS [40].

Maintenance Operations Optimization & Control

Optimization in swamp/tidal irrigation needs to blend discrete–continuous decisions—door open/close status, pump ON/OFF, discharge, and target level—into a realistic and executable formulation. In this context, Mixed-Integer Linear Programming (MILP) is commonly used because it is able to accommodate aggregated water balances, capacity/headloss, switching time, and quality/level limits explicitly; In the study of the scheduling of weir gates during floods, MILP was shown to reduce peak outflow by around 11.5–15.6% while resulting in a stable and executable operating policy [41]. In the in-season phase of operations, the need shifts from scheduling to dynamic control of the channel network. Here, Nonlinear Model Predictive Control (NMPC) utilizes a multi-segment process model to minimize loss (leakage/seepage) while maintaining the fulfillment of needs; case tests show water loss can be suppressed by up to ~50%, an approach that is relevant for swamp canals that fluctuate following the tides [42]. In order for DSS to respond quickly to weather/weather dynamics on a daily–weekly horizon, computational acceleration is achieved through surrogate: a ReLU network reformulated into a MIQP for irrigation scheduling MPC cuts compute time by ~99.5% without any decrease in control performance, making near-real-time optimization iterations practical [43].

Operating policies in the swamp must also be sensitive to water quality and field processes. Flushing at moderate tides is effective in lowering acidity without increasing salinity excessively, while one-way buildings (flap gates) prevent salt water from returning at low tide; however, the operation design must still consider the limitations of drainage and the risk of local copy [44]. In coastal marsh systems involving groundwater, additional constraints come from safe yields and intrusion/subsidy hazards: MODFLOW–SEAWAT coupled modeling in coastal alluvial plains shows pumping can push chloride plumes more than 1 km in ±20 years and is sensitive to sea-level rise scenarios, so annual take-safes need to be used as a hard constraint in optimization models [45].

METHODS RESEARCH

This study uses the Systematic Literature Review (SLR) method, which is a systematic way to collect, critically evaluate, and synthesize research results from various primary studies relevant to the topic of hydroinformatics-based swamp irrigation optimization. In contrast to traditional literature reviews, SLRs follow strict protocols to minimize researcher bias and ensure that the resulting findings are transparent and reproducible by other researchers in the future.

Each literature that enters the inclusion stage is evaluated for quality based on the credibility of the publisher's journal and the relevance of the findings to the research question (RQ). The data extraction process is carried out using a synthesis table that includes variables: author name, year of publication, optimization method used, sensor parameters monitored, and novelty offered. This approach allows researchers to map global research trends and accurately identify research gaps in the context of swamp irrigation management in Indonesia.

RESULTS AND DISCUSSION

Based on the analysis of the selected literature, there are three main pillars in the development of swamp irrigation O&P optimization models: (1) Hydroinformatics monitoring technology, (2) Optimization algorithms, and (3) Swamp-specific water quality parameters.

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Synthesis of the Main Literature

Table 1 summarizes some of the key research that is the foundation in the development of rawai irrigation optimization models.

Table 1. Research Synthesis Related to Irrigation Optimization and Hydroinformatics

Author (Year)	Research Focus	Methods/Technologies	Key Findings & Contributions to the Model
Su et al. (2022)	Prediction-based automatic irrigation by control.	Nonlinear Model Predictive Control (NMPC)	Deal with the uncertainty of water flow and non-linear dynamics. It is very effective for stabilizing the elevation of water in channels affected by load fluctuations (tides).
Luo et al. (2020)	Optimization of by operation schedules on large irrigation networks.	Mixed-Integer Linear Programming (MILP)	Reduce operational energy costs and prevent excess water loss through optimal by opening synchronization.
Imanudin et al. (2011/2021)	Conservation of Sour Sulfate Swamp Land in Indonesia.	Controlled Drainage & Groundwater Level Management (MAT)	Maintain MAT thresholds to prevent pyrite oxidation. Emphasizing that O&P should be based on soil quality conservation, not just water quantity.
Hadi et al. (2024)	Digitize water quality monitoring on marginalized land.	IoT, Cloud Computing, and Low-cost Sensors	Proving that low-cost LoRaWAN-based sensors are capable of transmitting real-time pH and salinity data from remote locations to data centers continuously.
Suryadi & Schultz (2001)	Water management strategy in lowlands (Tidal Lowlands).	Rule-based Operation & Hydrodynamic Modeling	Establish a standard that door operations should follow daily tidal charts. It became the basis for the development of automation algorithms
Taheri et al. (2024)	Sustainable allocation of agricultural water resources.	Soft Computing (Fuzzy Logic & Genetic Algorithm)	Intelligent algorithms are able to simultaneously handle conflicts of interest between irrigation needs, water availability, and environmental impact.
Horváth et al. (2020)	Implementation of Hydroinformatics on a watershed scale.	Integrated Decision Support System (DSS)	The integration of spatial data (GIS) with sensor data provides 85% higher accuracy in predicting water deficits than manual methods.
Setyorini et al. (2017)	Optimization of water use in tidal swampland.	Analysis of Plant Water Needs & Water Balance	Identifying that a planting schedule synchronized with the availability of fresh water is key to optimization in tidal lands.

