

BEYOND IRRIGATION: THE ROLE OF DRAINAGE IN BUILDING CLIMATE RESILIENT PADDY SYSTEMS

AU-DELA DE L'IRRIGATION : LE ROLE JOUE PAR LE DRAINAGE DANS LA MISE EN PLACE DES SYSTEMES RIZICOLES RESISTANTS AU CHANGEMENT CLIMATIQUE

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ABSTRACT

Climate change is intensifying extreme rainfall events, severely increasing flash flood and waterlogging risks within global irrigated agricultural systems. Paddy cultivation is highly sensitive to prolonged inundation caused by heavy monsoonal precipitation and inadequate hydraulic discharge capacity (Bouman & Tuong, 2001; Tuong & Bouman, 2003). While prevailing adaptation strategies prioritize irrigation efficiency, the critical role of drainage networks as active climate adaptation tools remains heavily underemphasized (Ouyang et al., 2020; Hossain et al., 2016). This paper addresses this knowledge gap by analyzing the drainage adaptation pathways deployed at the IADA Kerian irrigation scheme, a vital rice granary managed by Malaysia's Department of Irrigation and Drainage (DID). Utilizing a simplified conceptual framework, this study demonstrates how targeted structural, operational, and institutional drainage interventions can successfully mitigate flood vulnerabilities, preserve crop integrity, and reinforce agricultural resilience against hydrological extremes (ICID, 2016; Pathak et al., 2012).

Keywords: Extreme rainfall events; Irrigation efficiency; Simplified conceptual framework; Flood vulnerabilities.

RESUME

Le changement climatique intensifie les événements de précipitations extrêmes, augmentant de manière considérable les risques de crues soudaines et d'engorgement au sein des systèmes agricoles irrigués à l'échelle mondiale. La culture du riz est très sensible aux inondations prolongées causées par de fortes précipitations de mousson et à une capacité d'évacuation hydraulique insuffisante (Bouman & Tuong, 2001; Tuong & Bouman, 2003). Etant donné que les stratégies d'adaptation dominantes accordent la priorité à l'efficacité de l'irrigation, le rôle essentiel joué par les réseaux de drainage en tant qu'outils actifs d'adaptation au changement climatique reste largement sous-estimé (Ouyang et al., 2020; Hossain et al., 2016).

Cet article adresse ce vide de connaissances en analysant les stratégies d'adaptation en matière de drainage mises en œuvre au sein du périmètre irrigué d'IADA Kerian, un grenier rizicole essentiel géré par le Département de l'irrigation et du drainage (DID) de Malaisie. En utilisant un cadre conceptuel simplifié, cette étude démontre comment des interventions ciblées en matière de drainage – tant sur le plan structurel, opérationnel qu'institutionnel – peuvent réussir à atténuer les vulnérabilités aux inondations, préserver l'intégrité des cultures et renforcer la résistance agricole aux phénomènes hydrologiques extrêmes (ICID, 2016 ; Pathak et al., 2012).

Mots-clés : Événements de précipitations extrêmes; Efficacité de l'irrigation; Cadre conceptuel simplifié; Vulnérabilité aux inondations.

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1. Introduction

Climate change is altering global hydrological regimes, leading to more frequent and intense rainfall events that elevate flood risks across key irrigated agricultural regions (Pathak et al., 2012). Paddy cultivation is highly sensitive to excess water and prolonged inundation. Over-saturation damages crop tissues, delays mechanical field operations, and degrades soil structural conditions. While the current climate adaptation discourse focuses heavily on improving irrigation efficiency, the systemic impacts of excess water and inadequate drainage receive comparatively less attention (Bouman & Tuong, 2001).

In paddy ecosystems, irrigation and drainage do not operate in isolation; they function as an integrated hydrological system. Historically, irrigation networks were engineered primarily to secure water supply during dry periods. However, climate change necessitates a paradigm shift. Contemporary extreme weather patterns alternate rapidly between intense downpours and severe dry spells, frequently pushing traditional infrastructure past its design thresholds.

Effective drainage regulates local water tables, controls inundation duration, and protects the structural integrity of crops during sudden, heavy precipitation events. Redefining drainage networks from passive runoff conduits into active, managed climate adaptation systems is therefore vital to sustaining rice self-sufficiency in flood-prone granary regions worldwide.