Author (Year)	Research Focus	Methods/Technologies	Key Findings & Contributions to the Model
Munir et al. (2023)	Artificial intelligence-based sluice gate automation.	Machine Learning (ANN / Random Forest)	The use of AI to predict tidal heights at river mouths that do not have official shear stations, improves the operational accuracy of the gates. .
Ghazali et al. (2021)	Monitoring of saltwater intrusion on irrigation canals.	Telemetry Integrated Salinity Sensor	Early detection of seawater intrusion through an early warning system can prevent damage to rice plants by up to 40%.

The Role of Hydroinformatics in Decision Making

Based on the synthesis of the literature (Table 1), hydroinformatics has transformed from just a data processing tool to an intelligent and adaptive decision-making ecosystem. This integration involves three main pillars:

a. Low-Cost Real-Time Data Quiz: Research by Hadi et al. (2024) and Ghazali et al. (2021) shows that the use of IoT technology with widely distributed salinity and water level sensors allows for continuous data collection. This solves a classic problem in Indonesia's tidal swamp irrigation network which often has remote locations with difficult accessibility. Data sent over wireless protocols (such as LoRaWAN or cellular) ensures that decision-makers have an overview of field conditions every second

b. Predictive Modeling and Automated Control: The role of hydroinformatics is amplified by control algorithms such as NMPC [46] and MILP [47]. Compared to manual rules (rule-based) which are reactive, hydroinformatics systems are able to perform "anticipatory" functions. For example, the system can predict sea tide rise a few hours in advance and set up sluice gate opening automatically to prevent saltwater intrusion into farmland before disaster occurs.

c. Spatial Visualization and Decision Dashboard: The integration of GIS (Sweeney, 1999) and DSS (Horváth et al., 2020) transforms raw data into visual information. Network managers can view the health status of the entire system through digital maps, making it easy to identify which blocks are experiencing water deficits or spatial-temporal increases in acidity.

Analysis of Critical Parameters in Swamp Irrigation

Unlike conventional irrigation systems, swamp irrigation has the characteristics of interlocking parameters. Based on the literature analysis:

a. Dynamics of Groundwater Level (MAT): As emphasized by Imanudin et al. (2011/2021), MAT is not just an indicator of water adequacy for plants, but an environmental control instrument. Too low MAT will trigger the oxidation of the pyrite layer, while too high a MAT without circulation can lead to a buildup of toxic substances. Therefore, optimization must find a dynamic MAT optimal set-point.

b. Water Quality (pH and Salinity): These chemical parameters are critical constraints. A review of Setyorini et al. (2017) shows that without considering salinity, water quantity optimization models become irrelevant because the available water may not be suitable for use. Hydroinformatics allows for strict monitoring of pH thresholds so that they do not fall below safe limits for rice growth.

c. Tidal Interactions: A study by Suryadi & Schultz (2001) identified that tidal energy is the primary driver of the system. Optimization must synchronize the opening time of the door with the paste curve to maximize acid leaching and minimize salt intrusion.

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Identifying Research Gaps

Although sensor technology and control algorithms have advanced extensively, this systematic review found significant gaps that became research opportunities for this dissertation:

a. Lack of Multi-Parameter Integration in Optimization Models: Most optimization research today is still fragmented. Research such as Luo (2020) focuses on energy efficiency and water levels, while Imanudin's (2021) research focuses on land geochemistry. No NMPC or AI optimization model has been found that explicitly includes pH and Salinity parameters as the main control variables in a single integrated system for tidal swamps.

b. Model Adaptability to Limited Infrastructure: Most advanced optimization models assume a fully automated and precise sluice infrastructure. There is a large gap in research on how the hydroinformatics model can be applied to existing irrigation networks in Indonesia that have varied by mechanical characteristics and high sediment levels.

c. Hybridization of Physics and Artificial Intelligence: There is a need to combine physics-based hydrodynamics models with Machine Learning (Munir et al., 2023) to predict the behavior of water in tertiary channels for which data are very scarce and uncertain.

CONCLUSION

This systematic literature review confirms that the transformation of the O&M of swamp irrigation networks to hydroinformatics-based is no longer an option, but rather a need to maintain sub-optimal food land sustainability. The use of optimization algorithms such as NMPC and MILP has been proven to improve the precision of water regulation, but its success relies heavily on the quality of IoT sensor data input and a deep understanding of critical parameters such as pH, salinity, and pyrite oxidation. The main gap in the research lies in the development of a model that is able to simultaneously integrate aspects of water quantity and quality in a highly dynamic environment. There are some suggestions that may need to be made as follows: 1) model Development: Researchers are then advised to build a multi-objective optimization model that prioritizes soil conservation (pH) in addition to water sufficiency, 2) field Scale Test: It is necessary to conduct a pilot project that implements a low-cost sensor with a control algorithm on a real swamp irrigation block to validate the performance of the predictive model, 3) policy: Water resource managers need to start designing digital standard operating protocols (SOPs) that accommodate the outputs of hydroinformatics systems as the basis for formal decision-making in the field.

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