The irrigation system within the Integrated Agricultural Development Area (IADA) Kerian relies on a complex network of storage, diversion, pumping, and conveyance infrastructure. This includes the Bukit Merah Dam, river abstractions, pump houses, and primary irrigation canals. The operational reliability of these interconnected components is essential to support double-cropping paddy cultivation and to meet irrigation demands during both the main and off-season planting periods.

Water availability in IADA Kerian is highly dependent on seasonal rainfall, spillway releases from the Bukit Merah Dam, and agricultural return flows. During dry spells and low-flow conditions, competition for water among irrigation, domestic, and industrial sectors intensifies, increasing the risk of acute water shortages within the scheme. Inefficient water distribution, system losses, and limited storage regulation further compound these challenges, threatening crop yields and overall farm productivity. Consequently, an Integrated Water Resources Management (IWRM) approach is required to optimize allocation, improve operational efficiency, and ensure equitable water distribution across the scheme.

2. Case Study Context: IADA Kerian, Perak

The Kerian Irrigation Scheme, located within the Integrated Agricultural Development Area (IADA) in northern Perak, represents Malaysia's second-largest rice granary. Encompassing over 21,000 hectares of paddy fields, it serves as a critical asset for national food security. The scheme depends heavily on the Bukit Merah Dam for its primary irrigation supply, exposing IADA Kerian to severe, dual-spectrum climate risks:

- **The Dry Spectrum:** Critical drops in dam water levels delay scheduled irrigation phases, forcing farmers to defer planting, manage aggressive weed outbreaks, and risk seed degradation.
- **The Wet Spectrum:** Due to its low-lying terrain and coastal proximity, the region experiences acute drainage vulnerabilities when intense tropical storms coincide with high river stages or tidal lockouts.

The scheme is structurally divided into eight (8) distinct compartments, as outlined in Table 1.1 and illustrated in Figure 1.1. The inland compartments (E, F, G, and H), collectively referred to as Kerian Darat, encompass approximately 10,684 hectares. This zone obtains its water supply from the Bukit Merah Reservoir, supplemented partially by the Padang Lalang Pump House.

Conversely, the coastal and estuarine compartments (A, B, C, and D), spanning roughly 13,978 hectares and known as Kerian Laut, draw irrigation water from the same reservoir, supplemented via the Bogak Pump House drawing from the Samagagah River. From these primary sources, water feeds into a 384 km network of primary and secondary canals via gravity. Additionally, water is supplied to Compartment A (IADA Pulau Pinang) via the Terusan Titi Serong–Terusan Sungai Aceh conveyance system (Figure 1.1). Beyond the Bukit Merah Reservoir and Bogak Pump House systems, direct rainfall constitutes approximately 15% of the total water utilization within the scheme.

A technical evaluation commissioned by the Division of Irrigation and Agricultural Drainage (BPSP) in 2024 and conducted by Ranhill Engineering Sdn. Bhd. analyzed the water resources, irrigation, and drainage infrastructure of IADA Kerian. Baseline structural densities derived from this study are compiled in Table 1.2.

Location	Compartment	Area (ha)	Length (m)						Farm Road
			Main Canal	Secondary Canal	Tertiary Canal	Main Drain	Secondary Drain	Tertiary Drain	
Kerian Laut	A (Perak)	1,166.17	3,235.32	21,843.95	20,322.12	18,856.04	28,835.17	32,119.96	83,705
	B	3,107.40	8,576.30	64,557.80	57,990.26	30,304.44	92,713.02	65,075.60	271,594
	C	3,460.67	4,118.45	47,084.20	86,279.02	34,241.52	76,746.25	51,505.49	293,235
	D	2,323.55	9,695.42	59,524.57	27,213.44	47,162.09	75,681.52	7,695.81	212,235
Kerian Darat	E	1,737.90	14,707.30	47,108.16	9,050.30	33,952.39	51,483.16	-	76,634
	F	2,232.93	8,969.30	44,373.56	19,546.32	31,845.37	40,199.22	2,077.20	160,485
	G	1,726.01	3,106.11	34,720.28	24,528.04	25,357.07	53,687.62	-	111,864
	H	2,324.73	13,905.10	54,714.95	29,884.28	26,614.47	49,098.99	3,775.66	202,196
Total		18,079.36	66,313.30	373,907.47	274,613.77	248,333.39	468,644.95	162,249.72	1,411,948.00

Details of Irrigation Canals, Drain and Farm Road Received from IADA Kerian (2025)

According to the investigation, the primary inflows driving the Kerian Irrigation Scheme are direct rainfall and the Bukit Merah Reservoir on the Kurau River. The reservoir features a live storage capacity of 76.49x10⁶ m³/s at an elevation of 8.69 m LSD. It supplies water by gravity to the Terusan Besar canal (designed maximum discharge = 22.62 m³/s servicing Compartments A, B, C, D, E, and F, and the Terusan Selinsing canal, Q= 11.45m³/s servicing Compartments G and H. This system is supplemented by the Sungai Bogak Pump House, which operates at a capacity of 4 x 5.1 m³/s pumping water from Sg. Samagagah, a tributary of Sg. Kerian, to into the Terusan Besar canal.

Discharge water from the irrigated fields is routed north into the Kerian River, south into the Kurau River, and west directly into the Straits of Melaka via a series of tidal gates. Prior to recent modernization works under this project, the scheme operated with an infrastructure density of approximately 26 m/ha for irrigation canals, 18 m/ha for drainage conduits, and 12 m/ha for farm roads. These farm roads feature 3.0 m to 3.66 m wide tarred or lateritic surfacing running alongside the primary channels, tying into the regional Jabatan Kerja Raya (JKR) road network.

Geomorphologically, the Kerian Irrigation Scheme was reclaimed from a flat coastal alluvial plain formed by the basins of the Kerian and Kurau rivers. The ground surface slopes gradually from 4.0 m LSD near the Bukit Merah Reservoir down to 0.8 m LSD within the *Kerian Laut* sector, leaving a substantial portion of the agricultural land below the mean sea level. Because natural gravity drainage is structurally inadequate under these conditions, a comprehensive artificial drainage grid and associated tidal control structures are vital to prevent catastrophic waterlogging.

3. Current Issues and Drainage Vulnerabilities at IADA Kerian

The Kerian Irrigation Scheme currently faces significant challenges in draining excess water from paddy fields. This infrastructure deficit results in frequent inundation events, localized waterlogging, and crop loss, particularly during monsoon transitions.

The Kerian Irrigation Scheme currently faces significant operational challenges in evacuating excess water from paddy fields. This structural deficit results in frequent, localized inundation events, prolonged waterlogging, and subsequent crop losses during peak monsoon transitions.

Systemic and Anthropogenic Deficiencies

- The prevailing drainage inefficiencies within the scheme are primarily driven by a combination of engineering, maintenance, and socio-behavioural factors:
- Topographical and Inflow Anomalies: Severe elevation mismatches exist where specific drainage channels are positioned higher than the adjacent irrigation canals. This "reverse slope" phenomenon restricts gravity-fed discharge. Additionally, uneven field micro-topography creates localized depressions that trap water.
- Hydraulic Command Failures: Secondary and tertiary canals frequently operate below their designed Full Supply Level (FSL). This lack of hydraulic command cascades downstream, rendering standard water distribution inefficient.
- Infrastructure Deficits and Silting: The existing drainage network lacks sufficient spatial coverage across remote paddy tracts. Furthermore, deferred maintenance has led to severe channel siltation, sediment accumulation, and dense weed infestation, heavily reducing the cross-sectional discharge capacity.
- Agronomic Paradigm Shifts: The widespread transition from traditional seedling transplantation to direct seeding (direct seeding) has altered field water depth requirements, placing a higher, more time-sensitive burden on both irrigation supply and rapid drainage evacuation.
- Unauthorized Water Abstraction: Systemic distribution imbalances often drive upstream farmers to practice unauthorized, uncontrolled water tapping from secondary canals. This results in counterproductive "constant-irrigation" practices. In desperate cases, farmers resort to "negative irrigation" by deliberately backing up water within the nearest drain to force an supply, which starves downstream users and causes severe backwater ponding.
- Institutional Boundaries: Runoff management is further complicated by JKR roadside drains. Engineered primarily as stormwater conduits for urban sectors, these networks lack the hydraulic capacity to absorb agricultural drainage flows, leading to systemic overflow.

Location-Specific Drainage Bottlenecks and Proposals

Field assessments across the scheme's compartments reveal critical, localized hydraulic bottlenecks. Targeted mitigation strategies are summarized below:

- Overbank Flooding (Bukit Merah Reservoir): Uncontrolled flood releases from the reservoir frequently inundate downstream agricultural tracts. Rather than executing channel modifications along the Sg. Kurau—which would trigger severe morphological instability and meandering along the flat coastal plain—the recommended strategy involves two parallel interventions: utilizing a Decision Support System (DSS) under the Irrigation Water Management System to pre-emptively lower reservoir levels and raising the existing flood bunds to contain peak flows.
- Compartment D (Parit Padri & Bagan Serai Town): This urban-agricultural interface suffers from heavy stormwater inundation. The proposed remedy involves structural channel enlargement utilizing an L-shaped concrete section (2.0 m deep by 5.0 m wide) paired with upgrading the existing road culvert to a twin 2.0 m diameter configuration.

- Compartments B and C (Parit Tg. Piandang): To decouple agricultural drainage from urban runoff, the existing JKR roadside drain must be decommissioned and replaced with a dedicated Parit Belakang Kampung and a new Drainage Control Structure (DEC).
- Compartment D (Parit Sg. Siakap): Similar to Parit Tg. Piandang, the JKR roadside drain will be replaced with a Parit Belakang Kampung, a new road culvert, and a corresponding DEC.
- Compartments G and H (Parit 444 / Parit Gula & Sg. Gedong): To relieve backwater pressure caused by an undersized twin 0.9 m dia culvert, a new twin box culvert (1.5 m x 1.5 m) is proposed across the Bagan Serai–Taiping road to link directly into Parit 444 and Parit Gula. For Sg. Gedong, structural stabilization of the channel section is required alongside an upgrade of the existing siphon/under-drainage culvert (UDC) at the Jalan Kuala Kurau–Pekan Semanggol crossing. A Tidal Control Gate (TCG) must also be constructed at the terminus of Parit Sg. Gedong to prevent saline water intrusion into the agricultural grid.
- Parit Piai Sector: Upgrading the primary canal infrastructure will eliminate the root cause of "negative irrigation" here. Channel slope stability must be restored through detailed slip analysis, supplemented by the installation of drainage regulators at Parit Teluk Piai and Parit Tok In near the compartment boundary.

Geotechnical Degradation

The Soft Soil (Tanah Jerlus) Phenomenon: Beyond surface crop damage, inadequate drainage introduces a severe geotechnical risk across IADA Kerian, particularly within the coastal tracts of Kerian Laut. Prolonged and recurrent flooding creates conditions where stagnant water remains on the field surface for extended periods, preventing the soil from undergoing essential seasonal drying phases.

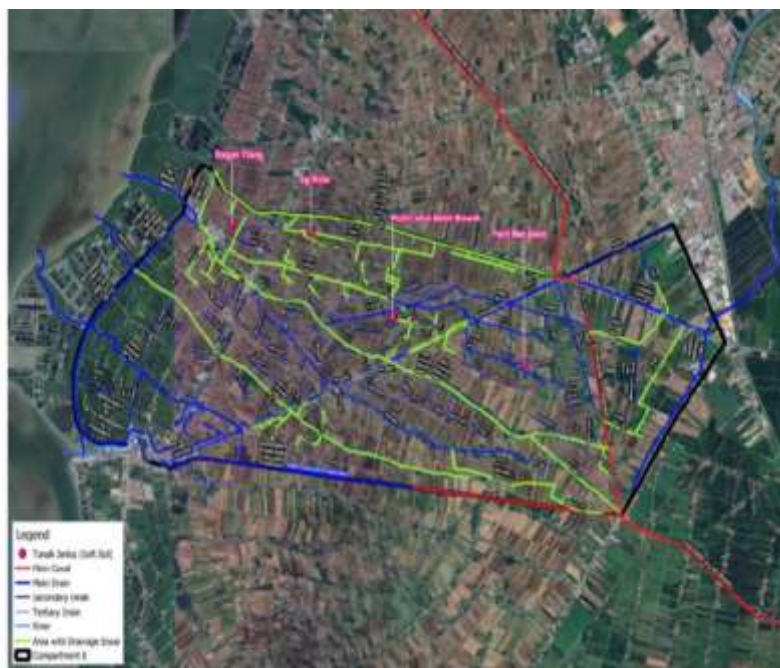


Figure 5.75: Tanah Jerlus Issue at Compartment B

From a soil mechanics perspective, this continuous saturation drastically reduces the effective stress within the alluvial soil mass. This reduction triggers a severe loss of shear strength and bearing capacity. The fine-grained clay soils characteristic of the Kerian lowlands is highly susceptible to this form of structural degradation, commonly referred to locally as Tanah Jerlus. Under these conditions, the soil cannot support standard engineering or agricultural loads. Even moderate surface weight such as mechanized combine harvesters, maintenance vehicles, or concrete canal lining structures induces

excessive, uneven settlement and localized bearing failures. Mitigating this hazard requires an integrated approach: accelerating drainage efficiency to decrease flood residence times, upgrading drainage pumping facilities to enforce rapid drying cycles, and implementing localized ground improvement techniques designed specifically for soft, low-bearing alluvial coastal strata.

4. The Drainage Adaptation Pathway

Transforming the drainage infrastructure of the Integrated Agricultural Development Area (IADA) Kerian from a passive runoff grid into an active climate defence line requires a multi-pronged, systemic intervention. This adaptation framework is structured across four primary axes, Structural & Design, Operational & Maintenance, Institutional & Governance, and Planning & Knowledge Base to convert climate vulnerabilities into agricultural resilience.

Table 4.1: Strategic Adaptation Matrix for Climate-Resilient Paddy Drainage Systems

Adaptation Axis	Strategic Action Plan	Targeted Resilience Objective
Structural & Design	Widening and deepening critical drainage canals. - Constructing dedicated agricultural bypass discharge volumes. Channels. - Upgrading coastal and estuarine tidal gates with automated backflow prevention flaps.	- Accommodate elevated peak - Minimize tidal lockouts and structural backwater ingress into low-lying zones.
Operational & Maintenance	Institutionalizing rigorous desilting and vegetation clearing schedules. Deploying high-capacity mobile and permanent drainage pumping units at known hydraulic bottlenecks.	- Sustain optimum cross-sectional hydraulic conveyance. - Enforce rapid artificial drainage during extreme river stages or concurrent high tides.
Institutional & Governance	Synchronizing seasonal planting and water distribution schedules between IADA Kerian, DID, and local water user - associations. - Restructuring institutional funding mechanisms.	- Align irrigation cut-offs with predictive, downscaled meteorological forecasts. - Guarantee sustained capital for routine, proactive preventive maintenance.
Planning & Knowledge-Based	Integrating downscaled regional climate change projections into engineering design standards. Deploying real-time telemetry systems paired with predictive hydrodynamic modeling.	- Future-proof new and rehabilitated civil works against evolving return periods. - Enable proactive flood routing and automated, early-stage water level management.

Together, these integrated adaptation pathways demonstrate how drainage infrastructure can be fundamentally re-engineered from a passive system component into a responsive climate adaptation tool. By dramatically reducing both the spatial depth and temporal duration of on-farm inundation, this multi-pronged approach enables accelerated field recovery and stabilizes regional rice production under highly variable, extreme climatic conditions (Bouman & Tuong, 2001; Ouyang et al., 2020).

5. Way Forward

To foster long-term climate resilience within the Integrated Agricultural Development Area (IADA) Kerian and across Malaysia's broader agricultural landscapes, several strategic, forward-looking initiatives must be prioritized:

- **Adoption of Climate-Resilient Agroecological Practices:** Agricultural policies must encourage the widespread deployment of submergence-tolerant and drought-resistant rice cultivars. Utilizing varieties capable of withstanding volatile water levels minimizes the traditional, rigid requirement to drain fields completely prior to direct seeding. This flexibility preserves vital on-farm water volumes during unpredictable seasonal transitions.
- **Transition to Automated Smart Infrastructure:** Traditional manual tidal gates and water regulators should be systematically upgraded with Supervisory Control and Data Acquisition (SCADA) systems. Integrating automated actuation allows for remote, real-time hydraulic adjustments based on live, telemetry-driven data regarding coastal tidal stages and upstream river discharges.
- **Integrated Water Resources Management (IWRM):** Water management frameworks must shift toward holistic river basin governance, treating the entire watershed—from the Bukit Merah catchment down to the coastal estuarine outfalls—as a single hydrological unit. This ensures that flood mitigation, ecological conservation, and irrigation security are co-optimized within a unified operational framework.



Action taking by IADA Kerian on removing soft soil (Tanah Jerlus).

6. Conclusion

The operational insights compiled by Malaysia's Department of Irrigation and Drainage (DID) underscore a critical structural shift: reinforcing drainage networks is no longer a secondary or supporting component of irrigation design, but a primary requirement for climate adaptation. Implementing these comprehensive drainage adaptation pathways at vital granaries like IADA Kerian directly mitigates agricultural flood risks, stabilizes regional rice yields, and safeguards national food security. Recognizing and engineering drainage networks as active climate defense systems is an essential prerequisite for building resilient irrigated agriculture in flood-prone alluvial regions worldwide.

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